DOCTORAL THESIS

UCAM

UNIVERSIDAD CATÓLICA
DE MURCIA

ESCUELA INTERNACIONAL DE DOCTORADO

Programa de Doctorado en Ciencias de la Salud

Aesthetic Result of Ceramic Restorations with Different Cements

Author:
Catarina Isabel Gomes Félix

Supervisors:
Dr María Piedad Ramírez Fernández
Dr Paulo João Bela Teiga de Durão Maurício
Dr Francisco Eduardo do Nascimento Martins

Murcia, June 2023

DOCTORAL THESIS

UCAM
UNIVERSIDAD CATÓLICA
DE MURCIA

ESCUELA INTERNACIONAL DE DOCTORADO

Programa de Doctorado en Ciencias de la Salud

Aesthetic Result of Ceramic Restorations with Different Cements

Author:
Catarina Isabel Gomes Félix

Supervisors:
Dr María Piedad Ramírez Fernández
Dr Paulo João Bela Teiga de Durão Maurício
Dr Francisco Eduardo do Nascimento Martins

Murcia, June 2023

UCAM
UNIVERSIDAD CATÓLICA
DE MURCIA

EIDUCAM
Escuela Internacional
de Doctorado

THESIS SUPERVISORS' AUTHORISATION FOR THESIS SUBMISSION

Prof. María Piedad Ramírez Fernández, Prof. Paulo João Bela Teiga de Durão Maurício and Prof. Francisco Eduardo do Nascimento Martins as Supervisors(1) of the Doctoral Thesis 'Aesthetic result of ceramic restorations with different cements' by Mr/Ms Catarina Isabel Gomes Félix in the Doctorate Programme in Health Sciences, **authorise(s) its submission**, given that it meets the required conditions for its defence.

Which I hereby sign in compliance with Spanish Royal Decree 99/2011, of 28 January, in Murcia, on June 6th, 2023.

Dr. María Piedad Ramírez Fernández	Dr. Paulo João Bela Teiga de Durão Maurício	Dr. Francisco Eduardo do Nascimento Martins

(1) If the Thesis is supervised by more than one Supervisor, both must be mentioned and both must sign.

ABSTRACT

Objective: The purpose of this study is to assess the aesthetic outcome of glass ceramic restorations of various thicknesses cemented to composite resin substrates of different shades with multiple cements.

Material and Methods: 120 samples of *IPS e.max® CAD (HT)* (Ivoclar Vivadent, Schaan, Liechtenstein) lithium disilicate ceramic and 120 samples of *VitaBlocs® Mark II* (VITA Zahnfabrik, Bad Säckingen, Germany) feldspathic ceramic in colour A1 were obtained. The samples were cut with a thickness of 0,5mm and 0,8mm. For the simulation of the substrate, 240 samples of *Filtek™ Supreme XTE Universal Restorative Body* (3M ESPE, Minnesota, USA) composite resin in colours A2 and A3 were produced with a thickness of 1mm. All samples were polished. After surface treatment, the ceramic samples were cemented to the composite resin samples, according to the groups formed, initially with glycerine and subsequently with *RelyX™ Veneer Cement System* (3M ESPE, Minnesota, USA) in the *Translucent* (*TR*) and *White Opaque* (*WO*) shades, and *RelyX™ Universal Resin Cement* (3M ESPE, Minnesota, USA) in the *Translucent* (*TR*) shade. The results were obtained through the *EasyShade® V* (VITA Zahnfabrik, Bad Säckingen, Germany) spectrophotometer. The analysis of colour difference was carried out through the calculation of ΔE_{ab} and ΔE_{00} and the analysis of the L*, a* and b* coordinates, as well as their differences (ΔL^*, Δa^* and Δb^*) were also calculated for each pair of samples.

Results: The highest lightness values were obtained from a 0,8mm *VitaBlocs® Mark II* ceramic cemented to an A2 composite resin base with *Veneer WO* cement (88,59 ± 1,77) and the lowest from a 0,5mm *IPS e.max®* ceramic cemented to an A3 composite resin base with *Universal TR* cement (80,91 ± 0,31). The highest ΔE_{ab} and ΔE_{00} were obtained from an A3 composite resin base masked with a 0,8mm *VitaBlocs® Mark II* ceramic and cemented with *Veneer WO* (20,20 ± 0,65 and 11,16 ± 0,46, respectively). The lowest ΔE_{ab} and ΔE_{00} were obtained from an A2 composite resin base masked with a 0,5mm *IPS e.max®* ceramic and cemented with *Universal TR* (7,50 ± 0,44 and 4,35 ± 0,23, respectively).

Conclusions: The aesthetic outcome of glass ceramic restorations can be influenced by a variety of factors, including the ceramic type and thickness, the cement colour used, and the shade of the substrate.

KEY WORDS

Ceramics; Dental veneers, Resin cements; Spectrophotometry; Dental esthetic; Dental materials

RESUMEN

Objetivo: El propósito de este estudio es evaluar el resultado estético de las restauraciones de cerámica de vidrio de varios espesores cementadas en sustratos de resina compuesta de diferentes tonos con múltiples cementos.

Materiales y Métodos: Se obtuvieron 120 muestras de cerámica de dissilicato de litio *IPS e.max® CAD* (HT) (Ivoclar Vivadent, Schaan, Liechtenstein) y 120 muestras de cerámica de feldespato *VitaBlocs® Mark II* (VITA Zahnfabrik, Bad Säckingen, Alemania) en color A1. Las muestras se cortaron con un espesor de 0,5mm y 0,8mm. Para la simulación del sustrato, se produjeron 240 muestras de resina compuesta *Filtek™ Supreme XTE Universal Restorative Body* (3M ESPE, Minnesota, EE.UU.) en colores A2 y A3 con un espesor de 1mm. Todas las muestras fueron pulidas. Después del tratamiento superficial, las muestras de cerámica se cementaron a las muestras de resina compuesta, de acuerdo con los grupos formados, inicialmente con glicerina y posteriormente con *RelyX™ Veneer Cement System* (3M ESPE, Minnesota, EE.UU.) en los tonos *Translucent (TR)* y *White Opaque (WO)*, y *RelyX™ Universal Resin Cement* (3M ESPE, Minnesota, EE.UU.) en el tono *Translucent (TR)*. Los resultados se obtuvieron a través del espectrofotómetro *EasyShade® V* (VITA Zahnfabrik, Bad Säckingen, Alemania). El análisis de la diferencia de color se realizó a través del cálculo de ΔE_{ab} y ΔE_{00} y el análisis de las coordenadas L*, a* y b*, así como sus diferencias (ΔL^*, Δa^* y Δb^*) también se calcularon para cada par de muestras.

Resultados: Los valores de luminosidad más altos se obtuvieron de una cerámica *VitaBlocs® Mark II* de 0,8mm cementada a una base de resina compuesta A2 con cemento *Veneer WO* (88,59 ± 1,77) y los más bajos de una cerámica *IPS e.max®* de 0,5mm cementada a una base de resina compuesta A3 con cemento *Universal TR* (80,91 ± 0,31). Los ΔE_{ab} y ΔE_{00} más altos se obtuvieron de una base de resina compuesta A3 enmascarada con una cerámica *VitaBlocs® Mark II* de 0,8mm y cementada con *Veneer WO* (20,20 ± 0,65 y 11,16 ± 0,46, respectivamente). Los ΔE_{ab} y

ΔE_{00} más bajos se obtuvieron de una base de resina compuesta A2 enmascarada con una cerámica *IPS e.max®* de 0,5mm y cementada con *Universal TR* (7,50 ± 0,44 y 4,35 ± 0,23, respectivamente)

Conclusiones: El resultado estético de las restauraciones de cerámica de vidrio puede verse influenciado por una variedad de factores, incluyendo el tipo y espesor de la cerámica, el color del cemento utilizado y el tono del sustrato.

PALABRAS CLAVE

Cerámicas; Carillas dentales; Cementos de resina; Espectrofotometría; Estética dental; Materiales dentales

ACKNOWLEDGEMENTS

I would like to unconditionally express my heartfelt gratitude to all the people who, in some way, contributed to the completion of this doctoral journey. This journey, which was personally rewarding and gratifying, was also tough and at times challenging. In no way would it have been possible to reach this moment without the tireless support, guidance, and motivation of various people who generously contributed their time, expertise, knowledge, patience, and resources throughout the process. They were tireless and invaluable, leaving a permanent mark on my academic and personal path. To all of them, a huge thank you.

First and foremost, I would like to thank my entire family, especially my grandparents, Cecília and Jaime, for all the support they have always given me throughout my life, to Carlos, for always being a father to me, and especially to my mother, Paula, for her strength, education, motivation and values that she passed on to me over the years and for always being the pillar of my life at all times. Without them, none of this would be possible.

I would like to thank the Universidad Católica San Antonio de Murcia (UCAM) for providing me with the opportunity to carry out this project, for always receiving me in the best possible way, and for always helping me throughout this journey.

To my supervisor, Professor María Piedad Ramírez Fernández, I want to thank her for her guidance, support, and availability demonstrated during the realization of this work. I thank her for sharing her vast knowledge and experience in the field of research that allowed the completion of this project.

I also want to thank Professor Sílvia Montoro Garcia, for her remarkable availability that she demonstrated from the beginning, always available for all the clarifications and doubts that arose over these four years in order to simplify and facilitate the whole path. I also thank the way she welcomed me, and all the participants in this project.

I would also like to thank the institution that shaped me, for having been my home for the last eight years and for all the opportunities they have been offering me, making me a better professional and person every day. I will be eternally grateful to Egas Moniz School of Health & Science for all the help, training, and support they have provided me since day one.

To my supervisor, Professor Paulo João Bela Teiga de Durão Maurício, I want to thank him for his tireless dedication and motivation that he always demonstrated throughout the entire course. His broad experience, in various areas, made me open horizons, always conveying his precious knowledge over the years and for believing in me to complete this challenge.

To my supervisor, Professor Francisco Eduardo do Nascimento Martins, to whom I owe my deepest gratitude for all the roles he has played throughout my academic and personal life. I thank him for always walking by my side since day one, for believing in me from the beginning, and for never letting me give up. I thank the person responsible for the beginning of this journey and for all his accompaniment throughout it, not only for his teachings and wisdom in moments of doubt, for the tireless persistence, motivation and patience in all difficult moments but also for sharing with me all moments of joy and achievement. I couldn't ask for a better teammate and life partner.

To Professor José Alexandre Reis, for the indispensable help he provided in carrying out the work, both in the theoretical part and in the experimental part. Thank you for always providing insightful perspectives and constructive criticism throughout the entire process, always reminding that not everything in life are problems. His dedication, attention to detail, and enthusiasm for the work were truly inspiring.

I also want to thank the other teachers of the Oral Rehabilitation team at Egas Moniz School of Health & Science, to Professor Sónia Silvério, to Professor Joana Pereira, to Professor Maria João Barreto and to Professor Ana Forjaz, for teaching me their knowledge and values and for accompanying and motivating me throughout the journey.

My sincere thanks to *3M ESPE*, and especially to Professor Elena Cabrera, for the generous sponsorship and supply of most of the materials used in the present work, enabling the correct execution of its experimental part. The quality of their products and their contribution to academic research have allowed for the obtaining of relevant and reliable results. Without their support, this process would not have been possible.

Finally, I would like to thank the brand *VITA Zahnfabrik*, especially Doctor Luis Pinela, for his kind availability that he always demonstrated. I will be eternally grateful for the way he embraced and assisted this project, providing not only part of the ceramics used but also making available the spectrophotometer used in all the measurements made in the present work. His valuable contribution had a significant impact in the academic field, being admirable.

My sincere acknowledgements to all the people mentioned for their guidance, mentorship, and support. Their contributions are immeasurable to my academic journey and for this, I am eternally grateful.

"Tudo vale a pena quando a alma não é pequena".
Fernando Pessoa (1888 - 1935).

GENERAL TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

AT, Acceptability

Al_2O_3, Aluminium oxide

$Al_2Si_2O_5[OH]_4$, Kaolin

a*, CIELAB a* coordinate, green and red scale of colour

a′, CIEDE2000 a′ coordinate, green and red scale of colour

a_1, Initial sample a* value

a_2, Final sample a* value

Bis-EMA, Bisphenol A Ethoxylated Dimethacrylate

Bis-GMA, Bisphenol A-glycidyl methacrylate

b*, CIELAB b* coordinate, blue and yellow scale of colour

b′, CIEDE2000 b′ coordinate, blue and yellow scale of colour

b_1, Initial sample b* value

b_2, Final sample b* value

CAD-CAM, Computer-aided design/ computer-aided manufacturing

CaO, Calcium oxide

CCT, Correlated colour temperature

CIE, *Commission Internationale de l'Eclairage*

CR, Composite resin

C^*_{ab}, CIELAB chroma

C′, CIEDE2000 chroma

$\bar{C}'$, Arithmetic mean of the CIEDE2000 chromas of two-colour stimuli

D, Dentine

D65, CIE standard illuminate, representing midday daylight

G, Switching function used in the modification of a*

HF, Hydrofluoric acid
HO, High opacity
HT, High translucency
h_{ab}, CIELAB hue angle
h', CIEDE2000 hue angle
$\bar{h}'$, Arithmetic mean of the CIEDE2000 hue angles of two-colour stimuli
H_0, Null hypothesis
H_1, Alternative hypothesis
ISO, International Organization for Standardization
IST, Instituto Superior Técnico
$KaISi_3O_8$-$NaAlSi_3O_8$-$CaAl_2Si_2O_8$, Feldspar
k_C, Chroma parametric factor
Kg, Kilograms
k_H, Hue parametric factor
k_L, Lightness parametric factor
K_2O, Potassium oxide
Li_2O, Lithium oxide
LT, Low translucency
lx, Unit of illuminance in the International System of Units (SI)
L^*, CIELAB lightness
L', CIEDE2000 lightness
$\bar{L}'$, Arithmetic mean of the CIEDE2000 lightnesses of two-colour stimuli
L_1, Initial sample lightness
L_2, Final sample lightness
MacOS, Computer operating system for Apple$^{®}$ desktops and laptops
MB, Milky bright
MgO, Magnesium oxide
min., Minutes
mm, Millimetres

MO, Medium opacity

MPa, Megapascal pressure unit

MT, Medium translucency

mw/cm^2, Milliwatts per square centimetre

Na_2O, Sodium oxide

nm, Nanometre

OP, Opaque

PT, Perceptibility

P_2O_5, Phosphorus pentoxide

R_C, Chroma dependence of rotation function

rpm, Rotations per minute

R_T, Rotation function

S_C, Chroma weighting function

S_H, Hue weighting function

SiO_2, Silicon dioxide

S_L, Lightness weighting function

SPSS, Statistics Package for the Social Sciences

T, T-function for hue weighting

TEGMA, Triethylene glycol dimethacrylate

TiO_2, Titanium dioxide

TR, Translucent

UDMA, Urethane dimethacrylate

UV, Ultra-violet

WO, White opaque

ZrO_2, Zirconia dioxide

3D, Three-dimensional

10-MDP, Methacryloyloxydecyl dihydrogen phosphate

°C, Degrees Celsius

μg/cm^2, Microgram per square centimetre

Δa_1, Variation in green and red scale of colour between the composite resin samples and the composite resin samples attached to ceramic with glycerine

Δa_2, Variation in green and red scale of colour between the composite resin samples and the composite resin samples cemented to ceramic using the studied cements

Δa_3, Variation in green and red scale of colour between the composite resin samples attached to ceramic with glycerine and the composite resin samples cemented to ceramic using the studied cements

Δb_1, Variation in blue and yellow colour scale (b^*) between the composite resin samples and the composite resin samples attached to ceramic with glycerine

Δb_2, Variation in blue and yellow colour scale (b^*) between the composite resin samples and the composite resin samples cemented to ceramic using the studied cements

Δb_3, Variation in blue and yellow colour scale (b^*) between the composite resin samples attached to ceramic with glycerine and the composite resin samples cemented to ceramic using the studied cements

ΔC′, CIEDE2000 chroma difference

ΔE, Colour difference

ΔE_{ab}, Colour difference according to CIELab system

ΔE_{ab1}, Colour variation (ΔE_{ab}) between the composite resin samples and the composite resin samples attached to ceramic with glycerine

ΔE_{ab2}, Colour variation (ΔE_{ab}) between the composite resin samples and the composite resin samples cemented to ceramic using the studied cements

ΔE_{ab3}, Colour variation (ΔE_{ab}) between the composite resin samples attached to ceramic with glycerine and the composite resin samples cemented to ceramic using the studied cements

ΔE_{00}, Colour difference according to CIEDE2000 system

ΔE_{001}, Colour variation (ΔE_{00}) between the composite resin samples and the composite resin samples attached to ceramic with glycerine

ΔE_{002}, Colour variation (ΔE_{00}) between the composite resin samples and the composite resin samples cemented to ceramic using the studied cements

ΔE_{003}, Colour variation (ΔE_{00}) between the composite resin samples attached to ceramic with glycerine and the composite resin samples cemented to ceramic using the studied cements

$\Delta h'$, CIEDE2000 hue-angle difference

$\Delta H'$, CIEDE2000 hue difference

$\Delta L'$, CIEDE2000 lightness difference

ΔL_1, Lightness variation between the composite resin samples and the composite resin samples attached to ceramic with glycerine

ΔL_2, Lightness variation between the composite resin samples and the composite resin samples cemented to ceramic using the studied cements

ΔL_3, Lightness variation between the composite resin samples attached to ceramic with glycerine and the composite resin samples cemented to ceramic using the studied cements

$\Delta\theta$, Hue dependence of rotation function

LIST OF FIGURES AND TABLES

LIST OF FIGURES

LIST OF TABLES

I – INTRODUCTION

I - INTRODUCTION

1.1. DENTAL CERAMICS

The word "ceramic" is derived from the Greek word “keramos”, which means pottery. This concept is associated with a Sanskrit term meaning "burned earth" because the foundation of ceramics was heated clays obtained from the earth and used to create ceramic objects (R. Alla, 2013; Rosenblum & Schulman, 1997).

Ceramics is one of the oldest industries in human history, having existed for thousands of years. The discovery of clay as a raw material for the creation of objects was a significant achievement, as it was not only abundant but also malleable. The earliest ceramists shaped clay with water and then fired it to create utilitarian and ornamental objects, which contributed to the emergence of an important industry for the advancement of society (Al-Wahadni, 1999; Kelly & Benetti, 2011).

Ceramics have been used in dentistry for over a century to restore or even replace missing teeth. The addition of leucite in the 1950s allowed the fusing of ceramics to certain gold alloys and the creation of the first complete crowns and partial fixed prostheses (Al-Wahadni, 1999; Kelly & Benetti, 2011). Later, in 1965, John McLean and T.H. Hughes introduced the first all-ceramic restorations by combining feldspathic porcelain with alumina. Due to their fragility, these types of restorations were intended only for anterior teeth (Helvey, 2010).

The ceramic material has become one of the most widely used restorative materials in dentistry today as a result of numerous advancements aimed at developing stronger and more biocompatible materials with enhanced optical properties (Bacchi & Cesar, 2022; Giordano, 2022). They are primarily used in dentistry today for the fabrication of all-ceramic or metal-ceramic crowns, fixed partial dentures, indirect restorations (inlays, overlays, or veneers), certain implant components, and even aesthetically pleasing orthodontic brackets (Babu et al., 2015; Gomes et al., 2008; Ho & Matinlinna, 2011; Matos et al., 2020; S. Sharma et al., 2022).

Ceramics are inorganic, non-metallic materials comprised of compounds such as borides, nitrides, carbides, and metallic oxides (Giordano & McLaren, 2010; McLaren & Figueira, 2015). They are manufactured at high temperatures, followed by the cooling of their initial compounds (McLaren & Figueira, 2015).

There is a mixture of vitreous and crystalline components in dental ceramics. These substances may have a crystalline or partially crystalline structure, exhibiting a periodic arrangement of their atoms, and may exhibit covalent or ionic bonds. Some ceramics may also contain glassy particles, giving them an amorphous structure. Nevertheless, because most ceramics contain at least one crystalline component, some authors restrict the definition of ceramics to crystalline inorganic materials (Giordano, 2022; Giordano & McLaren, 2010; McLaren & Figueira, 2015; Rosenblum & Schulman, 1997).

The greater a ceramic's polycrystalline content, the greater its mechanical strength and abrasion resistance. Conversely, the greater its vitreous content, the greater its translucency and, therefore, its aesthetic result (Kelly & Benetti, 2011). Depending on its clinical application, the relative vitreous or crystalline content of a ceramic can be altered. The addition of crystalline components can improve the restoration's mechanical properties, such as its fracture resistance, but may compromise its aesthetics. Typically, aesthetic restorations in anterior teeth benefit from a ceramic with a higher vitreous content, whereas ceramics used for fixed rehabilitation in posterior teeth benefit from a higher crystalline content, which increases their mechanical strength (Giordano & McLaren, 2010; Ho & Matinlinna, 2011; Matos et al., 2020; Zhang & Kelly, 2017).

Ceramics have variable chemical compositions. Their composition also varies according to their clinical indication and manufacturing method. In general, dental ceramics are composed of metal oxides such as aluminium oxide (Al_2O_3), silicon dioxide (SiO_2), lithium oxide (Li_2O), zirconia dioxide (ZrO_2), titanium dioxide (TiO_2), calcium oxide (CaO), sodium oxide (Na_2O), magnesium oxide (MgO), and potassium oxide (K_2O). In addition, they consist of a combination of non-metallic elements, including silicon, boron, fluorine, and oxygen. Different combinations and proportions of these elements produce ceramics with distinct mechanical and physical properties and, therefore, clinical applications. The presence of metal oxides can alter the ceramic's fracture resistance, translucency, opalescence, and thermal expansion coefficient, among other characteristics (Babu et al., 2015; Gomes et al., 2008; Ho & Matinlinna, 2011; Li et al., 2014).

1.1.1. Classification of dental ceramics

Ceramics have been one of the preferred materials in dentistry for many years, not only for their aesthetic qualities but also for their mechanical properties and biocompatibility. Numerous advancements have been made in the development of ceramics over the years, resulting in an abundance of marketable products (Bacchi & Cesar, 2022; Giordano, 2022; Gracis et al., 2015).

Currently available dental ceramics vary in chemical composition, microstructure, fabrication method, and clinical application (Giordano, 2022). The unique properties of each type of ceramic can affect its tensile strength, colour stability, and marginal adaptation, among other factors, and thus its long-term clinical success (Ho & Matinlinna, 2011; Matos et al., 2020).

It becomes necessary to have a classification method for dental ceramics that associates the properties and applicability of each type of material to different clinical situations, allowing the practitioner to select the most suitable material for each clinical scenario. In addition, the classification of ceramics facilitates better communication between professionals and laboratory technicians and is necessary for educational purposes (Giordano, 2022; Gracis et al., 2015; McLaren & Figueira, 2015; Talibi, Kaur, Patanwala, et al., 2022).

Various classifications of ceramics have been developed over time based on their clinical indications, chemical properties, processing techniques, melting temperature, microstructure, translucency, fracture resistance, and abrasiveness, among other characteristics (Anusavice et al., 2013; Giordano & McLaren, 2010; Talibi, Kaur, Patanwala, et al., 2022).

The classification based on microstructure (Figure 1) categorizes ceramics according to the percentage of their glassy or crystalline content. This classification system divides ceramics into four categories (Giordano & McLaren, 2010; Talibi, Kaur, Patanwala, et al., 2022):

1. Glass/silica-based ceramics;
2. Glass-based ceramics with crystalline fillers;
3. Crystal-based ceramics with glass fillers;
4. Polycrystalline ceramics.

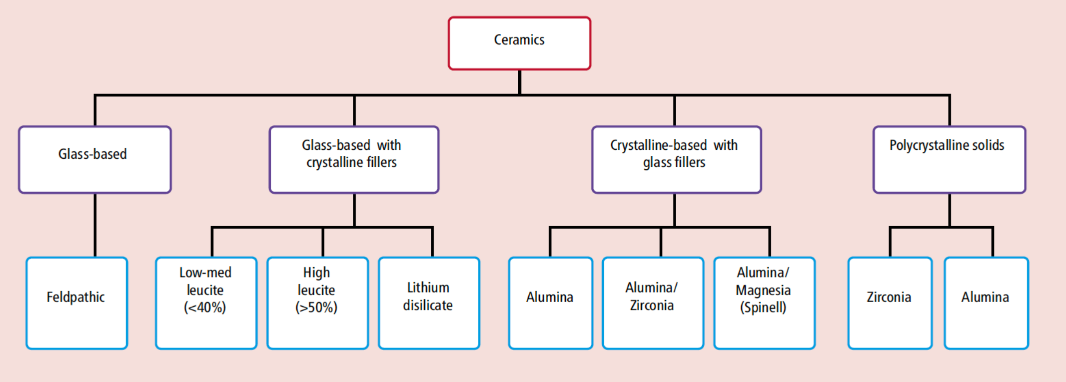


Figure 1. Ceramics classification according to their microstructure
Retrieved from (Talibi, Kaur, Patanwala, et al., 2022)

Ceramics are further subdivided based on their chemical composition (Table 1) into glass-based ceramics and oxide ceramics. Oxide ceramics are crystalline materials with a relatively insignificant glass phase. This final category includes alumina, zirconia, and polycrystalline ceramics (Talibi, Kaur, Patanwala, et al., 2022).

Table 1. Ceramics classification according to their chemical composition

Category		
1: Glass ceramics	Category 1 (a)	Porcelain-based
		Feldspathic porcelain
		Leucite-reinforced porcelain
	Category 1 (b)	Not porcelain-based
		Fluoromica glass
		Lithium ceramics
2: Oxide ceramics	Category 2 (a)	Alumina/ alumina oxide
		Glass-infiltrated alumina
		Densely-sintered alumina
	Category 2 (b)	Zirconia / zirconia oxide
		Glasse-infiltrated zirconia
		Densely-sintered zirconia

Adapted from (Talibi, Kaur, Patanwala, et al., 2022)

According to ISO (*The International Organization for Standardization*), ceramics can also be categorized based on their flexural strength and chemical solubility to organize them into classes according to their clinical indications (Table 2) (International Organization for Standardization [ISO], 2015):

Table 2. Ceramics classification according to ISO 6872:2015 standards

Class	**Recommended clinical indications**	**Mechanical and chemical properties**	
		Flexural strength [MPa]	Chemical solubility [µg/cm^2]
1	a) Monolithic ceramic for single-unit anterior prostheses, veneers, inlays or onlays adhesively cemented.	50	<100
	b) Ceramic for coverage of a metal framework or a ceramic substructure.	50	<100
2	a) Monolithic ceramic for single-unit anterior or posterior prostheses adhesively cemented.	100	<100
	b) Partially or fully covered substructure ceramic for single-unit anterior or posterior prostheses adhesively cemented.	100	<2000
3	a) Monolithic ceramic for single-unit anterior or posterior prostheses and for three-unit prostheses not involving molar restoration adhesively or non- adhesively cemented.	300	<100
	b) Partially or fully covered substructure ceramic for single-unit anterior or posterior prostheses and for three-unit prostheses not involving molar restoration adhesively or non-adhesively cemented.	300	<2000
4	a) Monolithic ceramic for three-unit prostheses involving molar restoration.	500	<100
	b) Partially or fully covered substructure for three-unit prostheses involving molar restoration.	500	<2000

5	Monolithic ceramic for prostheses involving partially or fully covered substructure for four or more units or fully covered substructures for prostheses involving four or more units.	800	<100

Adapted from ISO 6872:2015

Despite the availability of numerous classifications, the classification of ceramics remains a subjective and ambiguous process that varies between authors. However, one of the most popular classifications based on chemical composition is that of Gracis et al. (2015), which divides ceramics into three main groups: glass ceramics, polycrystalline ceramics, and resin-matrix ceramics (Figure 2) (Gracis et al., 2015; Matos et al., 2020).

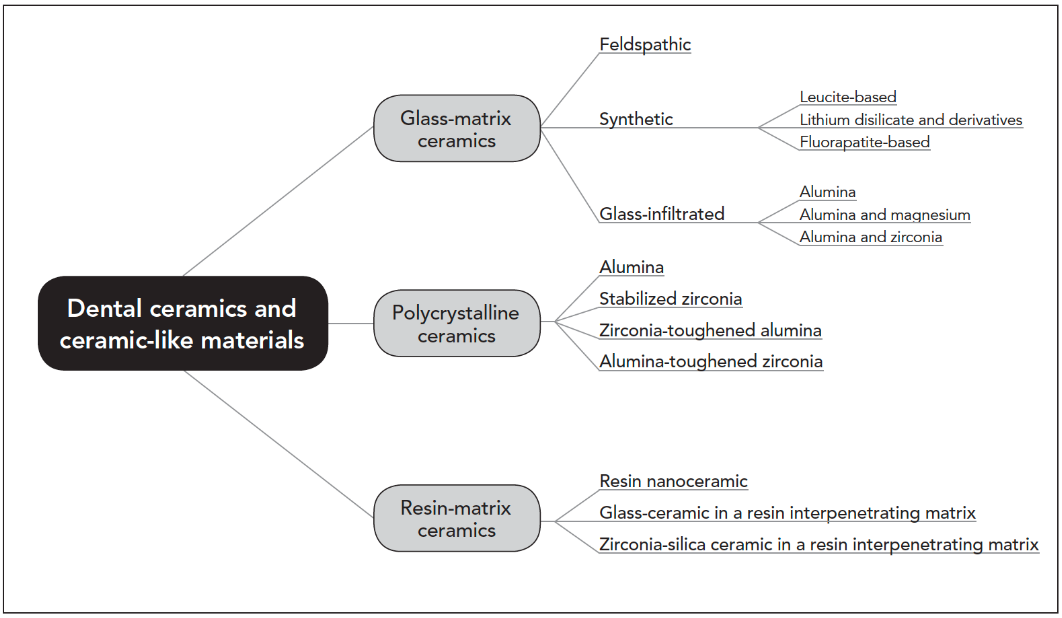


Figure 2. Gracis et al. (2015) classification according to chemical composition

Retrieved from (Gracis et al., 2015)

The chemical composition-based classification of ceramics is based on the presence or absence of glassy content and organic matrix. Ceramics with a glassy matrix consist of non-metallic, inorganic materials with a glass phase. The group of polycrystalline ceramics must also contain inorganic substances, but no glass phase. Lastly, the group of resin matrix ceramics must have a polymeric matrix with organic refractory compounds predominating (Gracis et al., 2015; Matos et al., 2020).

1.1.1.1. ***Glass ceramics***

Glass ceramics are inorganic, non-metallic substances that consist of a functional crystalline phase and a residual glassy phase (Deubener et al., 2018). This category consists of feldspathic, synthetic, and glass-infiltrated ceramics (Gracis et al., 2015).

This category of ceramics consists primarily of aluminium oxide (alumina) and silicon dioxide (silica or quartz). Natural aluminosilicates, also known as feldspars, contain varying amounts of sodium and potassium and are modified to create the glasses used in contemporary dentistry (Giordano & McLaren, 2010).

The mechanical and physical properties of these materials include resistance to bending, fracture, corrosion, and thermal shock. The amount and dimensions of their crystals, as well as the interaction between their crystal matrix and glass phase, are responsible for these properties. Typically, finer crystals produce stronger materials (Giordano & McLaren, 2010).

In terms of their optical properties, this group of ceramics can exhibit greater opacity or translucence, depending on their chemical composition and crystalline content percentage (Giordano & McLaren, 2010).

1.1.1.1.1. Feldspathic ceramics

In dentistry, feldspathic ceramics were introduced around 1723 (S. Chu & Ahmad, 2005). This type of ceramics is predominantly composed of silica (SiO_2), kaolin ($Al_2Si_2O_5[OH]_4$), and feldspar ($KaISi_3O_8$-$NaAlSi_3O_8$-$CaAl_2Si_2O_8$), a combination of potassium and sodium, but also contains metal oxides that affect the physical and optical properties of the ceramic (Babu et al., 2015; Gracis et al., 2015; Talibi, Kaur, & Parmar, 2022a).

Kaolin is a hydrated aluminium silicate used to bind ceramic particles. Due to its opacity, however, its quantity must be restricted lest it affect the optical properties of the restoration. Typically, this compound is employed in low concentrations (less than 4%). After sintering, the ceramic is organized in a glassy matrix of silica incorporated into a crystalline core containing particles of silica and silicates that are subsequently reduced to a powder (Babu et al., 2015; Ho & Matinlinna, 2011).

The silica, in the form of quartz, fortifies the ceramic structure and does not change during the firing process, thereby limiting its shrinkage. It contributes to the translucency and crystalline phase of dental ceramics, of which it comprises 15 percent (Ho & Matinlinna, 2011).

Feldspar is a crystalline mineral that can be found in nature in rocks from a variety of geographic locations, or it can be produced synthetically, with all of its structural impurities eliminated to improve its aesthetics (Babu et al., 2015).

During the ceramic's sintering process, feldspar subdivides into a glassy phase and a crystalline phase, producing leucite crystals (Matos et al., 2020). Leucite imparts strength to the ceramic and defines its thermal expansion coefficient. Nonetheless, the amount of leucite crystals in this type of ceramics is insufficient to provide exceptional mechanical strength (Ho & Matinlinna, 2011).

This category of ceramics is predominately composed of a glassy phase, resulting in greater translucency, excellent aesthetics, and colour stability (Federizzi et al., 2016). However, they lack crystalline structure and tend to be more fragile (Babu et al., 2015; Talibi, Kaur, & Parmar, 2022a).

As this is an optical property of natural teeth, the high translucency of ceramics creates an aesthetically pleasing result, allowing for a greater transmission of light (Bacchi & Cesar, 2022; Joiner, 2004). Its thickness is also crucial, as it can affect light transmission and its ability to conceal the substrate's colour (Federizzi et al., 2016; Sari et al., 2018).

In fact, feldspathic ceramics are renowned for their fragility. During the chewing process, tension and shear stresses can develop and, over time, result in the formation of microcracks in the ceramic. These cracks can even lead to the fracture of the ceramic, thereby risking the restoration (Babu et al., 2015). In comparison to other types of ceramics, the flexural and fracture resistance of these materials ranges between 55 and 87 MPa (Byeon & Song, 2018).

Resin cements have been used to prevent the propagation of these microcracks, thereby increasing the fracture resistance of the ceramic restorations (Federizzi et al., 2016; Talibi, Kaur, & Parmar, 2022a).

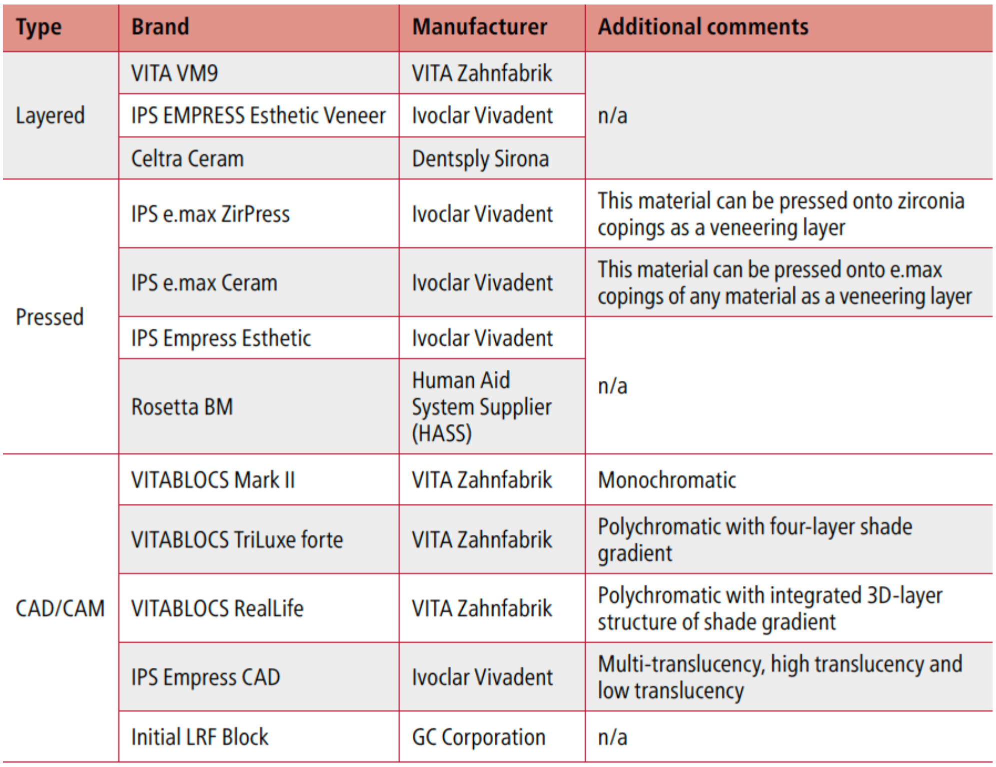
Nevertheless, feldspathic ceramics are not recommended for posterior restorations or those subjected to high masticatory forces due to their inadequate mechanical strength (Byeon & Song, 2018; Talibi, Kaur, & Parmar, 2022a). In addition to their location, it is important to consider their use in cases of deep bite and to avoid placing ceramic restorations in areas without support or where tooth enamel adhesion is not achieved. They are also not recommended when the goal is to mask the colour of the underlying tooth (Babu et al., 2015; Talibi, Kaur, & Parmar, 2022a).

However, this type of ceramic restorations is widely employed in the aesthetic restoration of anterior teeth, primarily in veneers, but also inlays and onlays (Byeon & Song, 2018; Giordano, 2022; Mizrahi, 2008). Additionally, they are used as a coating for metallic or other ceramic substrates (Gracis et al., 2015).

Feldspathic ceramics are recommended for veneer cases requiring a change in dental anatomy and a slight change in tooth colour, with minimal tooth wear (Federizzi et al., 2016).

There are numerous types of feldspathic ceramics on the market, each with distinct characteristics, manufacturing processes, and optical properties. The selection of each depends on clinical indications and the preference of the dental professional. Table 3 depicts the principal brands currently available on the market (Talibi, Kaur, & Parmar, 2022a).

Table 3. Main feldspathic ceramic brands available on the market



Type	Brand	Manufacturer	Additional comments
Layered	VITA VM9	VITA Zahnfabrik	n/a
	IPS EMPRESS Esthetic Veneer	Ivoclar Vivadent	
	Celtra Ceram	Dentsply Sirona	
Pressed	IPS e.max ZirPress	Ivoclar Vivadent	This material can be pressed onto zirconia copings as a veneering layer
	IPS e.max Ceram	Ivoclar Vivadent	This material can be pressed onto e.max copings of any material as a veneering layer
	IPS Empress Esthetic	Ivoclar Vivadent	n/a
	Rosetta BM	Human Aid System Supplier (HASS)	
CAD/CAM	VITABLOCS Mark II	VITA Zahnfabrik	Monochromatic
	VITABLOCS TriLuxe forte	VITA Zahnfabrik	Polychromatic with four-layer shade gradient
	VITABLOCS RealLife	VITA Zahnfabrik	Polychromatic with integrated 3D-layer structure of shade gradient
	IPS Empress CAD	Ivoclar Vivadent	Multi-translucency, high translucency and low translucency
	Initial LRF Block	GC Corporation	n/a

Retrieved from (Talibi, Kaur, & Parmar, 2022a)

Despite not having the same physical and mechanical properties as other types of ceramics, feldspathic ceramics are still a valuable option due to their optical properties. This type of ceramics can provide the patient with satisfactory results and should not be ruled out as a treatment option (Talibi, Kaur, & Parmar, 2022a).

1.1.1.1.2. Synthetic ceramics

Synthetic ceramics emerge as a potential substitute to the use of natural resources in the ceramics industry, with synthetic materials taking precedence

(Gracis et al., 2015). This group includes leucite-reinforced and lithium disilicate-based ceramics.

These materials can be manufactured via pressing or milling (CAD/CAM) (Giordano & McLaren, 2010; Gracis et al., 2015; Ho & Matinlinna, 2011). Depending on the manufacturer, these ceramics typically contain silicon dioxide, potassium oxide, sodium oxide, and aluminium oxide. In addition to being associated with leucite, their glassy phases can also be combined with apatite to increase thermal expansion and resistance when bonded to metals (Gracis et al., 2015).

As leucite-reinforced ceramics were developed in 1990 and incorporate 45 percent of this material into their composition, they are considered to be relatively new. Leucite imparts greater flexural strength and modifies the ceramic material's thermal expansion coefficient, thereby enhancing its strength. Due to their high translucency, these ceramics are highly aesthetic and suitable for veneers, anterior restorations, and some posterior ones (Ho & Matinlinna, 2011; McLaren & Figueira, 2015).

This material is available in a range of translucencies (high and low), expanding the options for reproducing the structure of the adjacent tooth and enhancing the ability to mask discoloured substrates by reducing light transmission through the low translucency restorative material (Bacchi & Cesar, 2022).

The *IPS Empress®* (Ivoclar Vivadent, Schaan, Liechtenstein) system, created in 1983, consists of a ceramic reinforced with leucite crystals (35-55%) in the *IPS Empress® I* system or lithium disilicate crystals (60-65%) in the *IPS Empress® II* system (Gomes et al., 2008). In the *IPS Empress® I* system, the ceramic is pressed between 1150 and 1180°C. This system permits the fabrication of ceramic veneers, inlays, onlays, and crowns for anterior and posterior teeth (Conrad et al., 2007; Gomes et al., 2008).

The lithium disilicate-based ceramics were introduced by *Ivoclar Vivadent* in 1988 (Kaur et al., 2022a; Lien et al., 2015). They consist of approximately 70% lithium disilicate in the crystalline phase, resulting in a highly filled glass matrix that provides greater flexural and fracture resistance than leucite-reinforced ceramics. The combination of an increase in crystalline content and a decrease in crystal size increases the material's translucency (Giordano & McLaren, 2010; Ho &

Matinlinna, 2011; Noda et al., 2017). The nanoscale structure of the crystals, such as their density and size, can also regulate the various translucency options. Various hues and opacities that are suited to particular circumstances can be achieved by employing various processing techniques (Kaur et al., 2022a).

The primary components of lithium disilicate ceramics are quartz (SiO_2), lithium oxide (Li_2O), phosphorus pentoxide (P_2O_5), alumina (Al_2O_3), potassium oxide (K_2O), and colorants. Phosphorus pentoxide is the principal substance that promotes the volume nucleation of lithium silicate stages (P_2O_5). When crystals nucleate and grow throughout a glass, volume crystallization occurs. The crystallization of lithium disilicate is heterogeneous, which means that, depending on the desired product (milling block or pressable ingot), its sintering can be achieved via two distinct processing techniques (Shen & Kosmac, 2013).

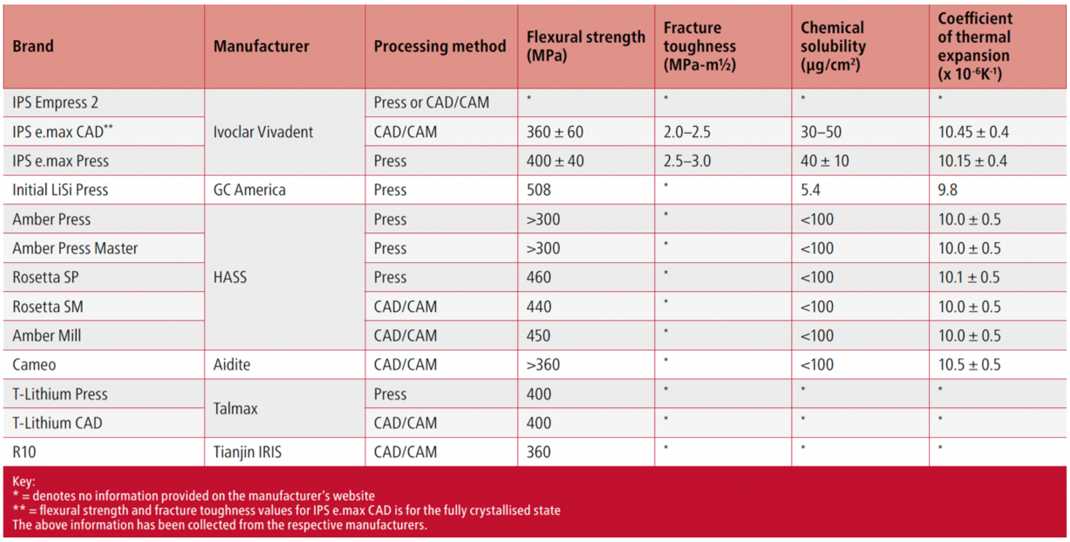
Lithium disilicate products are renowned for their versatility and superior mechanical properties, which enables their use in functionally demanding posterior areas. In addition, their translucency and different shades are adjustable, unlike the more fragile feldspathic ceramics. This type of ceramics has enhanced optical properties, structural strength, and chemical stability, making them an excellent clinical option for indirect restorations (Bacchi & Cesar, 2022; Kaur et al., 2022a).

However, these products are typically not suggested for extremely deep subgingival preparations in patients with bruxism or severely diminished dentition (Kaur et al., 2022a).

Due to their adequate biomechanical properties, this class of ceramics is recommended for veneers, inlays, onlays, overlays, endocrowns, partial crowns, anterior and posterior crowns, implant-supported crowns, and fully ceramic bridges (Ho & Matinlinna, 2011; Kaur et al., 2022a; Li et al., 2014). However, this type of ceramic is not considered to be the most aesthetically pleasing, and in cases with high aesthetic requirements, it is recommended to use it for the production of internal structures due to its high strength, whereas feldspathic ceramics are used to coat the restoration (Ho & Matinlinna, 2011).

There are numerous brands of lithium disilicate ceramics on the market, each with distinct properties such as bending strength, chemical solubility, and processing techniques (Kaur et al., 2022a). Some of these brands can be found in Table 4.

Table 4. Principal lithium disilicate ceramic brands available on the market



Brand	Manufacturer	Processing method	Flexural strength (MPa)	Fracture toughness (MPa-m½)	Chemical solubility (μg/cm^2)	Coefficient of thermal expansion (x 10^{-6}K^{-1})
IPS Empress 2	Ivoclar Vivadent	Press or CAD/CAM	*	*	*	*
IPS e.max CAD**		CAD/CAM	360 ± 60	2.0–2.5	30–50	10.45 ± 0.4
IPS e.max Press		Press	400 ± 40	2.5–3.0	40 ± 10	10.15 ± 0.4
Initial LiSi Press	GC America	Press	508	*	5.4	9.8
Amber Press	HASS	Press	>300	*	<100	10.0 ± 0.5
Amber Press Master		Press	>300	*	<100	10.0 ± 0.5
Rosetta SP		Press	460	*	<100	10.1 ± 0.5
Rosetta SM		CAD/CAM	440	*	<100	10.0 ± 0.5
Amber Mill		CAD/CAM	450	*	<100	10.0 ± 0.5
Cameo	Aidite	CAD/CAM	>360	*	<100	10.5 ± 0.5
T-Lithium Press	Talmax	Press	400	*	*	*
T-Lithium CAD		CAD/CAM	400	*	*	*
R10	Tianjin IRIS	CAD/CAM	360	*	*	*

Key:
* = denotes no information provided on the manufacturer's website
** = flexural strength and fracture toughness values for IPS e.max CAD is for the fully crystallised state
The above information has been collected from the respective manufacturers.

Retrieved from (Kaur et al., 2022a)

In the *IPS Empress® II system* (Ivoclar Vivadent, Schaan, Liechtenstein), the ceramic is injected under high pressure at a temperature between 880 and 920°C into a lost-wax investment mould, thereby reducing the issue of shrinkage during firing. This system is appropriate for the fabrication of anterior three-unit fixed partial dentures that can be extended to the second premolar (Conrad et al., 2007; Gomes et al., 2008).

Subsequently, the IPS e.max® line system (Ivoclar Vivadent, Schaan, Liechtenstein) replaced the prior system and was introduced in two versions: *IPS e.max® CAD* and *IPS e.max® Press*. The former is a block that can be machined using a CAD/CAM system, while the latter is an ingot used to create pressed crowns using the lost wax method (Willard & Chu, 2018).

As an evolution of *IPS Empress® II*, the *IPS e.max® Press* system (Ivoclar Vivadent, Schaan, Liechtenstein) was introduced in 2005. This material is also composed of pressed glass ceramic with lithium disilicate, but its translucency and physical properties are enhanced through a different firing process, with fewer material defects and a more uniform crystal distribution (Conrad et al., 2007; Willard & Chu, 2018).

With the development of digital and computer-assisted dentistry, *Ivoclar Vivadent* introduced the *IPS e.max® CAD* system in 2006, specially prepared for CAD/CAM use. The material has an initial bluish/purplish shade and is primarily composed of lithium metasilicate, making it easier to cut. After milling, the material is subjected to heat treatment and vitrification, resulting in the restoration's final colour. It is also possible to modify the piece's shade and pigmentation, approaching the aesthetics of a natural tooth (Li et al., 2014; Willard & Chu, 2018).

The *IPS e.max® CAD* system is indicated for veneers, inlays, onlays, anterior and posterior fixed partial dentures with three units, and partial or complete crowns. Several authors include monolithic crowns as well (McLaren & Figueira, 2015; Willard & Chu, 2018).

Except for the multi-range, *IPS e.max® CAD* blocks have comparable levels of translucency to *IPS e.max® Press*. There are currently four levels of brightness and the A-D spectrum of colours available. It is essential to recognize that different colours and translucencies are more suitable for particular clinical situations. The choice between these various options is largely determined by the preparation and technique used to ensure a harmonious combination with adjacent teeth or restorations (Kaur et al., 2022a).

Therefore, the numerous benefits of lithium disilicate ceramics make them an attractive option in dentistry. Among these benefits, their superior mechanical strength, which allows them to be used in areas with a greater functional load, as well as their adjustable translucency and variety of shades, which allow for a better aesthetic match with adjacent teeth, stand out. In addition, compatibility with CAD/CAM systems improves the accuracy and productivity of restoration fabrication. Together, these qualities make lithium disilicate ceramics a dependable and aesthetically pleasing option for a vast array of clinical applications (Giordano, 2022; Gracis et al., 2015; Kaur et al., 2022a).

1.1.1.1.3. Glass-infiltrated ceramics

This group includes ceramics containing alumina, zirconia, and alumina, or alumina and magnesium infiltrated with glass. The glassy phase of lanthanum oxide permeates the porous matrix of this type of ceramic, which is composed of approximately 85% alumina. This dense interaction between materials enhances the ceramic's fracture resistance (Gracis et al., 2015; Ho & Matinlinna, 2011).

Their clinical applications include anterior crown structures, posterior single crowns, and posterior bridges with less extensive coverage (Ho & Matinlinna, 2011; Li et al., 2014). Due to their high opacity in aesthetic areas, feldspathic ceramics are sometimes required to cover the restoration (Gracis et al., 2015; Kaur et al., 2022b).

In 1989, *In-Ceram Alumina* system (VITA Zahnfabrik, Bad Säckingen, Germany) was introduced for alumina-based ceramics indicated for anterior restorations, single-unit implant coatings, and three-unit fixed partial dentures (Kaur et al., 2022b). Consequently, the *In-Ceram Zirconia* system (VITA Zahnfabrik, Bad Säckingen, Germany) was developed as a modification of the *In-Ceram Alumina* system, with the addition of partially stabilized zirconia oxide (35%) to reinforce the ceramic (Bacchi & Cesar, 2022; Conrad et al., 2007; Giordano, 2022; Gracis et al., 2015).

Later, in 1994, the *In-Ceram Spinell* system (VITA Zahnfabrik, Bad Säckingen, Germany) was introduced with the intention of increasing the ceramic's translucency. Composed of alumina and magnesium, this system enables the fabrication of inlays and anterior crowns (Conrad et al., 2007; Kaur et al., 2022b).

Survival and strength of glass-infiltrated alumina are highly dependent on design and material selection (Kaur et al., 2022b).

1.1.1.2. ***Polycrystalline ceramics***

Polycrystalline ceramics are inorganic, non-metallic substances without the presence of a glass phase. This category includes alumina and zirconia-based ceramics. Their crystals are arranged in a dense network, resulting in excellent mechanical properties but limited transparency. The lack of a glass phase prevents hydrofluoric acid from etching these ceramics (Gracis et al., 2015; Li et al., 2014).

The inherent opacity of this group of ceramics restrains their use in anterior regions, and they are typically recommended for the fabrication of crown and bridge structures in posterior regions. The piece should also be coated with feldspathic ceramic to improve its aesthetics (Li et al., 2014).

In 1993, the *Procera AllCeram®* (Nobel Biocare AB, Goteborg, Switzerland) was the first CAD/CAM-based polycrystalline ceramic system to be introduced to the market (Conrad et al., 2007; Giordano & McLaren, 2010). This material is composed of a base of nearly pure alumina (99,9 %), which is typically coated with feldspathic ceramic and possesses high hardness, resistance, and elasticity modulus (Gracis et al., 2015; Kaur et al., 2022b).

Both anterior and posterior teeth can be restored with *Procera AllCeram®*. The presence of metal cores and pins does not detract from the aesthetics of the product. Poor oral hygiene, atypical occlusal loads such as night-time bruxism, and lack of sufficient coronal tooth tissue for retention and resistance are contraindications for *In-Ceram* systems, as they are for the majority of all-ceramic materials. Despite its flexural strength and fracture toughness, this product is primarily indicated for single-unit restorations, as the current system is incapable of compensating for the complex shrinkage necessary for multi-unit prostheses (Kaur et al., 2022b; Naji et al., 2018).

Techceram (Techceram Ltd., Baildon, UK) is another commercially available ceramic system that provides alumina in a nearly pure form (Helvey, 2010; Kaur et al., 2022b).

Alumina's desirable and advantageous properties make it an excellent ceramic material for use in clinical settings where it is appropriate. However, due to a number of factors, its popularity among clinicians and laboratories has declined over time. First, because the material is more opaque than other ceramic systems, such as lithium disilicate, its aesthetics are inferior. In addition, its biaxial flexural strength is inferior to that of its solid polycrystalline counterpart, zirconia. However, with the proper dentist, patient, and laboratory, alumina can be a very useful dental material with long-term success (Y.-M. Chen et al., 2008; Kaur et al., 2022b).

Zirconia ceramics are mechanically more effective than alumina ceramics due to their exceptional dimensional stability, high fracture resistance, and excellent mechanical strength (Conrad et al., 2007; Giordano & McLaren, 2010; Noda et al., 2017).

Widely used by health professionals, the term zirconia refers to the crystalline dioxide of the metal zirconium. In dentistry, zirconia is commonly used to create indirect restorations that are aesthetically pleasing. It is the ceramic material of first choice for posterior indirect restorations, while layered zirconia is the ceramic material of second choice for anterior indirect restorations (Makhija et al., 2016; Talibi, Kaur, & Parmar, 2022b).

Zirconia is a polycrystalline ceramic that lacks a vitreous matrix and is entirely crystalline. Zirconia behaves as a polymorphic material, resulting in three different crystalline forms: monoclinic, tetragonal, and cubic. This means that temperature can cause the material to exist in different structural forms, each with different physical and chemical properties (Giordano, 2022; Giordano & McLaren, 2010; Gracis et al., 2015; Li et al., 2014). During the transformation of zirconia from the tetragonal phase to the monoclinic phase (phase transformation), a shear deformation with a 4% increase in volume occurs. Increased volume has the capacity to close fissures, thereby enhancing fracture resistance. This phenomenon, known as transformation toughening, can be advantageous for restorative dentistry from a clinical standpoint (Gracis et al., 2015).

Various zirconia-based ceramics are currently available on the market, such as fully sintered, partially sintered, unsintered, pure zirconia, pre-coloured zirconia, multi-layered, and extra multi-layered. Frequently, the choice of brand reflects the restoration's specifications (Burgess, 2018; Talibi, Kaur, & Parmar, 2022b).

Zirconias can also be classified according to their molar percentage of yttrium oxide, which in dentistry corresponds to 3% (first generation), 4% (second generation), and 5% (third generation), with the grain size influencing their physical and mechanical properties (Burgess, 2018; Talibi, Kaur, & Parmar, 2022b).

First generation zirconias provide strong and opaque restorations, such as the low translucency (LT) and medium opacity (MO) *IPS e.max® ZirCAD* (Ivoclar Vivadent, Schaan, Liechtenstein) and *Lava™ Plus* (3M ESPE, MN, USA), which are utilized more frequently in posterior restorations. Second-generation zirconias permit more translucent restorations, such as the medium translucency (MT) *IPS e.max® ZirCAD* (Ivoclar Vivadent, Schaan, Liechtenstein) and the ultra-translucent *Katana* (Kuraray Noritake). The most translucent restorations are possible with third-generation ceramics, such as *IPS e.max® ZirCAD* multi-translucency (Ivoclar Vivadent, Schaan, Liechtenstein) and *Lava™ Esthetic* (3M ESPE, MN, USA) (Bacchi & Cesar, 2022; Burgess, 2018; Talibi, Kaur, & Parmar, 2022b).

In the case of anterior restorations, such as veneers, zirconias are not recommended because other materials produce a more aesthetically pleasing result. However, the majority of zirconia restorations are capable of masking their substrate, which can be useful when an aesthetically compromised tooth requires a restoration (Talibi, Kaur, & Parmar, 2022b).

However, zirconia has evolved significantly over the years to achieve its current properties. No material can be deemed superior, but each has particular applications for which it is superior. As constant research is conducted, it is inevitable that these ceramics and their properties will continue to evolve (Talibi, Kaur, & Parmar, 2022b).

1.1.1.3. ***Resin-matrix ceramics***

Resin-matrix ceramics consist of a polymeric matrix, which is typically reinforced with inorganic ceramic particles, and offer a unique combination of physical, mechanical, and aesthetic properties. This group is specially manufactured using the CAD/CAM system (Gracis et al., 2015).

These materials have been developed in recent years to combine the properties of traditional ceramics and composite resins. They offer advantages in terms of aesthetics, due to their hybrid composition, which allows them to mimic the appearance of natural teeth, including their translucency, colour, and texture, as well as in terms of strength and durability, due to the addition of ceramic particles, flexibility, due to the resin matrix, allowing for better adaptation to occlusal forces, lower abrasiveness, resulting in less wear on adjacent structures, and ease of fabrication, as the resin matrix facilitates the CAD/CAM machining process (Çelik et al., 2018; Gracis et al., 2015). The elastic modulus of dentin alters the stress distribution of resin matrix ceramics, making them safer for cutting than glass or polycrystalline ceramics (Çelik et al., 2018).

Currently, *Lava™ Ultimate* (3M ESPE, MN, USA), *Vita Enamic®* (VITA Zahnfabrik, Bad Säckingen, Germany), and *Cerasmart®* (GC Corporation) are some of the market-available materials. Indications for these materials include direct and indirect restorations, crowns, inlays, onlays, and veneers (Çelik et al., 2018; Gracis et al., 2015).

It is important to note that, despite the fact that resin matrix ceramics offer numerous benefits, they also have some limitations. For instance, the fracture resistance of these materials is occasionally inferior to that of conventional ceramics, and their long-term performance must still be evaluated (Araujo & Perdigão, 2021).

1.1.2. Ceramic processing techniques

In recent years, the manufacturing techniques for dental ceramics have progressed exponentially, keeping pace with technological advances. The development of computerized systems and the emergence of new microstructures for ceramic materials have significantly altered the production of ceramic restorations and the available treatment options for patients. The emergence of the CAD-CAM (computer-aided design/ computer-aided manufacturing) technique is largely responsible for this transformation (L. H. da Silva et al., 2017).

In dentistry, ceramics are processed through a series of steps in order to produce ceramic restorations with high precision, quality, and esthetic appeal. Depending on the type of ceramic desired, there are a variety of techniques, each with its own advantages and disadvantages (L. H. da Silva et al., 2017; Talibi, Kaur, Patanwala, et al., 2022).

Currently, the condensation technique, the hot isostatic pressing technique, and the computer-assisted milling technique are the most popular processes (Talibi, Kaur, Patanwala, et al., 2022).

Regardless of the fabrication technique employed, it is essential that the ceramic is correctly processed to ensure its long-term clinical success. The technique chosen depends on the uniqueness of each patient, the type of ceramic selected, the dentist's and prosthetic technician's skills, and the type of ceramic used (Talibi, Kaur, Patanwala, et al., 2022; Warreth & Elkareimi, 2020).

*1.1.2.1. **Condensation technique***

In the condensation technique, which is also known as the conventional or stratification technique, ceramic powder and liquid are mixed by hand to create a paste. Typically, the manufacturer supplies the liquid, but deionized water can also be used. The obtained paste is used to manually construct the restoration using a matrix, and excess liquid is removed by vibration to prevent the formation of air bubbles that could weaken the piece. The residual humidity is then eliminated through a sintering process, which involves heating the piece in a vacuum at a high temperature. The constituent particles of the ceramic fuse at their contact points during the sintering process, resulting in a denser and more aesthetically pleasing material (L. H. da Silva et al., 2017; Talibi, Kaur, Patanwala, et al., 2022; Warreth & Elkareimi, 2020).

For this technique to be successful, the powder and liquid mixture must be as homogeneous as possible to ensure a good consistency and mechanical properties suitable for ceramic restoration (Talibi, Kaur, Patanwala, et al., 2022).

This technique is widely used to produce a variety of ceramic restorations, and its benefits include excellent aesthetics, marginal adaptation, and mechanical strength. However, this technique requires a high level of dental technician skill to achieve accurate and functional results (L. H. da Silva et al., 2017).

*1.1.2.2. **Hot isostatic pressing technique***

The pressing technique is one of the most popular because it permits the creation of a variety of ceramic restorations, including inlays, onlays, crowns, and veneers. However, this method is more detailed and requires more modern materials and equipment, resulting in higher expenses. In addition, the technique is more time-consuming and requires the technician to possess skill and experience (Talibi, Kaur, Patanwala, et al., 2022).

This process involves applying high temperatures to a prefabricated ceramic ingot while simultaneously applying external pressure, allowing it to flow into a preformed mould and acquire its shape. This method is comparable to the conventional lost wax method (Giordano & McLaren, 2010; Talibi, Kaur, Patanwala, et al., 2022).

A precise wax model of the restoration to be created is used to create the mould, which is then immediately inserted into a phosphate-bound refractory material. Next, the wax is melted to create an empty restoration mould. The selected ceramic ingot is then heated and pressed into the mould under vacuum, filling the void and creating the restoration (Giordano & McLaren, 2010; Talibi, Kaur, Patanwala, et al., 2022; Warreth & Elkareimi, 2020).

At the final point of this procedure, the piece can be pigmented and glazed to replicate the aesthetic appearance of natural teeth as near as possible (Giordano & McLaren, 2010).

1.1.2.3. ***Computer-assisted milling technique***

The computer-aided milling technique utilizing CAD-CAM entails the printing, design, and production of indirect restorations from an automated subtractive cutting process of a prefabricated ceramic block using 3D moulding software. It is currently one of the most highly regarded techniques because it permits the production of ceramic restorations with high precision and fineness (Li et al., 2014; L. H. da Silva et al., 2017; Warreth & Elkareimi, 2020).

Using an intra-oral scanner, the first step involves the digitization of the dental preparation and surrounding tissues in the mouth or on the plaster model. Next, a 3D design application is used to create a digital model of the restoration that is requested. The obtained model is then sent to the milling machine, which, under computer control and guidance, creates the idealized piece from a prefabricated ceramic block. At the conclusion of the sequence, the piece undergoes a finishing process, which may include sintering, pigmentation, and/or glazing in order to meet the aesthetic requirements (Baroudi & Ibraheem, 2015; Giordano & McLaren, 2010; Talibi, Kaur, Patanwala, et al., 2022).

Ceramic blocks designed for the CAD-CAM system are extensively available on the market for a variety of ceramic types and different shades. These blocks can be fully or partially sintered (Gracis et al., 2015; Li et al., 2014; Warreth & Elkareimi, 2020).

The milling machine consists of specialized drills that cut the material to the desired specifications. The high-speed rotation of the drills generates heat, which can damage the ceramic; therefore, it is essential to use water to prevent excessive heat of the cutting tool and the ceramic block. However, there are "wet" and "dry" milling machines, depending on whether or not a cooling or lubricating fluid is used (Pyo et al., 2020).

In wet milling machines, glass-ceramics and hybrid composites can be utilized, whereas zirconia, plaster, composite resins, wax, and fiberglass composites are typically utilized in dry milling machines. This type of milling machine removes material from the cutting surface using compressed air or vacuum (Pyo et al., 2020; Talibi, Kaur, Patanwala, et al., 2022).

This milling method is a more efficient and precise alternative to previous pressing and condensation methods, allowing to produce high-quality restorations in fewer steps and less time. In addition, the milling machine can be programmed to operate overnight without the need for a laboratory technician to be present. Being a computer-controlled procedure, it naturally reduces human error, increasing the pieces' uniformity and precision, and reducing the number of required work repetitions (Poticny & Klim, 2010; Talibi, Kaur, Patanwala, et al., 2022).

In addition, the expense associated with this method is extremely high, necessitating a substantial investment by the dental clinic or laboratory. Another drawback is the need for high-quality intraoral scanning or impressions to ensure a proper marginal fit of the ceramic restoration in the mouth (Baroudi & Ibraheem, 2015; Giordano & McLaren, 2010).

Each health professional is free to select the indirect ceramic restoration technique that best suit their particular needs and resources. However, as the world becomes increasingly automated and digital, dentistry tends to naturally fall into line (Talibi, Kaur, Patanwala, et al., 2022).

1.2. DENTAL CEMENTS

The long-term clinical success of ceramic restorations depends on the cementation procedure, which varies according to the periodontal condition of the patient, the ceramic material and its composition, and the cement used (Heboyan et al., 2023; Soares et al., 2005).

Cements used in dentistry are available in powder, liquid, and, more recently, two pastes. The chemical reaction between powder and liquid is an acid-base reaction in which the liquid is typically the acidic solution (proton donor) and the powder, which contains glass particles and metal oxides, is the basic component. They acquire a paste-like consistency upon mixing, which hardens over a variable period based on the particle size and powder-to-liquid ratio. After setting, the cements have sufficient strength for use (Anusavice et al., 2013).

Cements are predominantly used as luting agents for metal, ceramic, and metal-ceramic crowns, bridges, veneers, inlays, onlays, and overlays in dentistry. They can also be used to cement orthodontic brackets and bands, as well as cores and posts for the retention of restorations. Other applications include pulp protection, cavity liners, pulp isolation, and root canal sealing, as well as fissure sealants containing fluoride and, in some cases, as restorative material (Pameijer, 2012; Ramaraju et al., 2014).

A cementing agent is a substance that promotes adhesion between two surfaces, such as the restorative material and the tooth surface or preparation. The viscosity should be low enough to completely fill the interface between the restoration and dental tissues, securing the restoration effectively. The selection of this material should be based on the unique requirements of each clinical case and a thorough understanding of the market's options (Barbon et al., 2019; Dapieve et al., 2023; Heboyan et al., 2023; Marcondes et al., 2020; Yu et al., 2014).

The primary function of dental cements is to fill the space between the restorative material and the prepared tooth, to hold the restoration in the desired location, to prevent dislodgement during chewing, and to improve aesthetic conditions associated with the indirect restoration (Heintze et al., 2015; Yu et al., 2014). In the context of resin bonding, the luting agent should infiltrate surface defects, seal microcracks, and consequently strengthen the restorative assembly (Rosa et al., 2022).

Ideal dental cement should meet specific physical-mechanical, biological, and handling requirements to ensure the durability of the restoration. In terms of its biological properties, the material must be compatible with soft tissues and dental pulp. Physically, it must have a sufficient thickness to accommodate the restoration, low solubility, a sufficiently long working time to permit the removal of excess, decreased viscosity, and radiopacity. It should have high shear and tensile strength, as well as compression resistance, in terms of its mechanical properties. Regarding handling, it should be simple to combine and clean (Barbon et al., 2019; Dapieve et al., 2023; Heintze et al., 2015; Yu et al., 2014).

Dental cements can be classified based on their chemical composition and clinical applications. They can be categorized as temporary (short-term) or permanent, based on their duration (long-term) (Yu et al., 2014).

Calcium hydroxide cements and zinc oxide eugenol cements, which consist of a mixture of zinc oxide powder and eugenol, are examples of temporary cements (liquid). However, temporary cements, whether with or without eugenol, can alter the tooth surface, affecting the permanent cement's adhesion. However, research indicates that the adhesive strength of self-adhesive resin cement is unaffected using a temporary cement beforehand (Pameijer, 2012; Yu et al., 2014).

There are zinc phosphate cements, zinc polycarboxylate cements, conventional glass ionomer cements, resin-modified glass ionomer cements, and resin cements among the permanent cements (Yu et al., 2014).

Each cementing agent possesses unique biological, mechanical, and physical properties due to its unique chemical structure. As new products are introduced to the market and clinical procedures continue to develop, the selection of dental materials becomes progressively challenging. Therefore, to be successful, the professional must understand the properties, benefits, and drawbacks of each type of dental cement (Ramaraju et al., 2014; Yu et al., 2014).

In current clinical practice, the use of resin cements is growing in popularity. This is not only due to their aesthetics, low solubility, and superior mechanical properties, but also to their versatility (Yu et al., 2014).

1.2.1. Resin cements

In the 1960s, resin-based cements appeared as an alternative to acid-base reaction cements. The constituents of these materials are an organic resinous matrix, inorganic fillers, initiators, and colour adjusters (Fleming & Addison, 2009; Pameijer, 2012; Yu et al., 2014). *Addent* (3M), a chemically polymerizing material based on the Bis-GMA (bisphenol A-glycidyl methacrylate) molecule developed by Dr. Bowen in 1960, was one of the first composites to hit the market in 1964. Since then, composite resins and cements have undergone numerous adjustments (Araujo & Perdigão, 2021). *Biomer*, introduced by Dentsply in 1987, was one of the first cements on the market, a few years after the first composite resin (Fleming & Addison, 2009; Pameijer, 2012; Yu et al., 2014).

Despite recent developments in the dental industry regarding new materials for aesthetic restorations, resin cements continue to be the most conservative and greater option available (Araujo & Perdigão, 2021).

Resin cements are composed primarily of polymers to which elements are added to reduce the thermal expansion coefficient and polymerization shrinkage, thereby increasing the polymers' strength. Polymerization is responsible for the setting of these cements, which consist of dimethacrylates formed by a resin matrix of Bis-GMA (bisphenol A-glycidyl methacrylate) or UDMA (urethane dimethacrylate) and inorganic filler elements. Bis-GMA is a dimethacrylate aromatic ester derived from an epoxy resin and methyl methacrylate. Due to its high viscosity, this molecule is typically combined with a lower viscosity resin, TEGMA (triethylene glycol dimethacrylate), to reduce the cement's viscosity (Fleming & Addison, 2009; Heboyan et al., 2023; Ramaraju et al., 2014; Yu et al., 2014). Depending on their surface treatment and storage method, the mechanical strength of ceramics can be affected by variations in the viscosity of resin cements. The lower viscosity of the cement permits easier penetration into surface irregularities on the ceramic, resulting in a stronger bond (Dapieve et al., 2023).

Manufacturers vary in the amount, type, shape, and size of inorganic fillers added to cements. It is necessary to achieve a balance between the resin and filler components in order to optimize cement handling and thickness, thereby enhancing their mechanical properties and resistance to oral environment-related damage (Barbon et al., 2019; Fleming & Addison, 2009; Heboyan et al., 2023).

Cementation of restorations is typically performed with resin cements because they provide adequate aesthetics, low solubility in relation to oral fluids, high mechanical properties, and a strong interaction between the tooth structure and ceramic restoration, resulting in a favourable clinical outcome (Dede et al., 2017; Kilinc et al., 2011; Yu et al., 2014).

Some resin cements may have cariostatic potential because they contain ytterbium trifluoride or aluminum and barium fluosilicates that are able to release fluoride after application (Yu et al., 2014).

Due to incomplete polymerization, however, this type of cement can undergo chemical alteration and internal discoloration of the restoration, generating residual monomers and oxygen by-products that can cause pulp irritation (Kilinc et al., 2011; Lopes et al., 2015; Pameijer, 2012; Ramaraju et al., 2014).

Due to the adhesive properties of resin cements, the preparation of tooth retention is minimized in restorations that employ resin cements, thereby preserving healthy tooth structure (Tian et al., 2014). Resin cements are available in powder/liquid systems, capsules, and mixable pastes, and are divided into three activation types: self-curing (chemically activated), light-curing (activated by light), and dual-cured (activated chemically and by light). According to the adhesive system, they are also classified as total-etch, self-etch, or self-adhesive (Heboyan et al., 2023; Heintze et al., 2015; Ramaraju et al., 2014; Tian et al., 2014; Yu et al., 2014).

Dual-cure cements are composed of chemical initiators such as benzoyl peroxide and photo initiators such as camphorquinone, resin cements are adapted for polymerization both by chemical action (self-cure) and by light (photo-cure). These materials enable the dentist to control the working time and cement polymerization more precisely, even in areas where light does not reach the cement (Archegas et al., 2011).

Autopolymerizable resin cements are typically used when the restorative material is extremely opaque and/or extremely thick, or in metal crowns where light transmission is difficult. These cements are produced by combining two constituent components, the base and the catalyst. This mixture initiates the polymerization reaction by combining the chemical initiator (benzoyl peroxide) with the activator (tertiary amine) (Fleming & Addison, 2009; Öztürk et al., 2013).

Both photopolymerizable and dual-cure resin cements have advantages over autopolymerizable cements. However, these cements can only be used with thin ceramic veneers and restorations that allow light to pass through the restoration to ensure complete polymerization of the cement (Santos et al., 2010; Yu et al., 2014). They contain photo-initiators (camphorquinones) that bind to the activator (tertiary amine) present in the resin cement when activated by blue light in the visible spectrum. Thus, the polymerization process is initiated by the release of free radicals (Fleming & Addison, 2009; Öztürk et al., 2013). Photopolymerizable cements offer an extended working time and superior colour stability (Santos et al., 2010).

Resin self-adhesive cements were introduced in 2002 to simplify the application of conventional resin cements and have since become one of the most widely used groups of cements.(Yu et al., 2014).

Crowns, inlays, and onlays made entirely of ceramic are the most common dental restorations that utilize auto-adhesive cements. These cements are composed of acrylic or acrylate monomers and adhesive monomers that are sufficiently acidic to generate their own adhesive properties. Their primary benefit is a simplified cementation process, as they do not require a separate adhesive agent (Ferracane et al., 2011; Ramaraju et al., 2014).

Compared to conventional resin cements, auto adhesive cements exhibit less sensitivity after application and superior mechanical performance, such as modulus of elasticity, hardness, flexural strength, and conversion degree. However, due to the presence of aromatic tertiary amines, these materials may discolour over time, affecting the long-term aesthetics of the restoration (Archegas et al., 2011; Yu et al., 2014).

1.2.2. Optical properties of cements

Several factors, including the colour of the underlying tooth, the thickness of the ceramic restoration, and the colour of the cement used, can influence the final aesthetic result of a ceramic restoration (Azer et al., 2011; Rodrigues et al., 2017; Turgut & Bagis, 2013). Other elements, such as manufacturing processes, laboratory procedures, and clinical factors, can also influence the final restoration's colour (Tabatabaian, 2019).

Various types and shades of cements are currently available on the market to improve the aesthetic result of ceramic restorations (Kaur et al., 2022a). In order to achieve an ideal aesthetic result in the cementation of ceramic restorations, it is crucial to choose the type and colour of cement. Long-term clinical success is contingent upon the colour stability of the cement beneath the restoration (Chang et al., 2009; Kilinc et al., 2011).

When light reaches the oral cavity and strikes a restoration, it can be transmitted through the different layers, reflected, or refracted, resulting in variations in colour perception (Tabatabaian, 2019). The remaining tooth structure or restoration's core serves as a background, and its colour is affected by the ceramic material's translucency (Tabatabaian, 2019).

Both the optical properties of the restoration and the substrate can be altered by dental cement. A more translucent ceramic restoration necessitates a more rational selection of cement, which may be transparent or opaque. Opaque cements are utilized to conceal colour changes in discoloured dental remnants, devitalized teeth, or metallic cores, which necessitates an increase in ceramic thickness (Archegas et al., 2011; Chaiyabutr et al., 2011; Tabatabaian, 2019).

As a result of their high aesthetics and excellent mechanical properties, resin cements are commonly used to cement ceramic restorations. They come in a variety of shades, allowing them to mimic the colour of natural teeth (Dede et al., 2017; Pires et al., 2017; Rodrigues et al., 2017; Yu et al., 2014).

Long-term discoloration of the resin cement layer, typically due to degradation of the non-photopolymerized polymer matrix and other external factors, can negatively impact the restoration's final colour. In this instance, cement polymerization must be accurate and complete (Rodrigues et al., 2017; Yu et al., 2014).

1.3. ADHESION TO DENTAL CERAMICS

The bond between the restoration, the cement, and the tooth surface is crucial to the long-term clinical success of ceramic restorations. It is essential to treat the inner surface of the ceramic to promote its adhesion to the resin cement. Due to the different microstructure and chemical composition of contemporary ceramics, however, different bonding procedures may be required for the various ceramic types. The adhesive procedure applied to the tooth surface also plays a crucial role in the ceramic restoration's final stability (Öztürk et al., 2013; Tian et al., 2014).

For the purpose of bonding diverse ceramic restorations, resin cements were introduced. Cementation with resin cements and dental adhesives produces mechanically stronger restorations than other cementation techniques (Spazzin et al., 2016).

Chemical adhesion and micromechanical adhesion are responsible for the bond between cement and ceramic. Conditioning the internal surface of the ceramic with hydrofluoric acid and/or sandblasting promotes micromechanical adhesion, while the addition of a bonding agent results in chemical adhesion (silane) (Tian et al., 2014).

Silane forms chemical bonds, one end to the hydrolysed silicon dioxide on the ceramic surface and the other end, via its methacrylate group, to the cement. The application of silanes decreases the contact angle and increases the wettability of the ceramic surface (Peumans et al., 2000; Tian et al., 2014).

Regarding chemical adhesion methods, hydrofluoric acid is utilized to dissolve the glassy surface of the ceramic, reacting with silica dioxide to increase the ceramic's adhesion area, surface energy, and roughness. This microroughness increases the micromechanical bonding between the ceramic surface and cement. Orthophosphoric acid is also utilized, typically for cleaning the ceramic's internal surface and creating microporosity (Fleming & Addison, 2009; Tian et al., 2014).

The most widely acknowledged cementation process for vitreous ceramics involves applying hydrofluoric acid (HF) to the interior surface of the ceramic, followed by the application of a primer containing silane molecules (El-Damanhoury & Gaintantzopoulou, 2018; Lima et al., 2022; Romanini-Junior et al., 2018). Hydrofluoric acid reveals the crystalline structure of the ceramic by dissolving a portion of its vitreous phase, so producing a rough surface that facilitates micromechanical retention (Li et al., 2014; Lima et al., 2022). Silane is then added to facilitate chemical bonding between the inorganic ceramic particles and the resin cement (Lima et al., 2022; Zaghloul et al., 2014).

Hydrofluoric acid may etch the great majority of glass ceramics, including lithium disilicate and feldspathic ceramics. Due to the structural differences between ceramics, however, the concentration and etching time may vary (Araujo & Perdigão, 2021; Neis et al., 2015).

In an effort to simplify adhesive procedures, universal adhesives have been created. These systems mix monomers with functional chemicals such as silane and 10-MDP (methacryloyloxydecyl dihydrogen phosphate) in a same solution. The objective is to employ a single adhesive to connect materials with distinct chemical structures, such as ceramics and cements, to the tooth structure (Cardenas et al., 2017; Cuevas-Suárez et al., 2020; Lima et al., 2022).

However, there is no consensus in the literature regarding the efficacy of these adhesives in comparison to conventional methods (Araujo & Perdigão, 2021; Guimarães et al., 2018; Lima et al., 2022; Scotti et al., 2017).

Consideration must be given to the fact that ceramics with diverse chemical compositions, microstructures, and vitreous phase contents require different surface treatments. Ceramics containing alumina or zirconia are resistant to hydrofluoric acid conditioning, reducing the effectiveness of resin cementation in these ceramics. Therefore, it is sometimes necessary to master alternative adhesive techniques in order to achieve clinically adequate and durable adhesion (Neis et al., 2015; Santos et al., 2010; Tian et al., 2014).

1.4. OPTICAL PROPERTIES IN DENTISTRY

The colour of teeth is determined by a complex interaction of a number of optical properties. Perception of tooth colour is influenced by light diffraction, lighting environment or source, transparency, opacity, gloss, and visual and brain processing (Joiner, 2004; Joiner & Luo, 2017).

A light source is an object or body that emits electromagnetic radiation in the visible spectrum. A phenomenon referred to as metamerism occurs when several light sources cause distinct colour perceptions (Heymann et al., 2013).

The light source is characterized by its energy distribution over the visible light spectrum's multiple wavelengths. When the incident light reaches the surface of an object, it can have multiple effects, such as light transmission through the tooth, light reflection on its surface, light absorption, and light scattering through the dental tissues. The colour of an object is determined by its spectral reflectance, which is the proportion of incident light reflected at different wavelengths. When light energy reaches the human eye, photoreceptors in the retina convert it into a signal that is then interpreted by the brain (Joiner, 2004; Joiner & Luo, 2017).

Even though daylight is frequently used to determine tooth colour, it varies depending on the time of day, humidity, and pollution levels. However, tooth colour is typically assessed using fluorescent, incandescent, and/or natural light sources (International Commission on Illumination [CIE], 2004; Paravina et al., 2019; Shammas & Krishna Alla, 2011).

Teeth do not have a specific colour; instead, they reflect a certain wavelength from the colour spectrum. Visible light, which is visible to the human eye, has a wavelength between 360 and 780 nanometres (nm) on the visible spectrum (Figure 3) (Joiner & Luo, 2017; Shammas & Krishna Alla, 2011).

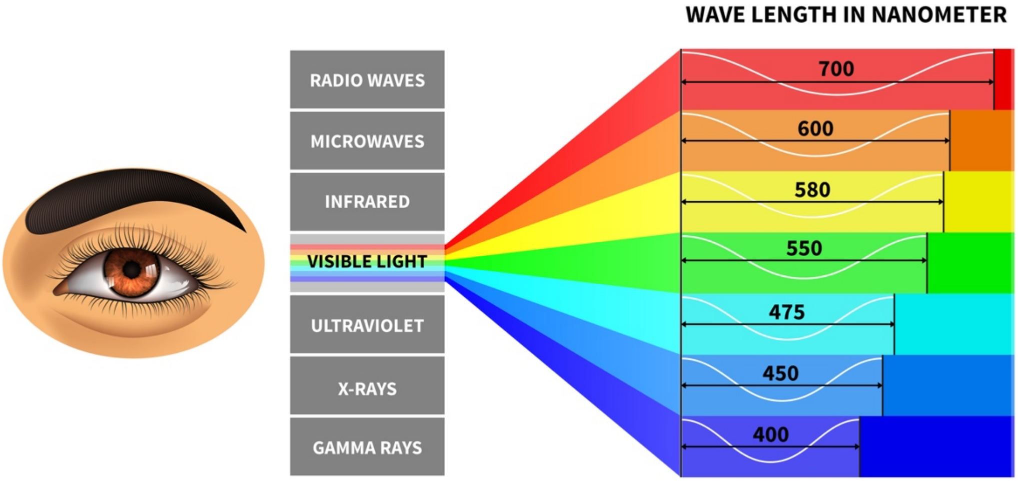


Figure 3. Visible light spectrum

Acquired at: https://www.shutterstock.com/pt/image-vector/visible-light-spectrum-color-waves-length-1240992208

The tooth's colour is determined by the combination of its intrinsic and extrinsic colours. Extrinsic colour is related to the deposition of external components on the surface of the enamel and can be impacted by insufficient brushing, coffee intake, tobacco use, a diet high in coloured foods, and continuous exposure to products containing chlorhexidine (Mortazavi et al., 2014). The intrinsic colour of certain dental structures is related to the absorption and diffusion qualities of light. The colour of the tooth is mostly dictated by the colour of the dentin, whereas the enamel, being more translucent, cannot entirely conceal the colour of the underlying dentin and is responsible for the diffusion of blue wavelengths (Battersby & Battersby, 2015; Joiner, 2004; Joiner & Luo, 2017).

Numerous colour combinations contribute to tooth colour, which varies between individuals and over the course of a person's lifetime, typically displaying a colour gradient from the darker gingival region to the more translucent incisal region. Due to the absence of enamel, root surfaces typically appear darker when they are exposed (Heymann et al., 2013).

The appearance and colour of teeth is one of the primary concerns of patients seeking increasingly demanding aesthetic solutions in the present day. Attempting to imitate the visual qualities of natural teeth with synthetic materials is one of dentistry's greatest obstacles. For excellent long-term aesthetic results, it is essential to comprehend the optical qualities of dental materials used for various types of aesthetic restorations (Alayad et al., 2021; Araujo & Perdigão, 2021; Joiner & Luo, 2017).

Ceramics, among these materials, have an optical behaviour quite similar to those of natural teeth and aim to imitate their aesthetic appearance as closely as possible (Li et al., 2014; Matos et al., 2020). Numerous ceramic systems are currently available on the market and require constant updating by health professionals. However, the aesthetic goal of ceramic restorations is dependent not only on the type of material employed, but also on its proper selection, tooth preparation, resin cement employed, and surface treatments (Günal-Abduljalil & Ulusoy, 2022; Matos et al., 2020). The colour of the underlying tooth or the base where the ceramic restoration will be placed, as well as the cement utilized, can also impact the overall outcome (Comba et al., 2022; Dede et al., 2017; Șoim et al., 2018; Sonza et al., 2021).

Due to its advantageous optical qualities, dental ceramics have become an indispensable treatment material, particularly in the anterior region, where colour and translucency play a crucial role (Dede et al., 2017; Zhou et al., 2022). Translucency, fluorescence, biocompatibility, chemical stability, compressive strength, and a coefficient of thermal expansion comparable to that of real teeth are some of the optical characteristics of ceramics (Soares et al., 2005).

In addition to these characteristics, the thickness, type of material, and combination of ceramic layers determine the colour of the final restoration. Depending on the sort of restoration desired, several ceramic thicknesses might be utilized. To optimize the aesthetic result, it is necessary to assess the effect of material thickness on the restoration's optical properties (Günal-Abduljalil & Ulusoy, 2022; Subaşı et al., 2018; Xing et al., 2017).

In general, more resistant ceramic systems have higher opacity and, consequently, a less acceptable aesthetics due to their large concentration of crystals. However, more translucent ceramic systems, such as feldspathic ceramics, allow for greater passage of light through the material, providing a more natural appearance to the restoration. However, this translucency can make the colour matching process more complicated (Bacchi et al., 2019; Dede et al., 2017).

One of the key benefits of all-ceramic crowns is their translucency, allowing light to travel through the material. This optical property improves the aesthetics of all-ceramic crowns compared to metal-ceramic crowns, which do not allow light transmission due to their metallic component (Chang et al., 2009; Thilagar et al., 2019).

1.4.1. Primary optical properties

Professionals consider the transmission of colour information as a challenging and subjective endeavour. In order to eliminate conflicts in this communication process, different colour scales have been devised (Salas et al., 2018). Hue, value, and chroma are the primary optical properties, typically used to describe colour (Joiner, 2004). It is suggested that the value be specified first, followed by chroma and hue (Ahn & Lee, 2008).

The tridimensionality idea of colour was proposed by Munsell in 1905 and subsequently accepted as a colour measurement technique, enabling its quantitative study (Y. K. Lee et al., 2010; Volpato et al., 2009).

The hue refers to the pigment or tonality of a colour, allowing for the differentiation between other colour groups such as red and yellow; it is what determines the basic colour (Hilton et al., 2013; Joiner, 2004). In the widely used VITA Classic scale (Vita Zahnfabrik, Bad Säckingen, Germany), hue is denoted by the letters A, B, C, and D (Shammas & Krishna Alla, 2011).

The value is one of the most important optical properties and corresponds to a colour's brightness or luminosity, enabling the differentiation between dark and light hues (Hilton et al., 2013). It relates to the brightness or darkness of the colour and is determined by the quantity of black or white present (Heymann et al., 2013; Joiner, 2004). Consequently, higher values correspond to lighter colours, while lower values correspond to darker colours (Joiner, 2004).

Chroma is proportional to the saturation or intensity of a specific colour, such as dark yellow or bright yellow. This setting provides for the distinction between vibrant and faded colours. Objects that are darker have a higher saturation (Hilton et al., 2013; Joiner, 2004). In the VITA Classic (Vita Zahnfabrik, Bad Säckingen, Germany) scale, chroma is defined by the numbers 1, 2, 3, and 4, and a higher number within the same hue corresponds to a higher chroma (Shammas & Krishna Alla, 2011).

1.4.2. Secondary optical properties

As previously mentioned, achieving a colour match similar to that of natural teeth is a very challenging task. Aesthetically acceptable restorations involve the incorporation of multiple criteria, including the colour differences between dentin and enamel and between the cervical and incisal areas of the same tooth, the size of the dental structure, its surface texture, brightness, and translucency (Alghazzawi et al., 2012; Joiner & Luo, 2017; Vichi et al., 2011).

In fact, it is believed that the hue, value, and chroma criteria are inadequate for a precise reproduction of dental colour due to the complicated optical features of natural teeth. To achieve a superior aesthetic effect, secondary optical properties like as translucency, opalescence, and fluorescence must be considered (Joiner, 2004).

1.4.2.1. ***Translucency***

Translucency can be defined as the physical property that describes the ability of a material to allow the passage of light, but in a way that underlying objects are not clearly visible. A translucent material diffuses light as it hits its surface, making it impossible to clearly see images through it (Shammas & Krishna Alla, 2011; Tabatabaian, 2019; Vichi et al., 2011).

Different wavelengths of light result in different degrees of translucency in teeth and restorative materials (Y.-K. Lee, 2016). The cervical regions of the tooth have shown low translucency compared to the rest of the tooth structure, with the incisal region being the most translucent (Joiner, 2004). This phenomenon is due to the decreasing thickness of enamel from the incisal to the cervical region, influenced by the thickness of the underlying dentin (Alghazzawi et al., 2012).

To quantify the translucency of a dental ceramic, it is necessary to analyze several factors that affect light transmission, such as light dispersion in the material and the thickness of the restoration. The same principles are applied to composite resins, where the thickness of restorations allowed is limited due to the restricted dimensions of teeth (Y.-K. Lee, 2016; Tabatabaian, 2019).

1.4.2.2. ***Opalescence***

Opalescence is the ability of a translucent material to exhibit blue colour by reflected light and red or orange colour by transmitted light. This opalescence effect is caused by the dispersion of the visible spectrum and is based on the translucent behaviour of natural teeth (Shammas & Krishna Alla, 2011; Vichi et al., 2011).

The optical properties of aesthetic dental restorations should be comparable to those of natural teeth in terms of opalescence. Human enamel possesses opalescent characteristics. It has a bluish coloration under reflected light and a reddish-orange tone under transmitted light. This opalescent effect is caused by hydroxyapatite crystals, which act as light-diffusing particles and give the tooth brilliance, depth, and vitality. In the third incisal region of the tooth, dental enamel displays more opalescence (Y.-K. Lee, 2016).

Opalescence is frequently achieved in dental materials, like as ceramics, by integrating crystalline particles into a glassy matrix. By altering the size, shape, and distribution of these particles as well as the composition of the glassy matrix, the opalescence of the material can be altered. Opalescence is difficult to recreate in ceramic restorations, as it requires a balance between translucency and opacity, and can be affected by the material's thickness, as well as the lighting and colour of the underlying tooth (Y. K. Lee et al., 2005).

1.4.2.3. ***Fluorescence***

Fluorescence is described as the absorption of electromagnetic radiation from the visible spectrum and its subsequent emission at longer wavelengths (usually in the ultraviolet range) (Shammas & Krishna Alla, 2011; Vichi et al., 2011).

This optical phenomenon occurs when invisible to the human eye, short-wavelength light, such as ultraviolet light, is absorbed. The light then excites the electrons, causing them to occupy higher energy levels. When the electron returns to its ground state, it returns to its normal orbit, releasing energy in the form of photons of visible light with a longer wavelength (Catelan et al., 2015; Rafael et al., 2017).

Natural teeth have fluorescence because they emit visible light when exposed to ultraviolet light (Shammas & Krishna Alla, 2011). This feature is responsible for the daily brilliance and clarity of the teeth, which gives it vitality (Catelan et al., 2015; Joiner, 2004).

A fluorescence is primarily determined by dentin through absorption of UV radiation generated by the sun with short wavelengths that stimulate photosensitive components present in dental tissues. The fluorescence of incisors, canines, premolars, and molars is identical (Catelan et al., 2015). The combination of stimulation of three fluorescent molecules produces the fluorescence of dentin proteins (tyrosine, tryptophan, and other fluorophores) (Y.-K. Lee, 2016).

Fluorescence is considered an important property for restorative procedures, especially in the anterior teeth region. A good restorative material should have properties such as light reflection, diffusion, and fluorescence similar to those of natural teeth. The basic components of restorative materials do not have fluorescence by themselves, and this property is obtained by incorporating luminescent elements into the material. In composite resins, europium, terbium, and neodymium are added for this purpose (Catelan et al., 2015).

When examined under natural lighting circumstances, the fluorescence phenomenon does not contribute to the colour of the tooth. However, in the absence of this property, the aesthetic quality of the restoration under ultraviolet lighting conditions is deemed unacceptable (Catelan et al., 2015).

1.4.3. Colour measurement

The measuring of the colour of natural teeth or restorative materials has become an indispensable instrument in both clinical practice and scientific study

(Johnston, 2009). In clinical practice, the evaluation of natural tooth colour is vital for effective communication with the laboratory and the selection of the most suitable restorative material for each case. This communication enables the manufacture of restorations that are more visually compatible with various natural tooth colours, resulting in an improved final product (Chang et al., 2009). In the field of research, colour measurement tools are also commonly employed, both for comparisons with visual evaluation and for evaluating the stability of colour over time or the interaction of dental materials and natural teeth (S. J. Chu et al., 2010).

In dentistry, colour can be determined using both visual approaches, such as colour scales, and instrumental methods. Instrumental colour measurement equipment is intended to improve the accuracy of colour matching, its standardization, and its numerical expression. However, whenever possible, this method should be supplemented with the visual method, which produces more predictable aesthetic results (Joiner & Luo, 2017; Liberato et al., 2019; Turgut & Bagis, 2011). Instrumental methods for measuring colour include, among others, spectrophotometers, colorimeters, spectroradiometers, and intraoral digital scanners (Joiner & Luo, 2017; Liberato et al., 2019).

Although the large number of instrumental methods are still used today, spectrophotometers are regarded as the most accurate and precise systems compared to others. However, they still require a clinical environment that permits the control of specific measurement conditions and technological advancements in order to function optimally (Malkondu et al., 2016; Tabatabaian et al., 2021).

Spectrophotometers were invented by Beckman in 1940 (Beckman et al., 1977). This device can detect colour variations that are imperceptible to the human eye. This technique is limited to measuring colour within the visible spectrum region (Tabatabaian et al., 2021; Vichi et al., 2011). The measurement geometry of spectrophotometers allows for classification. With certain specifications for the incidence/reflection angle, lighting, sensors, and filters, they may measure the complete tooth surface or a single location (H. Chen et al., 2012; Tabatabaian et al., 2021).

Visual shade matching via a commercial shade guide is the most popular way for clinically evaluating tooth colour. However, this visual method is inconsistent and subjective, as factors such as age and ocular fatigue can affect colour perception and, thus, the visual selection of its shade. Despite this, it is regarded a cost-effective and quick procedure, and individuals' colour discrimination skills can be enhanced with experience (Bahannan, 2014; Joiner & Luo, 2017).

Colorimeters assess colour values by filtering the object's reflected light in the red, green, and blue regions of the visible spectrum and transforming these values into three-dimensional coordinates (H. Chen et al., 2012; Joiner & Luo, 2017). The primary limitation of this technique in dentistry is that colorimeters are meant to measure flat surfaces, whereas teeth typically have uneven surfaces. Translucency of the tooth's incisal region can also result in inaccurate colour values (Joiner, 2004; Joiner & Luo, 2017).

Spectroradiometers measure radiometric quantities (irradiance and radiance) emitted or reflected from objects across the visible light spectrum. Their colorimetric values are expressed by luminance and illuminance for radiance units and can be converted to colour coordinates. The main differences between spectroradiometers and spectrophotometers are that the former do not have their own light source and their main advantage is that they do not need to directly contact the dental surface to measure colour (Johnston et al., 1996; Joiner & Luo, 2017).

Indeed, regardless of the instrumental method employed, colour measurement requires careful control of the measurement conditions, which can affect the perception or values obtained, such as the lighting conditions, the standard observer, the geometrical conditions, the illuminance, the visual angle of subtense, the background used, and the environment of the measured object (International Organization for Standardization [ISO], 2016).

1.4.3.1. ***CIELab system***

A colour order system devised by the *Commission Internationale de l'Eclairage* (CIE) in 1976 can be used to quantify colour parameters in a variety of fields, including dentistry. This system enables the three-dimensional determination of colour (Figure 4) using three coordinates (CIELab): (L*) which represents luminosity and ranges from 0 (black) to 100 (white), (a*) which quantifies red (positive value) and green (negative value), and (b*) which quantifies yellow (positive value) or blue (negative value) (negative value) (Ahn & Lee, 2008; International Commission on Illumination [CIE], 2004; Vichi et al., 2011).

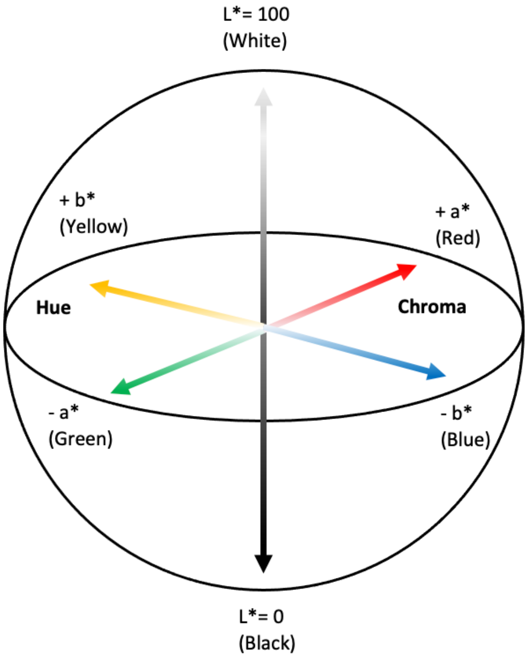


Figure 4. CIELab colour space
Author's elaboration

The colour difference (ΔE_{ab}) between two objects can be calculated by comparing the differences between their respective coordinates for each object, using the following formula (Douglas et al., 2007; International Commission on Illumination [CIE], 2004):

Equação 1. CIELab colour difference formula

$$\Delta \mathrm{E} = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}$$

The values of L_1, a_1, and b_1 correspond to the readings of the final sample, and L_2, a_2, and b_2 correspond to the readings of the initial sample (International Commission on Illumination [CIE], 2004).

Attributed to the reason that perception of colour difference differs from person to person, two thresholds have been created for colour difference evaluation: the perceptibility threshold (PT) and the acceptability threshold (AT). These thresholds serve as a quality control and guiding tool for the selection of dental materials, evaluating their clinical performance and assisting with the interpretation of clinical and research results and the subsequent standardization of such results (Paravina et al., 2015).

Perceptibility refers to the ability of the human eye to detect a colour difference between two objects, while acceptability refers to the threshold of colour difference that is considered tolerable by the observer (International Organization for Standardization [ISO], 2016).

The colour difference between two objects is only clinically relevant when trying to determine if there is a colour difference that is perceptible to the human eye and if that difference is acceptable to the observer. Nonetheless, the reference value of ΔE_{ab}, according to which colour changes are deemed perceptible or acceptable to the observer, is not consensual in the literature, differing considerably among authors, and there is no determined value (J. D. Da Silva et al., 2008; Vichi et al., 2011). However, the most used perceptibility values currently correspond to a 50:50% perceptibility value (PT) of 1,2 and a 50:50% acceptability value (AT) of 2,7 (Paravina et al., 2015; Sampaio et al., 2021).

*1.4.3.2. **CIEDE2000 system***

This new system was created as an upgrade on the previous colour difference formula, CIELab, which was determined to be incapable of adequately representing perceived colour differences. CIEDE2000 takes into account additional aspects connected to the human visual system's perception of colour and is widely used today to ensure colour constancy and accuracy in industries such as graphic design, printing, and manufacturing. This equation includes more than simply lightness, chroma, and hue functions. It also incorporates an interactive term that takes into account the distinctions between chroma and hue, which improves its accuracy when assessing blue colours. In addition, the CIELAB a* scale has a scaling factor that increases its accuracy when measuring grey colours (International Commission on Illumination [CIE], 2004; Luo et al., 2001).

The primary advantage of CIEDE2000 over CIELab is that it provides a more accurate representation of how humans perceive colour differences. CIELAB, on the other hand, is not

totally uniform, therefore the same colour difference can be perceived differently depending on which region of the colour space it occurs. This lack of uniformity is remedied by CIEDE2000's incorporation of a colour difference model that accounts for variances in human colour perception. CIELAB frequently underestimates colour variations in the blue and green spectrums. In contrast, CIEDE2000 provides particular modifications for certain hues, resulting in a more accurate portrayal. These enhancements render CIEDE2000 a more trustworthy and precise instrument for measuring and comparing colour differences (Comba et al., 2022; Ghinea et al., 2010; Paravina et al., 2019; Perez et al., 2011).

As previously mentioned, the reference value for the noticeable or acceptable colour difference between two objects based on the CIEDE2000 formula is also not consensus in the literature and varies significantly among authors, with no established value (J. D. Da Silva et al., 2008; Vichi et al., 2011). The currently considered values for the CIEDE2000 system are $\Delta E_{00}=0,8$ and $\Delta E_{00}=1,8$, respectively for the perceptibility (PT) and acceptability (AT) values (International Organization for Standardization [ISO], 2016; Paravina et al., 2015; Sampaio et al., 2021).

Before proceeding with the calculation of the ΔE_{00} formula through the CIEDE2000 system, it is important to understand the meaning of the acronyms used in the various formulas (Table 5).

Table 5. Meaning of CIEDE2000 abbreviations

Acronym	Meaning
L^*	CIELAB lightness
a^* , b^*	CIELAB *a**, *b** coordinates
C^*_{ab}	CIELAB chroma
h_{ab}	CIELAB hue angle
L'	CIEDE2000 lightness
$\bar{L}'$	Arithmetic mean of the CIEDE2000 lightnesses of two-colour stimuli
a', b'	CIEDE2000 *a'*, b' coordinates
C'	CIEDE2000 chroma
$\bar{C}'$	Arithmetic mean of the CIEDE2000 chromas of two-colour stimuli
h'	CIEDE2000 hue angle
$\bar{h}'$	Arithmetic mean of the CIEDE2000 hue angles of two-colour stimuli
G	Switching function used in the modification of *a**
$\Delta L'$	CIEDE2000 lightness difference
$\Delta C'$	CIEDE2000 chroma difference
$\Delta h'$	CIEDE2000 hue-angle difference
$\Delta H'$	CIEDE2000 hue difference
ΔE_{00}	CIEDE2000 colour difference
S_L	Lightness weighting function
S_C	Chroma weighting function
S_H	Hue weighting function
T	*T*-function for hue weighting
R_T	Rotation function
$\Delta\theta$	Hue dependence of rotation function
R_C	Chroma dependence of rotation function
k_L	Lightness parametric factor

$\boldsymbol{k_C}$	Chroma parametric factor
$\boldsymbol{k_H}$	Hue parametric factor

Adapt from (International Organization for Standardization [ISO], 2022)

The CIEDE2000 colour difference formula was first introduced by the International Commission on Illumination (CIE) in 2000 (International Commission on Illumination [CIE], 2001) and it has been continuously utilized up to the present day (International Organization for Standardization [ISO], 2022):

Equation 1. CIEDE2000 colour difference formula

$$\Delta\mathrm{E}_{00} = \sqrt{\left(\frac{\Delta\mathrm{L}'}{k_L S_L}\right)^2 + \left(\frac{\Delta\mathrm{C}'}{k_C S_C}\right)^2 + \left(\frac{\Delta\mathrm{C}'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta\mathrm{C}'}{k_C S_C}\right)\left(\frac{\Delta\mathrm{H}'}{k_H S_H}\right)}$$

Where the values of $\Delta\mathrm{L}'$, $\Delta\mathrm{C}'$e $\Delta\mathrm{H}'$ are calculated using formulas 2, 3, and 4:

Equation 2. Calculation of ΔL′

$$\Delta\mathrm{L}' = L_1' - L_0'$$

Where the L_1' represents the luminosity readings of the final sample and L_0' represents the luminosity readings of the initial sample.

Where

$$L' = L^*$$

Equation 3. Calculation of ΔC′

$$\Delta\mathrm{C}' = C_1' - C_0'$$

Where C_1' represents the chroma readings of the final sample and C_0' represents the chroma readings of the initial sample.

Where

$$C' = (a'^2 + b'^2)^{1/2}$$

$$b' = b^*$$

$$a' = (1 + G)a^*$$

For this preview formula, a modification of the scale is made along the a^* axis to improve agreement with the visual perception of colour difference in neutral colours. This modification increases the magnitude of the a' values compared to the a^* values for lower chromas. (International Commission on Illumination [CIE], 2004).

Where

$$G = 0{,}5\left(1 - \sqrt{\frac{\left(\overline{C^*_{ab}}\right)^7}{\left(\overline{C^*_{ab}}\right)^7 + 25^7}}\right)$$

$$C^*_{ab} = \sqrt{a^{*2} + b^{*2}}$$

Where $\overline{C^*_{ab}}$ is the arithmetic mean of the values of C^*_{ab} for two samples being analysed.

Equation 4. Calculation of ΔH′

$$\Delta\mathrm{H}' = 2(C'_0\, C'_1)^{1/2} \sin(\Delta h'/2)$$

Where

$$\begin{array}{ll} \Delta h' = 0° & \text{if } C'_0\,C'_1 = 0 \\ \Delta h' = h'_1 - h'_0 & \text{if } C'_0\,C'_1 \neq 0 \text{ and } |h'_1 - h'_0| \leq 180° \\ \Delta h' = h'_1 - h'_0 - 360° & \text{if } C'_0\,C'_1 \neq 0 \text{ and } (h'_1 - h'_0) > 180° \\ \Delta h' = h'_1 - h'_0 + 360° & \text{if } C'_0\,C'_1 \neq 0 \text{ and } (h'_1 - h'_0) < -180° \end{array}$$

The previous formulas avoid possible computational difficulties when h'_0 and h'_1 are positioned in different quadrants or when one of the chromas is zero (G. Sharma et al., 2005).

Where

$$h' = \begin{cases} arctan\left(\frac{b'}{a'}\right) & if\ a' > 0\ and\ b' \geq 0 \\ arctan\left(\frac{b'}{a'}\right) + 360° & if\ a' > 0\ and\ b' < 0 \\ arctan\left(\frac{b'}{a'}\right) + 180° & if\ a' < 0 \\ 90° & if\ a' = 0\ and\ b' > 0 \\ 270° & if\ a' = 0\ and\ b' < 0 \end{cases}$$

$$h' = 0°\ if\ \ a' = 0\ and\ b' = 0$$

The value of h' corresponds to the angular position of the point a' ,b' in the range of 0° to 360°, measured from the positive a' axis in the a' ,b' plane. If the value of $a' = b' = 0$, the value of h' is indeterminate and is assigned the value of zero as indicated above.

The values of $k_L, k_C\ and\ k_H$ correspond to the parametric factors and represent the correction terms for variation under reference experimental conditions (Table 6). Under standardized conditions, these factors are usually adjusted to a value of 1 (International Commission on Illumination [CIE], 2004).

Table 6. Reference conditions for colour assessment according to CIEDE2000

Illumination	Source simulating the relative spectral irradiance of CIE standard illuminate D65
Illuminance	1000 lx
Observer	Normal colour vision
Background field	Uniform, neutral grey with L^* = 50.
Viewing mode	Object
Sample size	Sample pair subtending a visual angle greater than 4°
Sample separation	Minimum sample separation achieved by placing the sample pair in direct edge contact.
Sample colour-difference magnitude	0 to 5 CIELAB units
Sample structure	Homogeneous colour without visually apparent pattern or non-uniformity

Adapt from (International Organization for Standardization [ISO], 2022)

These factors can be adjusted to correct for deviations from the reference conditions to the experimental conditions. Each industry can define the parametric factors according to its typical experimental conditions.

The values of $S_L, S_C \ and \ S_H$ correspond to weighting functions for lightness, chroma, and hue, respectively, and vary according to the location of the L*, a*, and b* coordinates of the samples in the CIELab colour space (Luo et al., 2001) and can be calculated using the following formulas:

Equation 5. Calculation of S_L

$$S_L = 1 + \frac{0{,}015(\overline{L'} - 50)^2}{\sqrt{20 + (\overline{L'} - 50)^2}}$$

Equation 6. Calculation of S_C

$$S_C = 1 + 0{,}045\overline{C'}$$

Equation 7. Calculation of S_H

$$S_H = 1 + 0{,}015\overline{C'}T$$

Where

$$T = 1 - 0{,}17\cos\left(\overline{h'} - 30°\right) + 0{,}24\cos\left(2\overline{h'}\right) + 0{,}32\cos\left(3\overline{h'} + 6°\right) - 0{,}20\cos 4\overline{h'} - 63°$$

Where $\overline{L'}, \overline{C'} and\ \overline{h'}$ are the arithmetic means of their corresponding values for the colour difference between the pair of samples.

Where

$$\overline{h'} = (h_0' + h_1')/2 \qquad if\ |h_0' - h_1'| \leq 180°\ and\ C_0'C_1' \neq 0$$
$$\overline{h'} = (h_0' + h_1' + 360°)/2 \qquad if\ |h_0' - h_1'| > 180°\ and\ (h_0' + h_1') < 360°\ and\ C_0'C_1' \neq 0$$
$$\overline{h'} = (h_0' + h_1' - 360°)/2 \qquad if\ |h_0' - h_1'| > 180°\ and\ (h_0' + h_1') \geq 360°\ and\ C_0'C_1' \neq 0$$
$$\overline{h'} = h_0' + h_1' \qquad if\ \ C_0'C_1' = 0$$

The value of R_T corresponds to a rotation function, with the aim of improving the performance of the colour difference equation, regarding the interaction between chroma and hue values in the blue region (Luo et al., 2001). The rotation function (R_T) can be calculated by (Luo et al., 2001):

Equation 8. Calculation of R_T

$$R_T = -\sin(2\Delta\theta)\,R_C$$

Where

$$\Delta\theta = 30°exp\left\{-\left[\left(\overline{h'} - 275°\right)/25°\right]^2\right\}$$

$$R_C = 2\sqrt{\frac{(\overline{C'})^7}{(\overline{C'})^7 + 25^7}}$$

II – JUSTIFICATION

II - JUSTIFICATION

Obtaining ceramic restorations that suit both practical and aesthetic requirements is one of the greatest issues that dental professionals face today. Aesthetics have grown increasingly significant for both patients and dentists as a result of modern society's emphasis on appearance. Consequently, the ability to conduct aesthetic treatments can be a determining element in a professional's reputation and clinical practice's success (Comba et al., 2022; Porojan et al., 2022).

To achieve aesthetic success in restorations, it is essential to correctly select materials, taking into account not only the type of ceramic material but also the colour of the underlying tooth and the type of cement used (Chaiyabutr et al., 2011; Giordano, 2022; Kandil et al., 2019; Tabatabaian et al., 2020). Therefore, it is essential to further investigate and examine the optical properties of dental materials (Archegas et al., 2011; Tabatabaian, 2019).

In addition to these properties, the thickness, type of material, and combination of ceramic layers also influence the final outcome of the restoration (Dozic et al., 2010; Subaşı et al., 2018). On a tooth with a less intense colour and no discoloration, a thin covering of translucent ceramic is an example of an aesthetically acceptable result. However, when a tooth is discoloured, opaque and chromatic ceramics, resin cement, and more tooth reduction may be required to conceal the discoloured substructure (X.-D. Chen et al., 2015).

Clinicians face challenges when selecting the colour of the cement for ceramic veneers, as different shades of resin cement are available. The appropriate choice of colour allows for adjusting the final outcome of the restoration (X.-D. Chen et al., 2015).

The demand for treatments that enhance dental aesthetics has increased across a variety of populations (Joiner & Luo, 2017), making it a subject that is always growing. Therefore, it is crucial for dental professionals to keep abreast of the most recent techniques and materials to exceed patient expectations and assure visually acceptable and natural restorations. Today, the research of the behaviour and interactions of dental materials is of the utmost importance (Araujo & Perdigão, 2021; Shadman et al., 2022).

III – OBJECTIVES

III - OBJECTIVES

3.1. GENERAL OBJECTIVE

The purpose of this study is to assess the aesthetic outcome of glass ceramic restorations of various thicknesses cemented to composite resin substrates of different shades with multiple cements.

3.2. SPECIFIC OBJECTIVES

1. Evaluate the L*, a* and b* coordinates when varying the two different colours composite resin bases.
2. Evaluate the L*, a* and b* coordinates when varying the glass ceramic types.
3. Evaluate the L*, a* and b* coordinates when varying the ceramic thickness.
4. Evaluate the L*, a* and b* coordinates when varying the cements.
5. Evaluate the masking ability of glass ceramics, ceramic thickness, and cements.

3.3. NULL HYPOTHESIS

H_0: The aesthetic outcome of the studied glass ceramics is not influenced by the cement, the ceramic type and thickness, and the substrate colour.

3.4. ALTERNATIVE HYPOTHESIS

H_1: The aesthetic outcome of the studied glass ceramics is influenced by the cement, the ceramic type and thickness, and the substrate colour.

IV – MATERIAL AND METHODS

IV -MATERIAL AND METHODS

4.1. METHODOLOGY

120 samples of lithium disilicate glass ceramic were obtained from *IPS e.max® CAD (HT)* (Ivoclar Vivadent, Schaan, Liechtenstein) in colour A1 through prefabricated blocks (Figure 5).

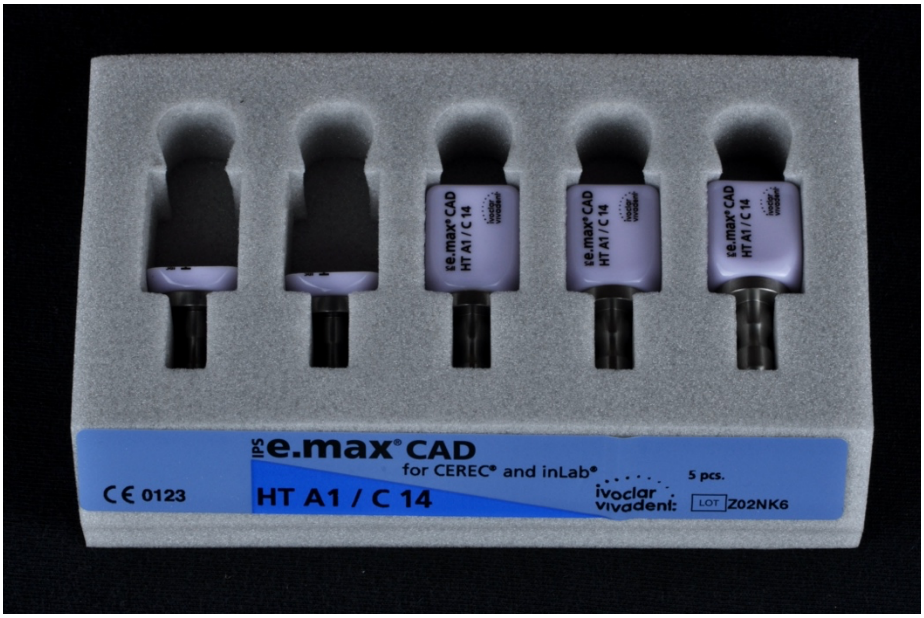


Figure 5. IPS e.max® CAD (HT) (Ivoclar Vivadent, Schaan, Liechtenstein), A1
Author's elaboration

Also, 120 samples of feldspathic ceramic *VitaBlocs® Mark II* (VITA Zahnfabrik, Bad Säckingen, Germany) in colour A1 were obtained through prefabricated blocks (Figure 6).

Figure 6. VitaBlocs® Mark II (VITA Zahnfabrik, Bad Säckingen, Germany), A1
Author's elaboration

Both ceramic samples were cut into two different thicknesses to obtain 60 samples with a thickness of 0,5mm and the remaining 60 with a thickness of 0,8mm.

The substrate samples were obtained using *Filtek™ Supreme XTE Universal Restorative Body* (3M ESPE, Minnesota, USA) composite resin, with 120 samples in colour A2 and the remaining 120 in colour A3. The 240 composite resin samples were made with a thickness of 1mm.

Three different resin cements were used to cement the samples: *RelyX™ Veneer Cement System* (3M ESPE, Minnesota, USA) in its *Translucent* (*TR*) colour (80 samples) and *White Opaque* (*WO*) colour (80 samples), and *RelyX™ Universal Resin Cement* (3M ESPE, Minnesota, USA) in its *Translucent (TR)* colour (80 samples).

The ceramic samples were cemented to the composite resin samples according to the manufacturer's instructions. The materials used are available in Table 7.

Table 7. Materials used in the study

Material	Composition	LOT	Clinical Indication
IPS e.max® CAD (HT) **(Ivoclar Vivadent, Schaan, Liechtenstein) A1 / C14**  	SiO_2, Li_2O, K_2O, P_2O_5, Al_2O_3, MgO, Colouring oxides	LOT Z02NK6	Veneers, Inlays, Onlays, partial crowns, Crowns for anterior and posterior restorations, Implant superstructures for single-tooth restorations
VitaBlocs® Mark II **(VITA Zahnfabrik, Bad Säckingen, Germany)** ***A1C / I-14***  	SiO_2, Al_2O_3, Na_2O, K_2O, CaO, TiO_2, pigments.	LOT 94840	Inlays, Onlays, Tabletop Partial crowns, Full crowns, Molar endo-crowns and Veneers
Filtek™ Supreme XTE Universal Restorative Body Shade A2 **(3M ESPE, Minnesota, USA)**	UDMA, TEGMA, Bis-GMA, Bis-EMA, silica (20nm), Zirconia	LOT NF22572	Direct anterior and posterior restorations (including occlusal surfaces), Core

	(4-11nm), pigments. Average particle size 0,6 to 10 µm. Inorganic particles represent 78,5% of the total charge.		build-ups, Splinting, Indirect restorations (including inlays, onlays and veneers)
Filtek™ Supreme XTE Universal Restaurative Body Shade A3 **(3M ESPE, Minnesota, USA)** 	UDMA, TEGMA, Bis-GMA, Bis-EMA, silica (20nm), Zirconia, pigments. (4-11nm). Average particle size 0,6 to 10 µm. Inorganic particles represent 78,5% of the total charge.	LOT N927242	Direct anterior and posterior restorations (including occlusal surfaces), Core build-ups, Splinting, Indirect restorations (including inlays, onlays and veneers)
RelyX™ Veneer Cement System **(3M ESPE, Minnesota, USA)** ***Translucent***	BisGMA, TEGDMA, Zirconia/silica and fumed silica fillers, pigments. The filler loading is approximately 66% by weight.	LOT W05218	Permanent cementation of ceramic or composite veneers

	The average particle size for the filler is approximately 0,6 mm.		
RelyX™ Veneer Cement System **(3M ESPE, Minnesota, USA)** ***White Opaque*** 	BisGMA, TEGDMA, Zirconia/silica and fumed silica fillers, pigments. The filler loading is approximately 66% by weight. The average particle size for the filler is approximately 0,6 mm.	LOT W05218	Permanent cementation of ceramic or composite veneers
RelyX™ Universal Resin Cement **(3M ESPE, Minnesota, USA)** ***Translucent***	BPA derivative free dimethacrylate monomers, Phosphorylated dimethacrylate	LOT 8906729	Endodontic post, Crown, Bridge, Restoration on abutment, Inlay, Onlay, Veneer, tabletop, Maryland

	adhesion monomers, Photoinitiator system, Novel amphiphilic redox initiator system, Radiopaque fillers and rheological additives, Pigments.		and Inlay/Onlay bridge
***Scotchbond™ Universal Plus* (3M ESPE, Minnesota, USA)** 	MDP, HEMA, 3M™ Vitrebond™ Copolymer, Filler, Etanol/ Water, Initiators, Optimized mixture of silanes, Dual-cure accelerator, BPA derivative-free crosslinking radiopaque monomer	LOT W05218	Bonding for all methacrylate-based light-, dual-, and self-cure composite and compomer filling materials, Protective varnish for glass ionomer fillings, Root surface desensitization, Repair of composite and compomer fillings, Cementation of indirect restorations
***IPS® Ceramic Etching Gel* (Ivoclar Vivadent, Schaan, Liechtenstein)**	HF	LOT Z037BV	Acid etching of ceramic indirect restorations

			
***Orthophosphoric acid* 37% (DentaFlux, Madrid, Spain)** 	H_3PO_4	LOT 030422	Acid etching of dentin and enamel
***Liquid Glycerin* (Tintinhas® produtos Químicos Unipessoal Lda, Lordelo, Portugal)**	$C_3H_8O_3$	LOT 210722113	Hydrates and softens the skin, protecting it from atmospheric conditions. It can also be used to shine tires after

			dilution with denatured alcohol. It has some medicinal and dietary indications

Author's elaboration

4.1.1. Study Groups

After obtaining all the samples, both the ceramic and composite resin pieces were numbered from 1 to 240. The 240 ceramic samples were randomly grouped with the 240 composite resin samples using the RAND() formula in Microsoft® Excel program, forming 24 groups with 10 samples each, respecting the study groups. The samples were then cemented according to the formed study groups (Table 8).

Out of the 30 lithium disilicate ceramic samples with a thickness of 0,5mm, 10 were cemented with *RelyX™ Veneer Cement System* (3M ESPE, Minnesota, USA) *TR*, 10 with *RelyX™ Veneer Cement System* (3M ESPE, Minnesota, USA) *WO*, and the remaining 10 with *RelyX™ Universal Resin Cement* (3M ESPE, Minnesota, USA) *TR*, using 30 composite resin samples in colour A2 as a base. The same process was carried out for 30 feldspathic ceramic samples with a thickness of 0,5mm.

Out of the 30 lithium disilicate ceramic samples with a thickness of 0,8mm, 10 were cemented with *RelyX™ Veneer Cement System* (3M ESPE, Minnesota, USA) *TR*, 10 with *RelyX™ Veneer Cement System* (3M ESPE, Minnesota, USA) *WO*, and the remaining 10 with *RelyX™ Universal Resin Cement* (3M ESPE, Minnesota, USA) *TR*, using 30 composite resin samples in colour A2 as a base. The same process was carried out for 30 feldspathic ceramic samples with a thickness of 0,8mm.

The entire procedure was repeated for the remaining 120 ceramic samples, using composite resin samples in colour A3 as a base.

Table 8. Distribution of samples by study groups

	Substrate	**Ceramic and thickness**	**Cement**	**Cement colour**	**n**
Study Groups	CR Sample Colour A2	*IPS e.max®* A1 **0,5mm**	*Relyx™ Universal*	*TR*	n=10
			Relyx™ Venneer	*TR*	n=10
				WO	n=10
		VitaBlocs Mark II A1 **0,5mm**	*Relyx™ Universal*	*TR*	n=10
			Relyx™ Venneer	*TR*	n=10
				WO	n=10
		IPS e.max® A1 **0,8mm**	*Relyx™ Universal*	*TR*	n=10
			Relyx™ Venneer	*TR*	n=10
				WO	n=10
		VitaBlocs Mark II A1 **0,8mm**	*Relyx™ Universal*	*TR*	n=10
			Relyx™ Venneer	*TR*	n=10
				WO	n=10
	CR Sample Colour A3	*IPS e.max®* A1 **0,5mm**	*Relyx™ Universal*	*TR*	n=10
			Relyx™ Venneer	*TR*	n=10
				WO	n=10

		VitaBlocs Mark II A1 **0,5mm**	*Relyx™ Universal*	*TR*	n=10
			Relyx™ Venneer	*TR*	n=10
				WO	n=10
		IPS e.max® A1 **0,8mm**	*Relyx™ Universal*	*TR*	n=10
			Relyx™ Venneer	*TR*	n=10
				WO	n=10
		VitaBlocs Mark II A1 **0,8mm**	*Relyx™ Universal*	*TR*	n=10
			Relyx™ Venneer	*TR*	n=10
				WO	n=10
Total Samples N=240					

Author's elaboration

4.1.2. Sample acquisition

4.1.2.1. ***Obtaining ceramic samples***

All ceramic samples were cut using a *Powermill Kondia Type FV-300* milling machine (serial number: S-913) (Figure 7) belonging to the Instituto Superior Técnico (IST) in Lisbon, Portugal. A 127mm diameter and 0,4mm thick *IsoMet™ Diamond Wafering Brades diamond disc* (Buehler®, Lake Bluff, IL, USA) was used at a constant speed of 240rpm using the manual feed technique and cooling with a mixture of 95% deionized water and 5% oil (Figure 8).

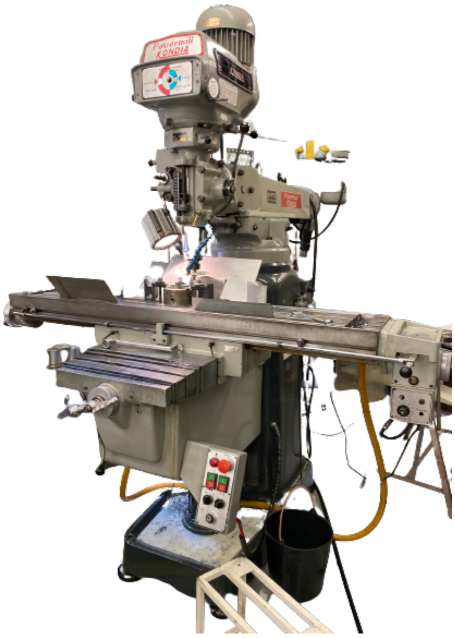


Figure 7. Powermill Kondia Type FV-300 (nº de série: S-913)
Author's elaboration

Figure 8. Cutting of lithium disilicate ceramic (on the left) and cutting of feldspathic ceramic (on the right)
Author's elaboration

It was decided to discard the first and last cuts of each ceramic block to standardize the samples.

120 lithium disilicate ceramic samples were obtained, with a length of 14mm and a width of 12mm. Of these 120 samples, 60 were cut to a thickness of 0,5mm and the remaining 60 were cut to a thickness of 0,8mm. After cutting, the lithium disilicate samples were subjected to a sintering process in a *Vario Press® 300.ezr* ceramic oven (Zubler®, Buchbrunnenweg, Germany), in a two-step cycle according to the manufacturer's instructions (Figure 9 and Table 9).

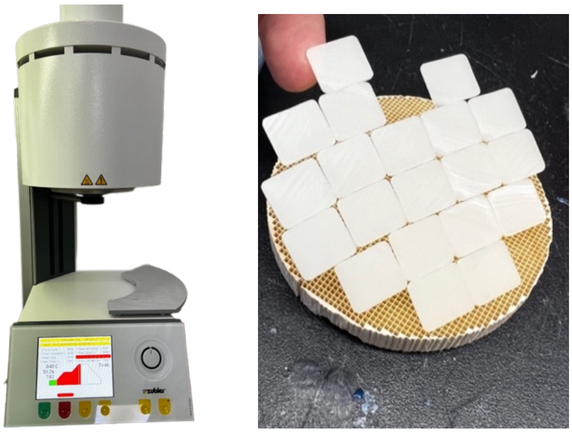


Figure 9. Ceramic furnace (on the left) and lithium disilicate ceramic samples after crystallization (on the right) Author's elaboration

Table 9. Crystallization parameters for IPS emax® CAD (HT)

Initial time	403ºC	**Maintenance time**	10min.
Pre-drying	No	**Heating rate**	30ºC
Closing time	6min.	**Final temperature 2**	840ºC
Soak temperature	550ºC	**Maintenance time 2**	7min.
Soak time	0min.	**Opening temperature**	700ºC
Heating rate	90ºC	**Opening time**	0min.
Final temperature 1	820ºC	**Vacuum end time**	7min.

Adapted from (Ivoclar Vivadent, 2009)

120 samples of feldspathic ceramic with a length of 14mm and width of 12mm were also obtained. Of these 120 samples, 60 were cut with a thickness of 0,5mm and the remaining 60 were cut with a thickness of 0,8mm.

The feldspathic ceramic samples being pre-sintered do not require the sintering process, according to the manufacturer's instructions.

All ceramic samples were polished by a polishing machine *(LaboPol-4, Struers®, Ballerup, Denmark)* using a sequence of 500, 1000, 1500 grit abrasive papers *(Buehler®, Lake Bluff, IL, USA)* for 15 seconds per paper at a constant speed of 100 rpm, using a silicone mould to fix the sample (Figure 10 and 11).

Figure 10. Polisher: LaboPol-4, Struers®, Ballerup, Denmark
Author's elaboration

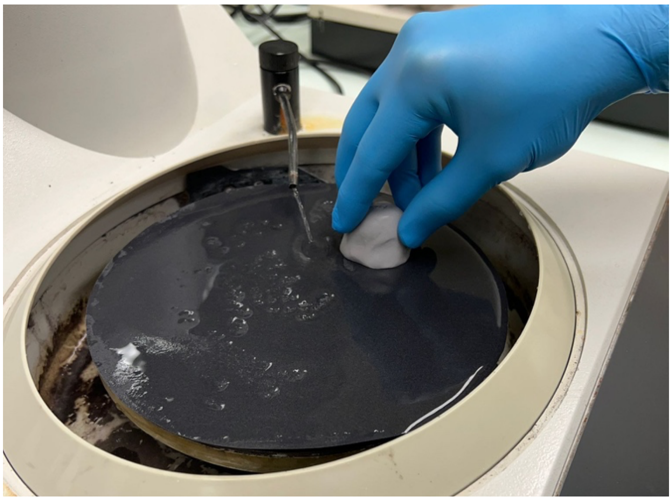


Figure 11. Polishing of a ceramic sample using a silicone mould
Author's elaboration

After polishing, a digital precision calliper *(Heavyware® Tools)* was used to check the thickness of the samples at three different points to standardize the thickness of the samples (Figure 12).

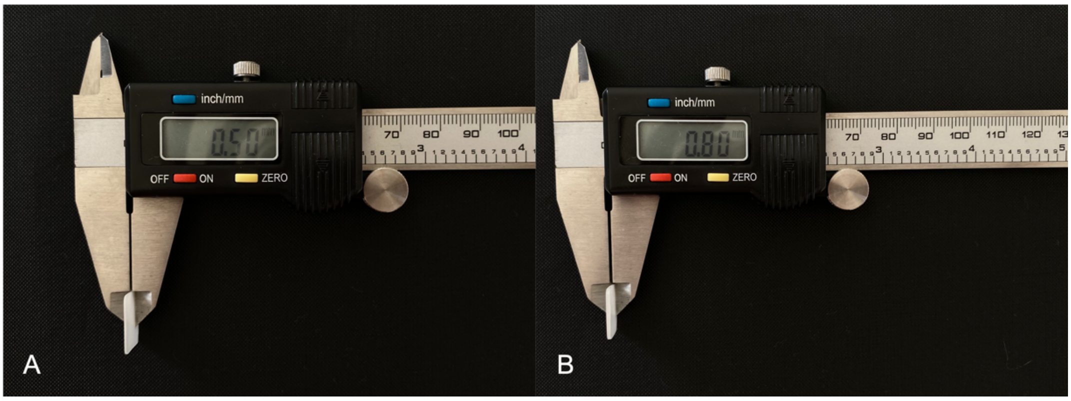


Figure 12. Measuring a ceramic sample with the digital calliper. A: 0,5mm and B: 0,8mm
Author's elaboration

4.1.2.2. ***Obtaining composite resin samples***

Composite resin samples in two different colours, A2 and A3, were used to simulate the tooth surface. The composite resin samples were obtained using a metal matrix made specifically for this purpose. The matrix consists of three parts: (1) a metal base, (2) a screwable metal surface formed by 40 holes with dimensions of 14mm length, 12mm width, and 1mm thickness, and (3) a tempered glass plate placed on top of the matrix (Figure 13).

The metal surface (2) was screwed onto the metal base (1) using a key. Then, the composite was placed into the cavities using an angled spatula, pressing it until it filled the entire cavity. Afterwards, the glass plate (3) was placed on top of the composite to standardize the samples, and photo-polymerized for 40 seconds with a light curing unit *Elipar™* (3M ESPE, Minnesota, USA), with a light intensity of 1470mw/cm^2, according to the manufacturer's instructions. Finally, the glass plate (3) was removed, and the metal surface (2) was unscrewed and removed, obtaining 40 composite resin samples.

This process was repeated until obtaining 120 samples of A2 composite resin and 120 samples of A3 composite resin.

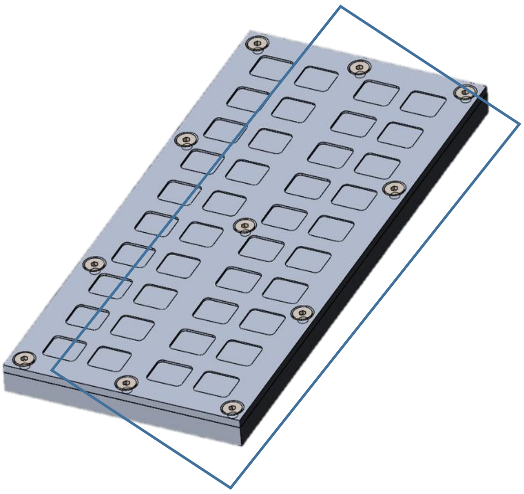


Figure 13. Matrix and glass model for making composite resin samples

Author's elaboration

The composite samples were also polished using a polisher *(LaboPol-4, Struers®, Ballerup, Denmark)* following a sequence of sandpapers with grain sizes of 500, 1000, 1500 *(Buehler®, Lake Bluff, IL, USA)* for 15 seconds each at a constant speed of 100 rpm, using a silicone mould to fix the sample.

A digital precision calliper *(Heavyware® Tools)* was again used to verify their thickness at 3 different points on the samples (Figure 14).

Figure 14. Measuring a composite resin sample with the digital calliper

Author's elaboration

4.1.3. Cementation of samples

4.1.3.1. ***Preparation of the substrate***

The cementation of the samples with *RelyX™ Universal Resin Cement* (3M ESPE, Minnesota, USA) was performed according to the manufacturer's instructions using the total etch adhesive technique.

The 37% orthophosphoric acid *(DentaFlux, Madrid, Spain)* was applied to the entire piece for 15 seconds to decontaminate the surface. The pieces were then washed and dried with an air syringe. Next, *Scotchbond™ Universal Plus* adhesive (3M ESPE, Minnesota, USA) was applied with a microbrush for 20 seconds using circular motions (Figure 15). Finally, the sample was dried again with the air syringe for 5 seconds without photo-polymerization.

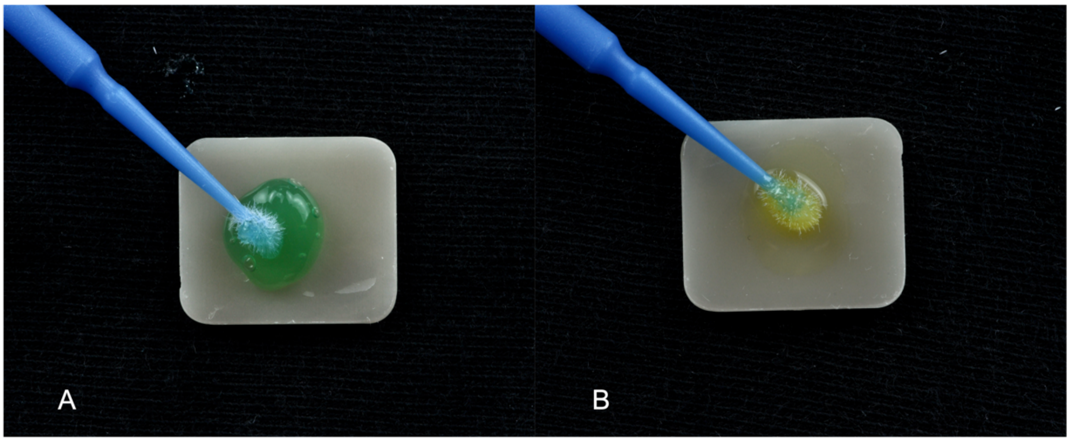


Figure 15. A: Application of orthophosphoric acid and B: Application of universal adhesive
Author's elaboration

The cementation of the samples with *RelyX™ Veneer Cement System* (3M ESPE, Minnesota, USA) was also carried out according to the manufacturer's instructions, using the total-etch adhesive technique.

The 37% orthophosphoric acid *(DentaFlux, Madrid, Spain)* was applied to the entire surface of the sample for 15 seconds to decontaminate it. The samples were washed for 10 seconds and dried with an air syringe. Then, the *Scotchbond™ Universal Plus* adhesive (3M ESPE, Minnesota, USA) was applied to the sample using a microbrush for 20 seconds with circular movements (Figure 15). Finally, the sample was dried with an air syringe for 5 seconds without light curing.

4.1.3.2. Preparation of the ceramic

All ceramic samples were subjected to an ultrasonic bath for surface decontamination and removal of any remaining oil.

Lithium disilicate samples underwent a surface treatment with *IPS® Ceramic Etching Gel* (Ivoclar Vivadent, Schaan, Liechtenstein) at 5% hydrofluoric acid for 20 seconds. Afterwards, the samples were washed with a water syringe for 60 seconds and dried with an air syringe for 20 seconds. *Scotchbond™ Universal Plus* (3M ESPE, Minnesota, USA) was applied with a microbrush for 20 seconds, and then dried again with an air syringe for 5 seconds without light polymerization (Figure 16).

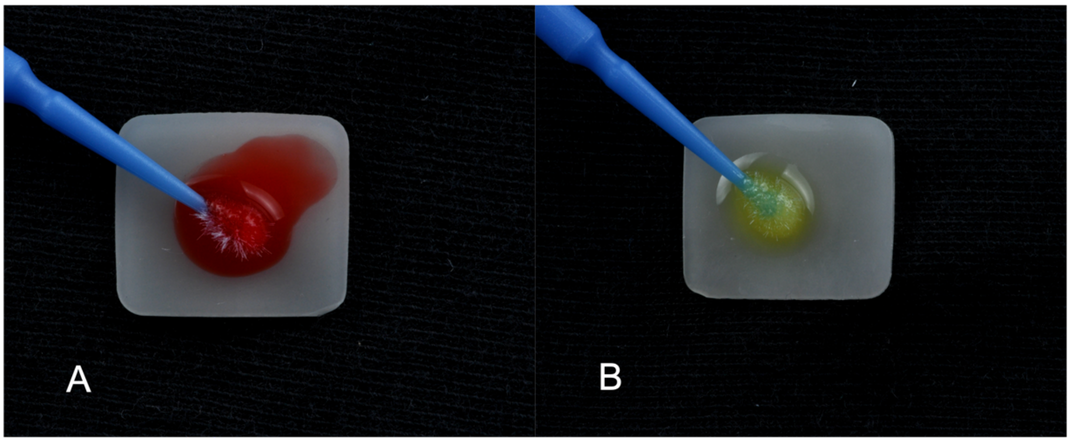


Figure 16. A: Application of hydrofluoric acid; B: Application of universal adhesive
Author's elaboration

All feldspathic ceramic samples were also subjected to a surface treatment. *IPS® Ceramic Etching Gel* (Ivoclar Vivadent, Schaan, Liechtenstein) 5% hydrofluoric acid was applied for 60 seconds, washed with a water syringe for 60 seconds, and dried with an air syringe for 20 seconds. Next, the *Scotchbond™ Universal Plus* adhesive (3M ESPE, Minnesota, USA) was applied with a microbrush for 20 seconds and dried again with the air syringe for 5 seconds without light polymerization (Figure 16).

4.1.3.3. Cementation of the samples

Initially, the samples were provisionally attached with *Liquid Glycerin (Tintinhas®, Lordelo, Portugal)*, and their colour was measured. Then, they were cleaned and dried with 96% alcohol and stored to be later cemented with the cements under study.

The distribution of cements on the ceramic and composite resin samples was done according to the study groups formed (Table 8). The *RelyX™ Universal* resin cement (3M ESPE, Minnesota, USA) was applied in its *Translucent* colour on the anterior prepared composite resin samples (Figure 17).

Figure 17. Application of RelyX™ Universal Resin Cement
Author's elaboration

The ceramic samples were bonded to the composite resin samples and the excess cement was removed with an angled spatula. Then, the cemented samples were placed between two glass plates, under a constant pressure represented by a weight of 2Kg, for 60 seconds (Figure 18).

Figure 18. Weight of 2Kg

Author's elaboration

Afterwards, the samples were light cured for 60 seconds on the glass plates using a curing light *Elipar™* (3M ESPE, Minnesota, USA) with a light intensity of 1470mw/cm². The same cementation protocol was performed for the samples cemented with *RelyX™ Veneer Cement System* (3M ESPE, Minnesota, USA) in *Translucent* and *White Opaque* shades (Figure 19).

Figure 19. Application of RelyX™ Veneer Cement System in Translucent (left) and White Opaque (right) colours

Author's elaboration

After this procedure, the samples were placed in a dry environment, at room temperature and in the absence of light, for 24 hours.

4.1.4. Measurement of the samples

4.1.4.1. *Colour reading*

The data was obtained by reading the samples, 24 hours after cementation, using an *EasyShade® V* spectrophotometer (VITA Zahnfabrik, Bad Säckingen, Germany), allowing the measurement of spectral transmittance and reflectance of the object under standardized conditions (Figure 20).

Figure 20. Spectrophotometer EasyShade® V (VITA Zahnfabrik, Bad Säckingen, Germany)
Author's elaboration

The spectrophotometer was calibrated according to the manufacturer's instructions before each reading, and colour measurement was performed at the centre of each sample, initially before cementation, again after adhesion with glycerine, and finally after cementation with the study cements. The device was positioned directly on the sample (Figure 21).

During measurement, the samples were placed on a grey background (grey card) and measured under standard CIE D65 illumination (representing midday daylight, CCT of 6500K) according to ISO/TR 28642:2016 standards.

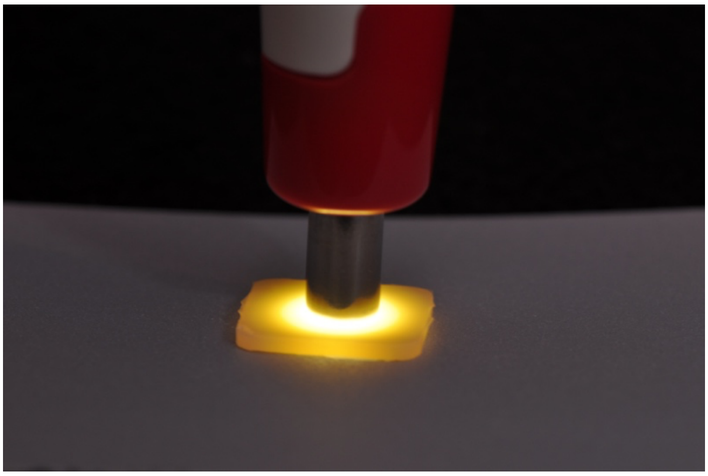


Figure 21. Measurement of samples with the spectrophotometer
Author's elaboration

The L*, C*, H*, a*, and b* parameters were obtained by the spectrophotometer, allowing the calculation of colour differences (ΔE) between the various samples through the calculation of ΔE^*_{ab} and ΔE_{00}, according to the CIELab and CIEDE2000 systems, respectively. The calculation of the colour difference (ΔE) was performed using the formula of ΔE_{ab} (Equation 9) and ΔE_{00} (Equation 10) (International Commission on Illumination [CIE], 2004; International Organization for Standardization [ISO], 2022):

Equation 9. Calculation of ΔEab

$$\Delta \mathrm{E}_{ab} = \sqrt{(\Delta \mathrm{L}^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Equation 10. Calculation of ΔE_{00}

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta C'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)}$$

The differences between the values of L*, a* and b* of the various pairs of samples were also calculated using the formulas of ΔL*, Δa* and Δb* respectively (Equation 11, 12 and 13) (International Commission on Illumination [CIE], 2004).

*Equation 11. Calculation of ΔL**

$$\Delta L^* = {L^*}_1 - {L^*}_0$$

*Equation 12. Calculation of Δa**

$$\Delta a^* = {a^*}_1 - {a^*}_0$$

*Equation 13. Calculation of Δb**

$$\Delta b^* = {b^*}_1 - {b^*}_0$$

The values of L^*_1 and L^*_0 represent the luminosity values corresponding to the final and initial samples, respectively, for each compared pair of samples. The values of a^*_1 and a^*_0 quantify the red and green colour of the respective final and initial samples, and the values of b^*_1 and b^*_0 quantify the yellow and blue colour of the compared final and initial samples, respectively.

R_T represents a function (rotation function) that expresses the interaction between chroma and hue differences in the blue region.

The acronyms S_L, S_C and S_H also represent weighting functions that adjust for the total colour difference variation in the location of the pair of L*, a* and b* colour difference coordinates.

The parametric factors k_L, k_C and k_H represent correction terms for variation under experimental conditions and were all adjusted to 1 according to the technical report of the CIE (International Commission on Illumination [CIE], 2004).

In this study, a pre-defined spreadsheet from the Microsoft® Excel program was used to calculate the CIEDE2000 formula available in Sharma et al. (2005) by inputting the L*, a*, and b* values into the software, thereby obtaining the ΔE_{00} values for different pairs of samples (G. Sharma et al., 2005).

The ΔE values were evaluated at 50:50% perceptibility and 50:50% acceptability, with the limits considered to be 0,8 and 1,8, respectively, for the CIEDE2000 system and 1,2 and 1,7, respectively, for the CIELab system.

4.2. STATISTICAL ANALYSIS

The data collected from various sources was entered into Microsoft® Excel. Using the scheme presented in Table 10 and Figure 22, three variations between the coordinates were calculated using the values of L*, a*, and b*, where:

Table 10. ΔL, Δa, Δb calculation formulas

ΔL_1	$L^*_{CR/Ceramic} - L^*_{CR}$
ΔL_2	$L^*_{CR/Cement/Ceramic} - L^*_{CR/Ceramic}$
ΔL_3	$L^*_{CR/Cement/Ceramic} - L^*_{CR}$
Δa_1	$a^*_{CR/Ceramic} - a^*_{CR}$
Δa_2	$a^*_{CR/Cement/Ceramic} - a^*_{CR/Ceramic}$
Δa_3	$a^*_{CR/Cement/Ceramic} - a^*_{CR}$
Δb_1	$b^*_{CR/Ceramic} - b^*_{CR}$
Δb_2	$b^*_{CR/Cement/Ceramic} - b^*_{CR/Ceramic}$
Δb_3	$b^*_{CR/Cement/Ceramic} - b^*_{CR}$

Author's elaboration

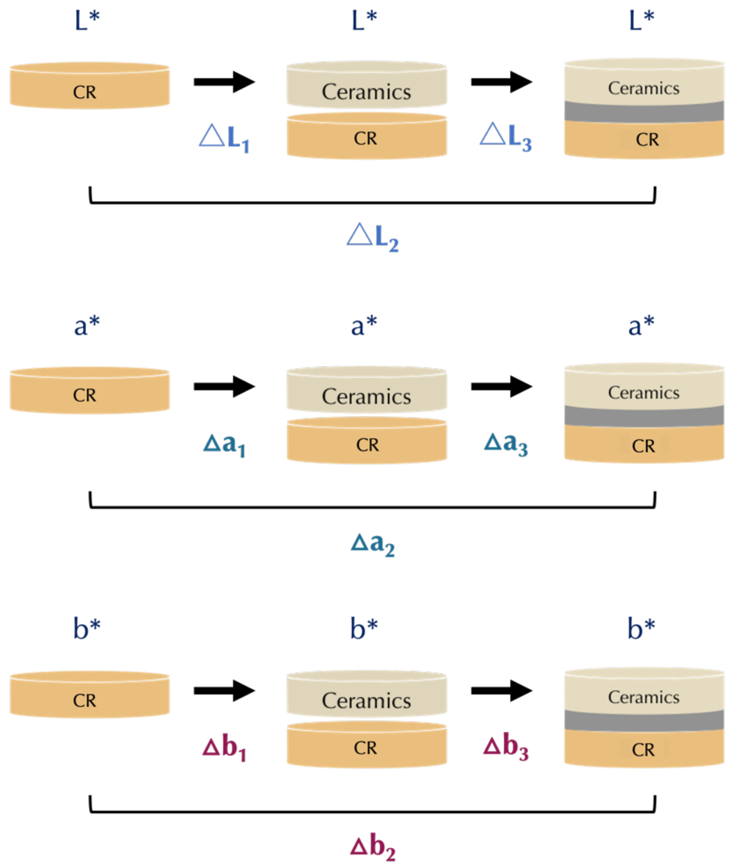


Figure 22. ΔL, Δa, Δb calculation scheme between composite resin (CR), ceramics with glycerine and cemented samples

Author's elaboration

The L*, a*, and b* values of the initial A2 and A3 composite samples were combined with the values of the paired samples with the two different ceramics and thicknesses to calculate the ΔE_{ab} value using the formula established by the CIELab system, for both the groups bonded with glycerine and the groups cemented with the various cements under investigation. Additionally, the ΔE_{00} value was obtained using a formula according to the CIEDE2000 system. Three variations ΔE_{ab} (ΔE_{ab1}, ΔE_{ab2} e ΔE_{ab3}) and ΔE_{00} (ΔE_{001}, ΔE_{002} e ΔE_{003}) were calculated using the same logic as the variations of the L*, a*, and b* coordinates.

The data were then processed and entered in the *SPSS® Statistics Package for the Social Sciences (IBM®, Chicago, IL, USA)* - Version 28 software for macOS. Before proceeding with parametric tests, the normality of the data distribution within each group was determined using the Shapiro-Wilk and Kolmogorov-Smirnov tests, and any potential outliers were identified using boxplots.

The purpose of the statistical analysis was to compare the groups' dependent variables relative to their independent variables. Initial comparisons of the dependent variables L*, a*, and b* between the A2 and A3 composite resin were made using a one-way ANOVA. Three-way ANOVA was used to analyse the data of L*, a*, b*, ΔL_1, Δa_1, Δb_1, ΔE_{ab1}, and ΔE_{001} when the composite samples were paired with two ceramics of differing thicknesses, resulting in three independent variables. Finally, when the cement used was added as a new variable, a Four-way ANOVA was conducted to analyse the data of L*, a*, b*, ΔL_2, ΔL_3, Δa_2, Δa_3, Δb_2, Δb_3, ΔE_{ab2}, ΔE_{ab3}, ΔE_{002} and ΔE_{003}. Levene's test revealed significant variance differences between the groups ($p<0{,}001$) despite the absence of potential outliers and confirmation of the normality assumption. Following this decision, a Split File of the composite resin independent variable and a three-way ANOVA were conducted. It is important to mention that the Levene´s test in this scenario continues to exhibit statistical significance ($p<0{,}001$). However, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and $n>15$ among groups (Ramsey, 1980).

To compare the studied groups across different composite resin bases that were split in the last analysis, an independent samples t-test was performed.

To complement our statistical analysis and data evaluation, we conducted a paired-samples t-test to compare the means of the L*, a*, and b* variables between the initial composite samples and the samples paired with ceramics bonded with glycerine, between the initial composite samples and the samples paired with ceramics cemented with cements, and between the samples paired with ceramics bonded with glycerine and the samples paired with ceramics cemented with cements, following the same sample group across the variables ($n=10$). Additionally, we conducted a comparison between the delta E_{ab} and delta E_{00} values to understand the differences between these obtained values and hence the difference between the two formulas used by the CIELab and CIEDE2000 systems.

In summary, the statistical analysis involved a comprehensive examination of the collected data through various ANOVA tests to assess the significance of the differences between the dependent and independent variables, providing valuable insights into the impact of different factors on the outcome of the study.

V – RESULTS

V - RESULTS

5.1. STUDY OF LIGHTNESS (L*)

5.1.1. Composite resin samples

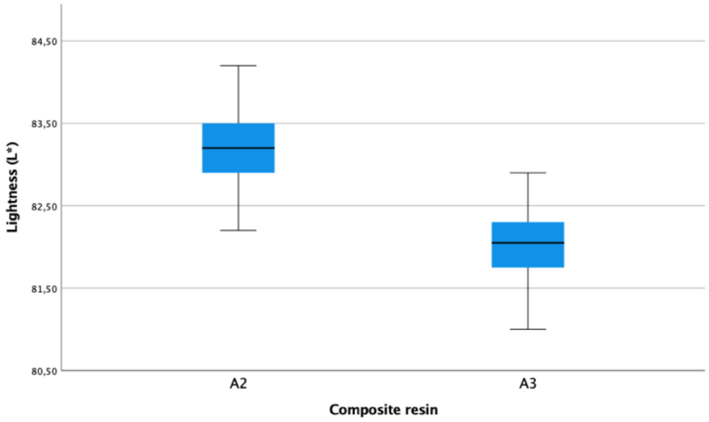
The composite samples lightness mean values and standard deviations utilized as the foundation for this study are displayed in Table 11 and Graphic 1. As shown in this table, the maximum lightness value for the composite resin samples of type A2 was 84,20, while the minimum value was 82,20. Additionally, for the composite resin samples of type A3, the maximum value obtained was 82,90, and the minimum value was 81,00.

Table 11. Composite lightness mean ± standard deviation, minimum, maximum and p-value (one-way ANOVA)

Composite resin	Mean ± Standard deviation	Minimum	Maximum
Filtek™ Supreme A2	83,17 ± 0,44	82,20	84,20
Filtek™ Supreme A3	81,99 ± 0,46	81,00	82,90
	$p<0{,}001^{(*)}$		

(*) Statistically significant difference for a 95% confidence interval

Graphic 1. Composite lightness mean ± standard deviation and p-value (one-way ANOVA) Boxplot



A one-way analysis of variance (ANOVA) was conducted to investigate the lightness difference between two types of composite resin materials, namely A2 composite resin (n=120) and A3 composite resin (n=120). Prior to the analysis, data screening procedures were applied to ensure that the data met the necessary assumptions for ANOVA.

Boxplots were examined to identify any potential outliers, and none were found (Graphic 1). To assess the normality assumption, a Shapiro-Wilk test was conducted on each group separately, and the results indicated that the data were normally distributed for both groups ($p>0,05$). Additionally, Levene's test was used to test for homogeneity of variances, and the results showed no significant differences in variances between the two groups ($p = 0,992$).

The ANOVA results showed a statistically significant difference in lightness between the two types of composite resin materials (Table 11), with a p-value of less than 0,001. Specifically, the A2 composite material exhibited greater lightness than the A3 composite material.

5.1.2. Composite resin and ceramic samples attached with glycerine

Composite materials *Filtek™ Supreme* A2 and A3 were paired with ceramics *IPS e.max® CAD (HT)* and *VitaBlocs® Mark II* with thicknesses of 0,5 mm and 0,8 mm, and their lightness was evaluated. The samples lightness mean values and standard deviations utilized as the foundation for this study are displayed in Table 12 and 13. Maximum and minimum lightness values (L^*) obtained were 93,50, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic with A2 composite resin and 84,20, corresponding to 0,5mm *IPS e.max®* ceramic with A3 composite resin, respectively.

Table 12. Composite paired with ceramics by thicknesses lightness mean ± standard deviation, minimum, and maximum.

		Thickness					
		0,5mm			*0,8mm*		
Composite resin	**Ceramic**	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
Filtek™ Supreme A2	*e.max®*	*86,80 ± 0,51*	*85,80*	*87,70*	*88,61 ± 0,38*	*88,00*	*89,40*
	Mark II	*89,37 ± 0,59*	*88,40*	*90,40*	*92,16± 0,67*	*91,00*	*93,50*
Filtek™ Supreme A3	*e.max®*	*85,24 ± 0,49*	*84,20*	*86,20*	*87,65 ± 0,39*	*86,90*	*88,60*
	Mark II	*88,69 ± 0,53*	*87,70*	*89,70*	*91,55± 0,49*	*90,50*	*92,40*

When considering the *Filtek™ Supreme* A2 base paired with *IPS e.max®* ceramic, the average lightness increased from 86,80 ± 0,51 to 88,61 ± 0,38 with an increase in ceramic thickness. Similarly, an increase in average lightness was observed when the *Filtek™ Supreme* A2 base was paired with *VitaBlocs® Mark II* ceramic, with average lightness values of 89,37 ± 0,59 and 92,16 ± 0,67 for 0,5 mm and 0,8 mm ceramic thicknesses, respectively.

When evaluating the pairing of *Filtek™ Supreme* A3 base with *IPS e.max®* ceramic, an increase in average lightness was observed with an increase in thickness, from 85,24 ± 0,49 to 87,65 ± 0,39. Similarly, an increase in average lightness was observed when *Filtek™ Supreme* A3 base was paired with *VitaBlocs® Mark II* ceramic, with average lightness values of 88,69 ± 0,53 and 91,55 ± 0,49 for 0,5 mm and 0,8 mm ceramic thicknesses, respectively.

Also when evaluating the same *Filtek™ Supreme* A2 composite resin base for the same 0,5mm ceramic thickness, it is possible to observe an increase in the average values of lightness from 86,80 ± 0,51 to 89,37 ± 0,59 for *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. In a similar manner, when examining the *Filtek™ Supreme* A3 composite resin base for a 0,5mm ceramic thickness, there was an increase in the average lightness values from 85,24 ± 0,49 to 88,69 ± 0,53 when paired with *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively.

Analogously, an increase in the average lightness values from 88,61 ± 0,38 to 92,16 ± 0,67 was observed when examining the same *Filtek™ Supreme* A2 composite resin base for a 0,8mm ceramic thickness and paired with *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. The same trend was observed when evaluating the *Filtek™ Supreme* A3 composite resin base for a 0,8mm ceramic thickness, where an increase in the average lightness values from 87,65 ± 0,39 to 91,55 ± 0,49 was observed when paired with *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively.

Considering *IPS e.max®* ceramic with a thickness of 0,5mm, a decrease in average lightness values from 86,80 ± 0,51 to 85,24 ± 0,49 is observed when it is paired with the *Filtek™ Supreme* A2 and *Filtek™ Supreme* A3 base, respectively. Similarly, a decrease in average lightness values from 88,61 ± 0,38 to 87,65 ± 0,39 is observed when *IPS e.max®* ceramic with a thickness of 0,8mm is paired with the A2 and A3 composite resin base, respectively.

Furthermore, considering *VitaBlocs® Mark II* ceramic with a thickness of 0,5mm, a decrease in average lightness values from 89,37 ± 0,59 to 88,69 ± 0,53 is also observed when it is paired with the *Filtek™ Supreme* A2 and *Filtek™ Supreme* A3 base, respectively. Similarly, when *VitaBlocs® Mark II* ceramic with a thickness of 0,8mm is paired with A2 and A3 composite resin base, a decrease in average lightness values from 92,16 ± 0,67 to 91,55 ± 0,49 is observed.

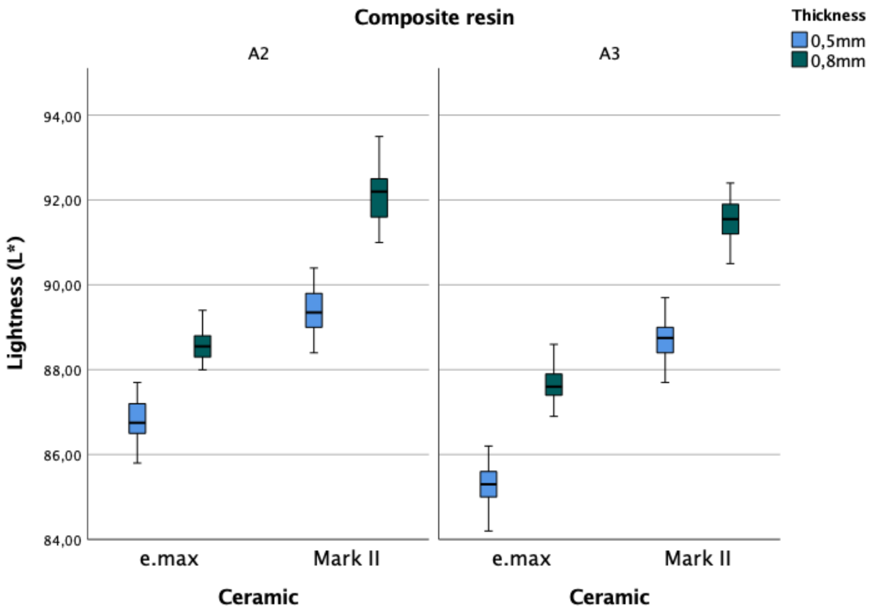
Table 13. Composite paired with ceramics by thicknesses lightness mean ± standard deviation and p-values (three-way ANOVA multiple comparisons Bonferroni test). Equal letters represent a direct comparison between the groups

		Thickness		
		0,5mm	*0,8mm*	
Composite resin	***Ceramic***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
Filtek™ Supreme A2	***e.max®***	*86,80 ± 0,51* $^{A\,(*)}$	*88,61 ± 0,38* $^{C\,(*)}$	*p<0,001*$^{(*)}$
	Mark II	*89,37 ± 0,59* $^{B\,(*)}$	*92,16 ± 0,67* $^{D\,(*)}$	*p<0,001*$^{(*)}$
		p<0,001$^{(*)}$	*p<0,001*$^{(*)}$	
Filtek™ Supreme A3	***e.max®***	*85,24 ± 0,49* $^{A\,(*)}$	*87,65 ± 0,39* $^{C\,(*)}$	*p<0,001*$^{(*)}$
	Mark II	*88,69 ± 0,53* $^{B\,(*)}$	*91,55 ± 0,49* $^{D\,(*)}$	*p<0,001*$^{(*)}$
		p<0,001$^{(*)}$	*p<0,001*$^{(*)}$	

(*) Statistically significant difference for a 95% confidence interval

A three-way analysis of variance (ANOVA) was conducted to investigate the effect of composite resin, ceramic, and ceramic thickness on lightness (Table 13). Boxplots were used to detect potential outliers, and none were identified (Graphic 2). To test for normality, a Shapiro-Wilk test was conducted on each group separately, and the results indicated normal distribution for both groups (p>0,05). However, Levene's test showed significant differences in variances between the groups (p=0,025). Despite this, the study design and the equal number of samples among groups provided sufficient security and robustness to proceed with the test.

Graphic 2. Composite paired with ceramics by thicknesses boxplot



A statistically significant three-way interaction was observed between composite, ceramic, and ceramic thickness (p=0,045). Simple two-way interactions and simple main effects were significant at the p<0,025 level. Furthermore, significant simple two-way interactions were observed between ceramic and ceramic thickness for A2 composite resin (p<0,001) and A3 composite resin (p=0,018). Simple simple main effects of ceramic thickness in A2 and A3 composite resin paired with *IPS e.max®* and *VitaBlocs® Mark II* ceramic were also statistically significant (p< 0,001).

All simple pairwise comparisons were run with a Bonferroni adjustment applied. Statistically significant differences were observed between thicknesses of the same ceramic paired with A2 composite resin or A3 composite resin, between *IPS e.max®* and *VitaBlocs® Mark II* ceramics for each thickness when paired with A2 and A3 composite resin, and between the same ceramic for 0,5mm and 0,8mm thicknesses varying the composite resin base (p<0,001) (Table 13). Thus, a statistically significant increase in L* was observed when increasing the thickness from 0,5 mm to 0,8 mm, regardless of the ceramic and composite resin base colour utilized. Additionally, a statistically significant increase in L* was observed upon changing the composite resin base from A3 to A2, irrespective of the ceramic type and thickness. When comparing the two ceramics, there is a statistically significant increase in lightness from the lithium disilicate ceramic to the feldspathic ceramic, for both colour bases and ceramic thicknesses.

5.1.3. Study of ΔL_1

The results concerning the variation in lightness between the composite resin samples and the composite resin samples attached to ceramic with glycerine (ΔL_1) are available in Table 14 and 15. The maximum and minimum ΔL_1 mean values obtained were 10,30, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic with A2 composite resin, and 2,10, corresponding to 0,5mm *IPS e.max®* ceramic with A3 composite resin, respectively.

Table 14. Composite paired with ceramics by thicknesses ΔL_1 mean ± standard deviation, minimum and maximum values

		Thickness					
		0,5mm			*0,8mm*		
Composite	***Ceramic***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
Filtek™ Supreme A2	*e.max®*	*3,82 ± 0,45*	*2,90*	*4,60*	*5,51 ± 0,41*	*4,70*	*6,40*
	Mark II	*6,04 ± 0,67*	*5,10*	*7,50*	*8,90 ± 0,72*	*7,70*	*10,30*
Filtek™ Supreme A3	*e.max®*	*3,52 ± 0,63*	*2,10*	*4,50*	*5,76 ± 0,49*	*5,00*	*7,10*
	Mark II	*6,53 ± 0,53*	*5,50*	*7,60*	*9,34 ± 0,45*	*8,50*	*10,20*

The results of the Table 14 showed that when using *Filtek™ Supreme* A2 with *IPS e.max®* ceramic, an increase in ceramic thickness led to an increase in average ΔL_1 values from 3,82 ± 0,45 to 5,51 ± 0,41. Similarly, when pairing *Filtek™ Supreme* A2 with *VitaBlocs® Mark II* ceramic, an increase in ceramic thickness resulted in an increase in average ΔL_1 values, with values of 6,04 ± 0,67 and 8,90 ± 0,72 observed for ceramic thicknesses of 0,5mm and 0,8mm, respectively.

The results also indicate that an increase in thickness led to an increase in average ΔL_1 values when pairing *Filtek™ Supreme* A3 base with *IPS e.max®* ceramic, with values increasing from 3,52 ± 0,63 to 5,76 ± 0,49. Similarly, an increase in average ΔL_1 values was observed when *Filtek™ Supreme* A3 base was paired with *VitaBlocs® Mark II* ceramic, with average ΔL_1 values of 6,53 ± 0,53 and 9,34 ± 0,45 for 0,5 mm and 0,8 mm ceramic thicknesses, respectively.

When considering the A2 colour base pair with a ceramic thickness of 0,5mm, an increase in the mean ΔL_1 values from 3,82 ± 0,45 to 6,04 ± 0,67 can be observed between the use of the *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. Similarly, when the same A2 colour base pair is considered but with a ceramic thickness of 0,8mm, an increase in the mean ΔL_1 values from 5,51 ± 0,41 to 8,90 ± 0,72 for the *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively, is also visible.

It is also observable that, when using the *Filtek™ Supreme* A3 base with a 0,5mm ceramic, there is also an increase in the mean ΔL_1 values from 3,52 ± 0,63 to 6,53 ± 0,53 for the *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. When using the same A2 composite resin base, but with a ceramic thickness of 0,8mm, there is a similar increase in the mean ΔL_1 values for the *IPS e.max®* ceramic (5,76 ± 0,49) and the *VitaBlocs® Mark II* ceramic (9,34 ± 0,45).

On the other hand, when the 0,5mm thick *IPS e.max®* ceramic is considered, there is a decrease in the mean ΔL_1 values from 3,82 ± 0,45 to 3,52 ± 0,63 when changing the base from *Filtek™ Supreme* A2 to A3, respectively. Conversely, when the 0,8mm thick *IPS e.max®* ceramic is considered, there is an increase in the mean ΔL_1 values from 5,51 ± 0,41, corresponding to the *Filtek™ Supreme* A2 base, to 5,76 ± 0,49, corresponding to the *Filtek™ Supreme* A3 base.

There is an observed increase in the mean ΔL_1 values from 6,04 ± 0,67 to 6,53 ± 0,53 corresponding to the composite resin base of colour A2 to A3, respectively, when considering the *VitaBlocs® Mark II* ceramic with a thickness of 0,5mm.

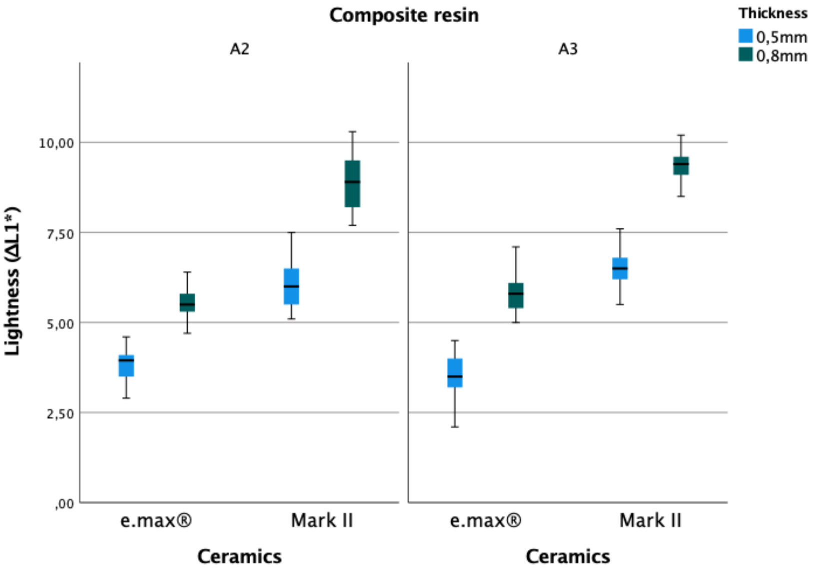
Similarly, when considering the *VitaBlocs® Mark II* ceramic with a thickness of 0,8mm, there is an observed increase in the mean ΔL_1 values from 8,90 ± 0,72 to 9,34 ± 0,45 corresponding to the composite resin base of colour A2 to A3, respectively.

Table 15. Composite paired with ceramics by thicknesses ΔL_1 mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Equal letters represent a direct comparison between the groups

		Thickness		
		0,5mm	*0,8mm*	
Composite	***Ceramic***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
Filtek™ Supreme A2	***e.max®***	*3,82 ± 0,45* $^{A\,(*)}$	*5,51 ± 0,41* ^{C}	*p<0,001*$^{(*)}$
	Mark II	*6,04 ± 0,67* $^{B\,(*)}$	*8,90 ± 0,72* $^{D\,(*)}$	*p<0,001*$^{(*)}$
		p<0,001$^{(*)}$	*p<0,001*$^{(*)}$	
Filtek™ Supreme A3	***e.max®***	*3,52 ± 0,63* $^{A\,(*)}$	*5,76 ± 0,49* ^{C}	*p<0,001*$^{(*)}$
	Mark II	*6,53 ± 0,53* $^{B\,(*)}$	*9,34 ± 0,45* $^{D\,(*)}$	*p<0,001*$^{(*)}$
		p<0,001$^{(*)}$	*p<0,001*$^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval.

Graphic 3. Composite paired with ceramics by thicknesses ΔL_1 boxplot



A three-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, and ceramic thickness on the variation of lightness (ΔL_1). The data was checked for potential outliers using boxplots, but none were detected (Graphic 3). The normality assumption was verified using the Shapiro-Wilk test, which indicated that both groups exhibited normal distribution (p>0,05). However, Levene's test revealed significant differences in variances between the groups (p=0,019). Despite this, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and n>15 among groups.

A significant three-way interaction was observed between composite, ceramic type, and ceramic thickness (p=0,033). Simple two-way interactions and simple main effects were also significant at the p<0,025 level. Additionally, significant simple two-way interactions were detected between ceramic type and ceramic thickness for A2 composite (p<0,001) and A3 composite (p=0,006). Simple main effects of ceramic thickness in A2 and A3 composite resin, paired with *IPS e.max®* and *VitaBlocs® Mark II* ceramic types, were also statistically significant (p< 0,001).

All pairwise comparisons were adjusted using the Bonferroni method. Statistically significant differences were found between thicknesses of the same ceramic paired with A2 or A3 composite resin, as well as between *IPS e.max®*and *VitaBlocs® Mark II* ceramics for each thickness when paired with A2 and A3 composite resin. Moreover, statistically significant differences were observed between samples of the same ceramic with identical thicknesses when comparing composite resin bases A2 and A3 (p<0,001), with the exception of *IPS e.max®*ceramic with a thickness of 0,8mm, where no statistically significant differences were found between the ΔL_1 values (p=0,078) (Table 15).

5.1.4. Composite resin and ceramic samples cemented with resin cements

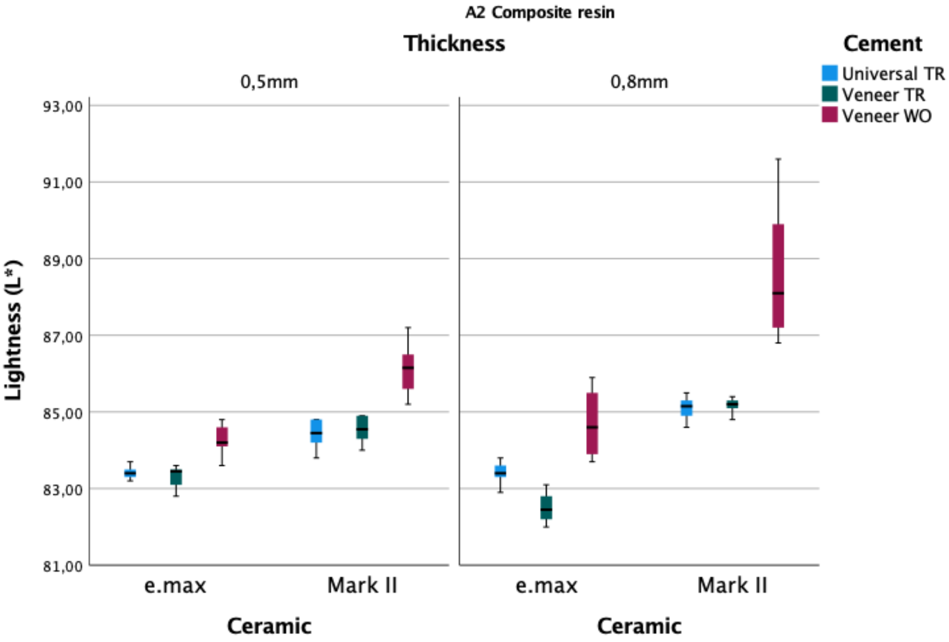
Composite materials *Filtek™ Supreme* A2 and A3 were cemented with ceramics *IPS e.max® CAD (HT)* and *VitaBlocs® Mark II*, with thicknesses of 0,5 mm and 0,8 mm, using the three resin cements under investigation, and their lightness was evaluated. The samples lightness mean values and standard deviations used as the foundation for this study are displayed in Table 16, 17 and 18. The maximum and minimum lightness values (L*) obtained were 91,60, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic cemented with *RelyX™ Veneer WO* to A2 composite resin, and 80,30, corresponding to 0,5mm *IPS e.max®* ceramic cemented with *RelyX™ Universal TR* to A3 composite resin, and also 0,8mm *IPS e.max®* ceramic cemented with *RelyX™ Veneer TR* to A3 composite resin, respectively.

The lightness mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A2 base are displayed in Table 16 and Graphic 4.

Table 16. Composite resin (A2) and ceramic samples cemented L mean ± standard deviation, minimum and maximum*

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*83,40 ± 0,16*	*83,20*	*83,70*	*83,39 ± 0,29*	*82,90*	*83,80*
	Veneer TR	*83,33 ± 0,28*	*82,80*	*83,60*	*82,49 ± 0,35*	*82,00*	*83,10*
	Veneer WO	*84,25 ± 0,40*	*83,60*	*84,80*	*84,69 ± 0,84*	*83,70*	*85,90*
Mark II	*Universal TR*	*84,41 ± 0,36*	*83,80*	*84,80*	*85,11 ± 0,27*	*84,60*	*85,50*
	Veneer TR	*84,54 ± 0,32*	*84,00*	*84,90*	*85,16 ± 0,22*	*84,80*	*85,40*
	Veneer WO	*86,12 ± 0,61*	*85,20*	*87,20*	*88,59 ± 1,77*	*86,80*	*91,60*

Graphic 4. Composite resin (A2) and ceramic samples cemented boxplot



Analyzing the results from Table 16, it is possible to observe that, when considering the *IPS e.max®*ceramic cemented with the *Universal TR* cement, there is a minimal reduction in average lightness values from 83,40 ± 0,16 to 83,39 ± 0,29 for a variation in ceramic thickness from 0,5mm to 0,8mm, respectively. Similarly, when considering the same *IPS e.max®* ceramic cemented with the *Veneer TR* cement, there is also a reduction in average lightness values from 83,33 ± 0,28 to 82,49 ± 0,35 for a variation in ceramic thickness from 0,5mm to 0,8mm, respectively. On the other hand, when considering the same *IPS e.max®* ceramic cemented with the *Veneer WO* cement, there is an increase in average lightness values from 84,25 ± 0,40 to 84,69 ± 0,84 for the same ceramic thickness variation, respectively.

When examining the *VitaBlocs® Mark II* ceramic cemented with the *Universal TR* cement, the average lightness values increase from 84,41 ± 0,36 to 85,11 ± 0,27 as the ceramic thickness varies from 0,5mm to 0,8mm, respectively. Similarly, with the *VitaBlocs® Mark II* ceramic cemented with the *Veneer TR* cement, there is also an increase in average lightness values from 84,54 ± 0,32 to 85,16 ± 0,22 with the same variation in ceramic thickness. When considering the *VitaBlocs® Mark II* ceramic cemented with the *Veneer WO* cement, the average lightness values also increase from 86,12 ± 0,61 to 88,59 ± 1,77 with the same variation in ceramic thickness.

Considering the *IPS e.max®* ceramic with a thickness of 0,5mm, an increase in average lightness values is observed, ranging from 83,33 ± 0,28, 83,40 ± 0,16, and 84,25 ± 0,40 for *Veneer TR*, *Universal TR*, and *Veneer WO* cements, respectively. Similarly, when examining the *VitaBlocs® Mark II* ceramic with the same thickness, an increase in average lightness values is observed, ranging from 84,41 ± 0,36, 84,54 ± 0,32, and 86,12 ± 0,61 for *Universal TR*, *Veneer TR*, and *Veneer WO* cements, respectively.

Likewise, when analyzing the *IPS e.max®* ceramic with a thickness of 0,8mm, an increase in average lightness values is observed, ranging from 82,49 ± 0,35, 83,39 ± 0,29, and 84,69 ± 0,84 for *Veneer TR, Universal TR*, and *Veneer WO* cements, respectively. Furthermore, when examining the *VitaBlocs® Mark II* ceramic with the same thickness, an increase in average lightness values is observed, ranging from 85,11 ± 0,27, 85,16 ± 0,22, and 88,59 ± 1,77 for *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively.

When analyzing the 0,5mm ceramic thickness and *Universal TR* cement, there is an increase in the average lightness values from 83,40 ± 0,16 to 84,41 ± 0,36 when changing from *IPS e.max®* ceramic to *VitaBlocs® Mark II*, respectively. When analyzing the same 0,5mm ceramic thickness with *Veneer TR* cement, there is also an increase in the average lightness values from 83,33 ± 0,28 to 84,54 ± 0,32, when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic, respectively. Similarly, when considering the same ceramic thickness and *Veneer WO* cement, there is also an increase in the average lightness values from *IPS e.max®* ceramic, of 84,25 ± 0,40, to *VitaBlocs® Mark II* ceramic of 86,12 ± 0,61.

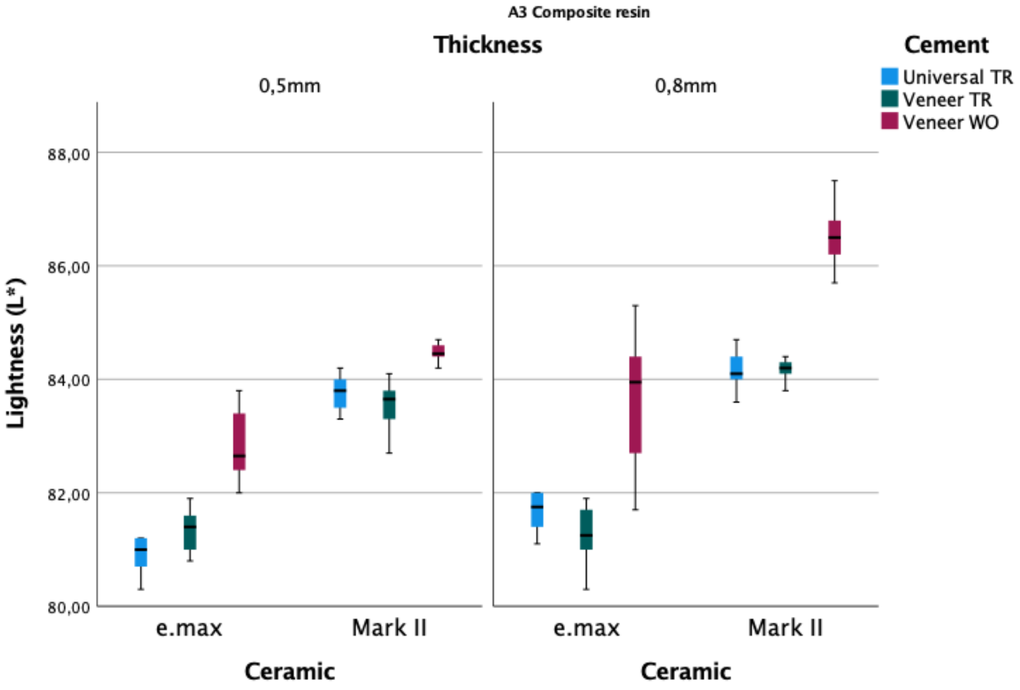
The analysis of 0,8mm ceramic thickness using *Universal TR* cement resulted in an increase in the average lightness values from 83,39 ± 0,29 to 85,11 ± 0,27 with the substitution of *IPS e.max®* ceramic with *VitaBlocs® Mark II*. Similarly, the analysis of the same ceramic thickness using *Veneer TR* cement showed an increase in the average lightness values from 82,49 ± 0,35 to 85,16 ± 0,22 when changing from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Likewise, for the same ceramic thickness and *Veneer WO* cement, the average lightness values increased significantly from 84,69 ± 0,84 for *IPS e.max®* ceramic to 88,59 ± 1,77 for *VitaBlocs® Mark II* ceramic.

The lightness mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A3 base are displayed in Table 17 and Graphic 5.

Table 17. Composite resin (A3) and ceramic samples cemented L mean ± standard deviation, minimum and maximum*

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*80,91 ± 0,31*	*80,30*	*81,20*	*81,68 ± 0,30*	*81,10*	*82,00*
	Veneer TR	*81,35 ± 0,40*	*80,80*	*81,90*	*81,21 ± 0,54*	*80,30*	*81,90*
	Veneer WO	*82,79 ± 0,61*	*82,00*	*83,80*	*83,69 ± 1,12*	*81,70*	*85,30*
Mark II	*Universal TR*	*83,75 ± 0,30*	*83,30*	*84,20*	*84,15 ± 0,30*	*83,60*	*84,70*
	Veneer TR	*83,56 ± 0,45*	*82,70*	*84,10*	*84,18 ± 0,19*	*83,80*	*84,40*
	Veneer WO	*84,46 ± 0,15*	*84,20*	*84,70*	*86,56 ± 0,59*	*85,70*	*87,50*

Graphic 5. Composite resin (A3) and ceramic samples cemented boxplot



Upon analysing Table 17, it is evident that using *IPS e.max®* ceramic with *Universal TR* cement results in an increase in average lightness values from 80,91 ± 0,31 to 81,68 ± 0,30 as the ceramic thickness changes from 0,5mm to 0,8mm, respectively. However, using the same *IPS e.max®* ceramic with *Veneer TR* cement causes a slight decrease in average lightness values from 81,35 ± 0,40 to 81,21 ± 0,54 with the same thickness variation. Conversely, using *IPS e.max®* ceramic with *Veneer WO* cement leads to an increase in average lightness values from 82,79 ± 0,61 to 83,69 ± 1,12 with the same thickness variation.

Similarly, when *VitaBlocs® Mark II* ceramic is used with *Universal TR* cement, there is an increase in average lightness values from 83,75 ± 0,30 to 84,15 ± 0,30 as the ceramic thickness varies from 0,5mm to 0,8mm, respectively. Likewise, using *VitaBlocs® Mark II* ceramic with *Veneer TR* cement results in an increase in average lightness values from 83,56 ± 0,45 to 84,18 ± 0,19 with the same thickness variation. Using *VitaBlocs® Mark II* ceramic with *Veneer WO* cement also results in an increase in average lightness values from 84,46 ± 0,15 to 86,56 ± 0,59 with the same thickness variation.

For *IPS e.max®* ceramic with a thickness of 0,5mm, an increase in average lightness values was observed for all cements, ranging from 80,91 ± 0,31 to 82,79 ± 0,61 for *Universal TR*, *Veneer TR*, and *Veneer WO* cements, respectively. On the other hand, for *VitaBlocs® Mark II* ceramic with the same thickness, the increase in average lightness values ranged from 83,56 ± 0,45 to 84,46 ± 0,15 for *Veneer TR*, *Universal TR*, and *Veneer WO* cements, respectively. Similarly, for *IPS e.max®* ceramic with a thickness of 0,8mm, an increase in average lightness values was observed, ranging from 81,21 ± 0,54 to 83,69 ± 1,12 for *Veneer TR*, *Universal TR*, and *Veneer WO* cements, respectively. Additionally, for *VitaBlocs® Mark II* ceramic with the same thickness, the increase in average lightness values ranged from 84,15 ± 0,30 to 86,56 ± 0,59 for *Universal TR*, *Veneer TR*, and *Veneer WO* cements, respectively.

In terms of the 0,5mm ceramic thickness and the *Universal TR* cement, there is an increase in average lightness values when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic, with the values increasing from 80,91 ± 0,31 to 83,75 ± 0,30. Similarly, when using *Veneer TR* cement with the same thickness, the average lightness values increase from 81,35 ± 0,40 to 83,56 ± 0,45 when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. The same trend is observed for *Veneer WO* cement with an increase in average lightness values from 82,79 ± 0,61 for *IPS e.max®* ceramic to 84,46 ± 0,15 for *VitaBlocs® Mark II* ceramic.

For the 0,8mm ceramic thickness and *Universal TR* cement, there is an increase in average lightness values from 81,68 ± 0,30 to 84,15 ± 0,30 when changing from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic. Similarly, when using *Veneer TR* cement, the average lightness values increase from 81,21 ± 0,54 to 84,18 ± 0,19. When using *Veneer WO* cement, the average lightness values increase significantly from 83,69 ± 1,12 for *IPS e.max®* ceramic to 86,56 ± 0,59 for *VitaBlocs® Mark II* ceramic.

Table 18. Composite resin and ceramic samples cemented L mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Same lowercase letters within the same column indicate a non-statistically significant differences between cements for each ceramic. The p-values below each column, for each base, represent differences for the same cement between different ceramics*

			Thickness		
			0,5mm	*0,8mm*	
Composite	***Ceramic***	***Cement***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
A2	***e.max®***	*Universal TR*	*83,40 ± 0,16* ^{a}	*83,39 ± 0,29*	*p=0,969*
		Veneer TR	*83,33 ± 0,28* ^{a}	*82,49 ± 0,35*	*p=0,001*$^{(*)}$
		Veneer WO	*84,25 ± 0,40*	*84,69 ± 0,84*	*p=0,091*
	Mark II	*Universal TR*	*84,41 ± 0,36* ^{b}	*85,11 ± 0,27* ^{c}	*p=0,008*$^{(*)}$
		Veneer TR	*84,54 ± 0,32* ^{b}	*85,16 ± 0,22* ^{c}	*p=0,018*$^{(*)}$
		Veneer WO	*86,12 ± 0,61*	*88,59 ± 1,77*	*p<0,001*$^{(*)}$
			p<0,001$^{(*)}$	*p<0,001*$^{(*)}$	
A3	***e.max®***	*Universal TR*	*80,91 ± 0,31* ^{d}	*81,68 ± 0,30* ^{f}	*p=0,003*$^{(*)}$
		Veneer TR	*81,35 ± 0,40* ^{d}	*81,21 ± 0,54* ^{f}	*p=0,590*
		Veneer WO	*82,79 ± 0,61*	*83,69 ± 1,12*	*p<0,001*$^{(*)}$
	Mark II	*Universal TR*	*83,75 ± 0,30* ^{e}	*84,15 ± 0,30* ^{g}	*p=0,125*
		Veneer TR	*83,56 ± 0,45* ^{e}	*84,18 ± 0,19* ^{g}	*p=0,018*$^{(*)}$
		Veneer WO	*84,46 ± 0,15*	*86,56 ± 0,59*	*p<0,001*$^{(*)}$
			p<0,001$^{(*)}$	*p<0,001*$^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval.

A four-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, ceramic thickness, and cement on the lightness L*. The data was checked for potential outliers using boxplots, but none were detected (Graphic 4 and 5). The normality assumption was verified using the Shapiro-Wilk test, which indicated that both groups exhibited normal distribution (p>0,05). However, Levene's test revealed significant differences in variances between the groups (p<0,001). Henceforth, a decision was made to conduct a Split File of the composite resin independent variable, followed by a three-way ANOVA. To compare the studied groups across different composite resin bases, an independent samples t-test was performed. It is noteworthy to mention that the Levene´s test in this scenario continues to exhibit statistical significance (p<0,001). However, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and n>15 among groups.

A significant three-way interaction was observed between ceramic type, ceramic thickness, and cement for a A3 composite resin base (p = 0,002), unlike the same interaction for a composite base A2 (p=0,077). For the latter, two-way interactions were verified, which proved to be statistically significant (p<0,001), and pairwise comparisons were continued. Statistically significance of simple two-way interactions and simple main effects was accepted at a Bonferroni-ajusted alpha level of 0,025. Additionally, significant simple two-way interactions were detected between ceramic thickness and cement for *IPS e.max®* and *VitaBlocs® Mark II* ceramics in a A3 composite resin base (p=0,003 and p<0,001, respectively). There was a simple main effect of cements for each thickness and type of ceramic in an A3 composite resin base (p<0,001).

All pairwise comparisons were adjusted using the Bonferroni method. Comparing the thicknesses of *IPS e.max®* and *VitaBlocs® Mark II* ceramics cemented to A2 composite resin bases, we found that ceramic thickness does not cause statistically significant changes in the L* variable when using *Universal TR* cement (p=0,969) and *Veneer WO* (p=0,091) in *IPS e.max®*ceramics (Table 18). When cemented to A3 composite resin base, it was found that ceramic thickness does not cause statistically significant changes in the L* variable when using *Veneer TR* cement (p=0,590) in *IPS e.max®* ceramics and when using *Universal TR* cement (p=0,125) in *VitaBlocs® Mark II* ceramics (Table 18). The *IPS e.max®* and *VitaBlocs®*

Mark II ceramic samples, with 0,5mm and 0,8mm thicknesses, cemented with *Universal TR* cement and *Veneer TR* cement, do not present statistically significant differences when cemented to an A3 composite resin base (p>0,05). When cemented to an A2 base with *Universal TR* cement and *Veneer TR* cement, the *IPS e.max®* ceramic samples with 0,5mm thickness and *VitaBlocs® Mark II* with 0,5mm and 0,8mm thickness do not present statistically significant differences (p>0,05). When cemented to an A2 or A3 colour base with any of the studied cements, for both thicknesses, there are statistically significant differences when changing from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic (p<0,001).

Table 19. Lightness independent samples t-test between A2 and A3 composite resin base for each ceramic and thickness and each cement

			Thickness	
			0,5mm	*0,8mm*
Composite	***Ceramic***	***Cement***	***p-values***	***p-values***
A2 vs. A3	***e.max®***	*Universal TR*	*p<0,001(*)*	*p<0,001(*)*
		Veneer TR	*p<0,001(*)*	*p<0,001(*)*
		Veneer WO	*p<0,001(*)*	*p=0,037(*)*
	Mark II	*Universal TR*	*p<0,001(*)*	*p<0,001(*)*
		Veneer TR	*p<0,001(*)*	*p<0,001(*)*
		Veneer WO	*p<0,001(*)*	*p=0,005(*)*

(*) Statistically significant differences for a 95% confidence interval

An independent samples t-test showed a statistically significant difference (p< 0,001) when using the same ceramic material, with the same thickness and cement type, varying the base shade from A2 to A3 (Table 19). In addition, there was a significant difference observed in the use of *IPS e.max®* ceramic with *Veneer WO* cement for the 0,8mm thickness (p=0,037) and in the use of *VitaBlocs® Mark II* ceramic with *Veneer WO* cement for the 0,8mm thickness (p=0,005) when comparing bases of A2 and A3 shades.

5.1.5. Study of ΔL_2

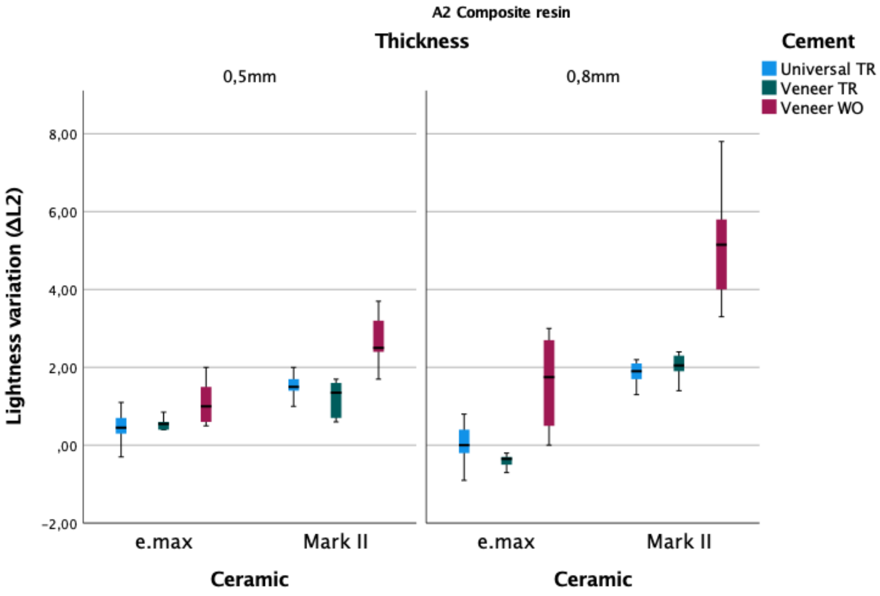
The results concerning the variation in lightness between the composite resin samples and the composite resin samples cemented to ceramic using the studied cements (ΔL_2) are available in Table 20, 21 and 22. The maximum and minimum absolute ΔL_2 mean values obtained were 7,80, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic, cemented to A2 composite resin base with *Veneer WO* cement, and 0,00, corresponding to 0,8mm *IPS e.max®* ceramic cemented to A2 composite resin base with *Veneer WO* cement and 0,5mm *IPS e.max®* ceramic cemented to A3 composite resin base with *Universal TR* cement, respectively.

The lightness variation (ΔL_2) mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A2 base are displayed in Table 20 and Graphic 6.

Table 20. Composite resin (A2) and ceramic samples cemented ΔL_2 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*0,46 ± 0,38*	*-0,30*	*1,10*	*0,02 ± 0,49*	*-0,90*	*0,80*
	Veneer TR	*0,55 ± 0,17*	*0,40*	*0,85*	*-0,40 ± 0,17*	*-0,70*	*-0,20*
	Veneer WO	*1,05 ± 0,49*	*0,50*	*2,00*	*1,64 ± 1,08*	*0,00*	*3,00*
Mark II	*Universal TR*	*1,52 ± 0,27*	*1,00*	*2,00*	*1,86 ± 0,31*	*1,30*	*2,20*
	Veneer TR	*1,23 ± 0,43*	*0,60*	*1,70*	*1,99 ± 0,33*	*1,40*	*2,40*
	Veneer WO	*2,67 ± 0,65*	*1,70*	*3,70*	*5,23 ± 1,55*	*3,30*	*7,80*

Graphic 6. Composite resin (A2) and ceramic samples cemented ΔL_2 *Boxplot*



From Table 20, it can be observed that for *IPS e.max®* ceramic cemented with *Universal TR* cement, there is a decrease in average ΔL_2 values from 0,46 ± 0,38 to 0,02 ± 0,49 when the ceramic thickness changes from 0,5mm to 0,8mm. Similarly, for the same ceramic cemented with *Veneer TR* cement, there is also a decrease in average ΔL_2 values from 0,55 ± 0,17 to -0,40 ± 0,17 for the same variation in ceramic thickness. However, with *Veneer WO* cement, there is an increase in average ΔL_2 values from 1,05 ± 0,49 to 1,64 ± 1,08 for the same ceramic thickness variation.

In the case of *VitaBlocs® Mark II* ceramic cemented with *Universal TR* cement, the average ΔL_2 values increase from 1,52 ± 0,27 to 1,86 ± 0,31 when the ceramic thickness varies from 0,5mm to 0,8mm. Similarly, with the same ceramic cemented with *Veneer TR* cement, there is also an increase in average ΔL_2 values from 1,23 ± 0,43 to 1,99 ± 0,33 with the same variation in ceramic thickness. When considering *VitaBlocs® Mark II* ceramic cemented with *Veneer WO* cement, the average ΔL_2 values also increase from 2,67 ± 0,65 to 5,23 ± 1,55 for the same variation in ceramic thickness.

Considering *IPS e.max®* ceramic with a thickness of 0,5mm, it is apparent that the average ΔL_2 values increase for *Universal TR, Veneer TR,* and *Veneer WO* cements, with values ranging from 0,46 ± 0,38, 0,55 ± 0,17, and 1,05 ± 0,49, respectively. The same pattern is observed when evaluating the *VitaBlocs® Mark II* ceramic with the same thickness, with average ΔL_2 values ranging from 1,23 ± 0,43, 1,52 ± 0,27, and 2,67 ± 0,65 for *Veneer TR, Universal TR,* and *Veneer WO* cements, respectively. Similarly, for *IPS e.max®* ceramic with a thickness of 0,8mm, there is an increase in average ΔL_2 values for *Veneer TR, Universal TR,* and *Veneer WO* cements, ranging from -0,40 ± 0,17, 0,02 ± 0,49, and 1,64 ± 1,08, respectively. Furthermore, when examining the *VitaBlocs® Mark II* ceramic with the same thickness, there is an increase in average ΔL_2 values for *Universal TR, Veneer TR,* and *Veneer WO* cements, with values ranging from 1,86 ± 0,31, 1,99 ± 0,33, and 5,23 ± 1,55, respectively.

When examining ceramic thickness of 0,5mm and using *Universal TR* cement, there is an observable rise in the average ΔL_2 values from 0,46 ± 0,38 to 1,52 ± 0,27 when transitioning from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. This same pattern is also seen when using *Veneer TR* cement, with an increase in average ΔL_2 values from 0,55 ± 0,17 to 1,23 ± 0,43 when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Additionally, for the same ceramic thickness and using *Veneer WO* cement, the average ΔL_2 values also increase from 1,05 ± 0,49 for *IPS e.max®* ceramic to 2,67 ± 0,65 for *VitaBlocs® Mark II* ceramic.

For the analysis of 0,8mm ceramic thickness using *Universal TR* cement, there is an increase in average ΔL_2 values from 0,02 ± 0,49 to 1,86 ± 0,31 when replacing *IPS e.max®* ceramic with *VitaBlocs® Mark II*. The same holds true when using *Veneer TR* cement, with an increase in average ΔL_2 values from -0,40 ± 0,17 to 1,99 ± 0,33 when transitioning from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Similarly, for the same ceramic thickness and using *Veneer WO* cement, there is a significant increase in the average ΔL_2 values from 1,64 ± 1,08 for *IPS e.max®* ceramic to 5,23 ± 1,55 for *VitaBlocs® Mark II* ceramic.

The lightness variation (ΔL_2) mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A3 base are displayed in Table 21 and Graphic 7.

Table 21. Composite resin (A3) and ceramic samples cemented ΔL_2 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			0,8mm		
Ceramic	**Cement**	Mean ± Std. Dev.	Min.	Max.	Mean ± Std. Dev	Min.	Max.
e.max®	Universal TR	-0,50 ± 0,47	-1,50	0,00	-0,32 ± 0,31	-0,90	0,20
	Veneer TR	0,41 ± 0,45	-1,10	0,40	-0,51 ± 0,64	-1,80	0,40
	Veneer WO	0,80 ± 0,65	0,10	1,80	1,75 ± 0,97	0,60	3,00
Mark II	Universal TR	1,41 ± 0,29	1,10	1,90	2,01 ± 0,21	1,70	2,30
	Veneer TR	1,58 ± 0,38	0,90	2,20	2,00 ± 0,19	1,70	2,40
	Veneer WO	2,31 ± 0,24	1,90	2,70	4,39 ± 0,42	3,80	5,00

Graphic 7. Composite resin (A2) and ceramic samples cemented ΔL_2 Boxplot

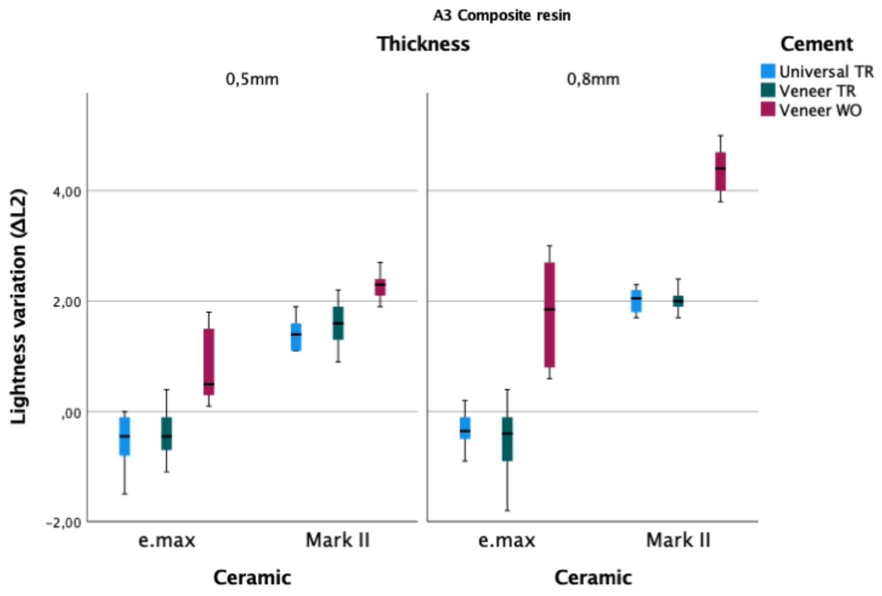


Table 21 reveals that the average ΔL_2 values for *IPS e.max®* ceramic cemented with *Universal TR* cement increase from -0,50 ± 0,47 to -0,32 ± 0,31 when the ceramic thickness is increased from 0,5mm to 0,8mm. However, for the same ceramic cemented with *Veneer TR* cement, the average ΔL_2 values decrease from 0,41 ± 0,45 to -0,51 ± 0,64 with the same variation in ceramic thickness. Conversely, when using *Veneer WO* cement, there is an increase in the average ΔL_2 values from 0,80 ± 0,65 to 1,75 ± 0,97 for the same ceramic thickness variation.

In the case of *VitaBlocs® Mark II* ceramic cemented with *Universal TR* cement, the average ΔL_2 values increase from 1,41 ± 0,29 to 2,01 ± 0,21 when the ceramic thickness varies from 0,5mm to 0,8mm. Similarly, with the same ceramic cemented with *Veneer TR* cement, there is an increase in average ΔL_2 values from 1,58 ± 0,38 to 2,00 ± 0,19 with the same variation in ceramic thickness. When considering *VitaBlocs® Mark II* ceramic cemented with *Veneer WO* cement, the average ΔL_2 values also increase from 2,31 ± 0,24 to 4,39 ± 0,42 for the same variation in ceramic thickness.

The average ΔL_2 values for *IPS e.max®* ceramic with a thickness of 0,5mm increased with all three cements (*Universal TR, Veneer TR*, and *Veneer WO*), ranging from -0,50 ± 0,47, 0,41 ± 0,45, and 0,80 ± 0,65. The same trend was observed for *VitaBlocs® Mark II* ceramic, with values ranging from 1,41 ± 0,29, 1,58 ± 0,38, and 2,31 ± 0,24 for *Universal TR, Veneer TR*, and *Veneer WO*, respectively. For *IPS e.max®* ceramic with a thickness of 0,8mm, average ΔL_2 values increased for *Veneer TR, Universal TR*, and *Veneer WO* cements (ranging from -0,51 ± 0,64, -0,32 ± 0,31, and 1,75 ± 0,97, respectively). Similarly, *VitaBlocs® Mark II* ceramic showed an increase in average ΔL_2 values for the same cements (ranging from 2,00 ± 0,19, 2,01 ± 0,21, and 4,39 ± 0,42, respectively).

When examining ceramic thickness of 0,5mm and using *Universal TR* cement, there is a noticeable increase in average ΔL_2 values from -0,50 ± 0,47 to 1,41 ± 0,29 when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. This same trend is observed when using *Veneer TR* cement, with an increase in average ΔL_2 values from 0,41 ± 0,45 to 1,58 ± 0,38 when transitioning from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Similarly, for the same ceramic thickness and using *Veneer WO* cement, the average ΔL_2 values also increase from 0,80 ± 0,65 for *IPS e.max®* ceramic to 2,31 ± 0,24 for *VitaBlocs® Mark II* ceramic.

In the analysis of 0,8mm ceramic thickness using *Universal TR* cement, there is an increase in average ΔL_2 values from -0,32 ± 0,31 to 2,01 ± 0,21 when replacing *IPS e.max®* ceramic with *VitaBlocs® Mark II*. The same holds true when using *Veneer TR* cement, with an increase in average ΔL_2 values from -0,51 ± 0,64 to 2,00 ± 0,19 when transitioning from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Similarly, for the same ceramic thickness and using *Veneer WO* cement, there is a significant increase in the average ΔL_2 values from 1,75 ± 0,97 for *IPS e.max®* ceramic to 4,39 ± 0,42 for *VitaBlocs® Mark II* ceramic.

Table 22. Composite resin and ceramic samples cemented ΔL_2 mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Same lowercase letters within the same column indicate a non-statistically significant differences between cements for each ceramic. The p-values below each column, for each base, represent differences for the same cement between different ceramics

			Thickness		
			0,5mm	*0,8mm*	
Composite	***Ceramic***	***Cement***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
A2	***e.max®***	*Universal TR*	*0,46 ± 0,38* ^{a}	*0,02 ± 0,49* ^{c}	$p=0,135$
		Veneer TR	*0,55 ± 0,17* ^{a}	*-0,40 ± 0,17* ^{c}	$p<0,001^{(*)}$
		Veneer WO	*1,05 ± 0,49* ^{a}	*1,64 ± 1,08*	$p=0,046^{(*)}$
	Mark II	*Universal TR*	*1,52 ± 0,27* ^{b}	*1,86 ± 0,31* ^{d}	$p=0,247$
		Veneer TR	*1,23 ± 0,43* ^{b}	*1,99 ± 0,33* ^{d}	$p=0,011^{(*)}$
		Veneer WO	*2,67 ± 0,65*	*5,23 ± 1,55*	$p<0,001^{(*)}$
			$p<0,001^{(*)}$	$p<0,001^{(*)}$	
A3	***e.max®***	*Universal TR*	*-0,50 ± 0,47* ^{e}	*-0,32 ± 0,31*	$p=0,410$
		Veneer TR	*0,41 ± 0,45* ^{e}	*-0,51 ± 0,64*	$p=0,647$
		Veneer WO	*0,80 ± 0,65*	*1,75 ± 0,97*	$p<0,001^{(*)}$
	Mark II	*Universal TR*	*1,41 ± 0,29* ^{f}	*2,01 ± 0,21*	$p=0,007^{(*)}$
		Veneer TR	*1,58 ± 0,38* ^{f}	*2,00 ± 0,19*	$p=0,056$
		Veneer WO	*2,31 ± 0,24*	*4,39 ± 0,42*	$p<0,001^{(*)}$
			$p<0,001^{(*)}$	$p<0,001^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval

A four-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, ceramic thickness, and cement on the lightness variation ΔL_2. The data was checked for potential outliers using boxplots, but none were detected (Graphic 6 and 7). The normality assumption was verified using the Shapiro-Wilk test, which indicated that both groups exhibited normal distribution (p>0,05). However, Levene's test revealed significant differences in variances between the groups (p<0,001). Henceforth, a decision was made to conduct a Split File of the composite resin independent variable, followed by a three-way ANOVA. To compare the studied groups across different composite resin bases, an independent samples t-test was performed. It is noteworthy to mention that the Levene´s test in this scenario continues to exhibit statistical significance (p<0,001). However, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and N > 15 among groups.

A non-significant three-way interaction was observed between ceramic type, ceramic thickness, and cement for a A2 (p = 0,105) and A3 (p=0,215) composite resin base. Two-way interactions were verified, which proved to be statistically significant (p<0,001) except between ceramic and cement for a A3 composite resin base (p=0,706), and pairwise comparisons were continued.

All pairwise comparisons were adjusted using the Bonferroni method. Comparing the thicknesses of *IPS e.max®* and *VitaBlocs® Mark II* ceramics cemented to A2 composite bases, we found that ceramic thickness does not cause statistically significant changes in the ΔL_2 variable when using *Universal TR* cement in *IPS e.max®* ceramics (p=0,135) and *VitaBlocs® Mark II* (p=0,247) (Table 22). When cemented to A3 composite base, we found that ceramic thickness does not cause statistically significant changes in the ΔL_2 variable when using *Universal TR* (p=0,410) and *Veneer TR* cement (p=0,647) in *IPS e.max®* ceramics and when using *Veneer TR* cement (p=0,056) in *VitaBlocs® Mark II* ceramics (Table 22).

The *IPS e.max®* ceramic samples, with 0,5mm cemented with *Universal TR*, *Veneer TR* and *Veneer WO* cement, do not present statistically significant differences when cemented to an A2 composite base (p>0,05). The *VitaBlocs® Mark II* with 0,5mm and the *IPS e.max®* and *VitaBlocs® Mark II* with 0,8mm thicknesses, cemented with *Universal TR* cement and *Veneer TR* cement, do not present statistically significant differences when cemented to an A2 composite base (p>0,05). When cemented to an A3 base with *Universal TR* cement and *Veneer TR* cement, the *IPS e.max®* and *VitaBlocs® Mark II* ceramic samples with 0,5mm and 0,8mm thickness do not present statistically significant differences (p>0,05).

When cemented to an A2 or A3 colour base with any of the studied cements, for both thicknesses, there are statistically significant differences when changing from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic (p<0,001).

Table 23. ΔL_2 independent samples t-test between A2 and A3 composite resin base for each ceramic and thickness and each cement

			Thickness	
			0,5mm	*0,8mm*
Composite	***Ceramic***	***Cement***	***p-values***	***p-values***
A2 vs. A3	***e.max®***	*Universal TR*	*p<0,001(*)*	*p=0,080*
		Veneer TR	*p<0,001(*)*	*p=0,609*
		Veneer WO	*p=0,344*	*p=0,814*
	Mark II	*Universal TR*	*p=0,397*	*p=0,223*
		Veneer TR	*p=0,070*	*p=0,935*
		Veneer WO	*p=0,128*	*p=0,127*

(*) Statistically significant differences for a 95% confidence interval

The use of *IPS e.max®* ceramic material with a thickness of 0,5mm and cemented with *Universal TR* and *Veneer TR* cements, while varying the base shade from A2 to A3, resulted in a statistically significant difference (p < 0,001) according to an independent samples t-test (Table 23).

5.1.6. Study of ΔL_3

The results concerning the variation in lightness between the composite resin samples attached to ceramic with glycerine and the composite resin samples cemented to ceramic using the studied cements (ΔL_3) are available in Table 24, 25 and 26. The maximum and minimum ΔL_3 mean absolute values obtained were 8,10, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic, cemented to A3 composite resin base with *Veneer TR* cement, and 1,80, corresponding to 0,5mm *IPS e.max®* ceramic cemented to A3 composite resin base with *Veneer WO* cement, respectively.

The lightness variation (ΔL_3) mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A2 base are displayed in Table 24 and Graphic 8.

Table 24. Composite resin (A2) and ceramic samples cemented ΔL_3 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*-3,20 ± 0,53*	*-4,00*	*-2,20*	*-5,51 ± 0,22*	*-5,80*	*-5,20*
	Veneer TR	*-3,53 ± 0,45*	*-4,20*	*-2,80*	*-5,91 ± 0,33*	*-6,40*	*-5,20*
	Veneer WO	*-2,69 ± 0,30*	*-3,10*	*-2,30*	*-3,83 ± 0,89*	*-4,90*	*-2,40*
Mark II	*Universal TR*	*-4,08 ± 0,26*	*-4,40*	*-3,60*	*-6,61 ± 0,33*	*-7,20*	*-6,20*
	Veneer TR	*-4,93 ± 0,44*	*-5,80*	*-4,40*	*-7,15 ± 0,48*	*-7,90*	*-6,40*
	Veneer WO	*-3,60 ± 0,67*	*-4,60*	*-2,30*	*-3,87 ± 1,46*	*-6,00*	*-1,90*

Graphic 8. Composite resin (A2) and ceramic samples cemented ΔL_3 Boxplot

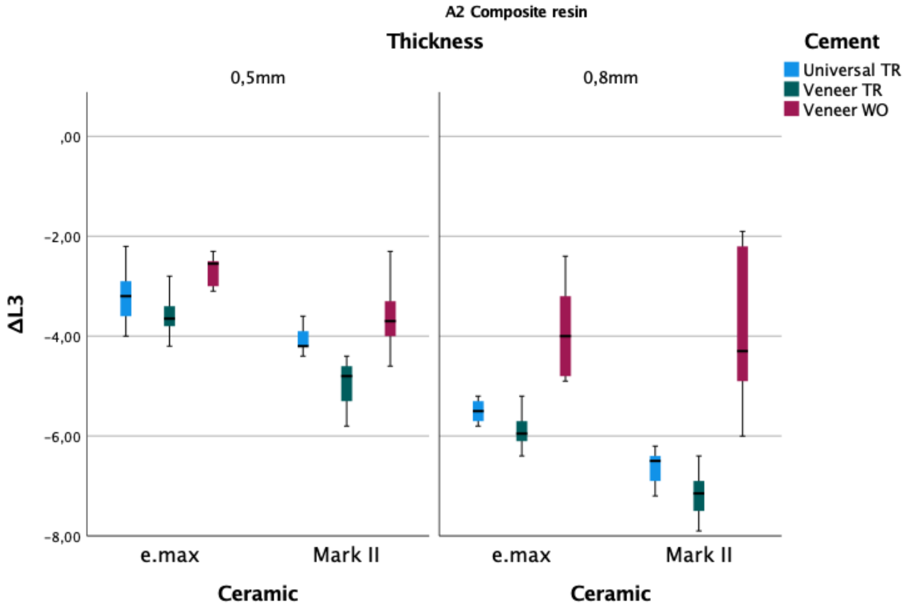


Table 24 displays the data showing that when *IPS e.max®* ceramic is cemented with *Universal TR* cement, the average ΔL_3 values increase from 3,20 ± 0,53 to 5,51 ± 0,22 as the ceramic thickness increases from 0,5mm to 0,8mm. Similarly, when the same ceramic is cemented with *Veneer TR* cement, the average ΔL_3 values also increase from 3,53 ± 0,46 to 5,91 ± 0,33 for the same thickness variation. The use of *Veneer WO* cement also leads to an increase in average ΔL_3 values from 2,69 ± 0,30 to 3,83 ± 0,89 for the same thickness variation.

For *VitaBlocs® Mark II* ceramic cemented with *Universal TR* cement, the average ΔL_3 values increase from 4,07 ± 0,25 to 6,61 ± 0,33 when the ceramic thickness varies from 0,5mm to 0,8mm. Similarly, the use of *Veneer TR* cement also leads to an increase in average ΔL_3 values from 4,93 ± 0,44 to 7,15 ± 0,48 for the same thickness variation. When *VitaBlocs® Mark II* ceramic is cemented with *Veneer WO* cement, the average ΔL_3 values increase from 3,60 ± 0,67 to 3,87 ± 1,46 for the same thickness variation.

When considering *IPS e.max®* ceramic with a thickness of 0,5mm, it is evident that the average ΔL_3 values increase for *Veneer WO*, *Universal TR*, and *Veneer TR* cements. The values range from 2,69 ± 0,30, 3,20 ± 0,53, and 3,53 ± 0,46, respectively. The same trend is observed when evaluating *VitaBlocs® Mark II* ceramic with the same thickness. The average ΔL_3 values range from 3,60 ± 0,67, 4,07 ± 0,25, and 4,93 ± 0,44 for *Veneer WO, Universal TR*, and *Veneer TR* cements, respectively.

Similarly, when examining *IPS e.max®* ceramic with a thickness of 0,8mm, there is an increase in average ΔL_3 values for *Veneer WO, Universal TR*, and *Veneer TR* cements. The values range from 3,83 ± 0,89, 5,51 ± 0,22, and 5,91 ± 0,33, respectively. Additionally, when analyzing *VitaBlocs® Mark II* ceramic with the same thickness, there is an increase in average ΔL_3 values for *Veneer WO, Universal TR*, and *Veneer TR* cements. The values range from 3,87 ± 1,46, 6,61 ± 0,33, and 7,15 ± 0,48, respectively.

When examining ceramic thickness of 0,5mm and using *Universal TR* cement, there is a noticeable increase in the mean ΔL_3 values when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. Specifically, the average ΔL_3 values rise from 3,20 ± 0,53 to 4,07 ± 0,25. The same pattern is observed when using *Veneer TR* cement, where average ΔL_3 values increase from 3,53 ± 0,46 to 4,93 ± 0,44. Additionally, when using *Veneer WO* cement, the average ΔL_3 values increase from 2,69 ± 0,30 for *IPS e.max®* ceramic to 3,60 ± 0,67 for *VitaBlocs® Mark II* ceramic, with the same ceramic thickness.

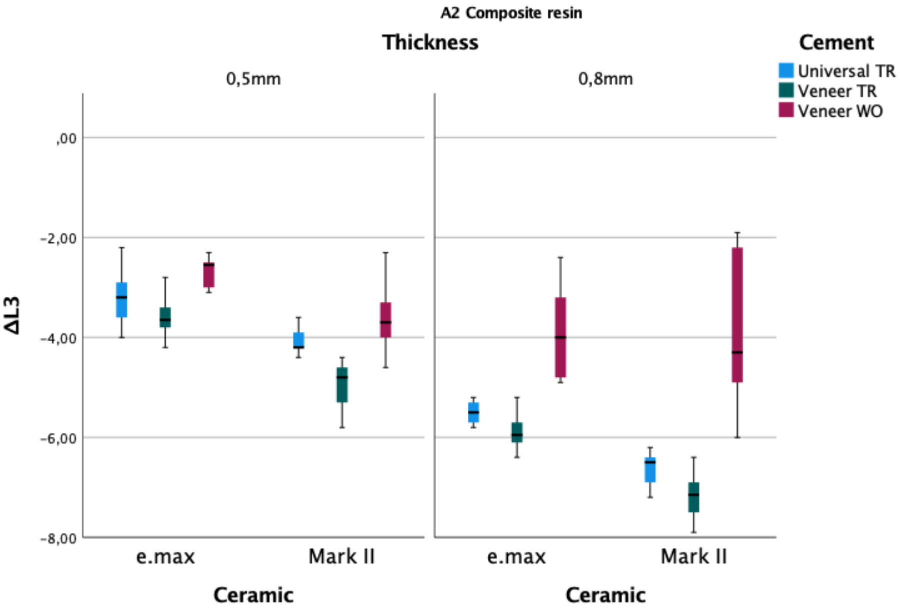
For the analysis of 0,8mm ceramic thickness using *Universal TR* cement, there is an increase in average ΔL_3 values from 5,51 ± 0,22 to 6,61 ± 0,33 when replacing *IPS e.max®* ceramic with *VitaBlocs® Mark II*. The same holds true when using *Veneer TR* cement, with an increase in average ΔL_3 values from 5,91 ± 0,33 to 7,15 ± 0,48 when transitioning from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Similarly, there is a slight increase in average ΔL_3 values when using *Veneer WO* cement, rising from 3,83 ± 0,89 for *IPS e.max®* ceramic to 3,87 ± 1,46 for *VitaBlocs® Mark II* ceramic, with the same ceramic thickness.

The lightness variation (ΔL_3) mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A3 base are displayed in Table 25 and Graphic 9.

Table 25. Composite resin (A3) and ceramic samples cemented ΔL_3 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			0,8mm		
Ceramic	**Cement**	Mean ± Std. Dev.	Min.	Max.	Mean ± Std. Dev	Min.	Max.
e.max®	Universal TR	-3,98 ± 0,54	-4,80	-3,00	-6,16 ± 0,32	-6,60	-5,80
	Veneer TR	-3,73 ± 0,62	-4,50	-2,50	-6,38 ± 0,44	-7,20	-5,70
	Veneer WO	-2,83 ± 0,57	-3,80	-1,80	-3,82 ± 0,85	-5,20	-2,70
Mark II	Universal TR	-4,81 ± 0,27	-5,20	-4,40	-7,07 ± 0,38	-7,70	-6,50
	Veneer TR	-5,20 ± 0,75	-6,20	-3,60	-7,56 ± 0,41	-8,10	-7,20
	Veneer WO	-4,29 ± 0,37	-4,70	-3,70	-5,12 ± 0,72	-6,50	-4,00

Graphic 9. Composite resin (A3) and ceramic samples cemented ΔL_3 Boxplot



The data presented in Table 25 demonstrates that with increasing ceramic thickness from 0,5mm to 0,8mm, there is a significant rise in average ΔL_3 values when *IPS e.max®* ceramic is cemented with *Universal TR* cement. Specifically, the values increase from 3,98 ± 0,54 to 6,16 ± 0,32. A similar pattern is seen when *Veneer TR* cement is used, with average ΔL_3 values increasing from 3,73 ± 0,62 to 6,38 ± 0,44 for the same thickness variation. *Veneer WO* cement also results in a higher average ΔL_3 values, rising from 2,83 ± 0,57 to 3,82 ± 0,85 with the same thickness variation.

For *VitaBlocs® Mark II* ceramic cemented with *Universal TR* cement, there is a noticeable increase in average ΔL_3 values from 4,81 ± 0,27 to 7,07 ± 0,38 as the ceramic thickness increases from 0,5mm to 0,8mm. A similar pattern is observed when *Veneer TR* cement is used, with average ΔL_3 values rising from 5,20 ± 0,75 to 7,56 ± 0,41 for the same thickness variation. When *VitaBlocs® Mark II* ceramic is cemented with *Veneer WO* cement, the average ΔL_3 values increase from 4,29 ± 0,37 to 5,12 ± 0,72 for the same thickness variation.

When examining *IPS e.max®* ceramic with a 0,5mm thickness, it is clear that the average ΔL_3 values increase for *Veneer WO, Veneer TR*, and *Universal TR* cements, with values ranging from 2,83 ± 0,57, 3,73 ± 0,62, and 3,98 ± 0,54, respectively. However, when evaluating *VitaBlocs® Mark II* ceramic with the same thickness, it is observed that the average ΔL_3 values range from 4,29 ± 0,37, 4,81 ± 0,27, and 5,20 ± 0,75 for *Veneer WO, Universal TR*, and *Veneer TR* cements, respectively.

Likewise, when analyzing *IPS e.max®* ceramic with an 0,8mm thickness, there is an increase in average ΔL_3 values for *Veneer WO, Universal TR*, and *Veneer TR* cements, with values ranging from 3,82 ± 0,85, 6,16 ± 0,32, and 6,38 ± 0,44, respectively. Additionally, when examining *VitaBlocs® Mark II* ceramic with the same thickness, there is an increase in average ΔL_3 values for *Veneer WO, Universal TR*, and *Veneer TR* cements, with values ranging from 5,12 ± 0,72, 7,07 ± 0,38, and 7,56 ± 0,41, respectively.

When considering a ceramic thickness of 0,5mm and utilizing *Universal TR* cement, there is an evident rise in the mean ΔL_3 values when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. More specifically, the average ΔL_3 values increase from 3,98 ± 0,54 to 4,81 ± 0,27. A similar trend is observed with *Veneer TR* cement, where the average ΔL_3 values increase from 3,73 ± 0,62 to 5,20 ± 0,75.

Additionally, with the same ceramic thickness, using *Veneer WO* cement increases the average ΔL_3 values from 2,83 ± 0,57 for *IPS e.max®* ceramic to 4,29 ± 0,37 for *VitaBlocs® Mark II* ceramic.

For 0,8mm ceramic thickness analysis using *Universal TR* cement, the average ΔL_3 values increase from 6,16 ± 0,32 to 7,07 ± 0,38 when *IPS e.max®* ceramic is replaced with *VitaBlocs® Mark II*. This trend holds true when using *Veneer TR* cement, with an increase in average ΔL_3 values from 6,38 ± 0,44 to 7,56 ± 0,41 when transitioning from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Similarly, there is an increase in average ΔL_3 values when using *Veneer WO* cement, rising from 3,82 ± 0,85 for *IPS e.max®* ceramic to 5,12 ± 0,72 for *VitaBlocs® Mark II* ceramic, with the same ceramic thickness.

Table 26. Composite resin and ceramic samples cemented ΔL_3 mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Same lowercase letters within the same column indicate a non-statistically significant differences between cements for each ceramic. The p-values below each column, for each base, represent differences for the same cement between different ceramics. Same capital letters within the same column indicate a non-statistically significant differences for the same cement between different ceramics

			Thickness		
			0,5mm	*0,8mm*	
Composite	***Ceramic***	***Cement***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
A2	***e.max®***	*Universal TR*	-3,20 ± 0,53 ^{ab}	-5,51 ± 0,22 ^{d}	$p<0,001^{(*)}$
		Veneer TR	-3,53 ± 0,46 ^{a}	-5,91 ± 0,33 ^{d}	$p<0,001^{(*)}$
		Veneer WO	-2,69 ± 0,30 ^{b}	-3,83 ± 0,89 ^{A}	$p<0,001^{(*)}$
	Mark II	*Universal TR*	-4,07 ± 0,25 ^{c}	-6,61 ± 0,33 ^{e}	$p<0,001^{(*)}$
		Veneer TR	-4,93 ± 0,44	-7,15 ± 0,48 ^{e}	$p<0,001^{(*)}$
		Veneer WO	-3,60 ± 0,67 ^{c}	-3,87 ± 1,46 ^{A}	$p=0,001^{(*)}$
			$p<0,001^{(*)}$	$p=0,887$ ^{A}	
A3	***e.max®***	*Universal TR*	-3,98 ± 0,54 ^{f}	-6,16 ± 0,32 ^{i}	$p<0,001^{(*)}$
		Veneer TR	-3,73 ± 0,62 ^{f}	-6,38 ± 0,44 ^{i}	$p<0,001^{(*)}$
		Veneer WO	-2,83 ± 0,57	-3,82 ± 0,85	$p<0,001^{(*)}$
	Mark II	*Universal TR*	-4,81 ± 0,27 ^{gh}	-7,07 ± 0,38 ^{j}	$p<0,001^{(*)}$
		Veneer TR	-5,20 ± 0,75 ^{g}	-7,56 ± 0,41 ^{j}	$p<0,001^{(*)}$
		Veneer WO	-4,29 ± 0,37 ^{h}	-5,12 ± 0,72	$p=0,337$
			$p<0,001^{(*)}$	$p<0,001^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval

A four-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, ceramic thickness, and cement on the lightness variation ΔL_3. The data was checked for potential outliers using boxplots, but none were detected (Graphic 8 and 9). The normality assumption was verified using the Shapiro-Wilk test, which indicated that both groups exhibited normal distribution (p>0,05). However, Levene's test revealed significant differences in variances between the groups (p<0,001). Henceforth, a decision was made to conduct a Split File of the composite resin independent variable, followed by a three-way ANOVA. In order to compare the studied groups across different composite resin bases, an independent samples t-test was performed. It is noteworthy to mention that the Levene´s test in this scenario continues to exhibit statistical significance (p<0,001). However, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and N > 15 among groups.

A non-significant three-way interaction was observed between ceramic type, ceramic thickness, and cement for a A2 (p = 0,143) and A3 (p=0,748) composite resin base. Two-way interactions were verified, which proved to be statistically significant (p<0,001) except between ceramic and cement for a A3 composite resin base (p=0,079), between ceramic and thickness for A2 and A3 composite resin (p=0,243; p=0,540), and pairwise comparisons were continued.

All pairwise comparisons were adjusted using the Bonferroni method. Comparing the thicknesses of *IPS e.max®* and *VitaBlocs® Mark II* ceramics cemented to A2 composite bases, we found that variations in ceramic thickness did cause statistically significant changes in the ΔL_3 variable when cemented with any of the studied cements (Table 26). When cemented to A3 composite base, we found that ceramic thickness does not cause statistically significant changes in the ΔL_3 variable when using *Veneer WO* (p=0,337) in *VitaBlocs® Mark II* ceramics (Table 26).

When considering the *IPS e.max®* ceramic samples with 0,5mm thickness, there were no statistically significant differences observed between the use of *Universal TR* and *Veneer TR* cements and between *Universal TR* and *Veneer WO* cements when cemented to an A2 composite base (p>0,05). Similarly, the *VitaBlocs® Mark II* ceramic with 0,5mm thickness did not show any statistically significant differences when cemented with *Universal TR* and *Veneer WO* cements to the same A2 composite base (p>0,05). Additionally, when considering the *IPS e.max®* and *VitaBlocs® Mark II* ceramic samples with 0,8mm thickness, no statistically significant differences were observed between the use of *Universal TR* and *Veneer TR* cements, when cemented to an A2 composite base (p>0,05). When considering the *VitaBlocs® Mark II* ceramic samples with 0,5mm thickness and cemented to an A3 base, no statistically significant differences were observed between the use of *Universal TR* and *Veneer TR* cements, or between *Universal TR* and *Veneer WO* cements (p>0,05). Moreover, when considering the *IPS e.max®* ceramic samples with 0,5mm thickness, as well as *IPS e.max®* and *VitaBlocs® Mark II* ceramic samples with 0,8mm thickness, no statistically significant differences were observed between the use of *Universal TR* and *Veneer TR* cements, when cemented to an A3 composite base (p>0,05).

When cemented to an A2 or A3 colour base using any of the studied cements and for both thicknesses, statistically significant differences were observed when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic (p<0,001), except for the 0,8mm ceramic thickness cemented with *Veneer WO* to an A2 composite base between *IPS e.max®* and *VitaBlocs® Mark II* ceramic samples (p=0,887).

Table 27. ΔL_3 Independent samples t-test between A2 and A3 composite resin base for each ceramic and thickness and each cement

			Thickness	
			0,5mm	*0,8mm*
Composite	***Ceramic***	***Cement***	***p-values***	***p-values***
A2 vs. A3	***e.max®***	*Universal TR*	*p=0,004*$^{(*)}$	*p<0,001*$^{(*)}$
		Veneer TR	*p=0,412*	*p=0,015*$^{(*)}$
		Veneer WO	*p=0,498*	*p=0,980*
	Mark II	*Universal TR*	*p<0,001*$^{(*)}$	*p=0,010*$^{(*)}$
		Veneer TR	*p=0,341*	*p=0,055*
		Veneer WO	*p=0,011*$^{(*)}$	*p=0,030*$^{(*)}$

(*) Statistically significant differences for a 95% confidence interval

An independent samples t-test showed no statistically significant difference in the use of *IPS e.max®* ceramic material with 0,5mm thickness, cemented with *Veneer TR* (p=0,412) and *Veneer WO* (p=0,498), and in the use of *VitaBlocs® Mark II* ceramic with the same thickness, cemented with *Veneer TR* (p=0,341), when varying the base shade from A2 to A3 (Table 27). Additionally, there was no significant difference observed in the use of *IPS e.max®* ceramic with *Veneer WO* cement for the

0,8mm thickness (p=0,980), and in the use of *VitaBlocs® Mark II* ceramic with *Veneer TR* cement for the same thickness (p=0,055), when comparing bases of A2 and A3 shades.

5.2. STUDY OF GREEN AND RED SCALE OF COLOUR (a^*)

5.2.1. Composite resin samples

The composite samples green and red scale of colour (a^*) mean values and standard deviations utilized as the foundation for this study are displayed in Table 28 and Graphic 10. As shown in this table, the maximum a^* value for the composite resin samples of type A2 was 2,20, while the minimum value was 0,30. Additionally, for the composite resin samples of type A3, the maximum value obtained was 1,40, and the minimum value was 0,50.

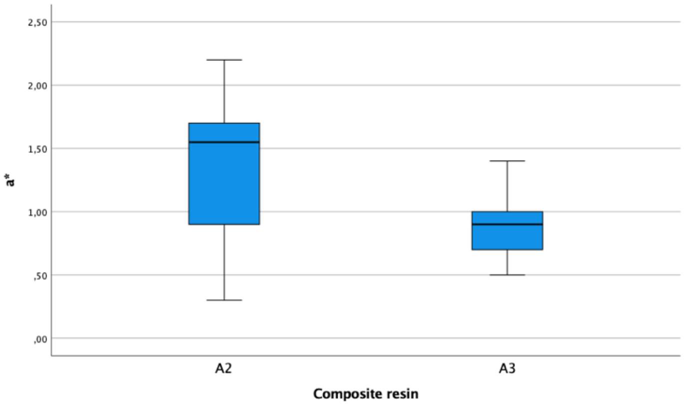
Table 28. Composite a mean ± standard deviation and p-value (one-way ANOVA)*

Composite	*Mean ± Standard deviation*	*Minimum*	*Maximum*
Filtek™ Supreme A2	*1,33 ± 0,19*	*0,30*	*2,20*
Filtek™ Supreme A3	*0,88 ± 0,19*	*0,50*	*1,40*
	$p<0{,}001^{(a)(*)}$		

(a) Welch-ANOVA

(*) Statistically significant differences for a 95% confidence interval

Graphic 10. Composite a* mean ± standard deviation and p-value (one-way ANOVA) Boxplot



A one-way analysis of variance (ANOVA) was conducted to investigate the a^* difference between A2 and A3 composite resin. Prior to the analysis, data screening procedures were applied to ensure that the data met the necessary assumptions for ANOVA.

Boxplots were examined to identify any potential outliers, and none were found (Graphic 10). To assess the normality assumption, a Kolmogorov-Smirnov test was conducted on each group separately, and the results indicated that the data were not normally distributed for both groups (p<0,05). Additionally, Levene's test was used to test for homogeneity of variances, and the results showed a significant difference in variances between the two groups (p<0,05). While there is no guarantee of a normal distribution in the population of each group, the one-way analysis of variance (ANOVA) test was chosen for its robustness in the face of a large number of samples in each group and an equal sample size (N) across groups. Notwithstanding, to examine the similarity of results when running non-parametric tests, a Kruskal-Wallis test for independent samples was also employed. To address the issue of heteroscedasticity, a Welch correction was implemented, which is a widely accepted method for handling violations of homogeneity of variances in the analysis of variance (ANOVA). This adjustment is known for its robustness in such situations and has been extensively used in previous studies, enabling the ANOVA to be appropriately applied despite the presence of unequal variances among groups.

The Welch-ANOVA results showed a statistically significant difference in *a** between the two types of composite materials (Table 28), with a p-value of less than 0,001. Specifically, the A2 composite material showed a greater mean value of *a** corresponding to 1,33 ± 0,19 than the A3 composite material, which had a value of 0,88 ± 0,19. The Kruskal-Wallis test confirmed the same result.

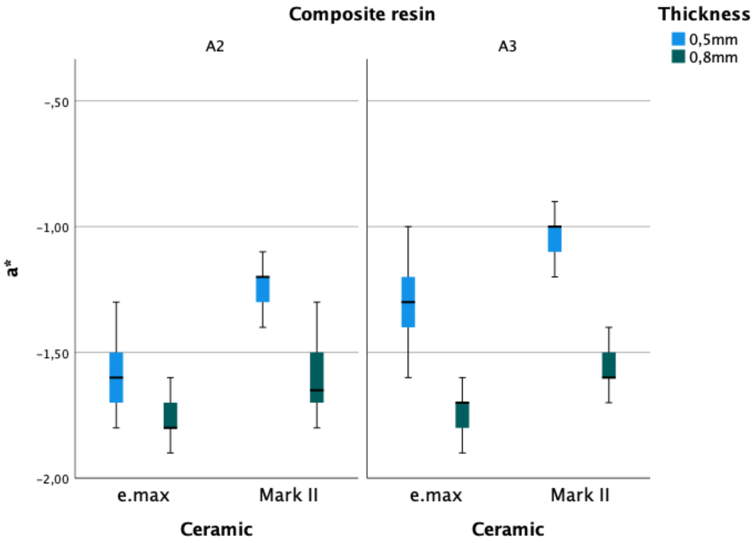
5.2.2. Composite resin and ceramic samples attached with glycerine

The green and red scale of colour (*a**) of composite materials *Filtek™ Supreme* A2 and A3 were examined when paired with ceramics *IPS e.max® CAD (HT)* and *VitaBlocs® Mark II*, each having thicknesses of 0,5mm and 0,8mm. The study was based on the mean values and standard deviations of the samples *a** measurements, which can be found in Table 29 and 30. The results indicated that the highest and lowest *a** values recorded were -0,90 for 0,5mm *VitaBlocs® Mark II* ceramic with A3 composite resin and -1,90 for 0,8mm *IPS e.max®* ceramic with A2 and A3 composite resin, respectively.

Table 29. Composite paired with ceramics by thicknesses a mean ± standard deviation, minimum and maximum*

		Thickness					
		0,5mm			0,8mm		
Composite	**Ceramic**	Mean ± Std. Dev.	Min.	Max.	Mean ± Std. Dev	Min.	Max.
Filtek™ Supreme A2	e.max®	-1,60 ± 0,12	-1,80	-1,30	-1,76 ± 0,08	-1,90	-1,60
	Mark II	-1,23 ± 0,09	-1,40	-1,10	-1,61 ± 0,14	-1,80	-1,30
Filtek™ Supreme A3	e.max®	-1,32 ± 0,13	-1,60	-1,00	-1,73 ± 0,07	-1,90	-1,60
	Mark II	-1,01 ± 0,08	-1,20	-0,90	-1,55 ± 0,10	-1,70	-1,40

Graphic 11. Composite paired with ceramics by thicknesses a mean ± standard deviation, minimum and maximum Boxplot*



The average green and red scale of colour (a^*) values of *Filtek™ Supreme* A2 composite decreased from -1,60 ± 0,12 to -1,76 ± 0,08 when paired with *IPS e.max®* ceramic and the ceramic thickness increased. Similarly, the average a^* values decreased when paired with *VitaBlocs® Mark II* ceramic, with values of -1,23 ± 0,09 and -1,61 ± 0,14 for 0,5 mm and 0,8 mm ceramic thicknesses, respectively.

In the case of *Filtek™ Supreme* A3 base, pairing with *IPS e.max®* ceramic also resulted in a decrease in average a^* values with an increase in thickness, from -1,32 ± 0,13 to -1,73 ± 0,07. Likewise, pairing with *VitaBlocs® Mark II* ceramic showed a decrease in average a^* values with values of -1,01 ± 0,08 and -1,55 ± 0,10 for 0,5 mm and 0,8 mm ceramic thicknesses, respectively.

Furthermore, the analysis of the same A2 composite resin base with 0,5mm ceramic thickness revealed a rise in the mean a^* values from -1,60 ± 0,12 to -1,23 ± 0,09 when using *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. Likewise, for the A3 composite resin base with the same ceramic thickness, there was an increase in mean a^* values from -1,32 ± 0,13 to -1,01 ± 0,08 when used with *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. Similarly, for a 0,8mm ceramic thickness and using the same A2 composite resin base, a rise in average a^* values from -1,76 ± 0,08 to -1,61 ± 0,14 was observed when paired with *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. The trend was consistent when evaluating the A3 composite resin base for a 0,8mm ceramic thickness, with an increase in mean *a** values from -1,73 ± 0,07 to -1,55 ± 0,10 when paired with *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively.

This study found that when *IPS e.max®* ceramic with a thickness of 0,5mm was used, there was a significant increase in the average *a** values from -1,60 ± 0,12 to -1,32 ± 0,13 when paired with the *Filtek™ Supreme* A2 and *Filtek™ Supreme* A3 base, respectively. Additionally, there was a slight increase in the average *a** values from -1,76 ± 0,08 to -1,73 ± 0,07 when using *IPS e.max®* ceramic with a thickness of 0,8mm and paired with the A2 and A3 composite resin base, respectively.

Similarly, when using *VitaBlocs® Mark II* ceramic with a thickness of 0,5mm, there was an increase in average *a** values from -1,23 ± 0,09 to -1,01 ± 0,08 when paired with the *Filtek™ Supreme* A2 and *Filtek™ Supreme* A3 base, respectively. Likewise, an increase in average *a** values from -1,61 ± 0,14 to -1,55 ± 0,10 was observed when *VitaBlocs® Mark II* ceramic with a thickness of 0,8mm was paired with A2 and A3 composite resin base.

Table 30. Composite paired with ceramics by thicknesses a mean ± standard deviation and p-values (three-way ANOVA and multiple comparisons Bonferroni test). Equal letters represent a direct comparison between the groups*

		Thickness		
		0,5mm	*0,8mm*	
Composite resin	***Ceramic***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
Filtek™ Supreme A2	***e.max®***	*-1,60 ± 0,19* $^{A\,(*)}$	*-1,76 ± 0,08* ^{C}	$p<0,001^{(*)}$
	Mark II	*-1,23 ± 0,09* $^{B\,(*)}$	*-1,61 ± 0,14* $^{D\,(*)}$	$p<0,001^{(*)}$
		$p<0,001^{(*)}$	$p<0,001^{(*)}$	
Filtek™ Supreme A3	***e.max®***	*-1,32 ± 0,13* $^{A\,(*)}$	*-1,73 ± 0,07* ^{C}	$p<0,001^{(*)}$
	Mark II	*-1,01 ± 0,08* $^{B\,(*)}$	*-1,55 ± 0,10* $^{D\,(*)}$	$p<0,001^{(*)}$
		$p<0,001^{(*)}$	$p<0,001^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval

A three-way analysis of variance (ANOVA) was conducted to investigate the effect of composite resin, ceramic, and ceramic thickness on lightness. Boxplots were used to detect potential outliers, and none were identified (Graphic 11). To test for normality, a Shapiro-Wilk test was conducted on each group separately, and the results indicated a normal distribution only for A3 composite resin with 0,5mm *IPS e.max®* ceramic group (p=0,178). Levene's test showed significant differences in variances between the groups (p<0,001). Despite this, the study design and the equal number of samples among groups provided sufficient security and robustness to proceed with the test.

There was no statistically significant three-way interaction between composite, ceramic, and ceramic thickness (p=0,064). Furthermore, a non-significant simple two-way interactions were observed between composite resin and ceramic (p=0,457). There was a simple main effect of thickness in *IPS e.max®* and *VitaBlocs® Mark II* ceramic paired with A2 and A3 composite resin (p<0,001). There was a simple main effect of A2 and A3 composite resin in *IPS e.max®* and *VitaBlocs® Mark II* ceramic and ceramic thickness (p<0,001). There was a simple main effect of *IPS e.max®* and *VitaBlocs® Mark II* ceramic in each level combination of other effects (p<0,001).

All simple pairwise comparisons were run with a Bonferroni adjustment applied. Statistically significant differences were observed between thicknesses of the same ceramic paired with A2 composite resin or A3 composite resin; between *IPS e.max®* and *VitaBlocs® Mark II* ceramics for each thickness when paired with A2 and A3 composite resin and between the same ceramic for 0,5mm and 0,8mm thicknesses varying the composite resin base (p<0,001) with the exception of 0,8mm *IPS e.max®* ceramic (p=0,264) (Table 30). Thus, a statistically significant decrease in a^* was observed when increasing the thickness from 0,5 mm to 0,8 mm, regardless of the ceramic and composite base colour utilized. Additionally, a statistically significant increase in a^* was observed upon changing the composite resin base from A2 to A3, irrespective of the ceramic type and thickness. When comparing the two ceramics with each other, there is a statistically significant a^* increase from the lithium disilicate ceramic to the feldspathic ceramic (p<0,001).

5.2.3. Study of Δa_1

The results concerning the variation in green and red scale of colour between the composite resin samples and the composite resin samples attached to ceramic with glycerine (Δa_1) are available in Table 31 and 32. The maximum and minimum absolute Δa_1 mean values obtained were -3,70, corresponding to 0,8mm *IPS e.max®* ceramic with A2 composite resin, and -1,60, corresponding to 0,5mm *VitaBlocs® Mark II* ceramic with A3 composite resin, respectively.

Table 31. Composite paired with ceramics by thicknesses Δa_1 *mean ± standard deviation, minimum and maximum*

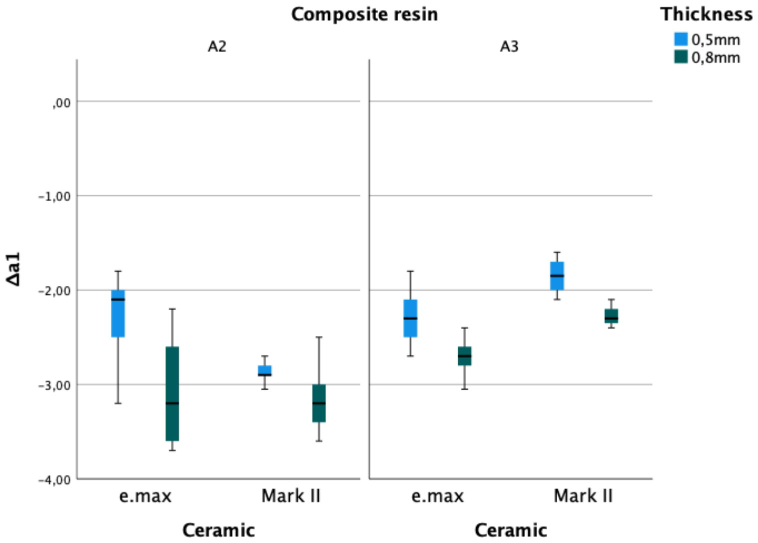
		Thickness					
		0,5mm			*0,8mm*		
Composite	***Ceramic***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
Filtek™ Supreme A2	*e.max®*	-2,34 ± 0,44	-3,20	-1,80	-3,13 ± 0,48	-3,70	-2,20
	Mark II	-2,86 ± 0,11	-3,05	-2,70	-3,16 ± 0,30	-3,60	-2,50
Filtek™ Supreme A3	*e.max®*	-2,29 ± 0,24	-2,70	-1,80	-2,71 ± 0,19	-3,05	-2,40
	Mark II	-1,84 ± 0,15	-2,10	-1,60	-2,27 ± 0,10	-2,40	-2,10

Table 31 presents the outcomes indicating that there is an increase in average Δa_1 values with an increase in ceramic thickness, for both *IPS e.max®* ceramic and *VitaBlocs® Mark II* ceramic, when paired with *Filtek™ Supreme* A2. The mean values increased from -2,34 ± 0,44 to -3,13 ± 0,48 and from -2,86 ± 0,11 to -3,16 ± 0,30, for 0,5mm and 0,8mm ceramic thicknesses, respectively.

Moreover, the results suggest that the average Δa_1 values also increased with an increase in thickness when pairing *Filtek™ Supreme* A3 with *IPS e.max®* ceramic, where the mean values increased from -2,29 ± 0,24 to -2,71 ± 0,19. Similarly, when *Filtek™ Supreme* A3 was paired with *VitaBlocs® Mark II* ceramic, the average Δa_1 values increased with an increase in ceramic thickness, with mean values of -1,84 ±

0,15 and -2,27 ± 0,10 observed for 0,5mm and 0,8mm ceramic thicknesses, respectively.

Graphic 12. Composite paired with ceramics by thicknesses Δa₁ mean ± standard deviation, minimum and maximum Boxplot



The results of Table 31 also reveal that for the A2 colour base pair, with a 0,5mm ceramic thickness, the average Δa_1 values increased from -2,34 ± 0,44 to -2,86 ± 0,11 when using *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. A similar increase in the mean Δa_1 values can be seen when the same A2 colour base pair is used with a 0,8mm ceramic thickness, with values increasing from -3,13 ± 0,48 to -3,16 ± 0,30 for *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. In contrast, when using the *Filtek™ Supreme* A3 base with a 0,5mm ceramic, the average Δa_1 values decreased from -2,29 ± 0,24 to -1,84 ± 0,15 for *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. Similarly, when the same A2 composite resin base is paired with a 0,8mm ceramic, a decrease in the mean Δa_1 values can be observed for both *IPS e.max®* ceramic (-2,71 ± 0,19) and *VitaBlocs® Mark II* ceramic (-2,27 ± 0,10).

When considering the 0,5mm thick *IPS e.max®* ceramic, there is a decrease in the mean Δa_1 values from -2,34 ± 0,44 to -2,29 ± 0,24 when changing the base from *Filtek™ Supreme* A2 to A3, respectively. Similarly, when considering the 0,8mm thick *IPS e.max®* ceramic, there is a decrease in the mean Δa_1 values from -3,13 ± 0,48 for the *Filtek™ Supreme* A2 base to -2,71 ± 0,19 for the *Filtek™ Supreme* A3 base.

For the *VitaBlocs® Mark II* ceramic with a thickness of 0,5mm, there is an observed decrease in the mean Δa_1 values from -2,86 ± 0,11 for the composite resin base of colour A2 to -1,84 ± 0,15 for colour A3. Similarly, for the *VitaBlocs® Mark II* ceramic with a thickness of 0,8mm, there is an observed decrease in the mean Δa_1 values from -3,16 ± 0,30 for the composite resin base of colour A2 to -2,27 ± 0,10 for colour A3.

Table 32. Composite paired with ceramics by thicknesses Δa_1 mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Equal letters represent a direct comparison between the groups

		Thickness		
		0,5mm	*0,8mm*	
Composite	***Ceramic***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
Filtek™ Supreme A2	***e.max®***	*-2,34 ± 0,44* ^{A}	*-3,13 ± 0,48* $^{C\,(*)}$	*p<0,001*$^{(*)}$
	Mark II	*-2,86 ± 0,11* $^{B\,(*)}$	*-3,16 ± 0,30* $^{D\,(*)}$	*p<0,001*$^{(*)}$
		p<0,001$^{(*)}$	*p=0,622*	
Filtek™ Supreme A3	***e.max®***	*-2,29 ± 0,24* ^{A}	*-2,71 ± 0,19* $^{C\,(*)}$	*p<0,001*$^{(*)}$
	Mark II	*-1,84 ± 0,15* $^{B\,(*)}$	*-2,27 ± 0,10* $^{D\,(*)}$	*p<0,001*$^{(*)}$
		p<0,001$^{(*)}$	*p<0,001*$^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval

A three-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, and ceramic thickness on the variation of a^* (Δa_1). The data was checked for potential outliers using boxplots, but none were detected (Graphic 12). The normality assumption was verified using the Shapiro-Wilk test, which indicated that groups does not exhibit normal distribution (p<0,05). Levene's test revealed significant differences in variances between the groups (p<0,001). Despite this, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and N > 15 among groups.

A significant three-way interaction was observed between composite, ceramic type, and ceramic thickness (p=0,001). Simple two-way interactions and simple main effects were also significant at the p<0,025 level. Additionally, significant simple two-way interactions were detected between ceramic type and ceramic thickness for A2 composite (p<0,001). A non-significant simple two-way interaction was found in A3 composite (p=0,975). Simple simple main effects of ceramic thickness in A2 and A3 composite resin, paired with *IPS e.max®* and *VitaBlocs® Mark II* ceramic types, were also statistically significant (p < 0,001).

All pairwise comparisons were adjusted using the Bonferroni method. Statistically significant differences were found between thicknesses of the same ceramic paired with A2 or A3 composite resin, as well as between *IPS e.max®* and *VitaBlocs® Mark II* ceramics for each thickness when paired with A2 and A3 composite resin (p<0,001), except in 0,8mm ceramic in a A2 composite resin base (p=0,622). Moreover, statistically significant differences were observed between samples of the same ceramic with identical thickness when comparing composite resin bases A2 and A3 (p<0,001), except for *IPS e.max®*ceramic with a thickness of 0,5mm, where no statistically significant differences were found between the Δa_1 values (p = 0,446) (Table 32).

5.2.4. Composite resin and ceramic samples cemented with resin cements

In this study, the composites *Filtek™ Supreme* A2 and A3 were paired with *IPS e.max®* and *VitaBlocs® Mark II* ceramics at thicknesses of 0,5 mm and 0,8 mm and three types of resin cements were used for the cementation. The samples were then evaluated for their green and red colour scales using a^* values. Table 33, 34 and 35 display the mean values and standard deviations of the a^* values of the samples used in the study. The maximum and minimum a^* values obtained were 0,30, corresponding to 0,5mm *IPS e.max®* ceramic cemented with *RelyX™ Veneer*

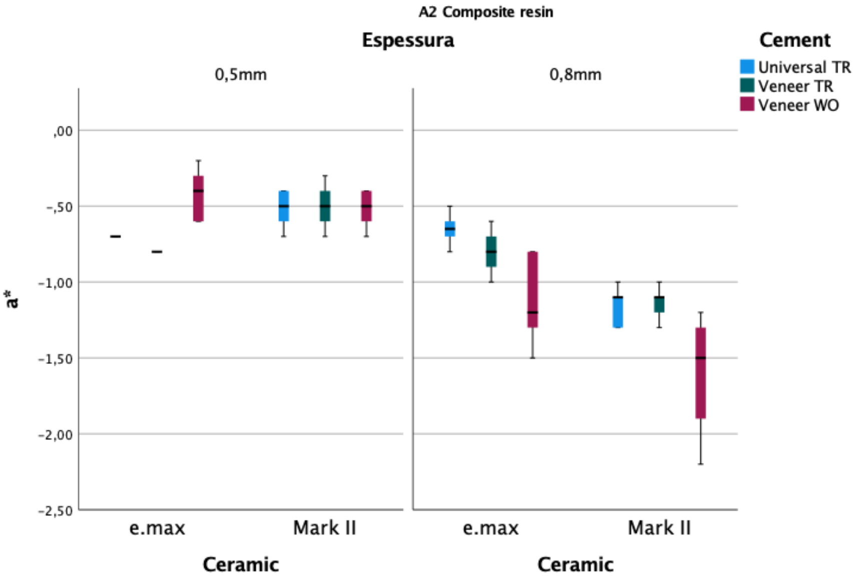
WO to A3 composite resin, and -2,20, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic cemented with *RelyX™ Veneer* WO to A2 composite resin, respectively.

The *a** mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A2 base are displayed in Table 33 and Graphic 13.

Table 33. Composite resin (A2) and ceramic samples cemented a mean ± standard deviation, minimum and maximum*

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	-0,70 ± 0,00	-0,70	-0,70	-0,65 ± 0,08	-0,80	-0,50
	Veneer TR	-0,80 ± 0,00	-0,80	-0,80	-0,82 ± 0,13	-1,00	-0,60
	Veneer WO	-0,42 ± 0,18	-0,60	-0,20	-1,14 ± 0,27	-1,50	-0,80
Mark II	*Universal TR*	-0,52 ± 0,10	-0,70	-0,40	-1,15 ± 0,12	-1,30	-1,00
	Veneer TR	-0,51 ± 0,14	-0,70	-0,30	-1,14 ± 0,11	-1,30	-1,00
	Veneer WO	-0,52 ± 0,11	-0,70	-0,40	-1,60 ± 0,35	-2,20	-1,20

Graphic 13. Composite resin (A2) and ceramic samples cemented a mean ± standard deviation, minimum and maximum Boxplot*



Upon reviewing Table 33, it becomes apparent that for *IPS e.max®* ceramic cemented with *Universal TR* cement, there is a rise in the mean *a** values from -0,70 ± 0,00 to -0,65 ± 0,08 when the ceramic thickness increases from 0,5mm to 0,8mm. In contrast, *IPS e.max®* ceramic cemented with *Veneer TR* cement results in a minor decrease in the mean *a** values from -0,80 ± 0,00 to -0,82 ± 0,13 when the ceramic thickness is increased from 0,5mm to 0,8mm. Similarly, *IPS e.max®* ceramic cemented with *Veneer WO* cement exhibits a reduction in mean *a** values from -0,42 ± 0,18 to -1,14 ± 0,27 for the same thickness variation.

When examining the *VitaBlocs® Mark II* ceramic cemented with the *Universal TR* cement, the average *a** values decrease from -0,52 ± 0,10 to -1,15 ± 0,12 as the ceramic thickness varies from 0,5mm to 0,8mm, respectively. Similarly, with the *VitaBlocs® Mark II* ceramic cemented with the *Veneer TR* cement, there is also a decrease in average *a** values from -0,51 ± 0,14 to -1,14 ± 0,11 with the same variation in ceramic thickness. When considering the *VitaBlocs® Mark II* ceramic cemented with the *Veneer WO* cement, the average *a** values also decrease from -0,52 ± 0,11 to -1,60 ± 0,35 with the same variation in ceramic thickness.

When considering the *IPS e.max®* ceramic with a thickness of 0,5mm, an increase in average *a** values is observed, ranging from -0,80 ± 0,00, -0,70 ± 0,00, and -0,42 ± 0,18 for *Veneer TR, Universal TR,* and *Veneer WO* cements, respectively. When examining the *VitaBlocs® Mark II* ceramic with the same thickness, the average *a** values observed are -0,52 ± 0,11, -0,52 ± 0,10, and -0,51 ± 0,14 for *Veneer WO, Universal TR,* and *Veneer TR* cements, respectively.

Likewise, when analyzing the *IPS e.max®* ceramic with a thickness of 0,8mm, an increase in average *a** values is observed, ranging from -1,14 ± 0,27, -0,82 ± 0,13, and -0,65 ± 0,08 for *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively. Furthermore, when examining the *VitaBlocs® Mark II* ceramic with the same thickness, an increase in average *a** values is observed, ranging from -1,60 ± 0,35, -1,15 ± 0,12, and -1,14 ± 0,11 for *Veneer WO, Universal TR,* and *Veneer TR* cements, respectively.

When analyzing the 0,5mm ceramic thickness and *Universal TR* cement, there is an increase in the average *a** values from *-0,70 ± 0,00* to *-0,52 ± 0,10* when changing from *IPS e.max®* ceramic to *VitaBlocs® Mark II,* respectively. When analyzing the same 0,5mm ceramic thickness with *Veneer TR* cement, there is also an increase in the average *a** values from *-0,80 ± 0,00* to *-0,51 ± 0,14*, when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic, respectively. Controversy, when considering the same ceramic thickness and *Veneer WO* cement, there is a decrease in the average *a** values from *IPS e.max®* ceramic, of *-0,42 ± 0,18*, to *VitaBlocs® Mark II* ceramic of *-0,52 ± 0,11*.

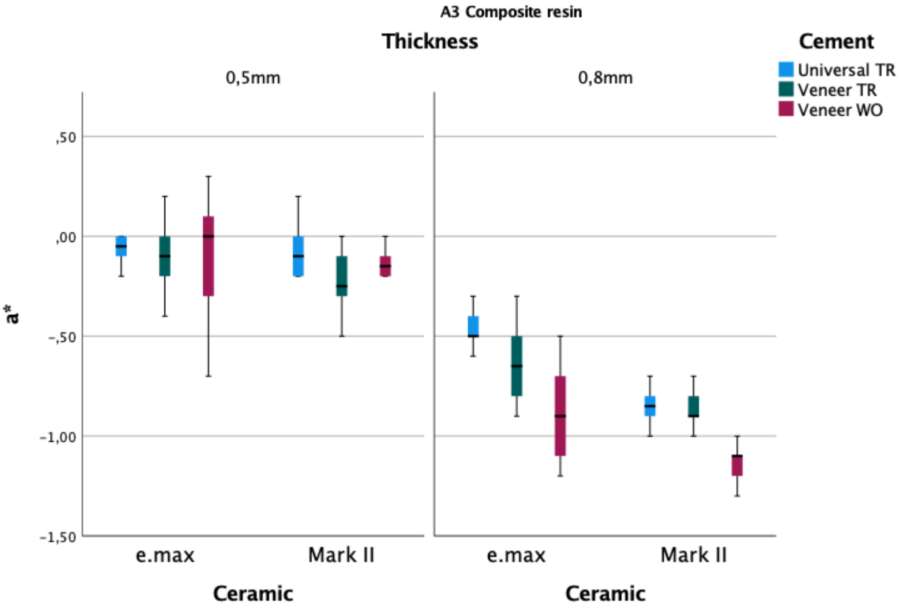
The analysis of 0,8mm ceramic thickness using *Universal TR* cement resulted in a decrease in the average *a** values from *-0,65 ± 0,08* to *-1,15 ± 0,12* with the substitution of *IPS e.max®* ceramic with *VitaBlocs® Mark II*. Similarly, the analysis of the same ceramic thickness using *Veneer TR* cement showed a decrease in the average *a** values from *-0,82 ± 0,13* to *-1,14 ± 0,11* when changing from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Likewise, for the same ceramic thickness and *Veneer WO* cement, the average *a** values decreased from *-1,14 ± 0,27* for *IPS e.max®* ceramic to *-1,60 ± 0,35* for *VitaBlocs® Mark II* ceramic.

The *a** mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A3 base are displayed in Table 34 and Graphic 14.

Table 34. Composite resin (A3) and ceramic samples cemented a mean ± standard deviation, minimum and maximum*

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*-0,06 ± 0,07*	*-0,20*	*0,00*	*-0,46 ± 0,08*	*-0,60*	*-0,30*
	Veneer TR	*-0,09 ± 0,18*	*-0,40*	*0,20*	*-0,62 ± 0,19*	*-0,90*	*-0,30*
	Veneer WO	*-0,11 ± 0,30*	*-0,70*	*0,30*	*-0,90 ± 0,22*	*-1,20*	*-0,50*
Mark II	*Universal TR*	*-0,08 ± 0,14*	*-0,20*	*0,20*	*-0,85 ± 0,08*	*-1,00*	*-0,70*
	Veneer TR	*-0,23 ± 0,16*	*-0,50*	*0,00*	*-0,86 ± 0,11*	*-1,00*	*-0,70*
	Veneer WO	*-0,13 ± 0,08*	*-0,20*	*0,00*	*-1,14 ± 0,11*	*-1,30*	*-1,00*

Graphic 14. Composite resin (A3) and ceramic samples cemented a mean ± standard deviation, minimum and maximum Boxplot*



After reviewing Table 34, it's apparent that *IPS e.max®* ceramic cemented with *Universal TR* cement exhibits a decrease in mean *a** values from -0,06 ± 0,07 to -0,46 ± 0,08 when the ceramic thickness increases from 0,5mm to 0,8mm. Similarly, *IPS e.max®* ceramic cemented with *Veneer TR* cement also shows a decrease in mean *a** values from -0,09 ± 0,18 to -0,62 ± 0,19 with an increase in ceramic thickness from 0,5mm to 0,8mm. Likewise, *IPS e.max®* ceramic cemented with *Veneer WO* cement demonstrates a reduction in mean *a** values from -0,11 ± 0,30 to -0,90 ± 0,22 for the same thickness variation.

When examining the *VitaBlocs® Mark II* ceramic cemented with *Universal TR* cement, the average *a** values decrease from -0,08 ± 0,14 to -0,85 ± 0,08 as the ceramic thickness varies from 0,5mm to 0,8mm, respectively. Similarly, with the *VitaBlocs® Mark II* ceramic cemented with *Veneer TR* cement, there is also a decrease in average *a** values from -0,23 ± 0,16 to -0,86 ± 0,11 with the same variation in ceramic thickness. When considering the *VitaBlocs® Mark II* ceramic cemented with *Veneer WO* cement, the average *a** values also decrease from -0,13 ± 0,08 to -1,14 ± 0,11 with the same variation in ceramic thickness.

Also, upon reviewing the data in Table 34, it can be noted that for *IPS e.max®* ceramic with a thickness of 0,5mm, there is an increase in the average *a** values, with values ranging from -0,11 ± 0,30, -0,09 ± 0,18, and -0,06 ± 0,07 for *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively. Similarly, for *VitaBlocs® Mark II* II ceramic with the same thickness, the average *a** values observed are -0,23 ± 0,16, -0,13 ± 0,08, and -0,08 ± 0,14 for *Veneer TR, Veneer WO,* and *Universal TR* cements, respectively.

Furthermore, for *IPS e.max®* ceramic with a thickness of 0,8mm, there is an increase in the average *a** values, with values ranging from -0,90 ± 0,22, -0,62 ± 0,19, and -0,46 ± 0,08 for *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively. Similarly, for *VitaBlocs® Mark II* ceramic with the same thickness, the average *a** values observed are -1,14 ± 0,11, -0,86 ± 0,11, and -0,85 ± 0,08 for *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively.

There is a noticeable decrease in the average *a** values when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic, with a 0,5mm thickness and using *Universal TR, Veneer TR,* or *Veneer WO* cement. Specifically, the average *a** values decrease from -0,06 ± 0,07 to -0,08 ± 0,14 for *Universal TR,* from -0,09 ± 0,18 to -0,23 ± 0,16 for *Veneer TR,* and from -0,11 ± 0,30 to -0,13 ± 0,08 for *Veneer WO* cement. For a 0,8mm ceramic thickness and using *Universal TR, Veneer TR,* or *Veneer WO* cement, the average *a** values decrease when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic. Specifically, the average *a** values decrease from -0,46 ± 0,08 to -0,85 ± 0,08 for *Universal TR,* from -0,62 ± 0,19 to -0,86 ± 0,11 for *Veneer TR,* and from -0,90 ± 0,22 to -1,14 ± 0,11 for *Veneer WO* cement.

Table 35. Composite resin and ceramic samples cemented a mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Same lowercase letters within the same column indicate a non-statistically significant differences between cements for each ceramic. Same capital letters within the same column indicate a non-statistically significant differences for the same cement between different ceramics*

			Thickness		
			0,5mm	*0,8mm*	
Composite	***Ceramic***	***Cement***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
A2	***e.max®***	*Universal TR*	$-0,70 \pm 0,00^{a}$	$-0,65 \pm 0,08^{c}$	$p=0,496$
		Veneer TR	$-0,80 \pm 0,00^{a}$	$-0,82 \pm 0,13^{c}$	$p=0,785$
		Veneer WO	$-0,42 \pm 0,18^{A}$	$-1,14 \pm 0,27$	$p<0,001^{(*)}$
	Mark II	*Universal TR*	$-0,52 \pm 0,10^{b}$	$-1,15 \pm 0,12^{d}$	$p<0,001^{(*)}$
		Veneer TR	$-0,51 \pm 0,14^{b}$	$-1,14 \pm 0,11^{d}$	$p<0,001^{(*)}$
		Veneer WO	$-0,52 \pm 0,11^{b\,A}$	$-1,60 \pm 0,35$	$p<0,001^{(*)}$
			$p=0,175^{(A)}$	$p<0,001^{(*)}$	
A3	***e.max®***	*Universal TR*	$-0,06 \pm 0,07^{e\,B}$	$-0,46 \pm 0,08^{g}$	$p<0,001^{(*)}$
		Veneer TR	$-0,09 \pm 0,18^{e\,C}$	$-0,62 \pm 0,19^{g}$	$p<0,001^{(*)}$
		Veneer WO	$-0,11 \pm 0,30^{e\,D}$	$-0,90 \pm 0,22$	$p<0,001^{(*)}$
	Mark II	*Universal TR*	$-0,08 \pm 0,14^{f\,B}$	$-0,85 \pm 0,08^{h}$	$p<0,001^{(*)}$
		Veneer TR	$-0,23 \pm 0,16^{f\,C}$	$-0,86 \pm 0,11^{h}$	$p<0,001^{(*)}$
		Veneer WO	$-0,13 \pm 0,08^{f\,D}$	$-1,14 \pm 0,11$	$p<0,001^{(*)}$
			$p=0,779^{(B)(D)}$ $p=0,052^{(C)}$	$p<0,001^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval

A four-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, ceramic thickness and cement on the *a** variable. The data was checked for potential outliers using boxplots, but none were detected (Graphic 13 and 14). The normality assumption was verified using the Shapiro-Wilk test, which indicated that both groups exhibited normal distribution (p>0,05). However, Levene's test revealed significant differences in variances between the groups (p<0,001). Henceforth, a decision was made to conduct a Split

File of the composite resin independent variable, followed by a three-way ANOVA. To compare the studied groups across different composite resin bases, an independent samples t-test was performed. It is noteworthy to mention that the Levene´s test in this scenario continues to exhibit statistical significance (p<0,001). However, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and N > 15 among groups.

A significant three-way interaction was observed between ceramic type, ceramic thickness, and cement for a A2 (p=0,047) and A3 composite resin base (p = 0,032). Statistically significance of simple two-way interactions and simple main effects was accepted at a Bonferroni-ajusted alpha level of 0,025. Simple two-way interactions were verified, which proved to be statistically significant (p<0,001), and pairwise comparisons were continued. There wasn´t a simple simple main effect of cement for a *VitaBlocs® Mark II* 0,5mm ceramic in an A2 (p=0,987) and A3 (p=0,105) composite resin base and for a *IPS e.max®* 0,5mm ceramic in a A3 composite resin base (p=0,779).

All pairwise comparisons were adjusted using the Bonferroni method. Comparing the thicknesses of *IPS e.max®* and *VitaBlocs® Mark II* ceramics cemented to A2 composite bases, we found that ceramic thickness does not cause statistically significant changes in the a^* variable when using *Universal TR* cement (p=0,496) and *Veneer TR* (p=0,785) in *IPS e.max®* ceramics (Table 35). The *IPS e.max®* and *VitaBlocs® Mark II* ceramic samples, with 0,5mm thickness, cemented with *Universal TR, Veneer TR* and *Veneer WO* cement do not present statistically significant differences when cemented to an A3 composite base (p>0,05). The *IPS e.max®* and *VitaBlocs® Mark II* ceramic samples, with 0,8mm thickness, cemented with *Universal TR* and *Veneer TR* cement do not present statistically significant differences when cemented to an A3 composite base (p>0,05). When cemented to an A2 base with *Universal TR* cement and *Veneer TR* cement, the *IPS e.max®* ceramic samples with 0,5mm and 0,8mm thickness and *VitaBlocs® Mark II* with 0,8mm thickness do not present statistically significant differences (p>0,05). When cemented to *Universal TR, Veneer TR* and *Veneer WO* with a *VitaBlocs® Mark II* 0,5mm thickness ceramic to a A2 base there is no statistically significant differences (p>0,05).

When cemented to an A2 colour base with *Veneer WO* (p=0,175) for 0,5mm thickness, there aren´t statistically significant differences when changing from *IPS* *e.max®* ceramic to *VitaBlocs® Mark II* ceramic. When cemented to a A3 composite resin base with a 0,5mm ceramic, *Universal TR* (p=0,779), *Veneer TR* (p=0,052) and *Veneer WO* (p=0,779) exhibits the same behavior between the ceramics.

Table 36. a variable independent samples t-test between A2 and A3 composite resin base for each ceramic and thickness and each cement*

			Thickness	
			0,5mm	*0,8mm*
Composite	***Ceramic***	***Cement***	***p-values***	***p-values***
A2 vs. A3	***e.max®***	*Universal TR*	*p<0,001(*)*	*p<0,001(*)*
		Veneer TR	*p<0,001(*)*	*p=0,014(*)*
		Veneer WO	*p=0,012(*)*	*p=0,041(*)*
	Mark II	*Universal TR*	*p<0,001(*)*	*p<0,001(*)*
		Veneer TR	*p<0,001(*)*	*p<0,001(*)*
		Veneer WO	*p<0,001(*)*	*p=0,002(*)*

(*) Statistically significant differences for a 95% confidence interval

The use of *IPS e.max®* and *VitaBlocs® Mark II* ceramic material with a thickness of 0,5mm and 0,8mm and cemented with *Universal TR*, *Veneer TR* and *Veneer WO* cements, while varying the base shade from A2 to A3, resulted in a statistically significant difference (p<0,05) according to an independent samples t-test (Table 36).

5.2.5. Study of Δa_2

The results concerning the variation in green and red scale of colour between the composite resin samples and the composite resin samples cemented to ceramic using the studied cements (Δa_2) are available in Table 37, 38 and 39. The maximum and minimum absolute Δa_2 mean values obtained were -3,80, corresponding to

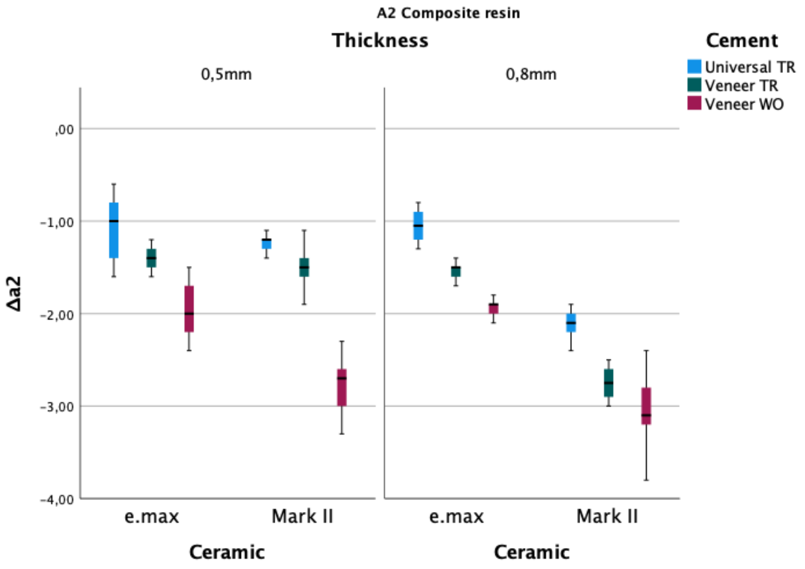
0,8mm *VitaBlocs® Mark II* ceramic, cemented to A2 composite resin base with *Veneer WO* cement, and -0,40, corresponding to 0,5mm *IPS e.max®* ceramic, cemented to A3 composite resin base with *Veneer TR* cement, respectively.

The Δa_2 mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A2 base are displayed in Table 37 and Graphic 15.

Table 37. Composite resin (A2) and ceramic samples cemented Δa_2 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	**Cement**	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	-1,06 ± 0,36	-1,60	-0,60	-1,06 ± 0,19	-1,30	-0,80
	Veneer TR	-1,39 ± 0,14	-1,60	-1,20	-1,52 ± 0,09	-1,70	-1,40
	Veneer WO	-2,00 ± 0,31	-2,40	-1,50	-1,92 ± 0,09	-2,10	-1,80
Mark II	*Universal TR*	-1,23 ± 0,09	-1,40	-1,10	-2,12 ± 0,15	-2,40	-1,90
	Veneer TR	-1,51 ± 0,23	-1,90	-1,10	-2,74 ± 0,17	-3,00	-2,50
	Veneer WO	-2,76 ± 0,30	-3,30	-2,30	-3,08 ± 0,40	-3,80	-2,40

Graphic 15. Composite resin (A2) and ceramic samples cemented Δa_2 mean ± standard deviation, minimum and maximum Boxplot



After examining Table 37, *IPS e.max®* ceramic cemented with *Universal TR* cement does not show any significant change in the mean Δa_2 values, which remain constant at -1,06 ± 0,36 and -1,06 ± 0,19 when the ceramic thickness is increased from 0,5mm to 0,8mm. On the other hand, when *IPS e.max®* ceramic is cemented with *Veneer TR* cement, the mean Δa_2 values increased from -1,39 ± 0,14 to -1,52 ± 0,09 with an increase in ceramic thickness from 0,5mm to 0,8mm. However, *IPS e.max®* ceramic cemented with *Veneer WO* cement displays a decrease in mean Δa_2 values from -2,00 ± 0,31 to -1,92 ± 0,09 for the same thickness variation.

In the case of *VitaBlocs® Mark II* ceramic, cemented with *Universal TR* cement, the average Δa_2 values increase from -1,23 ± 0,09 to -2,12 ± 0,15 as the ceramic thickness increases from 0,5mm to 0,8mm. Likewise, with *VitaBlocs® Mark II* ceramic cemented with *Veneer TR* cement, there is also an increase in average Δa_2 values from -1,51 ± 0,23 to -2,74 ± 0,17 with the same variation in ceramic thickness. When considering *VitaBlocs® Mark II* ceramic cemented with *Veneer WO* cement, the average Δa_2 values also increase from -2,76 ± 0,30 to -3,08 ± 0,40 with the same variation in ceramic thickness.

When the thickness of *IPS e.max®* ceramic is 0,5mm, the average Δa_2 values show an increase, with values ranging from -1,06 ± 0,36, -1,39 ± 0,14, and -2,00 ± 0,31 for *Universal TR, Veneer TR* and *Veneer WO* cements, respectively. Similarly, the *VitaBlocs® Mark II* ceramic with the same thickness shows average Δa_2 values of -1,23 ± 0,09, -1,51 ± 0,23, and -2,76 ± 0,30 for *Universal TR, Veneer TR* and *Veneer WO* cements, respectively. Additionally, an increase in average Δa_2 values is observed for *IPS e.max®* ceramic with a thickness of 0,8mm, with values ranging from -1,06 ± 0,19, -1,52 ± 0,09, and -1,92 ± 0,09 for *Universal TR, Veneer TR* and *Veneer WO* cements, respectively. Moreover, the *VitaBlocs® Mark II* ceramic with the same thickness shows an increase in average Δa_2 values, ranging from -2,12 ± 0,15, -2,74 ± 0,17, and -3,08 ± 0,40 for *Universal TR, Veneer TR* and *Veneer WO* cements, respectively.

When examining ceramic thickness of 0,5mm and using *Universal TR* cement, an increase in average Δa_2 values is observed when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II*, from -1,06 ± 0,36 to -1,23 ± 0,09, respectively. Similarly, when using *Veneer TR* cement with the same ceramic thickness, there is an increase in average Δa_2 values from -1,39 ± 0,14 to -1,51 ± 0,23 when switching from *IPS* *e.max®* to *VitaBlocs® Mark II* ceramic. Additionally, with *Veneer WO* cement, an increase in average Δa_2 values is observed when switching from *IPS e.max®* ceramic (-2,00 ± 0,31) to *VitaBlocs® Mark II* ceramic (-2,76 ± 0,30).

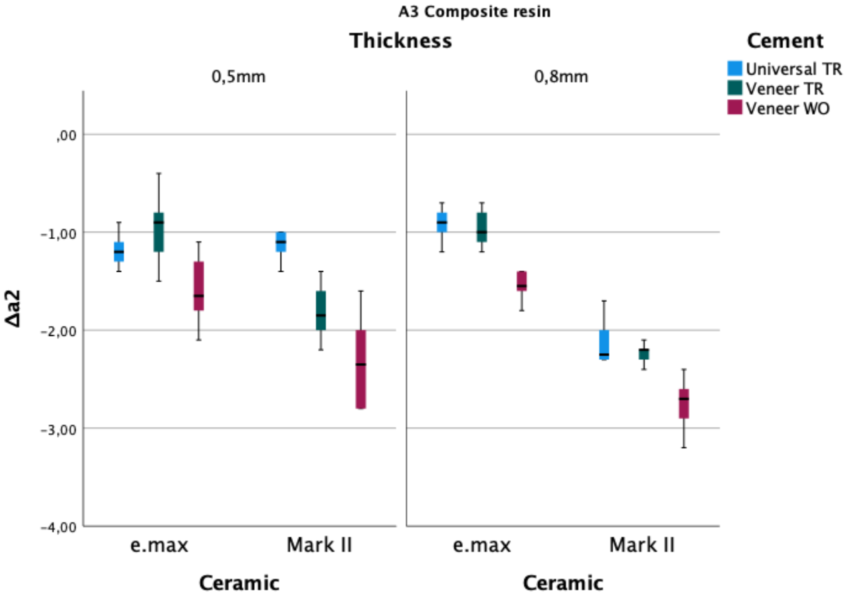
For a ceramic thickness of 0,8mm using *Universal TR* cement, there is an increase in average Δa_2 values from -1,06 ± 0,19 to -2,12 ± 0,15 when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. Similarly, using *Veneer TR* cement with the same thickness, an increase in average Δa_2 values is observed from -1,52 ± 0,09 to -2,74 ± 0,17 when changing from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Moreover, for the same ceramic thickness and *Veneer WO* cement, the average Δa_2 values increased from -1,92 ± 0,09 for *IPS e.max®* ceramic to -3,08 ± 0,40 for *VitaBlocs® Mark II* ceramic.

The Δa_2 mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A3 base are displayed in Table 38 and Graphic 16.

Table 38. Composite resin (A3) and ceramic samples cemented Δa_2 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*-1,17 ± 0,15*	*-1,40*	*-0,90*	*-0,91 ± 0,18*	*-1,20*	*-0,70*
	Veneer TR	*-0,94 ± 0,36*	*-1,50*	*-0,40*	*-0,97 ± 0,17*	*-1,20*	*-0,70*
	Veneer WO	*1,59 ± 0,30*	*-2,10*	*-1,10*	*-1,56 ± 0,15*	*-1,80*	*-1,40*
Mark II	*Universal TR*	*-1,13 ± 0,13*	*-1,40*	*-1,00*	*-2,14 ± 0,21*	*-2,30*	*-1,70*
	Veneer TR	*-1,83 ± 0,26*	*-2,20*	*-1,40*	*-2,24 ± 0,11*	*-2,40*	*-2,10*
	Veneer WO	*-2,33 ± 0,45*	*-2,80*	*-1,60*	*-2,74 ± 0,23*	*-3,20*	*-2,40*

Graphic 16. Composite resin (A3) and ceramic samples cemented Δa2 mean ± standard deviation, minimum and maximum Boxplot



After reviewing Table 38, it is evident that when *IPS e.max®* ceramic is cemented with *Universal TR* cement, there is a reduction in the mean Δ*a*2 values from -1,17 ± 0,15 to -0,91 ± 0,18 as the ceramic thickness increases from 0,5mm to 0,8mm. However, in the case of *Veneer TR* cement, the mean Δ*a*2 values increase from -0,94 ± 0,36 to -0,97 ± 0,17 for the same thickness variation. When cemented with *Veneer WO* cement, *IPS e.max®* ceramic exhibits a decline in mean Δ*a*2 values from 1,59 ± 0,30 to -1,56 ± 0,15 for the same thickness variation.

Similarly, with *VitaBlocs® Mark II* ceramic cemented with *Universal TR* cement, the average Δ*a*2 values rise from -1,13 ± 0,13 to -2,14 ± 0,21 as the ceramic thickness increases from 0,5mm to 0,8mm. For *VitaBlocs® Mark II* ceramic cemented with *Veneer TR* cement, the average Δ*a*2 values also increase from -1,83 ± 0,26 to -2,24 ± 0,11 for the same thickness variation. Finally, when considering *VitaBlocs® Mark II* ceramic cemented with *Veneer WO* cement, the average Δ*a*2 values increase from -2,33 ± 0,45 to -2,74 ± 0,23 with the same thickness variation.

The mean Δ*a*2 values for *IPS e.max®* ceramic with a thickness of 0,5mm exhibit an increase, with values of -0,94 ± 0,36, -1,17 ± 0,15, and 1,59 ± 0,30 for *Veneer TR*, *Universal TR*, and *Veneer WO* cements, respectively. Conversely, the *VitaBlocs® Mark II* ceramic with the same thickness shows average Δa_2 values of -1,13 ± 0,13, -1,83 ± 0,26, and -2,33 ± 0,45 for *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively. Similarly, an increase in average Δa_2 values is evident for *IPS e.max®* ceramic with a thickness of 0,8mm, with values of -0,91 ± 0,18, -0,97 ± 0,17, and -1,56 ± 0,15 for *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively. The *VitaBlocs® Mark II* ceramic with the same thickness also shows an increase in average Δa_2 values, ranging from -2,14 ± 0,21, -2,24 ± 0,11, and -2,74 ± 0,23 for *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively.

When comparing ceramic thicknesses of 0,5mm and using *Universal TR* cement, there is a slight decrease in average Δa_2 values when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II*, from -1,17 ± 0,15 to -1,13 ± 0,13, respectively. In contrast, when using *Veneer TR* cement with the same ceramic thickness, there is a significant increase in average Δa_2 values from -0,94 ± 0,36 to -1,83 ± 0,26 when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Furthermore, with *Veneer WO* cement, there is an increase in average Δa_2 values when switching from *IPS e.max®* ceramic (1,59 ± 0,30) to *VitaBlocs® Mark II* ceramic (-2,33 ± 0,45).

When using *Universal TR* cement and a ceramic thickness of 0,8mm, there is a noticeable increase in average Δa_2 values from -0,91 ± 0,18 to -2,14 ± 0,21 when changing from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. Similarly, using *Veneer TR* cement with the same thickness, an increase in average Δa_2 values is observed from -0,97 ± 0,17 to -2,24 ± 0,11 when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Additionally, for the same ceramic thickness and *Veneer WO* cement, the average Δa_2 values increased from -1,56 ± 0,15 for *IPS e.max®* ceramic to -2,74 ± 0,23 for *VitaBlocs® Mark II* ceramic.

Table 39. Composite resin and ceramic samples cemented Δa_2 mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Same lowercase letters within the same column indicate a non-statistically significant differences between cements for each ceramic. The p-values below each column, for each base, represent differences for the same cement between different ceramics. Same capital letters within the same column indicate a non-statistically significant differences for the same cement between different ceramics

			Thickness		
			0,5mm	*0,8mm*	
Composite	***Ceramic***	***Cement***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
A2	***e.max®***	*Universal TR*	*-1,06 ± 0,36* ^{A}	*-1,06 ± 0,19*	*p=1,000*
		Veneer TR	*-1,39 ± 0,14* ^{B}	*-1,52 ± 0,09*	*p=0,219*
		Veneer WO	*-2,00 ± 0,31*	*1,92 ± 0,09*	*p=0,449*
	Mark II	*Universal TR*	*-1,23 ± 0,09* ^{A}	*-2,12 ± 0,15*	*p<0,001*$^{(*)}$
		Veneer TR	*-1,51 ± 0,23* ^{B}	*-2,74 ± 0,17*	*p<0,001*$^{(*)}$
		Veneer WO	*-2,76 ± 0,30*	*-3,08 ± 0,40*	*p=0,003*$^{(*)}$
			p=0,109$^{(A)}$ *p=0,257*$^{(B)}$	*p<0,001*$^{(*)}$	
A3	***e.max®***	*Universal TR*	*-1,17 ± 0,15* $^{a\ C}$	*-0,91 ± 0,18* ^{b}	*p=0,020*$^{(*)}$
		Veneer TR	*-0,94 ± 0,36* ^{a}	*-0,97 ± 0,17* ^{b}	*p=0,785*
		Veneer WO	*-1,59 ± 0,30*	*-1,56 ± 0,15*	*p=0,785*
	Mark II	*Universal TR*	*-1,13 ± 0,13* ^{C}	*-2,14 ± 0,21* ^{c}	*p<0,001*$^{(*)}$
		Veneer TR	*-1,83 ± 0,26*	*-2,24 ± 0,11* ^{c}	*p<0,001*$^{(*)}$
		Veneer WO	*-2,33 ± 0,45*	*-2,74 ± 0,23*	*p<0,001*$^{(*)}$
			p=0,719$^{(C)}$	*p<0,001*$^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval

A four-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, ceramic thickness and cement on the variation of a^* (Δa_2). The data was checked for potential outliers using boxplots, but none were detected (Graphic 15 and 16). The normality assumption was verified using the Shapiro-Wilk test, which indicated that both groups exhibited normal distribution (p>0,05). However, Levene's test revealed significant differences in variances between the groups (p<0,001). Henceforth, a decision was made to conduct a Split File of the composite resin independent variable, followed by a three-way ANOVA. To compare the studied groups across different composite resin bases, an independent samples t-test was performed. It is noteworthy to mention that the Levene´s test in this scenario continues to exhibit statistical significance (p<0,001). However, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and N > 15 among groups.

A significant three-way interaction was observed between ceramic type, ceramic thickness, and cement for a A2 (p=0,004) and A3 (p<0,001) composite resin base. Simple two-way interactions were verified, which proved to be statistically significant (p<0,001) except between thicknesses and cements for a A2 (p=0,366) and A3 (p=0,148) composite resin base cemented to *IPS e.max®* ceramic. There was a simple simple main effect of cement in the other variables (p<0,001), and simple simple comparisons were made.

All pairwise comparisons were adjusted using the Bonferroni method. Comparing the thicknesses of *IPS e.max®* and *VitaBlocs® Mark II* ceramics cemented to A2 composite bases, we found that ceramic thickness does not cause statistically significant changes in the Δa_2 variable when using *Universal TR, Veneer TR* and *Veneer WO* cement in *IPS e.max®* ceramics (p>0,05) (Table 39). When cemented to A3 composite base, we found that ceramic thickness does not cause statistically significant changes in the Δa_2 variable when using *Veneer TR* and *Veneer WO* cement in *IPS e.max®*ceramic (Table 39).

The *IPS e.max®*ceramic samples, with 0,5mm and 0,8mm cemented with *Universal TR* and *Veneer TR* do not present statistically significant differences when cemented to an A3 composite base (p>0,05). The *VitaBlocs® Mark II* with 0,8mm thickness, cemented with *Universal TR* and *Veneer TR* cement, also do not present statistically significant differences when cemented to an A3 composite base (p>0,05).

When cemented to an A2 colour base with *Universal TR* (p=0,109) and *Veneer TR* (p=0,257), for 0,5mm thickness, there aren´t statistically significant differences when changing from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic. When cemented to a A3 composite resin base with a 0,5mm ceramic, *Universal TR* exhibits the same behavior between the ceramics (p=0,719).

Table 40. Δa_2 independent samples t-test between A2 and A3 composite resin base for each ceramic and thickness and each cement

			Thickness	
			0,5mm	*0,8mm*
Composite	***Ceramic***	***Cement***	***p-values***	***p-values***
A2 vs. A3	***e.max®***	*Universal TR*	*p=0,386*	*p=0,086*
		Veneer TR	*p=0,003(*)*	*p<0,001(*)*
		Veneer WO	*p=0,007(*)*	*p<0,001(*)*
	Mark II	*Universal TR*	*p=0,059*	*p=0,812*
		Veneer TR	*p=0,010(*)*	*p<0,001(*)*
		Veneer WO	*p=0,023(*)*	*p=0,033(*)*

(*) Statistically significant differences for a 95% confidence interval

The use of *IPS e.max®* and *VitaBlocs® Mark II* ceramic material with a thickness of 0,5mm and 0,8mm and cemented with *Veneer TR* and *Veneer WO* cements, while varying the base shade from A2 to A3, resulted in a statistically significant difference ($p<0,05$) according to an independent samples t-test (Table 40).

5.2.6. Study of Δa_3

The results concerning the variation in green and red scale of colour between the composite resin samples attached to ceramic with glycerine and the composite resin samples cemented to ceramic using the studied cements (Δa_3) are available in Table 41, 42 and 43. The maximum and minimum Δa_2 mean absolute values obtained were 1,50, corresponding to 0,5mm *IPS e.max®* ceramic, cemented to A3 composite resin base with *Veneer WO* cement, and 0,10, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic cemented to A3 composite resin base with *Veneer WO* cement, respectively.

The Δa_3 mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A2 base are displayed in Table 41 and Graphic 17.

Table 41. Composite resin (A2) and ceramic samples cemented Δa_3 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*0,95 ± 0,10*	*0,80*	*1,10*	*1,07 ± 0,07*	*1,00*	*1,20*
	Veneer TR	*0,87 ± 0,07*	*0,80*	*1,00*	*0,96 ± 0,11*	*0,80*	*1,10*
	Veneer WO	*1,07 ± 0,12*	*0,90*	*1,20*	*0,62 ± 0,23*	*0,30*	*0,90*
Mark II	*Universal TR*	*0,81 ± 0,07*	*0,70*	*0,90*	*0,51 ± 0,10*	*0,40*	*0,70*
	Veneer TR	*0,71 ± 0,12*	*0,60*	*0,90*	*0,42 ± 0,15*	*0,20*	*0,70*
	Veneer WO	*0,63 ± 0,13*	*0,40*	*0,80*	*0,00 ± 0,34*	*-0,50*	*0,40*

Graphic 17. Composite resin (A2) and ceramic samples cemented Δa_3 mean ± standard deviation, minimum and maximum Boxplot

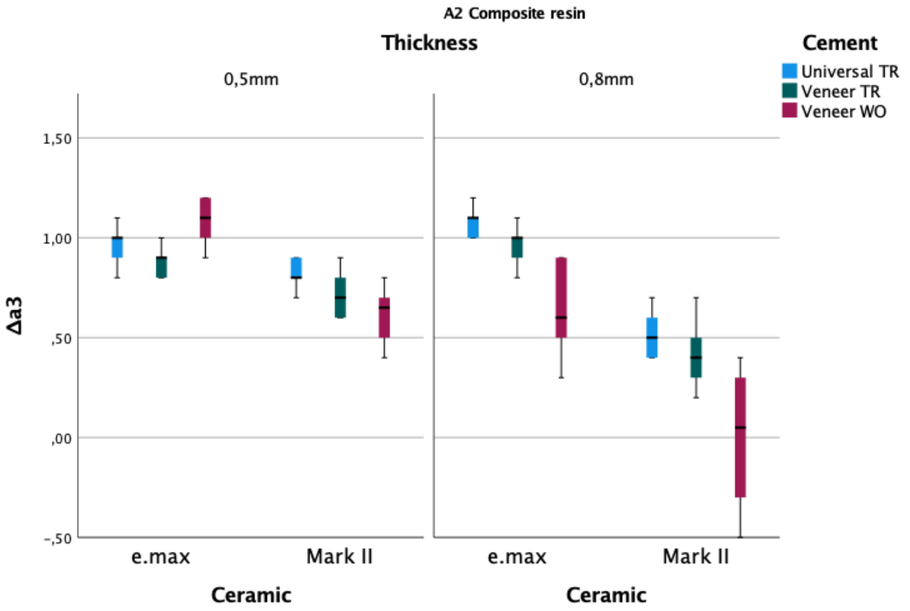


Table 41 reveals that *IPS e.max®* ceramic, when cemented with *Universal TR* cement, experiences an increase in mean Δa_3 values from 0,95 ± 0,10 to 1,07 ± 0,07 as the ceramic thickness increases from 0,5mm to 0,8mm. The use of *Veneer TR* cement shows a similar trend, with mean Δa_3 values increasing from -0,87 ± 0,07 to 0,96 ± 0,11 for the same thickness variation. However, when *Veneer WO* cement is employed, *IPS e.max®* ceramic exhibits a decrease in mean Δa_3 values from 1,07 ± 0,12 to 0,62 ± 0,23 with the same thickness variation.

When *VitaBlocs® Mark II* ceramic is cemented with *Universal TR* cement, the average Δa_3 values decrease from 0,81 ± 0,07 to 0,51 ± 0,10 as the ceramic thickness increases from 0,5mm to 0,8mm. Similarly, when *VitaBlocs® Mark II* ceramic is cemented with *Veneer TR* cement, the average Δa_3 values decrease from 0,71 ± 0,12 to 0,42 ± 0,15 for the same thickness variation. Lastly, *VitaBlocs® Mark II* ceramic cemented with *Veneer WO* cement experiences a decrease in average Δa_3 values from 0,63 ± 0,13 to 0,00 ± 0,34 with the same thickness variation.

When the thickness of *IPS e.max®* ceramic is 0,5mm, the average Δa_3 values show an increase, with values ranging from *0,87 ± 0,07*, *0,95 ± 0,10*, and *1,07 ± 0,12* for *Veneer TR, Universal TR* and *Veneer WO* cements, respectively. However, the *VitaBlocs® Mark II* ceramic with the same thickness shows average Δa_3 values of *0,63 ± 0,13*, *0,71 ± 0,12*, and *0,81 ± 0,07* for *Veneer WO, Veneer TR* and *Universal TR* cements, respectively. Additionally, an increase in average Δa_3 values is observed for *IPS e.max®* ceramic with a thickness of 0,8mm, with values ranging from *0,62 ± 0,23*, *0,96 ± 0,11*, and *1,07 ± 0,07* for *Veneer WO, Veneer TR* and *Universal TR* cements, respectively. Moreover, the *VitaBlocs® Mark II* ceramic with the same thickness shows an increase in average Δa_3 values, ranging from *0,00 ± 0,34*, *0,42 ± 0,15*, and *0,51 ± 0,10* for *Veneer WO, Veneer TR* and *Universal TR* cements, respectively.

When examining ceramic thickness of 0,5mm and using *Universal TR* cement, a decrease in average Δa_3 values is observed when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II*, with values dropping from 0,95 ± 0,10 to 0,81 ± 0,07, respectively. Similarly, when *Veneer TR* cement is used with the same ceramic thickness, there is a decrease in average Δa_3 values from 0,87 ± 0,07 to 0,71 ± 0,12 when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Additionally, with *Veneer WO* cement, a decrease in average Δa_3 values is observed when switching from *IPS e.max®* ceramic (1,07 ± 0,12) to *VitaBlocs® Mark II* ceramic (0,63 ± 0,13).

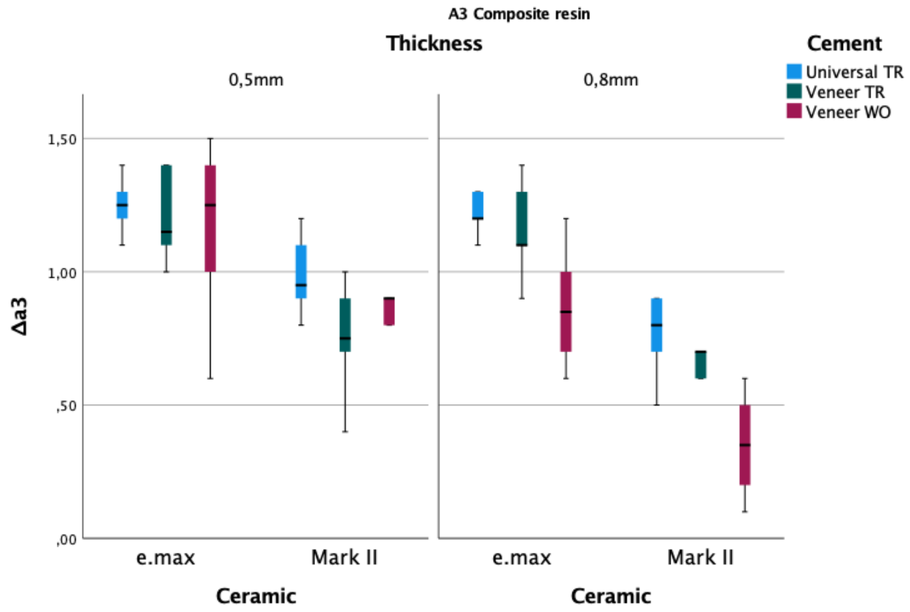
For a ceramic thickness of 0,8mm using *Universal TR* cement, there is a decrease in average Δa_3 values from 1,07 ± 0,07 to 0,51 ± 0,10 when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. Similarly, when using *Veneer TR* cement with the same thickness, a decrease in average Δa_3 values is observed from 0,96 ± 0,11 to 0,42 ± 0,15 when changing from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Moreover, for the same ceramic thickness and *Veneer WO* cement, the average Δa_3 values decreased from 0,62 ± 0,23 for *IPS e.max®* ceramic to 0,00 ± 0,34 for *VitaBlocs® Mark II* ceramic.

The Δa_3 mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A3 base are displayed in Table 42 and Graphic 18.

Table 42. Composite resin (A3) and ceramic samples cemented Δa_3 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*1,25 ± 0,08*	*1,10*	*1,40*	*1,23 ± 0,08*	*1,10*	*1,30*
	Veneer TR	*1,20 ± 0,15*	*1,00*	*1,40*	*1,13 ± 0,16*	*0,90*	*1,40*
	Veneer WO	*1,20 ± 0,57*	*0,60*	*1,50*	*0,85 ± 0,19*	*0,60*	*1,20*
Mark II	*Universal TR*	*0,97 ± 0,27*	*0,80*	*1,20*	*0,78 ± 0,14*	*0,50*	*0,90*
	Veneer TR	*0,76 ± 0,75*	*0,40*	*1,00*	*0,66 ± 0,05*	*0,60*	*0,70*
	Veneer WO	*0,86 ± 0,37*	*0,80*	*0,90*	*0,35 ± 0,16*	*0,10*	*0,60*

Graphic 18. Composite resin (A3) and ceramic samples cemented Δa3 mean ± standard deviation, minimum and maximum Boxplot



According to Table 42, as the thickness of the ceramic increases from 0,5mm to 0,8mm and *Universal TR* cement is used, *IPS e.max®* ceramic exhibits a slight reduction in mean Δ*a*3 values from -1,25 ± 0,08 to -1,23 ± 0,08. Similarly, when *Veneer TR* cement is used, mean Δ*a*3 values decrease from -1,20 ± 0,15 to -1,13 ± 0,16. When *Veneer WO* cement is used, there is a decrease in mean Δ*a*3 values for *IPS e.max®* ceramic from -1,20 ± 0,57 to -0,85 ± 0,19.

When *VitaBlocs® Mark II* ceramic is cemented with *Universal TR* cement, the average Δ*a*3 values decrease from -0,97 ± 0,27 to -0,78 ± 0,14 with the same increase in ceramic thickness. Similarly, when *VitaBlocs® Mark II* ceramic is cemented with *Veneer TR* cement, the average Δ*a*3 values decrease from -0,76 ± 0,75 to -0,66 ± 0,05. Lastly, *VitaBlocs® Mark II* ceramic cemented with *Veneer WO* cement experiences a decrease in average Δ*a*3 values from -0,86 ± 0,37 to -0,35 ± 0,16 with the same increase in ceramic thickness.

At a thickness of 0,5mm, *IPS e.max®* ceramic shows average Δa_3 values of -1,20 ± 0,57, -1,20 ± 0,15, and -1,25 ± 0,08 when cemented with *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively. However, the *VitaBlocs® Mark II* ceramic with the same thickness shows average Δa_3 values of -0,76 ± 0,75, -0,86 ± 0,37, and -0,97 ± 0,27 for *Veneer TR, Veneer WO,* and *Universal TR* cements, respectively. For a thickness of 0,8mm, average Δa_3 values for *IPS e.max®* ceramic increase to -0,85 ± 0,19, -1,13 ± 0,16, and -1,23 ± 0,08 for *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively. *VitaBlocs® Mark II* ceramic with the same thickness shows an increase in average Δa_3 values to -0,35 ± 0,16, -0,66 ± 0,05, and -0,78 ± 0,14 for the same cements.

The average Δa_3 values for ceramic thickness of 0,5mm show a decrease in values when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic with *Universal TR* cement, dropping from -1,25 ± 0,08 to -0,97 ± 0,27. The use of *Veneer TR* cement with the same thickness also results in a decrease from -1,20 ± 0,15 to -0,76 ± 0,75. Similar results are observed for *Veneer WO* cement, with values decreasing from -1,20 ± 0,57 to -0,86 ± 0,37.

For ceramic thickness of 0,8mm with *Universal TR* cement, there is a decrease in average Δa_3 values from -1,23 ± 0,08 to -0,78 ± 0,14 when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. Similarly, *Veneer TR* cement shows a decrease from -1,13 ± 0,16 to -0,66 ± 0,05 when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Moreover, the average Δa_3 values decreased from -0,85 ± 0,19 for *IPS e.max®* ceramic to -0,35 ± 0,16 for *VitaBlocs® Mark II* ceramic with the use of *Veneer WO* cement for the same ceramic thickness.

Table 43. Composite resin and ceramic samples cemented Δa_3 mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Same lowercase letters within the same column indicate a non-statistically significant differences between cements for each ceramic. The p-values below each column, for each base, represent differences for the same cement between different ceramics. Same capital letters within the same column indicate a non-statistically significant differences for the same cement between different ceramics

			Thickness		
			0,5mm	*0,8mm*	
Composite	**Ceramic**	**Cement**	**Mean ± Std. Dev**	**Mean ± Std. Dev**	**p-values**
A2	**e.max®**	Universal TR	-0,95 ± 0,10 ^{ab}	-1,07 ± 0,07 ^{e}	p=0,085
		Veneer TR	-0,87 ± 0,07 ^{a}	-0,96 ± 0,11 ^{e}	p=0,195
		Veneer WO	-1,07 ± 0,12 ^{b}	-0,62 ± 0,23	$p<0,001^{(*)}$
	Mark II	Universal TR	-0,81 ± 0,07 ^{c}	-0,51 ± 0,10 ^{f}	$p<0,001^{(*)}$
		Veneer TR	-0,71 ± 0,12 ^{cd}	-0,42 ± 0,15 ^{f}	$p<0,001^{(*)}$
		Veneer WO	-0,63 ± 0,13 ^{d}	0,00 ± 0,34	$p=0,001^{(*)}$
			$p<0,001^{(*)}$	$p<0,001^{(*)}$	
A3	**e.max®**	Universal TR	-1,25 ± 0,08 ^{g}	-1,23 ± 0,08 ^{j}	p=0,764
		Veneer TR	-1,20 ± 0,15 ^{g}	-1,13 ± 0,16 ^{j}	p=0,295
		Veneer WO	-1,20 ± 0,57 ^{g}	-0,85 ± 0,19	$p<0,001^{(*)}$
	Mark II	Universal TR	-0,97 ± 0,27 ^{h}	-0,78 ± 0,14 ^{k}	$p=0,005^{(*)}$
		Veneer TR	-0,76 ± 0,75 ^{i}	-0,66 ± 0,05 ^{k}	p=0,135
		Veneer WO	-0,86 ± 0,37 ^{hi}	-0,35 ± 0,16	$p<0,001^{(*)}$
			$p<0,001^{(*)}$	$p<0,001^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval

A four-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, ceramic thickness and cement on the Δa_3 variation. The data was checked for potential outliers using boxplots, but none were detected (Graphic 17 and 18). The normality assumption was verified using the Shapiro-Wilk test, which indicated that both groups exhibited normal distribution (p>0,05). However, Levene's test revealed significant differences in variances between the groups (p<0,001). Henceforth, a decision was made to conduct a Split File of the composite resin independent variable, followed by a three-way ANOVA. To compare the studied groups across different composite resin bases, an independent samples t-test was performed. It is noteworthy to mention that the Levene´s test in this scenario continues to exhibit statistical significance (p<0,001). However, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and N > 15 among groups.

A significant three-way interaction was observed between ceramic type, ceramic thickness, and cement for a A2 (p = 0,031) and A3 (p=0,013) composite resin base. Simple two-way interactions were verified, which proved to be statistically significant (p<0,001). There wasn´t a simple simple main effect of cement in *IPS e.max®* 0,5mm ceramic cemented to a A3 base (p=0,786), and simple simple comparisons were made.

All pairwise comparisons were adjusted using the Bonferroni method. Comparing the thicknesses of *IPS e.max®* and *VitaBlocs® Mark II* ceramics cemented to A2 composite bases, we found that variations in ceramic thickness did not cause statistically significant changes in the Δa_3 variable when *IPS e.max®* is cemented with *Universal TR* (p=0,085) and *Veneer TR* (p=0,195) (Table 43). When cemented to A3 composite base, we found that ceramic thickness does not cause statistically significant changes in the Δa_3 variable when using *Universal TR* (p=0,764), *Veneer TR* (p=0,295) in *IPS e.max®* ceramic, and *Veneer TR* (p=0,135) in *VitaBlocs® Mark II* ceramics (Table 43).

When considering the *IPS e.max®* ceramic samples with 0,5mm thickness, there were no statistically significant differences observed between the use of *Universal TR* and *Veneer TR* cements and between *Universal TR* and *Veneer WO* cements when cemented to an A2 composite base (p>0,05). The *VitaBlocs® Mark II* ceramic with 0,5mm thickness did not show any statistically significant differences between *Universal TR* and *Veneer TR* and between *Veneer TR* and *Veneer WO* when cemented to the same A2 composite base (p>0,05). When cemented to a A3 base, there is no statistically significant differences between the three cements with a *IPS e.max®*ceramic. When cemented to a *VitaBlocs® Mark II* ceramic, there is no difference between *Universal TR* and *Veneer WO* and between *Veneer TR* and *Veneer WO* (p>0,05). Additionally, when considering the *IPS e.max®* and *VitaBlocs® Mark II* ceramic samples with 0,8mm thickness, no statistically significant differences were observed between the use of *Universal TR* and *Veneer TR* cements, when cemented to an A2 and A3 composite base (p>0,05).

When cemented to an A2 or A3 colour base using any of the studied cements and for both thicknesses, statistically significant differences were observed when switching from *IPS e.max®*ceramic to *VitaBlocs® Mark II* ceramic (p<0,001).

Table 44. Δa3 independent samples t-test between A2 and A3 composite resin base for each ceramic and thickness and each cement

			Thickness	
			0,5mm	*0,8mm*
Composite	***Ceramic***	***Cement***	***p-values***	***p-values***
A2 vs. A3	***e.max®***	*Universal TR*	*p=0,004(*)*	*p<0,001(*)*
		Veneer TR	*p=0,412*	*p=0,015(*)*
		Veneer WO	*p=0,498*	*p=0,980*
	Mark II	*Universal TR*	*p<0,001(*)*	*p=0,010(*)*
		Veneer TR	*p=0,341*	*p=0,055*
		Veneer WO	*p=0,011(*)*	*p=0,030(*)*

(*) Statistically significant differences for a 95% confidence interval

An independent samples t-test showed no statistically significant difference in the use of *IPS e.max®* ceramic material with 0,5mm thickness, cemented with *Veneer TR* (p=0,412) and *Veneer WO* (p=0,498), and in the use of *VitaBlocs® Mark II* ceramic with the same thickness, cemented with *Veneer TR* (p=0,341), when varying the base shade from A2 to A3 (Table 44). Additionally, there was no statistically significant difference observed in the use of *IPS e.max®* ceramic with *Veneer WO* cement for the 0,8mm thickness (p=0,980), and in the use of *VitaBlocs® Mark II* ceramic with *Veneer TR* cement for the same thickness (p=0,055), when comparing bases of A2 and A3 shades.

5.3. STUDY OF BLUE AND YELLOW SCALE OF COLOUR (*b**)

5.3.1. Composite resin samples

The composite samples blue and yellow scale of colour (*b**) mean values and standard deviations utilized as the foundation for this study are displayed in Table 45 and Graphic 19. As shown in this table, the maximum *b** value for the composite resin samples of type A2 was 25,70, while the minimum value was 19,50. Additionally, for the composite resin samples of type A3, the maximum value obtained was 30,60, and the minimum value was 26,20.

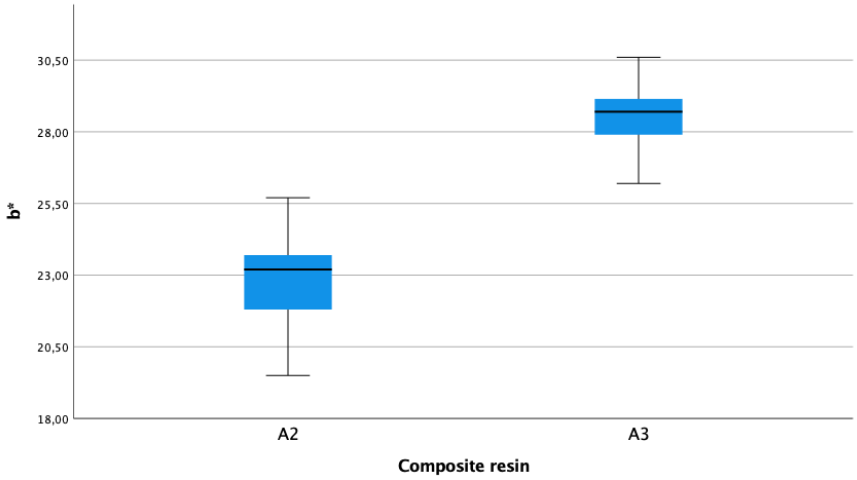
Table 45. Composite b mean ± standard deviation and p-value (one-way ANOVA)*

Composite	*Mean ± Standard deviation*	*Minimum*	*Maximum*
Filtek™ Supreme A2	*22,82 ± 1,26*	*19,50*	*25,70*
Filtek™ Supreme A3	*28,46 ± 1,00*	*26,20*	*30,60*
	$p<0,001^{(a)(*)}$		

(a) Welch-ANOVA.

(*) Statistically significant differences for a 95% confidence interval

Graphic 19. Composite b mean ± standard deviation and p-value (one-way ANOVA) Boxplot*



A one-way analysis of variance (ANOVA) was conducted to investigate the *b** difference between A2 composite resin and A3 composite resin. Prior to the analysis, data screening procedures were applied to ensure that the data met the necessary assumptions for ANOVA.

Boxplots were examined to identify any potential outliers, and none were found (Graphic 19). To assess the normality assumption, a Kolmogorov-Smirnov test was conducted on each group separately, and the results indicated that the data were not normally distributed for both groups ($p < 0,05$). Additionally, Levene's test was used to test for homogeneity of variances, and the results showed a significant difference in variances between the two groups ($p<0,05$). While there is no guarantee of a normal distribution in the population of each group, the one-way analysis of variance (ANOVA) test was chosen for its robustness in the face of many samples in each group and an equal sample size (N) across groups. Notwithstanding, to examine the similarity of results when running non-parametric tests, a Kruskal-Wallis test for independent samples was also employed. To address the issue of heteroscedasticity, a Welch correction was implemented, which is a widely accepted method for handling violations of homogeneity of variances in the analysis of variance (ANOVA). This adjustment is known for its robustness in such situations and has been extensively used in previous studies, enabling the ANOVA to be appropriately applied despite the presence of unequal variances among groups.

The Welch-ANOVA results showed a statistically significant difference in *b** between the two types of composite materials (Table 45), with a p-value of less than 0,001. Specifically, the A2 composite material showed a lower mean value of *b** corresponding to *22,82 ± 1,26* than the A3 composite material, which had a value of *28,46 ± 1,00*. The Kruskal-Wallis test confirmed the same result.

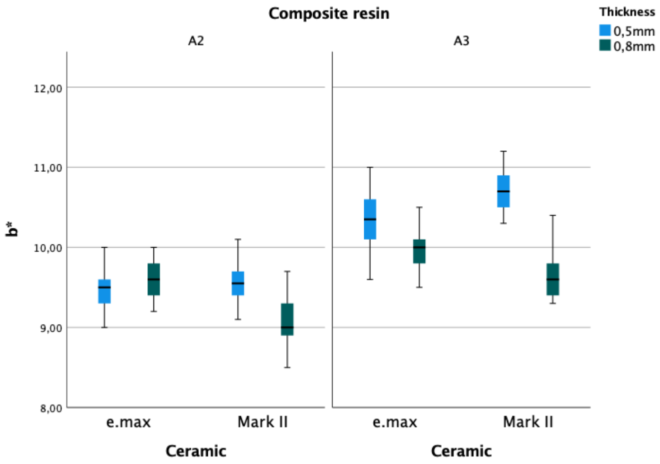
5.3.2. Composite resin and ceramic samples attached with glycerine

This study analysed the blue and yellow colour scale (*b**) of composite materials *Filtek™ Supreme* A2 and A3 in combination with 0,5mm and 0,8mm thick *IPS e.max® CAD (HT)* and *VitaBlocs® Mark II* ceramics. The mean values and standard deviations of *b** measurements are presented in Table 46 and 47. The results of the study showed that the *b** values ranged from 11,20, which was the highest value obtained for 0,5mm *VitaBlocs® Mark II* ceramic paired with A3 composite resin, to 8,50, which was the lowest value obtained for 0,8mm *VitaBlocs® Mark II* ceramic paired with A2 composite resin.

Table 46. Composite paired with ceramics by thicknesses b mean ± standard deviation, minimum and maximum*

		Thickness					
		0,5mm			0,8mm		
Composite	**Ceramic**	Mean ± Std. Dev.	Min.	Max.	Mean ± Std. Dev	Min.	Max.
Filtek™ Supreme A2	e.max®	9,50 ± 0,27	9,00	10,00	9,59 ± 0,23	9,20	10,00
	Mark II	9,57 ± 0,25	9,10	10,10	9,06 ± 0,31	8,50	9,70
Filtek™ Supreme A3	e.max®	10,36 ± 0,33	9,60	11,00	9,97 ± 0,27	9,50	10,50
	Mark II	10,69 ± 0,25	10,30	11,20	9,66 ± 0,30	9,30	10,40

Graphic 20. Composite paired with ceramics by thicknesses b mean ± standard deviation, minimum and maximum Boxplot*



When *IPS e.max®* ceramic thickness increased, *Filtek™ Supreme* A2 composite showed an increase in average blue and yellow scale of colour (*b**) values from 9,50 ± 0,27 to 9,59 ± 0,23. However, when paired with *VitaBlocs® Mark II* ceramic, average *b** values decreased, with values of 9,57 ± 0,25 and 9,06 ± 0,31 for 0,5mm and 0,8mm ceramic thicknesses, respectively.

Filtek™ Supreme A3 composite base showed a decrease in average *b** values when paired with *IPS e.max®* ceramic and an increase in thickness, with values decreasing from 10,36 ± 0,33 to 9,97 ± 0,27. Similarly, when paired with *VitaBlocs® Mark II* ceramic, there was a decrease in average *b** values, with values of 10,69 ± 0,25 and 9,66 ± 0,30 for 0,5mm and 0,8mm ceramic thicknesses, respectively.

The analysis of the A2 composite resin base with 0,5mm ceramic thickness revealed a rise in the mean *b** values from *9,50 ± 0,27* to *9,57 ± 0,25* when using *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. Likewise, for the A3 composite resin base with the same ceramic thickness, there was an increase in mean *b** values from *10,36 ± 0,33* to *10,69 ± 0,25* when used with *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. However, for a 0,8mm ceramic thickness and using the same A2 composite resin base, a decrease in average *b** values from *9,59 ± 0,23* to *9,06 ± 0,31* was observed when paired with *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. The trend was consistent when evaluating the A3 composite resin base for a 0,8mm ceramic thickness, with a decrease in mean *b** values from *9,97 ± 0,27* to *9,66 ± 0,30* when paired with *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively.

Furthermore, this study revealed that a significant rise in the average *b** values occurred when using *IPS e.max®* ceramic with a 0,5mm thickness, resulting in the average *b** values from *9,50 ± 0,27* to *10,36 ± 0,33* when paired with the *Filtek™ Supreme* A2 and *Filtek™ Supreme* A3 base, respectively. Likewise, a slight increase in the average *b** values was observed when using *IPS e.max®* ceramic with a thickness of 0,8mm, resulting in mean values of 9,59 ± 0,23 and 9,97 ± 0,27 for A2 and A3 composite resin base, respectively. Similarly, pairing *VitaBlocs® Mark II* ceramic with a thickness of 0,5mm led to an increase in the average *b** values, with mean values of 9,57 ± 0,25 and 10,69 ± 0,25 for *Filtek™ Supreme* A2 base and *Filtek™ Supreme* A3, respectively. Similarly, when using *VitaBlocs® Mark II* ceramic with a thickness of 0,8mm, an increase in the average *b** values was observed, with mean values of 9,06 ± 0,31 and 9,66 ± 0,30 for A2 and A3 composite resin base, respectively.

Table 47. Composite paired with ceramics by thicknesses b mean ± standard deviation and p-values (three-way ANOVA and multiple comparisons Bonferroni test). Equal letters represent a direct comparison between the groups*

		Thickness		
		0,5mm	*0,8mm*	
Composite resin	***Ceramic***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
Filtek™ Supreme A2	***e.max®***	*9,50 ± 0,27 (A) (*)*	*9,59 ± 0,23 (C) (*)*	*p=0,246*
	Mark II	*9,57 ± 0,25 (B) (*)*	*9,06 ± 0,31 (D) (*)*	*p<0,001(*)*
		p=0,353	*p<0,001(*)*	
Filtek™ Supreme A3	***e.max®***	*10,36 ± 0,33 (A) (*)*	*9,97 ± 0,27 (C) (*)*	*p<0,001(*)*
	Mark II	*10,69 ± 0,25 (B) (*)*	*9,66 ± 0,30 (D) (*)*	*p<0,001(*)*
		p<0,001(*)	*p<0,001(*)*	

(*) Statistically significant differences for a 95% confidence interval

A three-way analysis of variance (ANOVA) was conducted to investigate the effect of composite resin, ceramic, and ceramic thickness on lightness. Boxplots were used to detect potential outliers, and none were identified (Graphic 20). To test for normality, a Shapiro-Wilk test was conducted on each group separately, and the results indicated a normal distribution. Levene's test showed no significant differences in variances between the groups (p=0,748).

There was no statistically significant three-way interaction between composite, ceramic, and ceramic thickness (p=0,745). A significant simple two-way interaction was observed between composite resin and ceramic (p=0,046). There wasn´t a simple main effect of thickness in *IPS e.max®* ceramic paired with A2 composite resin (p=0,246). There was a simple main effect of A2 and A3 composite resin in *IPS e.max®* and *VitaBlocs® Mark II* ceramic and ceramic thickness (p<0,001).

There wasn´t a simple main effect of *IPS e.max®* and *VitaBlocs® Mark II* ceramic in 0,5mm thickness when paired with A2 composite resin base (p=0,353).

All simple pairwise comparisons were run with a Bonferroni adjustment applied. A statistically significant decrease in *b** was observed when increasing the thickness from 0,5 mm to 0,8 mm, regardless of the ceramic and composite base colour utilized (p<0,001), with the exception to *IPS e.max®* paired with a A2 composite resin base (p=0,246). Additionally, a statistically significant increase in *b** was observed upon changing the composite resin base from A2 to A3, irrespective of the ceramic type and thickness (p<0,05). When comparing the two ceramics with each other, there is a statistically significant *b** increase from the 0,5mm lithium disilicate ceramic to the 0,5mm feldspathic ceramic (p<0,001) in a A3 composite resin base. Furthermore, there was a statistically significant *b** decrease from the 0,8mm lithium disilicate ceramic to the 0,8mm feldspathic ceramic (p<0,001) in a A2 and A3 composite resin base.

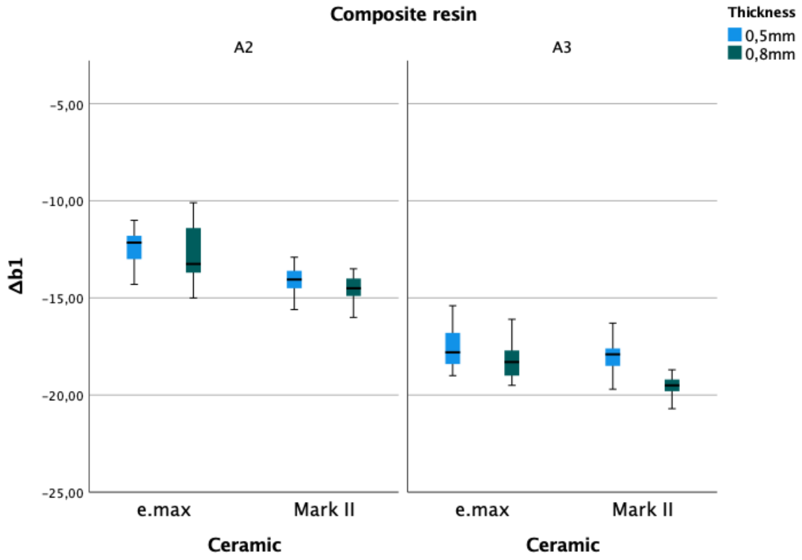
5.3.3. Study of Δb_1

The results concerning the variation in blue and yellow colour scale (*b**) between the composite resin samples and the composite resin samples attached to ceramic with glycerine (Δb_1) are available in Table 48 and 49. The maximum and minimum absolute Δb_1 mean values obtained were -20,70, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic with A3 composite resin, and -10,10, corresponding to 0,8mm *IPS e.max®* ceramic with A2 composite resin, respectively.

Table 48. Composite paired with ceramics by thicknesses Δb_1 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			0,8mm		
Composite	**Ceramic**	Mean ± Std. Dev.	Min.	Max.	Mean ± Std. Dev	Min.	Max.
Filtek™ Supreme A2	e.max®	-12,33 ± 0,87	-14,30	-11,00	-12,84 ± 1,37	-15,00	-10,10
	Mark II	-14,07 ± 0,63	-15,60	-12,90	-14,50 ± 0,59	-16,00	-13,50
Filtek™ Supreme A3	e.max®	-17,56 ± 1,05	-19,00	-15,40	-18,19 ± 0,88	-19,50	-16,10
	Mark II	-17,92 ± 0,80	-19,70	-16,30	-19,52 ± 0,53	-20,70	-18,70

Graphic 21. Composite paired with ceramics by thicknesses Δb_1 mean ± standard deviation, minimum and maximum Boxplot



The results presented in Table 48 indicate that an increase in ceramic thickness leads to a rise in average Δb_1 values for both *IPS e.max®* ceramic and *VitaBlocs® Mark II* ceramic when paired with *Filtek™ Supreme* A2. The mean values observed were -12,33 ± 0,87 and -14,07 ± 0,63 for 0,5mm ceramic thickness, which increased to -12,84 ± 1,37 and -14,50 ± 0,59 for 0,8mm ceramic thickness, respectively.

Furthermore, the outcomes suggest that the average Δb_1 values also increased with an increase in thickness when pairing *Filtek™ Supreme* A3 with *IPS e.max®* ceramic, with mean values rising from -17,56 ± 1,05 to -18,19 ± 0,88. A similar trend was observed when *Filtek™ Supreme* A3 was paired with *VitaBlocs® Mark II* ceramic, with average Δb_1 values of -17,92 ± 0,80 and -19,52 ± 0,53 for 0,5mm and 0,8mm ceramic thicknesses, respectively.

The results of Table 48 also reveal that for the A2 colour base pair, with a 0,5mm ceramic thickness, the average Δb_1 values increased from *-12,33 ± 0,87* to *-14,07 ± 0,63* when using *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. A similar increase in the mean Δb_1 values can be seen when the same A2 colour base pair is used with a 0,8mm ceramic thickness, with values increasing from *-12,84 ± 1,37* to *-14,50 ± 0,59* for *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. Furthermore, when using the *Filtek™ Supreme* A3 base with a 0,5mm ceramic, the average Δb_1 values increased from *-17,56 ± 1,05* to *-17,92 ± 0,80* for *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. Similarly, when the same A2 composite resin base is paired with a 0,8mm ceramic, an increase in the mean Δb_1 values can be observed for *IPS e.max®* ceramic *-18,19 ± 0,88* to *VitaBlocs® Mark II* ceramic *-19,52 ± 0,53*.

When examining the 0,5mm thick *IPS e.max®* ceramic, there is an uptick in the mean Δb_1 values from -12,33 ± 0,87 to -17,56 ± 1,05 when transitioning from the *Filtek™ Supreme* A2 base to the A3 base. Similarly, for the 0,8mm thick *IPS e.max®* ceramic, there is an increase in the mean Δb_1 values from -12,84 ± 1,37 for the *Filtek™ Supreme* A2 base to -18,19 ± 0,88 for the *Filtek™ Supreme* A3 base. In addition, the *VitaBlocs® Mark II* ceramic with a thickness of 0,5mm exhibits an increase in the mean Δb_1 values from -14,07 ± 0,63 for the A2 composite resin base to -17,92 ± 0,80 for the A3 base. Similarly, for the *VitaBlocs® Mark II* ceramic with a thickness of 0,8mm, an increase in the mean Δb_1 values can be observed from -14,50 ± 0,59 for the A2 composite resin base to -19,52 ± 0,53 for the A3 base.

Table 49. Composite paired with ceramics by thicknesses Δb_1 mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Equal letters represent a direct comparison between the groups

		Thickness		
		0,5mm	*0,8mm*	
Composite	***Ceramic***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
Filtek™ Supreme A2	***e.max®***	*-12,33 ± 0,87* $^{A\,(*)}$	*-12,84 ± 1,37* $^{C\,(*)}$	*p=0,025*
	Mark II	*-14,07 ± 0,63* $^{B\,(*)}$	*-14,50 ± 0,59* $^{D\,(*)}$	*p=0,059*
		p<0,001$^{(*)}$	*p<0,001*$^{(*)}$	
Filtek™ Supreme A3	***e.max®***	*-17,56 ± 1,05* $^{A\,(*)}$	*-18,19 ± 0,88* $^{C\,(*)}$	*p=0,006*$^{(*)}$
	Mark II	*-17,92 ± 0,80* $^{B\,(*)}$	*-19,52 ± 0,53* $^{D\,(*)}$	*p<0,001*$^{(*)}$
		p=0,117	*p<0,001*$^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval

A three-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, and ceramic thickness on the variation of b^* (Δb_1). The data was checked for potential outliers using boxplots, but none were detected (Graphic 21). The normality assumption was verified using the Shapiro-Wilk test, which indicated that groups does not exhibit normal distribution (p<0,05). Levene's test revealed significant differences in variances between the groups (p<0,001). Despite this, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and N > 15 among groups.

A significant three-way interaction was observed between composite, ceramic type, and ceramic thickness (p=0,023). Simple two-way interactions and simple main effects were also significant at the p<0,025 level. Additionally, significant simple two-way interactions were detected between ceramic type and ceramic thickness for A3 composite (p=0,003). A non-significant simple two-way interaction was found in A2 composite (p=0,803). Simple simple main effects of ceramic thickness in a A3 composite resin paired with *IPS e.max®* and *VitaBlocs®*

Mark II ceramic types, were statistically significant (p < 0,001). However, when paired *IPS e.max®* (p=0,025) and *VitaBlocs® Mark II* (p=0,059) to A2 composite resin, simple simple main effect of thickness was not statistically significant (Table 49).

All pairwise comparisons were adjusted using the Bonferroni method. Statistically significant differences were observed between samples of the same ceramic with identical thickness when comparing composite resin bases A2 and A3 (p<0,001) (Table 49). Between different ceramics with the same thickness and paired with the same base, Δb_1 was not statistically significant different when the two 0,5mm ceramics were paired to a A3 composite resin base (p=0,117).

5.3.4. Composite resin and ceramic samples cemented with resin cements

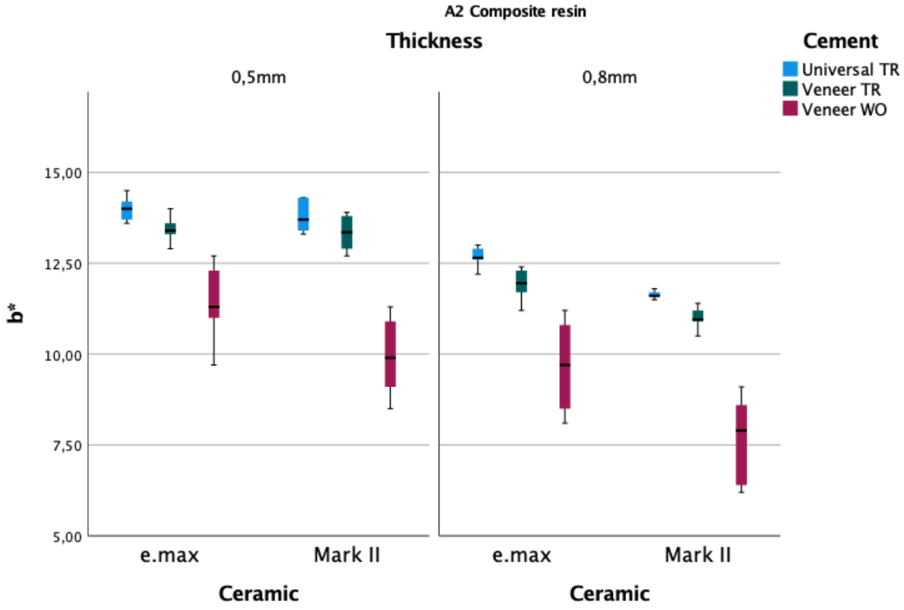
The composites *Filtek™ Supreme* A2 and A3 were paired with *IPS e.max®* and *VitaBlocs® Mark II* ceramics at thicknesses of 0,5 mm and 0,8 mm and three types of resin cements were used for the cementation. The samples were then evaluated for their blue and yellow colour scale (*b**). Table 50, 51 and 52 display the mean values and standard deviations of the *b** values of the samples used in the study. The maximum and minimum *b** values obtained were 18,00 corresponding to 0,5mm *IPS e.max®* ceramic cemented with *RelyX™ Veneer TR* to A3 composite resin, and 6,20, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic cemented with *RelyX™ Veneer* WO to A2 composite resin, respectively.

The *b** mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A2 base are displayed in Table 50 and Graphic 22.

Table 50. Composite resin (A2) and ceramic samples cemented b mean ± standard deviation, minimum and maximum*

		Thickness					
		0,5mm			0,8mm		
Ceramic	Cement	Mean ± Std. Dev.	Min.	Max.	Mean ± Std. Dev	Min.	Max.
e.max®	Universal TR	14,01 ± 0,30	13,60	14,50	12,65 ± 0,25	12,20	13,00
	Veneer TR	13,44 ± 0,28	12,90	14,00	11,92 ± 0,40	11,20	12,40
	Veneer WO	11,38 ± 0,92	9,70	12,70	9,66 ± 1,16	8,10	11,20
Mark II	Universal TR	13,76 ± 0,41	13,30	14,30	11,64 ± 0,11	11,50	11,80
	Veneer TR	13,34 ± 0,49	12,70	13,90	11,00 ± 0,25	10,50	11,40
	Veneer WO	9,94 ± 1,05	8,50	11,30	7,69 ± 1,08	6,20	9,10

Graphic 22. Composite resin (A2) and ceramic samples cemented b mean ± standard deviation, minimum and maximum Boxplot*



After reviewing Table 50, it is evident that as the thickness of *IPS e.max®* ceramic increases from 0,5mm to 0,8mm, there is a decline in mean *b** values when cemented with *Universal TR, Veneer TR,* and *Veneer WO* cements. For instance, for *IPS e.max®* ceramic cemented with *Universal TR,* the mean *b** values reduce from 14,01 ± 0,30 to 12,65 ± 0,25, while for *Veneer TR,* the values decrease from 13,44 ± 0,28 to 11,92 ± 0,40. Similarly, *IPS e.max®* ceramic cemented with *Veneer WO* exhibits a decrease in mean *b** values from 11,38 ± 0,92 to 9,66 ± 1,16 with the same thickness variation. Similarly, when examining *VitaBlocs® Mark II* ceramic cemented with *Universal TR,* there is a decrease in average *b** values from 13,76 ± 0,41 to 11,64 ± 0,11 as the ceramic thickness varies from 0,5mm to 0,8mm. The same trend is observed for *VitaBlocs® Mark II* ceramic cemented with *Veneer TR* and *Veneer WO* cements, with a reduction in average *b** values from 13,34 ± 0,49 to 11,00 ± 0,25 and 9,94 ± 1,05 to 7,69 ± 1,08, respectively, with the same variation in ceramic thickness.

When evaluating *IPS e.max®* ceramic at a thickness of 0,5mm, an elevation in average *b** values can be seen, with values ranging from 11,38 ± 0,92, 13,44 ± 0,28, and 14,01 ± 0,30 for *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively. Similarly, examination of *VitaBlocs® Mark II* ceramic with identical thickness indicates average *b** values of 9,94 ± 1,05, 13,34 ± 0,49, and 13,76 ± 0,41 for *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively.

Moreover, assessment of *IPS e.max®* ceramic at 0,8mm thickness also reveals an increase in average *b** values, ranging from 9,66 ± 1,16, 11,92 ± 0,40, and 12,65 ± 0,25 for *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively. Additionally, when investigating *VitaBlocs® Mark II* ceramic with the same thickness, an increase in average *b** values is observed, ranging from 7,69 ± 1,08, 11,00 ± 0,25, and 11,64 ± 0,11 for *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively.

When examining the ceramic thickness of 0,5mm with *Universal TR* cement, there is a decline in average *b** values from 14,01 ± 0,30 to 13,76 ± 0,41 when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic. Similarly, with *Veneer TR* cement, there is a slight decrease in average *b** values from 13,44 ± 0,28 to 13,34 ± 0,49 when substituting *IPS e.max®* with *VitaBlocs® Mark II* ceramic. Moreover, considering the same ceramic thickness and *Veneer WO* cement, the average *b** values decline from 11,38 ± 0,92 for *IPS e.max®* ceramic to 9,94 ± 1,05 for *VitaBlocs® Mark II* ceramic.

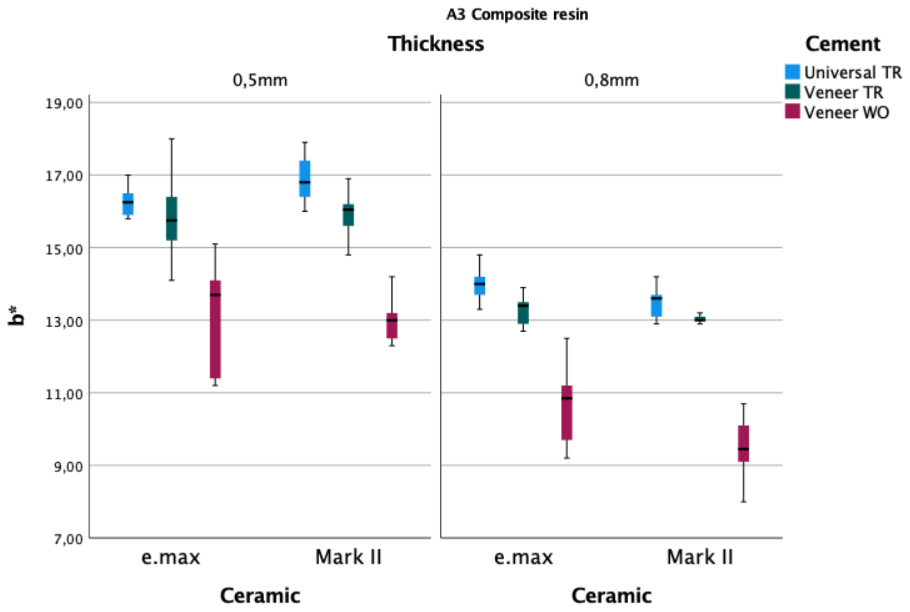
When analyzing the 0,8mm ceramic thickness with *Universal TR* cement, a decrease in average ***b****** values is observed from 12,65 ± 0,25 to 11,64 ± 0,11 when changing from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic. Similarly, with *Veneer TR* cement, the average ***b**** values decrease from 11,92 ± 0,40 to 11,00 ± 0,25 with the substitution of *IPS e.max®* with *VitaBlocs® Mark II* ceramic. Likewise, for the same ceramic thickness and *Veneer WO* cement, the average ***b**** values decrease from 9,66 ± 1,16 for *IPS e.max®* ceramic to 7,69 ± 1,08 for *VitaBlocs® Mark II* ceramic.

The ***b**** mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A3 base are displayed in Table 51 and Graphic 23.

Table 51. Composite resin (A3) and ceramic samples cemented b mean ± standard deviation, minimum and maximum*

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*16,30 ± 0,45*	*15,80*	*17,00*	*13,97 ± 0,44*	*13,30*	*14,80*
	Veneer TR	*15,85 ± 1,13*	*14,10*	*18,00*	*13,25 ± 0,40*	*12,70*	*13,90*
	Veneer WO	*13,13 ± 1,43*	*11,20*	*15,10*	*10,66 ± 1,00*	*9,20*	*12,50*
Mark II	*Universal TR*	*16,91 ± 0,67*	*16,00*	*17,90*	*13,46 ± 0,40*	*12,90*	*14,20*
	Veneer TR	*15,89 ± 0,60*	*14,80*	*16,90*	*13,03 ± 0,11*	*12,90*	*13,20*
	Veneer WO	*12,99 ± 0,59*	*12,30*	*14,20*	*9,49 ± 0,79*	*8,00*	*10,70*

Graphic 23. Composite resin (A3) and ceramic samples cemented b mean ± standard deviation, minimum and maximum Boxplot*



According to Table 51, there is a reduction in mean *b** values for *IPS e.max®* ceramic when cemented with *Universal TR* cement as the ceramic thickness increases from 0,5mm to 0,8mm. Specifically, the mean *b** values decrease from 16,30 ± 0,45 to 13,97 ± 0,44. Similarly, *IPS e.max®* ceramic cemented with *Veneer TR* cement also shows a decrease in mean *b** values from 15,85 ± 1,13 to 13,25 ± 0,40 when the thickness is increased from 0,5mm to 0,8mm. The same trend is observed for *IPS e.max®* ceramic cemented with *Veneer WO* cement, where there is a decrease in mean *b** values from 13,13 ± 1,43 to 10,66 ± 1,00 for the same thickness variation.

When evaluating *VitaBlocs® Mark II* ceramic cemented with *Universal TR* cement, the average *b** values decrease from 16,91 ± 0,67 to 13,46 ± 0,40 as the ceramic thickness increases from 0,5mm to 0,8mm. The same trend is observed for *VitaBlocs® Mark II* ceramic cemented with *Veneer TR* cement, where there is a decrease in average *b** values from 15,89 ± 0,60 to 13,03 ± 0,11. With the same variation in ceramic thickness and for the *VitaBlocs® Mark II* ceramic there is also a decrease in average *b** values from 12,99 ± 0,59 to 9,49 ± 0,79.

Additionally, it can be noted that for *IPS e.max®* ceramic with a thickness of 0,5mm, there is an increase in the average *b** values, with values ranging from 13,13 ± 1,43, 15,85 ± 1,13, and 16,30 ± 0,45 for *Veneer WO*, *Veneer TR*, and *Universal TR* cements, respectively. Similarly, for *VitaBlocs® Mark II* ceramic with the same thickness, the average *b** values observed are 12,99 ± 0,59, 15,89 ± 0,60, and 16,91 ± 0,67 for *Veneer WO*, *Veneer TR*, and *Universal TR* cements, respectively.

Furthermore, for *IPS e.max®* ceramic with a thickness of 0,8mm, there is an increase in the average *b** values, with values ranging from 10,66 ± 1,00, 13,25 ± 0,40, and 13,97 ± 0,44 for *Veneer WO, Veneer TR*, and *Universal TR* cements, respectively. Similarly, for *VitaBlocs® Mark II* ceramic with the same thickness, the average *b** values increased from 9,49 ± 0,79, 13,03 ± 0,11, and 13,46 ± 0,40 for *Veneer WO, Veneer TR*, and *Universal TR* cements, respectively.

Considering the 0,5mm ceramic thickness and the *Universal TR* cement, there is an increase in average *b** values when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic, with the values increasing from 16,30 ± 0,45 to 16,91 ± 0,67. Similarly, when using *Veneer TR* cement with the same thickness, the average *b** values increase from 15,85 ± 1,13 to 15,89 ± 0,60 when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. However, for *Veneer WO* cement, there is a decrease in average *b** values from 13,13 ± 1,43 for *IPS e.max®* ceramic to 12,99 ± 0,59 for *VitaBlocs® Mark II* ceramic.

For the 0,8mm ceramic thickness and *Universal TR* cement, there is a decrease in average *b** values from 13,97 ± 0,44 to 13,46 ± 0,40 when changing from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic. Similarly, when using *Veneer TR* cement, the average *b** values decrease from 13,25 ± 0,40 to 13,03 ± 0,11. When using *Veneer WO* cement, the average *b** values also decrease from 10,66 ± 1,00 for *IPS e.max®* ceramic to 9,49 ± 0,79 for *VitaBlocs® Mark II* ceramic.

Table 52. Composite resin and ceramic samples cemented b mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Same lowercase letters within the same column indicate a non-statistically significant differences between cements for each ceramic. Same capital letters within the same column indicate a non-statistically significant differences for the same cement between different ceramics*

			Thickness		
			0,5mm	*0,8mm*	
Composite	***Ceramic***	***Cement***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
A2	***e.max®***	*Universal TR*	*14,01 ± 0,30* $^{a\,A}$	*12,65 ± 0,25* ^{c}	*p<0,001*$^{(*)}$
		Veneer TR	*13,44 ± 0,28* $^{a\,B}$	*11,92 ± 0,40* ^{c}	*p<0,001*$^{(*)}$
		Veneer WO	*11,38 ± 0,92*	*9,66 ± 1,16*	*p<0,001*$^{(*)}$
	Mark II	*Universal TR*	*13,76 ± 0,41* $^{b\,A}$	*11,64 ± 0,11* ^{d}	*p<0,001*$^{(*)}$
		Veneer TR	*13,34 ± 0,49* $^{b\,B}$	*11,00 ± 0,25* ^{d}	*p<0,001*$^{(*)}$
		Veneer WO	*9,94 ± 1,05*	*7,69 ± 1,08*	*p<0,001*$^{(*)}$
			p=0,404$^{(A)}$ *p=0,738*$^{(B)}$	*p<0,001*$^{(*)}$	
A3	***e.max®***	*Universal TR*	*16,30 ± 0,45* $^{e\,C}$	*13,97 ± 0,44* $^{f\,F}$	*p<0,001*$^{(*)}$
		Veneer TR	*15,85 ± 1,13* $^{e\,D}$	*13,25 ± 0,40* $^{f\,G}$	*p<0,001*$^{(*)}$
		Veneer WO	*13,13 ± 1,43* ^{E}	*10,66 ± 1,00*	*p<0,001*$^{(*)}$
	Mark II	*Universal TR*	*16,91 ± 0,67* ^{C}	*13,46 ± 0,40* $^{g\,F}$	*p<0,001*$^{(*)}$
		Veneer TR	*15,89 ± 0,60* ^{D}	*13,03 ± 0,11* $^{g\,G}$	*p<0,001*$^{(*)}$
		Veneer WO	*12,99 ± 0,59* ^{E}	*9,49 ± 0,79*	*p<0,001*$^{(*)}$
			p=0,073$^{(C)}$ *p=0,906*$^{(D)}$ *p=0,679*$^{(E)}$	*p=0,133*$^{(F)}$ *p=0,515*$^{(G)}$	

(*) Statistically significant differences for a 95% confidence interval

A four-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, ceramic thickness and cement on the blue and yellow colour scale (*b**). The data was checked for potential outliers using boxplots, but none were detected (Graphic 22 and 23). The normality assumption was verified using the Shapiro-Wilk test, which indicated that both groups exhibited normal distribution (p>0,05). However, Levene's test revealed significant differences in variances between the groups (p<0,001). Henceforth, a decision was made to conduct a Split File of the composite resin independent variable, followed by a three-way ANOVA. To compare the studied groups across different composite resin bases, an independent samples t-test was performed. It is noteworthy to mention that the Levene´s test in this scenario continues to exhibit statistical significance (p<0,001). However, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and N > 15 among groups.

A significant three-way interaction was observed between ceramic type, ceramic thickness, and cement for a A2 (p=0,002) and A3 composite resin base (p = 0,018). Statistically significance of simple two-way interactions and simple main effects was accepted at a Bonferroni-ajusted alpha level of 0,025. Considering an A2 composite resin base, a simple two-way interaction wasn't statistically significant between thickness and cement with *IPS e.max®* (p=0,695) and *VitaBlocs® Mark II* (p=0,872) ceramics. Considering an A3 composite resin base, a simple two-way interaction wasn't statistically significant between thickness and cement with *IPS e.max®* (p=0,852) and *VitaBlocs® Mark II* (p=0,331) ceramics, and pairwise comparisons were continued.

All pairwise comparisons were adjusted using the Bonferroni method. Comparing the thicknesses of *IPS e.max®* and *VitaBlocs® Mark II* ceramics cemented to A2 and A3 composite bases, we found that ceramic thickness leads to a statistically significant change in the b^* variable with all cements studied (p<0,001) (Table 52). The *IPS e.max®* and *VitaBlocs® Mark II* ceramic samples, with 0,5mm and 0,8mm thickness, cemented with *Universal TR* and *Veneer TR* cement do not present statistically significant differences when cemented to an A2 composite base (p>0,05). The *IPS e.max®* with 0,5mm thickness and *VitaBlocs® Mark II* ceramic samples with 0,5mm and 0,8mm thickness, cemented with *Universal TR* and *Veneer TR* cement do not present statistically significant differences when cemented to an A3 composite base (p>0,05). When cemented to an A2 base with *Universal TR* cement (p=0,404) and *Veneer TR* cement (p=0,738), the *IPS e.max®*and *VitaBlocs® Mark II* ceramic samples with 0,5mm do not present statistically significant differences. When cemented to a A3 base with *Universal TR* (p=0,073), *Veneer TR* (p=0,906) and *Veneer WO* (p=0,679), the *IPS e.max®* and *VitaBlocs® Mark II* 0,5mm thickness ceramic do not present statistically significant differences. When cemented to an A3 base with *Universal TR* cement (p=0,133) and *Veneer TR* cement (p=0,515), the *IPS e.max®* and *VitaBlocs® Mark II* ceramic samples with 0,8mm do not present statistically significant differences (Table 52).

Table 53. b variable independent samples t-test between A2 and A3 composite resin base for each ceramic and thickness and each cement*

			Thickness	
			0,5mm	*0,8mm*
Composite	***Ceramic***	***Cement***	***p-values***	***p-values***
A2 vs. A3	***e.max®***	*Universal TR*	*p<0,001(*)*	*p<0,001(*)*
		Veneer TR	*p<0,001(*)*	*p<0,001(*)*
		Veneer WO	*p=0,005(*)*	*p=0,048(*)*
	Mark II	*Universal TR*	*p<0,001(*)*	*p<0,001(*)*
		Veneer TR	*p<0,001(*)*	*p<0,001(*)*
		Veneer WO	*p<0,001(*)*	*p<0,001(*)*

(*) Statistically significant differences for a 95% confidence interval

The use of *IPS e.max®* and *VitaBlocs® Mark II* ceramic material with a thickness of 0,5mm and 0,8mm and cemented with *Universal TR*, *Veneer TR* and *Veneer WO* cements, while varying the base shade from A2 to A3, resulted in a statistically significant difference (p<0,05) according to an independent samples t-test (Table 53).

5.3.5. Study of Δb_2

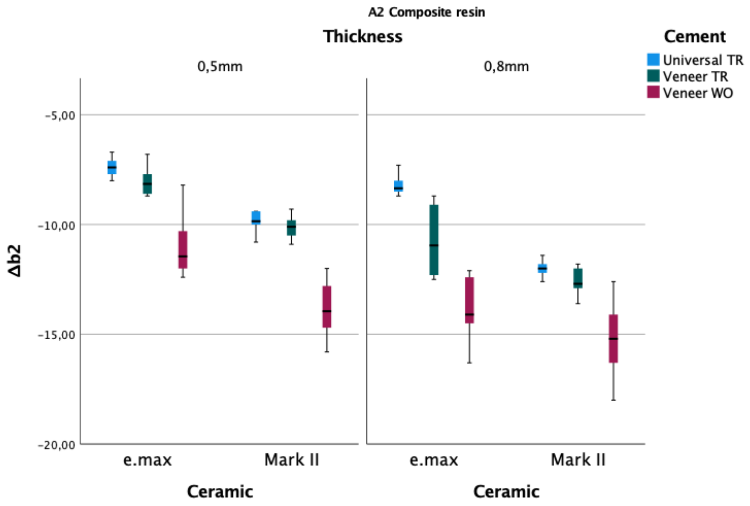
The results concerning the variation in blue and yellow colour scale (b^*) between the composite resin samples and the composite resin samples cemented to ceramic using the studied cements (Δb_2) are available in Table 54, 55 and 56. The maximum and minimum absolute Δb_2 mean values obtained were -20,50, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic, cemented to A3 composite resin base with *Veneer WO* cement, and -6,70, corresponding to 0,5mm *IPS e.max®* ceramic, cemented to A2 composite resin base with *Universal TR* cement, respectively.

The Δb_2 mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A2 base are displayed in Table 54 and Graphic 24.

Table 54. Composite resin (A2) and ceramic samples cemented Δb_2 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*-7,40 ± 0,43*	*-8,00*	*-6,70*	*-8,21 ± 0,44*	*-8,70*	*-7,30*
	Veneer TR	*-8,09 ± 0,59*	*-8,70*	*-6,80*	*-10,79 ± 1,46*	*-12,50*	*-8,70*
	Veneer WO	*-11,08 ± 1,25*	*-12,40*	*-8,20*	*-13,78 ± 1,33*	*-16,30*	*-12,10*
Mark II	*Universal TR*	*-9,86 ± 0,42*	*-10,80*	*-9,40*	*-11,99 ± 0,41*	*-12,60*	*-11,40*
	Veneer TR	*-10,16 ± 0,48*	*-10,90*	*-9,30*	*-12,62 ± 0,60*	*-13,60*	*-11,80*
	Veneer WO	*-13,85 ± 1,23*	*-15,80*	*-12,00*	*-15,20 ± 1,48*	*-18,00*	*-12,60*

Graphic 24. Composite resin (A2) and ceramic samples cemented Δb_2 mean ± standard deviation, minimum and maximum Boxplot



Upon analysis of Table 54, it can be observed that *IPS e.max®* ceramic, when cemented with *Universal TR* cement, exhibits a rise in the mean Δb_2 values, from -7,40 ± 0,43 to -8,21 ± 0,44, upon increasing the ceramic thickness from 0,5mm to 0,8mm. Similarly, an increase in ceramic thickness from 0,5mm to 0,8mm results in an increase in mean Δb_2 values of *IPS e.max®* ceramic cemented with *Veneer TR* cement, from -8,09 ± 0,59 to -10,79 ± 1,46. Correspondingly, *IPS e.max®* ceramic cemented with *Veneer WO* cement also displays an increase in mean Δb_2 values, from -11,08 ± 1,25 to -13,78 ± 1,33, for the same thickness variation.

In the case of *VitaBlocs® Mark II* ceramic, when cemented with *Universal TR* cement, there is an increase in average Δb_2 values, from -9,86 ± 0,42 to -11,99 ± 0,41, as the ceramic thickness is increased from 0,5mm to 0,8mm. Similarly, *VitaBlocs® Mark II* ceramic cemented with *Veneer TR* cement also exhibits an increase in average Δb_2 values, from -10,16 ± 0,48 to -12,62 ± 0,60, for the same variation in ceramic thickness. Furthermore, when *VitaBlocs® Mark II* ceramic is cemented with *Veneer WO* cement, the average Δb_2 values also increase, from -13,85 ± 1,23 to -15,20 ± 1,48, with the same variation in ceramic thickness.

When *IPS e.max®* ceramic has a thickness of 0,5mm, the average Δb_2 values display an upward trend, with values of -7,40 ± 0,43, -8,09 ± 0,59, and -11,08 ± 1,25 observed for *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively. Similarly, the *VitaBlocs® Mark II* ceramic with the same thickness shows average Δb_2 values of -9,86 ± 0,42, -10,16 ± 0,48, and -13,85 ± 1,23 for *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively.

Furthermore, an increase in average Δb_2 values is noted for *IPS e.max®* ceramic with a thickness of 0,8mm, with values of -8,21 ± 0,44, -10,79 ± 1,46, and -13,78 ± 1,33 observed for *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively. Similarly, the *VitaBlocs® Mark II* ceramic with the same thickness displays an increase in average Δb_2 values, with values of -11,99 ± 0,41, -12,62 ± 0,60, and -15,20 ± 1,48 for *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively.

Finally, with *Universal TR* cement, switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic results in an increase in average Δb_2 values from -7,40 ± 0,43 to -9,86 ± 0,42 for 0,5mm thickness, and from -8,21 ± 0,44 to -11,99 ± 0,41 for 0,8mm thickness. When using *Veneer TR* cement with 0,5mm ceramic thickness, the change in ceramic type results in an increase in average Δb_2 values from -8,09 ± 0,59 to -10,16 ± 0,48. With the same thickness and *Veneer WO* cement, switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic results in an increase in average Δb_2 values from -11,08 ± 1,25 to -13,85 ± 1,23. Similarly, with *Veneer TR* cement and 0,8mm ceramic thickness, changing from *IPS e.max®* to *VitaBlocs® Mark II* ceramic leads to an increase in average Δb_2 values from -10,79 ± 1,46 to -12,62 ± 0,60. With the same thickness and *Veneer WO* cement, the change in ceramic type results in an increase in average Δb_2 values from -13,78 ± 1,33 to -15,20 ± 1,48.

The Δb_2 mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A3 base are displayed in Table 55 and Graphic 25.

Table 55. Composite resin (A3) and ceramic samples cemented Δb_2 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*-10,45 ± 0,77*	*-11,80*	*-9,30*	*-14,42 ± 0,70*	*-15,40*	*-13,30*
	Veneer TR	*-12,40 ± 0,95*	*-13,60*	*-11,10*	*-15,30 ± 0,63*	*-16,30*	*-14,20*
	Veneer WO	*-15,62 ± 1,23*	*-17,70*	*-14,30*	*-16,89 ± 0,15*	*-19,00*	*-15,20*
Mark II	*Universal TR*	*-11,50 ± 1,41*	*-13,40*	*-8,80*	*-15,65 ± 0,30*	*-16,10*	*-15,20*
	Veneer TR	*-12,92 ± 0,90*	*-14,50*	*-11,40*	*-16,26 ± 0,70*	*-17,60*	*-15,40*
	Veneer WO	*-15,49 ± 0,81*	*-16,70*	*-14,30*	*-19,64 ± 0,64*	*-20,50*	*-18,70*

Graphic 25. Composite resin (A3) and ceramic samples cemented Δb_2 mean ± standard deviation, minimum and maximum Boxplot

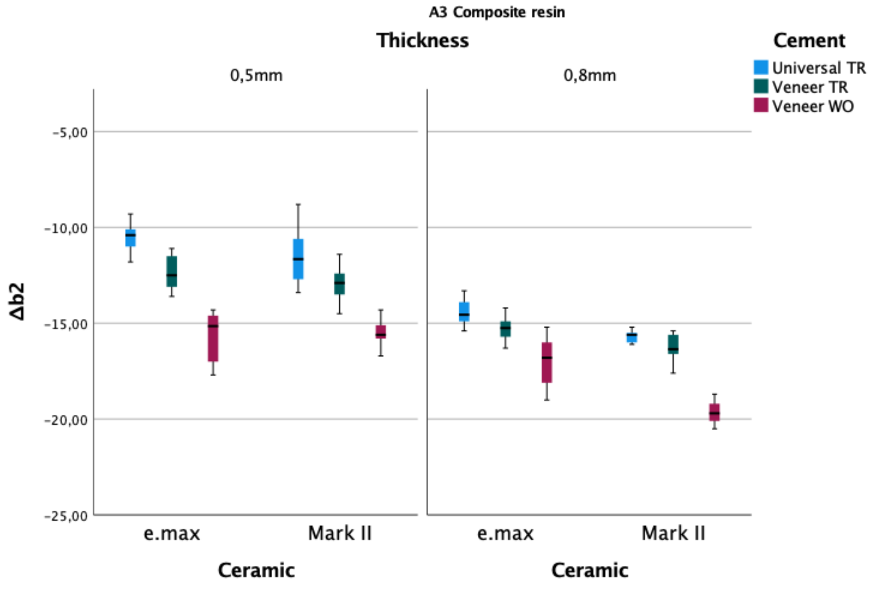


Table 55 displays an increase in mean Δb_2 values for *IPS e.max®* ceramic when *Universal TR* cement is used, and as the ceramic thickness increases from 0,5mm to 0,8mm. Specifically, the mean Δb_2 values increase from -10,45 ± 0,77 to -14,42 ± 0,70. *Veneer TR* cement shows the same trend, with an increase in mean Δb_2 values from -12,40 ± 0,95 to -15,30 ± 0,63 for the same ceramic thickness variation. Similarly, *IPS e.max®* ceramic cemented with *Veneer WO* cement also exhibits an increase in mean Δb_2 values, from -15,62 ± 1,23 to -16,89 ± 0,15. For *VitaBlocs® Mark II* ceramic cemented with *Universal TR* cement, there is an increase in average Δb_2 values from -11,50 ± 1,41 to -15,65 ± 0,30 as the ceramic thickness increases from 0,5mm to 0,8mm. The same trend is observed for *VitaBlocs® Mark II* ceramic cemented with *Veneer TR* cement, where there is an increase in average Δb_2 values from -12,92 ± 0,90 to -16,26 ± 0,70. Similarly, with the same variation in ceramic thickness for the *VitaBlocs® Mark II* ceramic, there is an increase in average Δb_2 values from -15,49 ± 0,81 to -19,64 ± 0,64.

Furthermore, it is worth noting that *IPS e.max®* ceramic with a thickness of 0,5mm shows an increase in average Δb_2 values ranging from -10,45 ± 0,77, -12,40 ± 0,95, and -15,62 ± 1,23 when cemented with *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively. A similar trend is observed for *VitaBlocs® Mark II* ceramic with the same thickness, where the average Δb_2 values were -11,50 ± 1,41, -12,92 ± 0,90, and -15,49 ± 0,81 for *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively. Moreover, for *IPS e.max®* ceramic with a thickness of 0,8mm, the average Δb_2 values increase from -14,42 ± 0,70, -15,30 ± 0,63, and -16,89 ± 0,15 when cemented with *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively. A similar trend is observed for *VitaBlocs® Mark II* ceramic with the same thickness, where the average Δb_2 values increase from -15,65 ± 0,30, -16,26 ± 0,70, and -19,64 ± 0,64 for *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively.

Considering the 0,5mm ceramic thickness and the *Universal TR* cement, there is an increase in average Δb_2 values when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic, with the values increasing from -10,45 ± 0,77 to -11,50 ± 1,41. Similarly, when using *Veneer TR* cement with the same thickness, the average Δb_2 values increase from -12,40 ± 0,95 to -12,92 ± 0,90 when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. However, for *Veneer WO* cement, there is a decrease in average Δb_2 values from -15,62 ± 1,23 for *IPS e.max®* ceramic to -15,49 ± 0,81 for *VitaBlocs® Mark II* ceramic.

For the 0,8mm ceramic thickness and *Universal TR* cement, there is an increase in average Δb_2 values from -14,42 ± 0,70 to -15,65 ± 0,30 when changing from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic. Similarly, when using *Veneer TR* cement, the average Δb_2 values increase from -15,30 ± 0,63 to -16,26 ± 0,70. When using *Veneer WO* cement, the average Δb_2 values also increase from -16,89 ± 0,15 for *IPS e.max®* ceramic to -19,64 ± 0,64 for *VitaBlocs® Mark II* ceramic.

Table 56. Composite resin and ceramic samples cemented Δb_2 mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Same lowercase letters within the same column indicate a non-statistically significant differences between cements for each ceramic. The p-values below each column, for each base, represent differences for the same cement between different ceramics

			Thickness		
			0,5mm	*0,8mm*	
Composite	***Ceramic***	***Cement***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
A2	***e.max®***	*Universal TR*	*-7,40 ± 0,43* ^{a}	*-8,21 ± 0,44*	*p=0,059*
		Veneer TR	*-8,09 ± 0,59* ^{a}	*-10,79 ± 1,46*	*p<0,001*$^{(*)}$
		Veneer WO	*-11,08 ± 1,25*	*-13,78 ± 1,33*	*p=0,002*$^{(*)}$
	Mark II	*Universal TR*	*-9,86 ± 0,42* ^{b}	*-11,99 ± 0,41* ^{c}	*p<0,001*$^{(*)}$
		Veneer TR	*-10,16 ± 0,48* ^{b}	*-12,62 ± 0,60* ^{c}	*p<0,001*$^{(*)}$
		Veneer WO	*-13,85 ± 1,23*	*-15,20 ± 1,48*	*p=0,002*$^{(*)}$
			p<0,001$^{(*)}$	*p<0,001*$^{(*)}$	
A3	***e.max®***	*Universal TR*	*-10,45 ± 0,77*	*-14,42 ± 0,70* ^{d}	*p<0,001*$^{(*)}$
		Veneer TR	*-12,40 ± 0,95* ^{A}	*-15,30 ± 0,63* ^{d}	*p<0,001*$^{(*)}$
		Veneer WO	*-15,62 ± 1,23* ^{B}	*-16,89 ± 0,15*	*p=0,002*$^{(*)}$
	Mark II	*Universal TR*	*-11,50 ± 1,41*	*-15,65 ± 0,30* ^{e}	*p<0,001*$^{(*)}$
		Veneer TR	*-12,92 ± 0,90* ^{A}	*-16,26 ± 0,70* ^{e}	*p<0,001*$^{(*)}$
		Veneer WO	*-15,49 ± 0,81* ^{B}	*-19,64 ± 0,64*	*p<0,001*$^{(*)}$
			p=0,206$^{(A)}$ *p=0,751*$^{(B)}$	*p<0,001*$^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval

A four-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, ceramic thickness and cement on the variation of b^* (Δb_2). The data was checked for potential outliers using boxplots, but none were detected (Graphic 24 and 25). The normality assumption was verified using the Shapiro-Wilk test, which indicated that both groups exhibited normal distribution ($p>0,05$). However, Levene's test revealed significant differences in variances between the groups ($p<0,001$). Henceforth, a decision was made to conduct a Split File of the composite resin independent variable, followed by a three-way ANOVA. To compare the studied groups across different composite resin bases, an independent samples t-test was performed. It is noteworthy to mention that the Levene´s test in this scenario continues to exhibit statistical significance ($p<0,001$). However, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and $N > 15$ among groups.

A significant three-way interaction was observed between ceramic type, ceramic thickness, and cement for a A2 ($p=0,009$) and A3 ($p=0,002$) composite resin base. Simple two-way interactions were verified, which proved to be statistically significant ($p<0,001$) except between thickness and cement for a A2 ($p=0,170$) and A3 ($p=0,275$) composite resin base cemented to *VitaBlocs® Mark II* ceramic. There was a simple simple main effect of cement in the other variables ($p<0,001$), and simple simple comparisons were made.

All pairwise comparisons were adjusted using the Bonferroni method. Comparing the thicknesses of *IPS e.max®* and *VitaBlocs® Mark II* ceramics cemented to A2 and A3 composite bases, we found that ceramic thickness leads to a statistically significant change in the Δb_2 variable when using all the cements, except when using a *IPS e.max®* with *Universal TR* in a A2 composite resin base ($p=0,059$) (Table 56).

The *IPS e.max®* ceramic samples, with 0,5mm cemented with *Universal TR* and *Veneer TR* do not present statistically significant differences when cemented to an A2 composite base ($p>0,05$). The *VitaBlocs® Mark II* with 0,5mm and 0,8mm thickness, cemented with *Universal TR* and *Veneer TR* cement, do not present statistically significant differences when cemented to an A2 composite base ($p>0,05$). The *IPS e.max®* and *VitaBlocs® Mark II* ceramic samples, with 0,8mm cemented with *Universal TR* and *Veneer TR* do not present statistically significant differences when cemented to an A3 composite base (p>0,05) (Table 56).

When cemented to an A3 colour base with *Veneer TR* (p=0,206) and *Veneer WO* (p=0,751), for 0,5mm thickness, there aren´t statistically significant differences when changing from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic (Table 56).

Table 57. Δb_2 independent samples t-test between A2 and A3 composite resin base for each ceramic and thickness and each cement

			Thickness	
			0,5mm	*0,8mm*
Composite	***Ceramic***	***Cement***	***p-values***	***p-values***
A2 vs. A3	***e.max®***	*Universal TR*	$p<0{,}001^{(*)}$	$p<0{,}001^{(*)}$
		Veneer TR	$p<0{,}001^{(*)}$	$p<0{,}001^{(*)}$
		Veneer WO	$p<0{,}001^{(*)}$	$p<0{,}001^{(*)}$
	Mark II	*Universal TR*	$p=0{,}005^{(*)}$	$p<0{,}001^{(*)}$
		Veneer TR	$p<0{,}001^{(*)}$	$p<0{,}001^{(*)}$
		Veneer WO	$p=0{,}002^{(*)}$	$p<0{,}001^{(*)}$

(*) Statistically significant differences for a 95% confidence interval

The use of *IPS e.max®* and *VitaBlocs® Mark II* ceramic material with a thickness of 0,5mm and 0,8mm and cemented with *Universal TR, Veneer TR* and *Veneer WO* cements, while varying the base shade from A2 to A3, resulted in a statistically significant difference (p<0,05) according to an independent samples t-test (Table 57).

5.3.6. Study of Δb_3

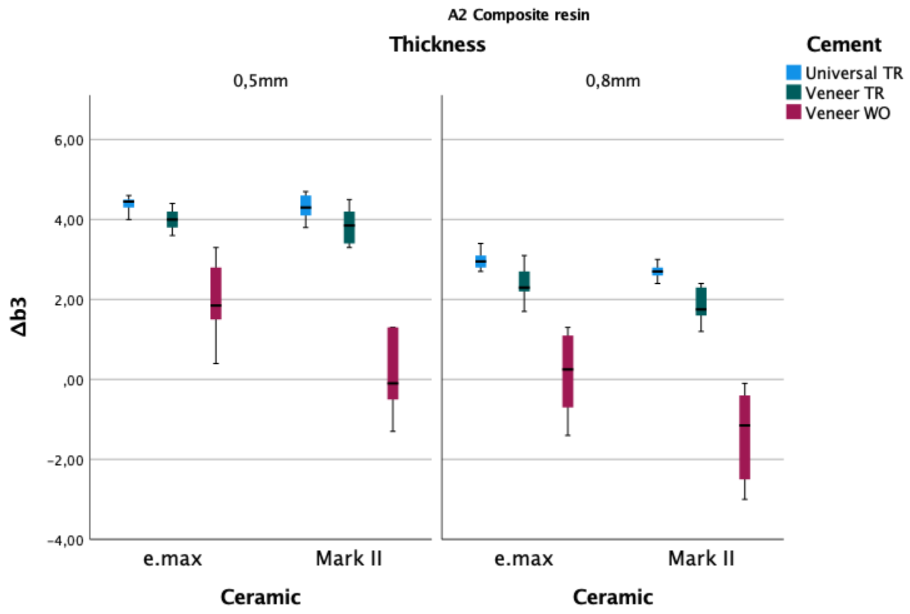
The results concerning the variation in blue and yellow colour scale (b^*) between the composite resin samples attached to ceramic with glycerine and the composite resin samples cemented to ceramic using the studied cements (Δb_3) are available in Table 58, 59 and 60. The maximum and minimum Δb_3 mean absolute values obtained were 7,30, corresponding to 0,5mm *VitaBlocs® Mark II* ceramic, cemented to A3 composite resin base with *Universal TR* cement, and -0,10, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic cemented to A2 composite resin base with *Veneer WO* cement, respectively.

The Δb_3 mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A2 base are displayed in Table 58 and Graphic 26.

Table 58. Composite resin (A2) and ceramic samples cemented Δb_3 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			0,8mm		
Ceramic	**Cement**	Mean ± Std. Dev.	Min.	Max.	Mean ± Std. Dev	Min.	Max.
e.max®	Universal TR	4,38 ± 0,19	4,00	4,60	3,00 ± 0,23	2,70	3,40
	Veneer TR	4,00 ± 0,29	3,60	4,40	2,41 ± 0,43	1,70	3,10
	Veneer WO	1,94 ± 0,85	0,40	3,30	0,06 ± 1,00	1,40	1,30
Mark II	Universal TR	4,30 ± 0,29	3,80	4,70	2,68 ± 0,19	2,40	3,00
	Veneer TR	3,98 ± 0,41	3,30	4,50	1,87 ± 0,43	1,20	2,40
	Veneer WO	0,18 ± 1,02	-1,30	1,30	-1,35 ± 1,11	-3,00	-0,10

Graphic 26. Composite resin (A2) and ceramic samples cemented Δb3 mean ± standard deviation, minimum and maximum Boxplot



According to Table 58, the *IPS e.max®* ceramic displays a decrease in mean Δ*b*3 values when cemented with *Universal TR* cement, as the ceramic thickness increases from 0,5mm to 0,8mm. Specifically, the mean Δ*b*3 values decrease from 4,38 ± 0,19 to 3,00 ± 0,23. The use of *Veneer TR* cement also demonstrates a similar trend, with mean Δ*b*3 values decreasing from 4,00 ± 0,29 to 2,41 ± 0,43 for the same thickness variation. When *Veneer WO* cement is utilized, *IPS e.max®* ceramic experiences a decrease in mean Δ*b*3 values from 1,94 ± 0,85 to 0,06 ± 1,00 with the same thickness variation.

Regarding *VitaBlocs® Mark II* ceramic, when cemented with *Universal TR* cement, the average Δ*b*3 values decrease from 4,30 ± 0,29 to 2,68 ± 0,19 as the ceramic thickness increases from 0,5mm to 0,8mm. Similarly, when *VitaBlocs® Mark II* ceramic is cemented with *Veneer TR* cement, the average Δ*b*3 values decrease from 3,98 ± 0,41 to 1,87 ± 0,43 for the same thickness variation. However, when *VitaBlocs® Mark II* ceramic is cemented with *Veneer WO* cement, there is an increase in average Δ*b*3 values from -0,18 ± 1,02 to 1,35 ± 1,11 with the same thickness variation.

When *IPS e.max®* ceramic has a thickness of 0,5mm, there is an increase in the average Δb_3 values. Specifically, for *Veneer WO, Veneer TR,* and *Universal TR* cements, the values range from 1,94 ± 0,85, 4,00 ± 0,29, and 4,38 ± 0,19, respectively. Similarly, for *VitaBlocs® Mark II* ceramic with the same thickness, the average Δb_3 values are 0,18 ± 1,02, 3,98 ± 0,41, and 4,30 ± 0,29 for *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively.

Furthermore, an increase in the average Δb_3 values is observed for *IPS e.max®* ceramic with a thickness of 0,8mm. The values for *Veneer WO, Veneer TR,* and *Universal TR* cements are 0,06 ± 1,00, 2,41 ± 0,43, and 3,00 ± 0,23, respectively. Similarly, for *VitaBlocs® Mark II* ceramic with the same thickness, there is an increase in the average Δb_3 values, ranging from -1,35 ± 1,11, 1,87 ± 0,43, and 2,68 ± 0,19 for *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively.

When using *Universal TR* cement with a ceramic thickness of 0,5mm, switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic results in a small decrease in average Δb_3 values, from 4,38 ± 0,19 to 4,30 ± 0,29, respectively. Similar trends are observed when *Veneer TR* cement is used, with average Δb_3 values decreasing from 4,00 ± 0,29 to 3,98 ± 0,41. When *Veneer WO* cement is employed with the same thickness, a decrease in average Δb_3 values is observed when switching from *IPS e.max®* ceramic (1,94 ± 0,85) to *VitaBlocs® Mark II* ceramic (0,18 ± 1,02).

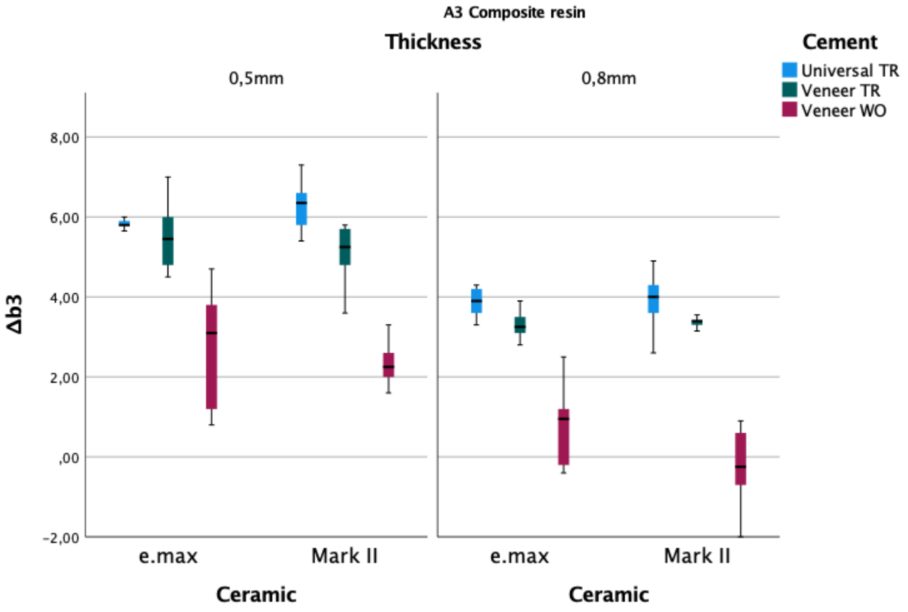
For a ceramic thickness of 0,8mm, using *Universal TR* cement results in a decrease in average Δb_3 values from 3,00 ± 0,23 to 2,68 ± 0,19 when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. Similarly, when using *Veneer TR* cement with the same thickness, average Δb_3 values decrease from 2,41 ± 0,43 to 1,87 ± 0,43 when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Conversely, for the same ceramic thickness and *Veneer WO* cement, the average Δb_3 values increase from 0,06 ± 1,00 for *IPS e.max®* ceramic to -1,35 ± 1,11 for *VitaBlocs® Mark II* ceramic.

The Δb_3 mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A3 base are displayed in Table 59 and Graphic 27.

Table 59. Composite resin (A3) and ceramic samples cemented Δb_3 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			0,8mm		
Ceramic	Cement	Mean ± Std. Dev.	Min.	Max.	Mean ± Std. Dev	Min.	Max.
e.max®	Universal TR	5,84 ± 0,11	5,65	6,00	3,88 ± 0,33	3,30	4,30
	Veneer TR	5,54 ± 0,83	4,50	7,00	3,31 ± 0,31	2,80	3,90
	Veneer WO	2,71 ± 1,36	0,80	4,70	0,78 ± 0,89	-0,40	2,50
Mark II	Universal TR	6,29 ± 0,57	5,40	7,30	3,91 ± 0,61	2,60	4,90
	Veneer TR	5,13 ± 0,67	3,60	5,80	3,37 ± 0,12	3,15	3,55
	Veneer WO	2,31 ± 0,50	1,60	3,30	-0,21 ± 0,87	-2,00	0,90

Graphic 27. Composite resin (A3) and ceramic samples cemented Δb_3 mean ± standard deviation, minimum and maximum Boxplot



Based on Table 59, the *IPS e.max®* ceramic shows a consistent reduction in mean Δb_3 values as ceramic thickness increases from 0,5mm to 0,8mm, regardless of the type of cement used. When *Universal TR* cement is utilized, mean Δb_3 values decrease from 5,84 ± 0,11 to 3,88 ± 0,33, while *Veneer TR* cement exhibits a decrease from 5,54 ± 0,83 to 3,31 ± 0,31. For *Veneer WO* cement, the decrease in mean Δb_3 values is from 2,71 ± 1,36 to 0,78 ± 0,89 for the same thickness variation.

For *VitaBlocs® Mark II* ceramic, a similar trend is observed as ceramic thickness increases from 0,5mm to 0,8mm, regardless of the type of cement used. When *Universal TR* cement is utilized, the average Δb_3 values decrease from 6,29 ± 0,57 to 3,91 ± 0,61. Similarly, when *Veneer TR* cement is used, the average Δb_3 values decrease from 5,13 ± 0,67 to 3,37 ± 0,12. When *Veneer WO* cement is utilized, there is also a decrease in average Δb_3 values from 2,31 ± 0,50 to -0,21 ± 0,87 for the same thickness variation.

When *IPS e.max®* ceramic has a thickness of 0,5mm, there is an increase in the average Δb_3 values. Specifically, for *Veneer WO, Veneer TR*, and *Universal TR* cements, the values range from 2,71 ± 1,36, 5,54 ± 0,83, and 5,84 ± 0,11, respectively. Similarly, for *VitaBlocs® Mark II* ceramic with the same thickness, the average Δb_3 values are 2,31 ± 0,50, 5,13 ± 0,67, and 6,29 ± 0,57 for *Veneer WO, Veneer TR*, and *Universal TR* cements, respectively.

Furthermore, an increase in the average Δb_3 values is observed for *IPS e.max®* ceramic with a thickness of 0,8mm. The values for *Veneer WO, Veneer TR*, and *Universal TR* cements are 0,78 ± 0,89, 3,31 ± 0,31, and 3,88 ± 0,33, respectively. Similarly, for *VitaBlocs® Mark II* ceramic with the same thickness, there is an increase in the average Δb_3 values, ranging from -0,21 ± 0,87, 3,37 ± 0,12, and 3,91 ± 0,61 for *Veneer WO, Veneer TR*, and *Universal TR* cements, respectively.

When *Universal TR* cement is used with a 0,5mm thick ceramic, replacing *IPS e.max®* with *VitaBlocs® Mark II* ceramic leads to an increase in average Δb_3 values, with a change from 5,84 ± 0,11 to 6,29 ± 0,57. The opposite happens when *Veneer TR* cement is used, with average Δb_3 values decreasing from 5,54 ± 0,83 to 5,13 ± 0,67. On the other hand, using *Veneer WO* cement with the same thickness results in a decrease in average Δb_3 values when switching from *IPS e.max®* ceramic (2,71 ± 1,36) to *VitaBlocs® Mark II* ceramic (2,31 ± 0,50). For a ceramic thickness of 0,8mm, switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II* using *Universal TR* cement leads to an increase in average Δb_3 values from 3,88 ± 0,33 to 3,91 ± 0,61. The same is observed when using *Veneer TR* cement with a thickness of 0,8mm, with average Δb_3 values increasing from 3,31 ± 0,31 to 3,37 ± 0,12. Conversely, for the same ceramic thickness and *Veneer WO* cement, the average Δb_3 values decrease from 0,78 ± 0,89 (*IPS e.max®* ceramic) to -0,21 ± 0,87 (*VitaBlocs® Mark II* ceramic).

Table 60. Composite resin and ceramic samples cemented Δb_3 mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Same lowercase letters within the same column indicate a non-statistically significant differences between cements for each ceramic. The p-values below each column, for each base, represent differences for the same cement between different ceramics. Same capital letters within the same column indicate a non-statistically significant differences for the same cement between different ceramics

			Thickness		
			0,5mm	*0,8mm*	
Composite	***Ceramic***	***Cement***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
A2	***e.max®***	*Universal TR*	*4,38 ± 0,19* $^{a\ A}$	*3,00 ± 0,23* $^{c\ C}$	*p<0,001*$^{(*)}$
		Veneer TR	*4,00 ± 0,29* $^{a\ B}$	*2,41 ± 0,43* $^{c\ D}$	*p<0,001*$^{(*)}$
		Veneer WO	*1,94 ± 0,85*	*0,06 ± 1,00*	*p<0,001*$^{(*)}$
	Mark II	*Universal TR*	*4,30 ± 0,29* $^{b\ A}$	*2,68 ± 0,19* ^{C}	*p<0,001*$^{(*)}$
		Veneer TR	*3,98 ± 0,41* $^{b\ B}$	*1,87 ± 0,43* ^{D}	*p<0,001*$^{(*)}$
		Veneer WO	*0,18 ± 1,02*	*-1,35 ± 1,11*	*p=0,001*$^{(*)}$
			p=0,778$^{(A)}$ *p=0,598*$^{(B)}$	*p=0,261*$^{(C)}$ *p=0,059*$^{(D)}$	
A3	***e.max®***	*Universal TR*	*5,84 ± 0,11* $^{d\ E}$	*3,88 ± 0,33* $^{e\ H}$	*p<0,001*$^{(*)}$
		Veneer TR	*5,54 ± 0,83* $^{d\ F}$	*3,31 ± 0,31* $^{e\ I}$	*p<0,001*$^{(*)}$
		Veneer WO	*2,71 ± 1,36* ^{G}	*0,78 ± 0,89*	*p<0,001*$^{(*)}$
	Mark II	*Universal TR*	*6,29 ± 0,57* ^{E}	*3,91 ± 0,61* $^{f\ H}$	*p<0,001*$^{(*)}$
		Veneer TR	*5,13 ± 0,67* ^{F}	*3,37 ± 0,12* $^{f\ I}$	*p<0,001*$^{(*)}$
		Veneer WO	*2,31 ± 0,50* ^{G}	*-0,21 ± 0,87*	*p<0,001*$^{(*)}$
			p=0,152$^{(E)}$ *p=0,186*$^{(F)}$ *p=0,197*$^{(G)}$	*p=0,923*$^{(H)}$ *p=0,846*$^{(I)}$	

(*) Statistically significant differences for a 95% confidence interval

A four-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, ceramic thickness, and cement on the variation of b^* (Δb_3). The data was checked for potential outliers using boxplots, but none were detected (Graphic 26 and 27). The normality assumption was verified using the Shapiro-Wilk test, which indicated that both groups exhibited normal distribution ($p>0,05$). However, Levene's test revealed significant differences in variances between the groups ($p<0,001$). Henceforth, a decision was made to conduct a Split File of the composite resin independent variable, followed by a three-way ANOVA. To compare the studied groups across different composite resin bases, an independent samples t-test was performed. It is noteworthy to mention that the Levene´s test in this scenario continues to exhibit statistical significance ($p<0,001$). However, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and $N > 15$ among groups.

A non-significant three-way interaction was observed between ceramic type, ceramic thickness, and cement for a A2 ($p = 0,389$) and A3 ($p=0,188$) composite resin base. Two-way interactions were verified between ceramic and cement for an A2 ($p<0,001$) and A3 ($p=0,012$) composite resin base, which proved to be statistically significant ($p<0,001$). The simple main effect of ceramic is not statistically significant for *Universal TR* and *Veneer TR* when used in a A2 and A3 composite resin base ($p>0,05$).

All pairwise comparisons were adjusted using the Bonferroni method. Comparing the thicknesses of *IPS e.max®* and *VitaBlocs® Mark II* ceramics cemented to A2 and A3 composite bases, we found that variations in ceramic thickness did cause statistically significant changes in the Δb_3 variable when cemented with any of the studied cements ($p<0,001$) (Table 60).

When considering the *IPS e.max®* ceramic samples with 0,5mm thickness, there were no statistically significant differences observed between the use of *Universal TR* and *Veneer TR* cements when cemented to an A2 and A3 composite base ($p>0,05$). Similarly, the *VitaBlocs® Mark II* ceramic with 0,5mm thickness did not show any statistically significant differences when cemented with *Universal TR* and *Veneer TR* cement to the A2 composite base ($p>0,05$). Additionally, when considering the *IPS e.max®* and *VitaBlocs® Mark II* ceramic samples with 0,8mm thickness, no statistically significant differences were observed between the use of

Universal TR and *Veneer TR* cements, when cemented to an A3 composite base (p>0,05). When considering the *IPS e.max®* ceramic samples with 0,8mm thickness and cemented to an A2 base, no statistically significant differences were observed between the use of *Universal TR* and *Veneer TR* cements (p>0,05) (Table 60).

When cemented to an A2 colour base using *Universal TR* (p=0,778) and *Veneer TR* (p=0,598) cements for 0,5mm thickness, statistically significant differences were not observed when switching from *IPS e.max®*ceramic to *VitaBlocs® Mark II* ceramic. In the same conditions with a 0,8mm thickness, statistically significant differences were not observed using *Universal TR* (p=0,261) and *Veneer TR* (p=0,059). When cemented to an A3 colour base using *Universal TR* (p=0,152), *Veneer TR* (p=0,186) and *Veneer WO* (p=0,197) cements for a 0,5mm thickness, statistically significant differences were not observed when switching from *IPS e.max®*ceramic to *VitaBlocs® Mark II* ceramic. In the same conditions with a 0,8mm thickness there were no statistically significant differences when using *Universal TR* (p=0,923) and *Veneer TR* (p=0,846) cements (Table 60).

Table 61. Δb_3 independent samples t-test between A2 and A3 composite resin base for each ceramic and thickness and each cement

			Thickness	
			0,5mm	*0,8mm*
Composite	***Ceramic***	***Cement***	***p-values***	***p-values***
A2 vs. A3	***e.max®***	*Universal TR*	*p<0,001*(*)	*p<0,001*(*)
		Veneer TR	*p<0,001*(*)	*p<0,001*(*)
		Veneer WO	*p<0,001*(*)	*p<0,001*(*)
	Mark II	*Universal TR*	*p=0,005*(*)	*p<0,001*(*)
		Veneer TR	*p<0,001*(*)	*p<0,001*(*)
		Veneer WO	*p=0,002*(*)	*p<0,001*(*)

(*) Statistically significant differences for a 95% confidence interval

The use of 0,5mm and 0,8mm *IPS e.max®* and *VitaBlocs® Mark II* ceramic material cemented with *Universal TR,* Veneer *TR* or *Veneer WO* cements, while varying the composite base shade from A2 to A3, resulted in a statistically significant difference (p<0,05) according to an independent samples t-test (Table 61).

5.4. STUDY OF ΔE_{ab}

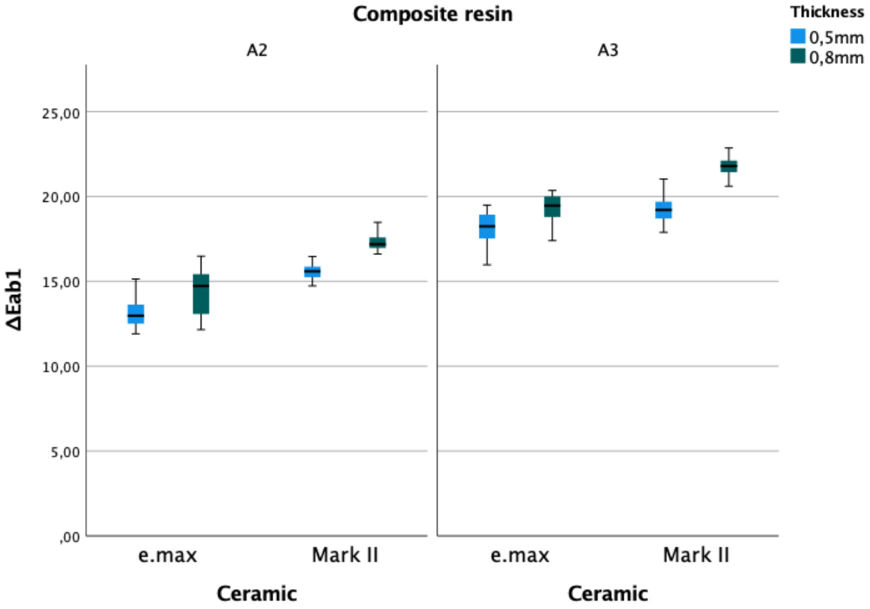
5.4.1. Study of $\Delta \boldsymbol{E_{ab1}}$

The results concerning the colour variation (ΔE_{ab}) between the composite resin samples and the composite resin samples attached to ceramic with glycerine (ΔE_{ab1}) are available in Table 62 and 63. The maximum and minimum absolute ΔE_{ab1} mean values obtained were 22,86, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic with A3 composite resin, and 11,91, corresponding to 0,5mm *IPS e.max®* ceramic with A2 composite resin, respectively.

Table 62. Composite paired with ceramics by thicknesses ΔEab1 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			*0,8mm*		
Composite	***Ceramic***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
Filtek™ Supreme A2	*e.max®*	*13,14 ± 0,88*	*11,91*	*15,14*	*14,34 ± 1,28*	*12,16*	*16,49*
	Mark II	*15,57 ± 0,44*	*14,73*	*16,47*	*17,32 ± 0,53*	*16,61*	*18,48*
Filtek™ Supreme A3	*e.max®*	*18,07 ± 1,01*	*15,97*	*19,49*	*19,29 ± 0,83*	*17,41*	*20,36*
	Mark II	*19,18 ± 0,77*	*17,89*	*21,03*	*21,75 ± 0,56*	*20,61*	*22,86*

Graphic 28. Composite paired with ceramics by thicknesses ΔEab1 mean ± standard deviation, minimum and maximum Boxplot



The data shown in Table 62 demonstrates that a growth in ceramic thickness corresponds to an increase in average ΔE_{ab1} values for both *IPS e.max®* ceramic and *VitaBlocs® Mark II* ceramic when combined with *Filtek™ Supreme* A2. The average values recorded were 13,14 ± 0,88 and 15,57 ± 0,44 for a 0,5mm ceramic thickness, which escalated to 14,34 ± 1,28 and 17,32 ± 0,53 for a 0,8mm ceramic thickness, respectively.

In addition, the findings imply that the average ΔE_{ab1} values also rose with a thickness increment when *Filtek™ Supreme* A3 was matched with *IPS e.max®* ceramic, with mean values climbing from 18,07 ± 1,01 to 19,29 ± 0,83. A comparable pattern was noticed when *Filtek™ Supreme* A3 was coupled with *VitaBlocs® Mark II* ceramic, displaying average ΔE_{ab1} values of 19,18 ± 0,77 and 21,75 ± 0,56 for 0,5mm and 0,8mm ceramic thicknesses, respectively.

The findings from Table 62 also demonstrate that for the A2 colour base pair, with a 0,5mm ceramic thickness, the average ΔE_{ab1} values rose from 13,14 ± 0,88 to 15,57 ± 0,44 when employing *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. A similar growth in the mean ΔE_{ab1} values is observed when the identical A2 colour base pair is utilized with a 0,8mm ceramic thickness, with values rising from 14,34 ± 1,28 to 17,32 ± 0,53 for *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. Additionally, when using the *Filtek™ Supreme* A3 base with a 0,5mm ceramic, the average ΔE_{ab1} values increased from 18,07 ± 1,01 to 19,18 ± 0,77 for *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. In the same vein, when the identical A2 composite resin base is combined with a 0,8mm ceramic, a growth in the mean ΔE_{ab1} values can be observed for *IPS e.max®* ceramic 19,29 ± 0,83 to *VitaBlocs® Mark II* ceramic 21,75 ± 0,56.

When analysing the 0,5mm thick *IPS e.max®* ceramic, there is a noticeable rise in the average ΔE_{ab1} values from 13,14 ± 0,88 to 18,07 ± 1,01 when shifting from the *Filtek™ Supreme* A2 base to the A3 base. In a similar manner, for the 0,8mm thick *IPS e.max®* ceramic, there is a growth in the average ΔE_{ab1} values from 14,34 ± 1,28 for the *Filtek™ Supreme* A2 base to 19,29 ± 0,83 for the *Filtek™ Supreme* A3 base. Moreover, the *VitaBlocs® Mark II* ceramic with a thickness of 0,5mm displays an escalation in the average ΔE_{ab1} values from 15,57 ± 0,44 for the A2 composite resin base to 19,18 ± 0,77 for the A3 base. Likewise, for the *VitaBlocs® Mark II* ceramic with a thickness of 0,8mm, an enhancement in the average ΔE_{ab1} values can be observed from 17,32 ± 0,53 for the A2 composite resin base to 21,75 ± 0,56 for the A3 base.

Table 63. Composite paired with ceramics by thicknesses ΔE_{ab1} mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Equal letters represent a direct comparison between the groups

		Thickness		
		0,5mm	*0,8mm*	
Composite	***Ceramic***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
Filtek™ Supreme A2	***e.max®***	*13,14 ± 0,88* $^{(A)(*)}$	*14,34 ± 1,28* $^{(C)(*)}$	*p<0,001*$^{(*)}$
	Mark II	*15,57 ± 0,44* $^{(B)(*)}$	*17,32 ± 0,53* $^{(D)(*)}$	*p<0,001*$^{(*)}$
		p<0,001$^{(*)}$	*p<0,001*$^{(*)}$	
Filtek™ Supreme A3	***e.max®***	*18,07 ± 1,01* $^{(A)(*)}$	*19,29 ± 0,83* $^{(C)(*)}$	*p<0,001*$^{(*)}$
	Mark II	*19,18 ± 0,77* $^{(B)(*)}$	*21,75 ± 0,56* $^{(D)(*)}$	*p<0,001*$^{(*)}$
		p<0,001$^{(*)}$	*p<0,001*$^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval.

A three-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, and ceramic thickness on colour variation ΔE_{ab} (ΔE_{ab1}). The data was checked for potential outliers using boxplots, but none were detected (Graphic 28). The normality assumption was verified using the Shapiro-Wilk test, which indicated that groups does not exhibit normal distribution (p<0,05). Levene's test revealed significant differences in variances between the groups (p<0,001). Despite this, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and N > 15 among groups.

A non-significant three-way interaction was observed between composite, ceramic type, and ceramic thickness (p=0,058). Significant two-way interactions were detected between composite resin and ceramic type (p<0,001), between composite resin and ceramic thickness (p=0,049) and between ceramic and thickness (p<0,001). There was a simple main effect of composite resin within each level combination of *IPS e.max®* and *VitaBlocs® Mark II* ceramic (p<0,001). There was a simple main effect of ceramic within each level combination of A2 and A3 composite resin (p < 0,001). There was a simple main effect of composite resin within each level combination of 0,5mm and 0,8mm thickness (p<0,001). There was a simple main effect of thickness within each level combination of A2 and A3 composite resin (p<0,001). There was a simple main effect of ceramic within each level combination of 0,5mm and 0,8mm thickness (p<0,001). There was a simple main effect of thickness within each level combination of *IPS e.max®* and *VitaBlocs® Mark II* ceramic (p<0,001).

All pairwise comparisons were adjusted using the Bonferroni method. Statistically significant differences were observed between samples of the same ceramic with identical thickness when comparing composite resin bases A2 and A3 (p<0,001) (Table 63). Between different ceramics with the same thickness and paired with the same base, ΔE_{ab1} was statistically significant different in all thicknesses and composite resin base (p<0,001). When comparing the 0,5mm and 0,8mm thickness for the same composite resin base and ceramic, there was a statistically significant difference between them (p<0,001) (Table 63).

5.4.2. Study of ΔE_{ab2}

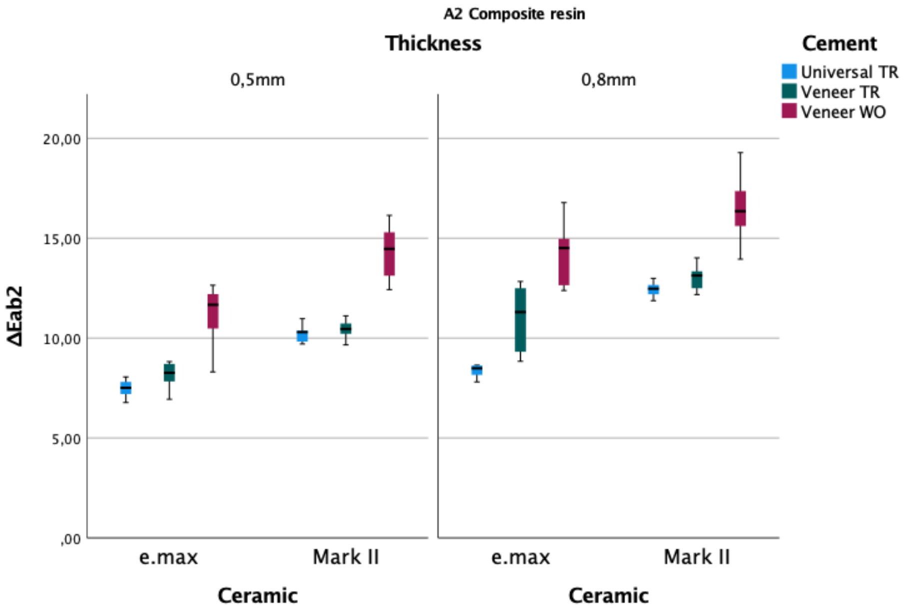
The results concerning the colour variation (ΔE_{ab}) between the composite resin samples and the composite resin samples cemented to ceramic using the studied cements (ΔE_{ab2}) are available in Table 64, 65 and 66. The maximum and minimum absolute ΔE_{ab2} mean values obtained were 21,12, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic, cemented to A3 composite resin base with *Veneer WO* cement, and 6,78, corresponding to 0,5mm *IPS e.max®* ceramic, cemented to A2 composite resin base with *Universal TR* cement, respectively.

The ΔE_{ab2} mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A2 base are displayed in Table 64 and Graphic 29.

Table 64. Composite resin (A2) and ceramic samples cemented ΔEab_2 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*7,50 ± 0,44*	*6,78*	*8,06*	*8,36 ± 0,33*	*7,81*	*8,65*
	Veneer TR	*8,20 ± 0,58*	*6,94*	*8,83*	*11,05 ± 1,50*	*8,85*	*12,84*
	Veneer WO	*11,28 ± 1,29*	*8,31*	*12,65*	*14,18 ± 1,43*	*12,39*	*16,79*
Mark II	*Universal TR*	*10,22 ± 0,38*	*9,71*	*10,28*	*12,44 ± 0,37*	*11,88*	*13,00*
	Veneer TR	*10,46 ± 0,43*	*9,67*	*11,12*	*13,07 ± 0,58*	*12,19*	*14,02*
	Veneer WO	*14,29 ± 1,27*	*12,43*	*16,15*	*16,44 ± 1,50*	*13,96*	*19,29*

Graphic 29. Composite resin (A2) and ceramic samples cemented ΔEab₂ mean ± standard deviation, minimum and maximum Boxplot



Upon examination of Table 64, it becomes evident that *IPS e.max®* ceramic, when bonded with *Universal TR* cement, displays an increase in the average ΔE_{ab2} values, from 7,50 ± 0,44 to 8,36 ± 0,33, as the ceramic thickness increases from 0,5mm to 0,8mm. A growth in ceramic thickness from 0,5mm to 0,8mm leads to a rise in average ΔE_{ab2} values of *IPS e.max®* ceramic cemented with *Veneer TR* cement, from 8,20 ± 0,58 to 11,05 ± 1,50. Similarly, *IPS e.max®* ceramic bonded with *Veneer WO* cement also exhibits an enhancement in average ΔE_{ab2} values, from 11,28 ± 1,29 to 14,18 ± 1,43, for the same change in thickness.

Regarding *VitaBlocs® Mark II* ceramic, when bonded with *Universal TR* cement, there is an increase in average ΔE_{ab2} values, from 10,22 ± 0,38 to 12,44 ± 0,37, as the ceramic thickness grows from 0,5mm to 0,8mm. *VitaBlocs® Mark II* ceramic cemented with *Veneer TR* cement demonstrates an escalation in average ΔE_{ab2} values, from 10,46 ± 0,43 to 13,07 ± 0,58, for the same alteration in ceramic thickness. Additionally, when *VitaBlocs® Mark II* ceramic is bonded with *Veneer WO* cement, the average ΔE_{ab2} values experience an increase from 14,29 ± 1,27 to 16,44 ± 1,50, with the same change in ceramic thickness.

When *IPS e.max®* ceramic has a thickness of 0,5mm, the average ΔE_{ab2} values exhibit a rising pattern, with values of 7,50 ± 0,44, 8,20 ± 0,58, and 11,28 ± 1,29 observed for *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively. In a similar vein, the *VitaBlocs® Mark II* ceramic with the same thickness presents average ΔE_{ab2} values of 10,22 ± 0,38, 10,46 ± 0,43, and 14,29 ± 1,27 for *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively.

Moreover, a growth in average ΔE_{ab2} values is noted for *IPS e.max®* ceramic with a thickness of 0,8mm, with values of 8,36 ± 0,33, 11,05 ± 1,50, and 14,18 ± 1,43 observed for *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively. In the same manner, the *VitaBlocs® Mark II* ceramic with the same thickness showcases an increase in average ΔE_{ab2} values, with values of 12,44 ± 0,37, 13,07 ± 0,58, and 16,44 ± 1,50 for *Universal TR, Veneer TR*, and *Veneer WO* cements, respectively.

When evaluating a ceramic thickness of 0,5mm and utilizing *Universal TR* cement, a rise in average ΔE_{ab2} values is seen when transitioning from *IPS e.max®* ceramic to *VitaBlocs® Mark II*, from 7,50 ± 0,44 to 10,22 ± 0,38, respectively. Similarly, when employing *Veneer TR* cement with the same ceramic thickness, there is a growth in average ΔE_{ab2} values from 8,20 ± 0,58 to 10,46 ± 0,43 when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Furthermore, with *Veneer WO* cement, an escalation in average ΔE_{ab2} values is observed when moving from *IPS e.max®* ceramic (11,28 ± 1,29) to *VitaBlocs® Mark II* ceramic (14,29 ± 1,27).

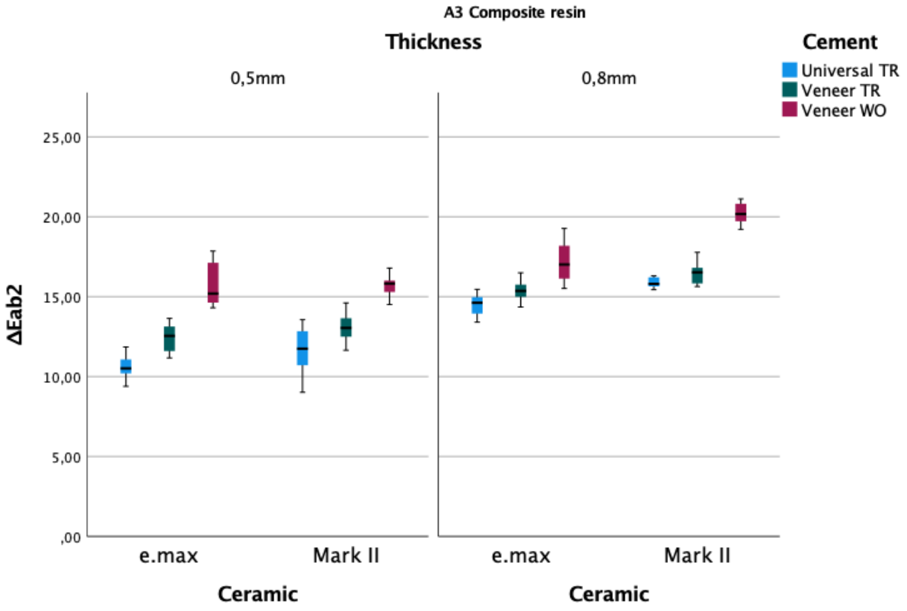
For a ceramic thickness of 0,8mm using *Universal TR* cement, there is a rise in average ΔE_{ab2} values from 8,36 ± 0,33 to 12,44 ± 0,37 when transitioning from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. In a similar manner, using *Veneer TR* cement with the same thickness, an increase in average ΔE_{ab2} values is observed from 11,05 ± 1,50 to 13,07 ± 0,58 when changing from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Additionally, for the same ceramic thickness and *Veneer WO* cement, the average ΔE_{ab2} values grew from 14,18 ± 1,43 for *IPS e.max®* ceramic to 16,44 ± 1,50 for *VitaBlocs® Mark II* ceramic.

The ΔE_{ab2} mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A3 base are displayed in Table 65 and Graphic 30.

Table 65. Composite resin (A3) and ceramic samples cemented ΔEab_2 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			0,8mm		
Ceramic	**Cement**	Mean ± Std. Dev.	Min.	Max.	Mean ± Std. Dev	Min.	Max.
e.max®	Universal TR	10,54 ± 0,76	9,39	11,85	14,49 ± 0,69	13,41	15,46
	Veneer TR	12,46 ± 0,94	11,17	13,64	15,41 ± 0,63	14,36	16,50
	Veneer WO	15,68 ± 1,27	14,31	17,85	17,12 ± 1,33	15,52	19,28
Mark II	Universal TR	11,63 ± 1,40	9,02	13,56	15,85 ± 0,31	15,44	16,31
	Veneer TR	13,07 ± 0,88	11,65	8,65	16,46 ± 0,67	15,63	17,78
	Veneer WO	15,68 ± 0,78	14,52	16,79	20,20 ± 0,65	19,22	21,12

Graphic 30. Composite resin (A3) and ceramic samples cemented ΔEab_2 mean ± standard deviation, minimum and maximum Boxplot



Upon reviewing Table 65, it becomes clear that IPS e.max® ceramic, when joined with Universal TR cement, exhibits an increase in the average ΔEab2 values, from 10,54 ± 0,76 to 14,49 ± 0,69, as the ceramic thickness expands from 0,5mm to 0,8mm. An increase in ceramic thickness from 0,5mm to 0,8mm results in a surge in average ΔEab2 values of IPS e.max® ceramic cemented with Veneer TR cement, from 12,46 ± 0,94 to 15,41 ± 0,63. Nonetheless, IPS e.max® ceramic bonded with Veneer WO cement displays an increase in average ΔEab2 values, from 15,68 ± 1,27 to 17,12 ± 1,33, for the same thickness adjustment.

As for VitaBlocs® Mark II ceramic, when bonded with Universal TR cement, there is an increase in average ΔEab2 values, from 11,63 ± 1,40 to 15,85 ± 0,31, as the ceramic thickness increases from 0,5mm to 0,8mm. VitaBlocs® Mark II ceramic cemented with Veneer TR cement exhibits a rise in average ΔEab2 values, from 13,07 ± 0,88 to 16,46 ± 0,67, for the same modification in ceramic thickness. Furthermore, when VitaBlocs® Mark II ceramic is joined with Veneer WO cement, the average ΔEab2 values show an increase, from 15,68 ± 0,78 to 20,20 ± 0,65, with the same alteration in ceramic thickness.

When *IPS e.max®* ceramic possesses a thickness of 0,5mm, the average ΔE_{ab2} values display an ascending trend, with values of 10,54 ± 0,76, 12,46 ± 0,94, and 15,68 ± 1,27 observed for *Universal TR, Veneer TR,* and *Veneer WO* cements, respectively. Similarly, the *VitaBlocs® Mark II* ceramic with the same thickness exhibits average ΔE_{ab2} values of 11,63 ± 1,40, 13,07 ± 0,88, and 15,68 ± 0,78 for *Universal TR, Veneer TR,* and *Veneer WO* cements, respectively.

Additionally, an increase in average ΔE_{ab2} values can be seen for *IPS e.max®* ceramic with a thickness of 0,8mm, with values of 14,49 ± 0,69, 15,41 ± 0,63, and 17,12 ± 1,33 observed for *Universal TR, Veneer TR,* and *Veneer WO* cements, respectively. Likewise, the *VitaBlocs® Mark II* ceramic with the same thickness demonstrates a rise in average ΔE_{ab2} values, with values of 15,85 ± 0,31, 16,46 ± 0,67, and 20,20 ± 0,65 for *Universal TR, Veneer TR,* and *Veneer WO* cements, respectively.

When assessing a ceramic thickness of 0,5mm and using *Universal TR* cement, an increase in average ΔE_{ab2} values is observed when moving from *IPS e.max®* ceramic to *VitaBlocs® Mark II,* from 10,54 ± 0,76 to 11,63 ± 1,40, respectively. Likewise, when applying *Veneer TR* cement with the same ceramic thickness, there is a growth in average ΔE_{ab2} values from 12,46 ± 0,94 to 13,07 ± 0,88 when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Moreover, with *Veneer WO* cement, a equality in average ΔE_{ab2} values is seen when transitioning from *IPS e.max®* ceramic (15,68 ± 1,27) to *VitaBlocs® Mark II* ceramic (15,68 ± 0,78).

For a ceramic thickness of 0,8mm using *Universal TR* cement, there is an increase in average ΔE_{ab2} values from 14,49 ± 0,69 to 15,85 ± 0,31 when moving from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. Similarly, using *Veneer TR* cement with the same thickness, an uptick in average ΔE_{ab2} values is observed from 15,41 ± 0,63 to 16,46 ± 0,67 when changing from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Furthermore, for the same ceramic thickness and *Veneer WO* cement, the average ΔE_{ab2} values rose from 17,12 ± 1,33 for *IPS e.max®* ceramic to 20,20 ± 0,65 for *VitaBlocs® Mark II* ceramic.

Table 66. Composite resin and ceramic samples cemented ΔE_{ab2} mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Same lowercase letters within the same column indicate a non-statistically significant differences between cements for each ceramic. The p-values below each column, for each base, represent differences for the same cement between different ceramics. Same capital letters within the same column indicate a non-statistically significant differences for the same cement between different ceramics.

			Thickness		
			0,5mm	*0,8mm*	
Composite	***Ceramic***	***Cement***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
A2	***e.max®***	*Universal TR*	*7,50 ± 0,44* ^{a}	*8,36 ± 0,33*	*p=0,052*
		Veneer TR	*8,20 ± 0,58* ^{a}	*11,05 ± 1,50*	*p<0,001*$^{(*)}$
		Veneer WO	*11,28 ± 1,29*	*14,18 ± 1,43*	*p<0,001*$^{(*)}$
	Mark II	*Universal TR*	*10,22 ± 0,38* ^{b}	*12,44 ± 0,37* ^{c}	*p<0,001*$^{(*)}$
		Veneer TR	*10,46 ± 0,43* ^{b}	*13,07 ± 0,58* ^{c}	*p<0,001*$^{(*)}$
		Veneer WO	*14,29 ± 1,27*	*16,44 ± 1,50*	*p<0,001*$^{(*)}$
			p<0,001$^{(*)}$	*p<0,001*$^{(*)}$	
A3	***e.max®***	*Universal TR*	*10,54 ± 0,76*	*14,49 ± 0,69* ^{d}	*p<0,001*$^{(*)}$
		Veneer TR	*12,46 ± 0,94* ^{A}	*15,41 ± 0,63* ^{d}	*p<0,001*$^{(*)}$
		Veneer WO	*15,68 ± 1,27* ^{B}	*17,12 ± 1,33*	*p<0,001*$^{(*)}$
	Mark II	*Universal TR*	*11,63 ± 1,40*	*15,85 ± 0,31* ^{e}	*p<0,001*$^{(*)}$
		Veneer TR	*13,07 ± 0,88* ^{A}	*16,46 ± 0,67* ^{e}	*p<0,001*$^{(*)}$
		Veneer WO	*15,68 ± 0,78* ^{B}	*20,20 ± 0,65*	*p<0,001*$^{(*)}$
			p=0,144$^{(A)}$ *p=0,994*$^{(B)}$	*p<0,001*$^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval

A four-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, ceramic thickness and cement on the colour variation (ΔE_{ab2}). The data was checked for potential outliers using boxplots, but none were detected (Graphic 29 and 30). The normality assumption was verified using the Shapiro-Wilk test, which indicated that both groups exhibited normal distribution (p>0,05). However, Levene's test revealed significant differences in variances between the groups (p<0,001). Henceforth, a decision was made to conduct a Split File of the composite resin independent variable, followed by a three-way ANOVA. In order to compare the studied groups across different composite resin bases, an independent samples t-test was performed. It is noteworthy to mention that the Levene´s test in this scenario continues to exhibit statistical significance (p<0,001). However, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and N > 15 among groups.

A significant three-way interaction was observed between ceramic type, ceramic thickness, and cement for a A2 (p=0,042) and A3 (p<0,001) composite resin base. Simple two-way interactions were verified, which proved to be statistically significant (p<0,001) for A2 for e.max, and not statistically significant (p=0,720) for Mark II. Simple two-way interactions for A3 proved to be statistically significant (p<0,001) for e.max, and not statistically significant (p=0,135) for Mark II. There was a simple simple main effect of cement in the other variables (p<0,001), and simple simple comparisons were made.

All pairwise comparisons were adjusted using the Bonferroni method. Comparing the thicknesses of *IPS e.max®* and *VitaBlocs® Mark II* ceramics cemented to A2 and A3 composite bases, we found that variations in ceramic thickness did cause statistically significant changes in the ΔE_{ab2} variable when cemented with any of the studied cements (p<0,001) with exception to the *IPS e.max®* cemented to a A2 composite resin base with *Universal TR* (p=0,052) (Table 66).

When considering the *e.max®* ceramic samples with 0,5mm thickness, there were no statistically significant differences observed between the use of *Universal TR* and *Veneer TR* cements when cemented to an A2 composite base (p>0,05). When considering the *VitaBlocs® Mark II* ceramic samples with 0,5mm and 0,8mm thickness, there were no statistically significant differences observed between the use of *Universal TR* and *Veneer TR* cements when cemented to an A2 composite base (p>0,05). When considering the *e.max®* and *VitaBlocs® Mark II* ceramic samples with 0,8mm thickness, there were no statistically significant differences observed between the use of *Universal TR* and *Veneer TR* cements when cemented to an A3 composite base (p>0,05).

When cemented to an A3 colour base using *Veneer TR* (p=0,144) and *Veneer TR* (p=0,994) cements and for 0,5mm thickness, statistically significant differences were not observed when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic (Table 66).

Table 67. ΔE_{ab2} independent samples t-test between A2 and A3 composite resin base for each ceramic and thickness and each cement

			Thickness	
			0,5mm	*0,8mm*
Composite	***Ceramic***	***Cement***	***p-values***	***p-values***
A2 vs. A3	***e.max®***	*Universal TR*	$p<0,001^{(*)}$	$p<0,001^{(*)}$
		Veneer TR	$p<0,001^{(*)}$	$p<0,001^{(*)}$
		Veneer WO	$p<0,001^{(*)}$	$p<0,001^{(*)}$
	Mark II	*Universal TR*	$p=0,011^{(*)}$	$p<0,001^{(*)}$
		Veneer TR	$p<0,001^{(*)}$	$p<0,001^{(*)}$
		Veneer WO	$p=0,010^{(*)}$	$p<0,001^{(*)}$

(*) Statistically significant differences for a 95% confidence interval

The use of *IPS e.max®* and *VitaBlocs® Mark II* ceramic material with a thickness of 0,5mm and 0,8mm and cemented with *Universal TR*, *Veneer TR* and *Veneer WO* cements, while varying the base shade from A2 to A3, resulted in a statistically significant difference (p<0,05) (Table 67).

5.4.3. Study of ΔE_{ab3}

The results concerning the colour variation (ΔE_{ab}) between the composite resin samples attached to ceramic with glycerine and the composite resin samples cemented to ceramic using the studied cements (ΔE_{ab3}) are available in Table 68, 69 and 70. The maximum and minimum ΔE_{ab3} mean absolute values obtained were 8,92, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic, cemented to A3 composite resin base with *Universal TR* cement, and 2,14, corresponding to 0,5mm *IPS e.max®* ceramic cemented to A3 composite resin base with *Veneer WO* cement, respectively.

The ΔE$_{ab3}$ mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A2 base are displayed in Table 68 and Graphic 31.

Table 68. Composite resin (A2) and ceramic samples cemented ΔEab3 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			0,8mm		
Ceramic	**Cement**	Mean ± Std. Dev.	Min.	Max.	Mean ± Std. Dev	Min.	Max.
e.max®	Universal TR	5,53 ± 0,27	4,98	5,79	6,37 ± 0,14	6,15	6,60
	Veneer TR	5,41 ± 0,34	5,02	6,16	6,47 ± 0,25	6,14	6,85
	Veneer WO	3,54 ± 0,62	2,69	4,62	4,00 ± 0,87	2,79	5,12
Mark II	Universal TR	6,03 ± 0,21	5,72	6,30	7,15 ± 0,29	6,74	7,53
	Veneer TR	6,31 ± 0,45	5,61	7,01	7,42 ± 0,46	6,58	8,07
	Veneer WO	3,78 ± 0,69	2,41	4,83	4,38 ± 0,92	3,15	6,01

Graphic 31. Composite resin (A2) and ceramic samples cemented ΔEab3 mean ± standard deviation, minimum and maximum Boxplot

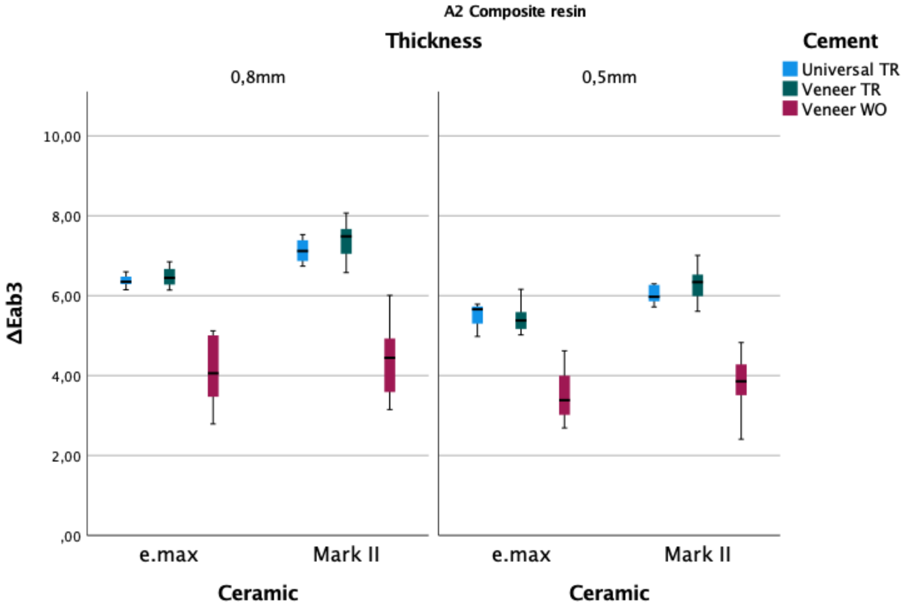


Table 68 indicates that for *IPS e.max®* ceramic, the mean ΔE_{ab3} values rise as the ceramic thickness grows from 0,5mm to 0,8mm when bonded with *Universal TR* cement. Specifically, the values escalate from 5,53 ± 0,27 to 6,37 ± 0,14. A similar pattern is observed with *Veneer TR* cement, where the mean ΔE_{ab3} values increase from 5,41 ± 0,34 to 6,47 ± 0,25 for the same change in thickness. Likewise, when *IPS e.max®* ceramic is bonded with *Veneer WO* cement, the mean ΔE_{ab3} values show an upward trend from 3,54 ± 0,62 to 4,00 ± 0,87 with the same alteration in thickness.

In the case of *VitaBlocs® Mark II* ceramic, when bonded with *Universal TR* cement, the average ΔE_{ab3} values rise from 6,03 ± 0,21 to 7,15 ± 0,29 as the ceramic thickness expands from 0,5mm to 0,8mm. In a similar manner, the average ΔE_{ab3} values increase from 6,31 ± 0,45 to 7,42 ± 0,46 for the same thickness change when *VitaBlocs® Mark II* ceramic is bonded with *Veneer TR* cement. Furthermore, with *Veneer WO* cement, *VitaBlocs® Mark II* ceramic exhibits a growth in average ΔE_{ab3} values from 3,78 ± 0,69 to 4,38 ± 0,92 for the same change in thickness.

For the *IPS e.max®* ceramic with a thickness of 0,5mm, there is an ascending trend in average ΔE_{ab3} values, with *Veneer WO, Veneer TR,* and *Universal TR* cements yielding values of 3,54 ± 0,62, 5,41 ± 0,34, and 5,53 ± 0,27, respectively. On the other hand, the *VitaBlocs® Mark II* ceramic with the same thickness presents average ΔE_{ab3} values of 3,78 ± 0,69, 6,03 ± 0,21, and 6,31 ± 0,45 for *Veneer WO, Universal TR,* and *Veneer TR* cements, respectively.

Furthermore, a growth in average ΔE_{ab3} values is noted for *IPS e.max®* ceramic with a thickness of 0,8mm, with values of 4,00 ± 0,87, 6,37 ± 0,14, and 6,47 ± 0,25 observed for *Veneer WO, Universal TR,* and *Veneer TR* cements, respectively. In the same manner, the *VitaBlocs® Mark II* ceramic with the same thickness showcases an increase in average ΔE_{ab3} values, with values of 4,38 ± 0,92, 7,15 ± 0,29, and 7,42 ± 0,46 for *Veneer WO, Universal TR,* and *Veneer TR* cements, respectively.

Upon examining a ceramic thickness of 0,5mm and using *Universal TR* cement, there is an increase in average ΔE_{ab3} values when transitioning from *IPS e.max®* ceramic to *VitaBlocs® Mark II,* moving from 5,53 ± 0,27 to 6,03 ± 0,21, respectively. In the same vein, when using *Veneer TR* cement with the same ceramic thickness, a rise in average ΔE_{ab3} values is noted from 5,41 ± 0,34 to 6,31 ± 0,45 upon switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Additionally, with *Veneer*

WO cement, an increase in average ΔE_{ab3} values is detected when changing from *IPS e.max®* ceramic (3,54 ± 0,62) to *VitaBlocs® Mark II* ceramic (3,78 ± 0,69).

Regarding a ceramic thickness of 0,8mm and employing *Universal TR* cement, an increase in average ΔE_{ab3} values is observed from 6,37 ± 0,14 to 7,15 ± 0,29 when moving from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. Similarly, when using *Veneer TR* cement with the same thickness, average ΔE_{ab3} values rise from 6,47 ± 0,25 to 7,42 ± 0,46 when switching between ceramics. Furthermore, for the same ceramic thickness and *Veneer WO* cement, the average ΔE_{ab3} values increased from 4,00 ± 0,87 for *IPS e.max®* ceramic to 4,38 ± 0,92 for *VitaBlocs® Mark II* ceramic.

The ΔE_{ab3} mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A3 base are displayed in Table 69 and Graphic 32.

Table 69. Composite resin (A3) and ceramic samples cemented ΔEab_3 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*7,63 ± 0,35*	*6,89*	*7,83*	*7,39 ± 0,26*	*6,93*	*7,82*
	Veneer TR	*6,83 ± 0,70*	*5,33*	*7,79*	*7,28 ± 0,41*	*6,55*	*7,81*
	Veneer WO	*4,17 ± 1,26*	*2,14*	*6,23*	*4,06 ± 0,95*	*2,79*	*5,37*
Mark II	*Universal TR*	*8,01 ± 0,23*	*7,70*	*8,35*	*8,13 ± 0,58*	*7,02*	*8,92*
	Veneer TR	*7,49 ± 0,43*	*6,97*	*8,25*	*8,29 ± 0,31*	*7,98*	*8,81*
	Veneer WO	*4,97 ± 0,38*	*4,55*	*5,49*	*5,21 ± 0,71*	*4,08*	*6,58*

Graphic 32. Composite resin (A3) and ceramic samples cemented ΔEab3 mean ± standard deviation, minimum and maximum Boxplot

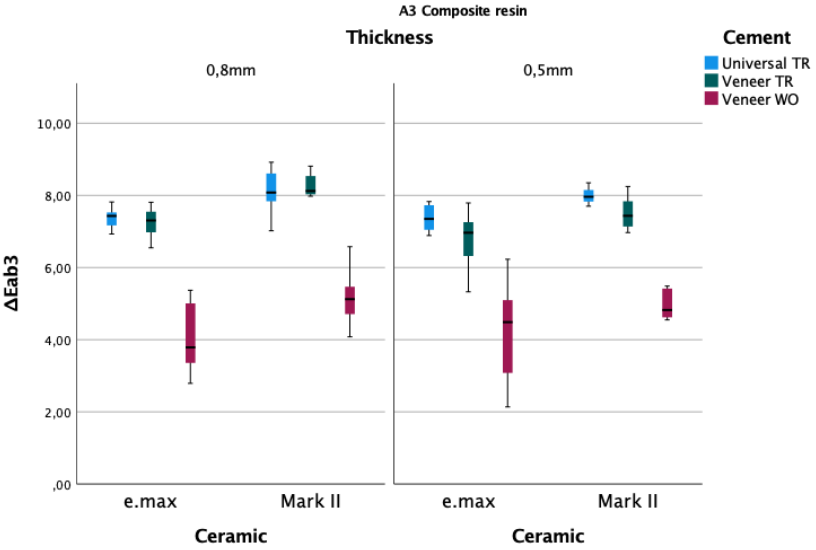


Table 69 reveals that for *IPS e.max®* ceramic, the average ΔE_{ab3} values exhibit a slight decrease from 7,63 ± 0,35 to 7,39 ± 0,26 as the ceramic thickness increases from 0,5mm to 0,8mm when bonded with *Universal TR* cement. On the other hand, with *Veneer TR* cement, the average ΔE_{ab3} values show an increase from 6,83 ± 0,70 to 7,28 ± 0,41 for the same thickness change. Similarly, when *IPS e.max®* ceramic is bonded with *Veneer WO* cement, a marginal downward trend in average ΔE_{ab3} values is observed, moving from 4,17 ± 1,26 to 4,06 ± 0,95 with the same thickness alteration.

For *VitaBlocs® Mark II* ceramic, when bonded with *Universal TR* cement, the average ΔE_{ab3} values experience an increase from 8,01 ± 0,23 to 8,13 ± 0,58 as the ceramic thickness changes from 0,5mm to 0,8mm. In a similar fashion, the average ΔE_{ab3} values rise from 7,49 ± 0,43 to 8,29 ± 0,31 for the same thickness adjustment when *VitaBlocs® Mark II* ceramic is bonded with *Veneer TR* cement. Moreover, when using *Veneer WO* cement, *VitaBlocs® Mark II* ceramic demonstrates an increase in average ΔE_{ab3} values from 4,97 ± 0,38 to 5,21 ± 0,71 with the same change in thickness.

For the *IPS e.max®* ceramic with a thickness of 0,5mm, there is a rising pattern in average ΔE_{ab3} values, with *Veneer WO, Veneer TR*, and *Universal TR* cements producing values of 4,17 ± 1,26, 6,83 ± 0,70, and 7,63 ± 0,35, respectively. In the same vein, the *VitaBlocs® Mark II* ceramic with an equal thickness displays average ΔE_{ab3} values of 4,97 ± 0,38, 7,49 ± 0,43, and 8,01 ± 0,23 for *Veneer WO, Veneer TR*, and *Universal TR* cements, respectively.

Additionally, an increase in average ΔE_{ab3} values is observed for *IPS e.max®* ceramic with a thickness of 0,8mm, presenting values of 4,06 ± 0,95, 7,28 ± 0,41, and 7,39 ± 0,26 for *Veneer WO, Veneer TR*, and *Universal TR* cements, respectively. Conversely, the *VitaBlocs® Mark II* ceramic with the same thickness exhibits a growth in average ΔE_{ab3} values, with measurements of 5,21 ± 0,71, 8,13 ± 0,58, and 8,29 ± 0,31 for *Veneer WO, Universal TR*, and *Veneer TR* cements, respectively.

When examining a ceramic thickness of 0,5mm and using *Universal TR* cement, a growth in average ΔE_{ab3} values is evident when transitioning from *IPS e.max®* ceramic to *VitaBlocs® Mark II*, with values of 7,63 ± 0,35 and 8,01 ± 0,23, respectively. Similarly, when employing *Veneer TR* cement at the same ceramic thickness, a rise in average ΔE_{ab3} values is observed from 6,83 ± 0,70 to 7,49 ± 0,43 upon shifting from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Moreover, with *Veneer WO* cement, an elevation in average ΔE_{ab3} values is seen when comparing *IPS e.max®* ceramic (4,17 ± 1,26) to *VitaBlocs® Mark II* ceramic (4,97 ± 0,38).

Regarding a ceramic thickness of 0,8mm and utilizing *Universal TR* cement, a growth in average ΔE_{ab3} values occurs from 7,39 ± 0,26 to 8,13 ± 0,58 when comparing *IPS e.max®* ceramic to *VitaBlocs® Mark II*. In the same manner, when employing *Veneer TR* cement with the same thickness, average ΔE_{ab3} values escalate from 7,28 ± 0,41 to 8,29 ± 0,31 when changing between ceramics. Additionally, for the same ceramic thickness and *Veneer WO* cement, the average ΔE_{ab3} values increased from 4,06 ± 0,95 for *IPS e.max®* ceramic to 5,21 ± 0,71 for *VitaBlocs® Mark II* ceramic.

Table 70. Composite resin and ceramic samples cemented ΔEab_3 mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Same lowercase letters within the same column indicate a non-statistically significant differences between cements for each ceramic. The p-values below each column, for each base, represent differences for the same cement between different ceramics. Same capital letters within the same column indicate a non-statistically significant differences for the same cement between different ceramics

			Thickness		
			0,5mm	0,8mm	
Composite	**Ceramic**	**Cement**	**Mean ± Std. Dev**	**Mean ± Std. Dev**	**p-values**
A2	**e.max®**	Universal TR	5,53 ± 0,27 ^{a}	6,37 ± 0,14 ^{c}	p<0,001(*)
		Veneer TR	5,41 ± 0,34 ^{a}	6,47 ± 0,25 ^{c}	p<0,001(*)
		Veneer WO	3,54 ± 0,62 ^{A}	4,00 ± 0,87 ^{B}	p=0,051
	Mark II	Universal TR	6,03 ± 0,21 ^{b}	7,15 ± 0,29 ^{d}	p<0,001(*)
		Veneer TR	6,31 ± 0,45 ^{b}	7,42 ± 0,46 ^{d}	p<0,001(*)
		Veneer WO	3,78 ± 0,69 ^{A}	4,38 ± 0,92 ^{B}	p=0,012(*)
			p=0,300(A)	p=0,110(B)	
A3	**e.max®**	Universal TR	7,63 ± 0,35 ^{e}	7,39 ± 0,26 ^{g}	p=0,900
		Veneer TR	6,83 ± 0,70 ^{e}	7,28 ± 0,41 ^{g}	p=0,102
		Veneer WO	4,17 ± 1,26	4,06 ± 0,95	p=0,704
	Mark II	Universal TR	8,01 ± 0,23 ^{f}	8,13 ± 0,58 ^{h}	p=0,657
		Veneer TR	7,49 ± 0,43 ^{f}	8,29 ± 0,31 ^{h}	p=0,005(*)
		Veneer WO	4,97 ± 0,38	5,21 ± 0,71	p=0,398
			p=0,062(A)	p<0,001(*)	

(*) Statistically significant differences for a 95% confidence interval

A four-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, ceramic thickness and cement on the colour variation (ΔE_{ab3}). The data was checked for potential outliers using boxplots, but none were detected (Graphic 31 and 32). The normality assumption was verified using the Shapiro-Wilk test, which indicated that both groups exhibited normal distribution (p>0,05). However, Levene's test revealed significant differences in variances between the groups (p<0,001). Henceforth, a decision was made to conduct a Split File of the composite resin independent variable, followed by a three-way ANOVA. To compare the studied groups across different composite resin bases, an independent samples t-test was performed. It is noteworthy to mention that the Levene´s test in this scenario continues to exhibit statistical significance (p<0,001). However, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and N > 15 among groups.

A non-significant three-way interaction was observed between ceramic type, ceramic thickness, and cement for a A2 (p = 0,887) and A3 (p=0,876) composite resin base. Two-way interactions were verified between ceramic and cement (p=0,038) and between thickness and cement (p=0,046) for an A2 composite resin base, which proved to be statistically significant. The other two-way interactions for A2 and A3 composite resin proved to be non-significant (p>0,05). The simple main effect of cement is statistically significant for all combination of variables (p<0,001).

All pairwise comparisons were adjusted using the Bonferroni method. Comparing the thicknesses of *IPS e.max®* and *VitaBlocs® Mark II* ceramics cemented to A2 and A3 composite bases, we found that variations in ceramic thickness didn´t cause statistically significant changes in the ΔE_{ab3} variable when cemented with *Veneer WO* (p=0,051) between *IPS e.max®* and A2 composite resin base (Table 70). The same situation occurred when cemented with *Universal TR* (p=0,900), *Veneer TR* (p=0,102) and *Veneer WO* (p=0,704) between *IPS e.max®* ceramic and A3 composite resin base, and with *Universal TR* (p=0,657) and *Veneer WO* (p=0,398) between *VitaBlocs® Mark II* and A3 composite resin base.

When considering the *IPS e.max®* and *VitaBlocs® Mark II* ceramic samples with 0,5mm and 0,8mm thickness, there were no statistically significant differences observed between the use of *Universal TR* and *Veneer TR* cements when cemented to an A2 and A3 composite resin base (p>0,05) (Table 70).

When cemented to an A2 colour base using *Veneer WO* cement for 0,5mm (p=0,300) and 0,8mm (p=0,110) ceramic thickness, there were no statistically significant differences when switching from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic (Table 70).

Table 71. ΔE_{ab3} independent samples t-test between A2 and A3 composite resin base for each ceramic and thickness and each cement

			Thickness	
			0,5mm	*0,8mm*
Composite	***Ceramic***	***Cement***	***p-values***	***p-values***
A2 vs. A3	***e.max®***	*Universal TR*	*$p<0,001^{(*)}$*	*$p<0,001^{(*)}$*
		Veneer TR	*$p<0,001^{(*)}$*	*$p<0,001^{(*)}$*
		Veneer WO	*p=0,182*	*p=0,885*
	Mark II	*Universal TR*	*$p<0,001^{(*)}$*	*$p<0,001^{(*)}$*
		Veneer TR	*$p<0,001^{(*)}$*	*$p<0,001^{(*)}$*
		Veneer WO	*$p<0,001^{(*)}$*	*$p=0,037^{(*)}$*

(*) Statistically significant differences for a 95% confidence interval

The use of *IPS e.max®* and *VitaBlocs® Mark II* ceramic material with a thickness of 0,5mm (p=0,182) and 0,8mm (p=0,885) cemented with *Veneer WO* cements, while varying the base shade from A2 to A3, resulted in a non-statistically significant difference according to an independent samples t-test (Table 71).

5.1. STUDY OF ΔE_{00}

5.1.1. Study of ΔE_{001}

The results concerning the colour variation (ΔE_{00}) between the composite resin samples and the composite resin samples attached to ceramic with glycerine (ΔE_{001}) are available in Table 72 and 73. The maximum and minimum absolute ΔE_{001} mean values obtained were 13,01, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic with A3 composite resin, and 7,45, corresponding to 0,5mm *IPS e.max®* ceramic with A2 composite resin, respectively.

Table 72. Composite paired with ceramics by thicknesses ΔE001 mean ± standard deviation, minimum and maximum.

		Thickness					
		0,5mm			0,8mm		
Composite	**Ceramic**	Mean ± Std. Dev.	Min.	Max.	Mean ± Std. Dev	Min.	Max.
Filtek™ Supreme A2	e.max®	8,27 ± 0,48	7,45	9,17	9,19 ± 0,69	8,05	10,21
	Mark II	9,59 ± 0,22	9,18	9,99	10,84 ± 0,36	10,10	11,39
Filtek™ Supreme A3	e.max®	10,12 ± 0,44	9,13	10,72	11,06 ± 0,33	10,35	11,61
	Mark II	10,65 ± 0,39	9,64	11,49	12,41 ± 0,27	11,86	13,01

Graphic 33. Composite paired with ceramics by thicknesses ΔE001 mean ± standard deviation, minimum and maximum Boxplot

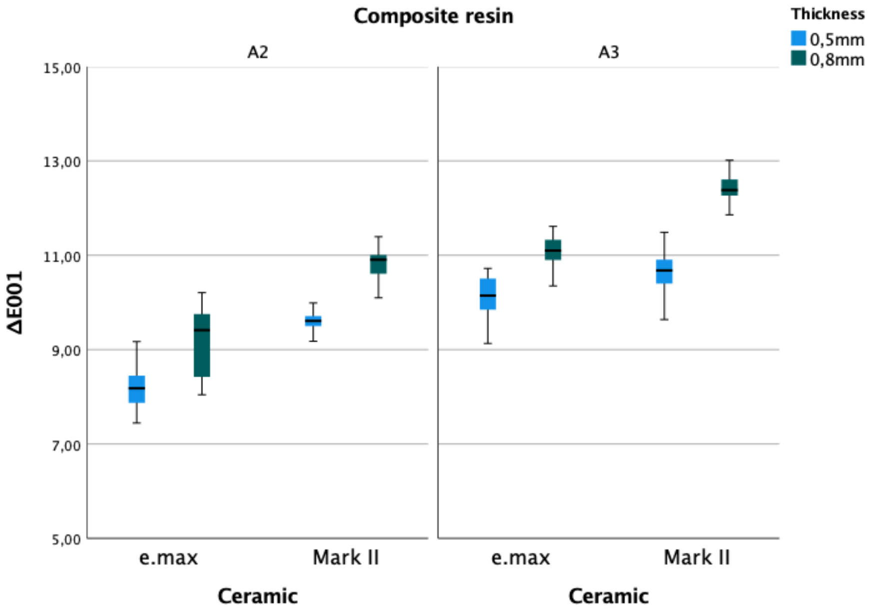


Table 72 presents the outcomes indicating that there is an increase in average ΔE_{001} values with an increase in ceramic thickness, for both *IPS e.max®* ceramic and *VitaBlocs® Mark II* ceramic, when paired with *Filtek™ Supreme* A2. The mean values increased from 8,27 ± 0,48 to 9,19 ± 0,69 and from 9,59 ± 0,22 and 10,84 ± 0,36, for 0,5mm and 0,8mm ceramic thicknesses, respectively.

Moreover, the results suggest that the average ΔE_{001} values also increased with an increase in thickness when pairing *Filtek™ Supreme* A3 with *IPS e.max®* ceramic, where the mean values increased from 10,12 ± 0,44 to 11,06 ± 0,33. Similarly, when *Filtek™ Supreme* A3 was paired with *VitaBlocs® Mark II* ceramic, the average ΔE_{001} values increased with an increase in ceramic thickness, with mean values of 10,65 ± 0,39 to 12,41 ± 0,27 observed for 0,5mm and 0,8mm ceramic thicknesses, respectively.

Table 72's findings also reveal that for the A2 colour base pair, with a 0,5mm ceramic thickness, the average ΔE_{001} values increased from 8,27 ± 0,48 to 9,59 ± 0,22 when using *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. A similar rise in the mean ΔE_{001} values is noted when the same A2 colour base pair is employed with a 0,8mm ceramic thickness, with values climbing from 9,19 ± 0,69 to 10,84 ± 0,36 for *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. Moreover, when utilizing the *Filtek™ Supreme* A3 base with a 0,5mm ceramic, the average ΔE_{001} values grew from 10,12 ± 0,44 to 10,65 ± 0,39 for *IPS e.max®* and *VitaBlocs® Mark II* ceramics, respectively. Similarly, when the same A3 composite resin base is paired with a 0,8mm ceramic, an increase in the mean ΔE_{001} values can be seen from *IPS e.max®* ceramic 11,06 ± 0,33 to *VitaBlocs® Mark II* ceramic 12,41 ± 0,27.

Upon examining the 0,5mm thick *IPS e.max®* ceramic, a discernible decline in the average ΔE_{001} values from 10,12 ± 0,44 to 8,27 ± 0,48 occurs when transitioning from the *Filtek™ Supreme* A3 base to the A2 base. Similarly, for the 0,8mm thick *IPS e.max®* ceramic, there is a reduction in the average ΔE_{001} values from 11,06 ± 0,33 for the *Filtek™ Supreme* A3 base to 9,19 ± 0,69 for the *Filtek™ Supreme* A2 base. Furthermore, the *VitaBlocs® Mark II* ceramic with a thickness of 0,5mm exhibits a decrease in the average ΔE_{001} values from 10,65 ± 0,39 for the A3 composite resin base to 9,59 ± 0,22 for the A2 base. In the same way, for the *VitaBlocs® Mark II* ceramic with a thickness of 0,8mm, a decline in the average ΔE_{001} values is seen from 12,41 ± 0,27 for the A3 composite resin base to 10,84 ± 0,36 for the A2 base.

Table 73. Composite paired with ceramics by thicknesses ΔE_{001} mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Equal letters represent a direct comparison between the groups.

		Thickness		
		0,5mm	0,8mm	
Composite	**Ceramic**	**Mean ± Std. Dev**	**Mean ± Std. Dev**	**p-values**
Filtek™ Supreme A2	**e.max®**	8,27 ± 0,48 $^{(A)\,(*)}$	9,19 ± 0,69 $^{(C)\,(*)}$	p<0,001$^{(*)}$
	Mark II	9,59 ± 0,22 $^{(B)\,(*)}$	10,84 ± 0,36 $^{(D)\,(*)}$	p<0,001$^{(*)}$
		p<0,001$^{(*)}$	p<0,001$^{(*)}$	
Filtek™ Supreme A3	**e.max®**	10,12 ± 0,44 $^{(A)\,(*)}$	11,06 ± 0,33 $^{(C)\,(*)}$	p<0,001$^{(*)}$
	Mark II	10,65 ± 0,39 $^{(B)\,(*)}$	12,41 ± 0,27 $^{(D)\,(*)}$	p<0,001$^{(*)}$
		p<0,001$^{(*)}$	p<0,001$^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval

A three-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, and ceramic thickness on the colour variation (ΔE_{001}). The data was checked for potential outliers using boxplots, but none were detected (Graphic 33). The normality assumption was verified using the Shapiro-Wilk test, which indicated that groups does not exhibit normal distribution (p<0,05). Levene's test revealed significant differences in variances between the groups (p<0,001). Despite this, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and N > 15 among groups.

A significant three-way interaction was observed between composite resin, ceramic type and ceramic thickness (p=0,020) composite resin base. Simple two-way interactions and simple simple main effects were also significant at the p<0,025 level. Simple two-way interactions were verified, which proved to be statistically significant in A3 composite resin base (p<0,001) but not for a A2 composite resin base (p=0,037). There was a simple simple main effect of thickness in the other variables (p<0,001), and simple simple comparisons were made.

All pairwise comparisons were adjusted using the Bonferroni method. Statistically significant differences were observed between samples of the same ceramic with the same thickness when comparing composite resin bases A2 and A3 (p<0,001) (Table 73). Between different ceramics with the same thickness and paired with the same base, ΔE_{001} was statistically significantly different for all thicknesses and composite resin bases (p<0,001). When comparing the 0,5mm and 0,8mm thicknesses for the same composite resin base and ceramic, a statistically significant difference was also found between them (p<0,001) (Table 73).

5.1.2. Study of ΔE_{002}

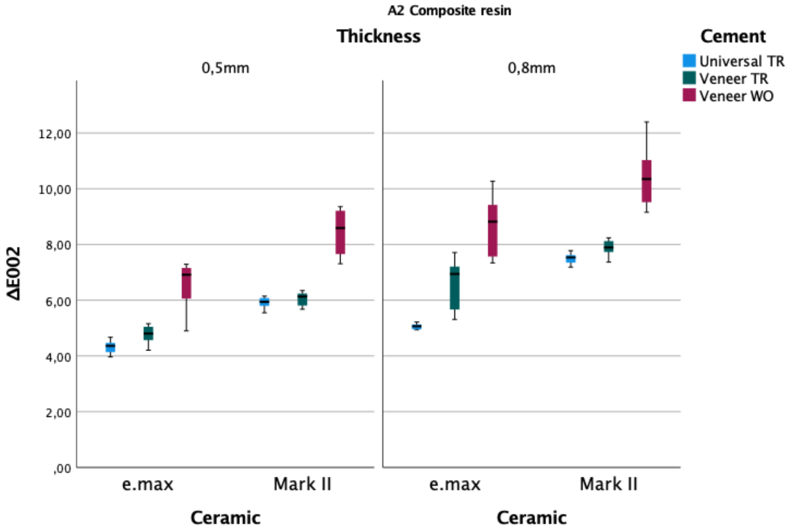
The results concerning the colour variation (ΔE_{00}) between the composite resin samples and the composite resin samples cemented to ceramic using the studied cements (ΔE_{002}) are available in Table 74, 75 and 76. The maximum and minimum absolute ΔE_{002} mean values obtained were 12,40, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic, cemented to A2 composite resin base with *Veneer WO* cement, and 3,97, corresponding to 0,5mm *IPS e.max®* ceramic, cemented to A2 composite resin base with *Universal TR* cement, respectively.

The ΔE_{002} mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A2 base are displayed in Table 74 and Graphic 34.

Table 74. Composite resin (A2) and ceramic samples cemented ΔE002 mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*4,35 ± 0,23*	*3,97*	*4,67*	*5,06 ± 0,11*	*4,94*	*5,22*
	Veneer TR	*4,79 ± 0,29*	*4,21*	*5,16*	*6,62 ± 0,83*	*5,31*	*7,71*
	Veneer WO	*6,63 ± 0,76*	*4,90*	*7,29*	*8,66 ± 1,01*	*7,34*	*10,27*
Mark II	*Universal TR*	*5,92 ± 0,18*	*5,55*	*6,15*	*7,50 ± 0,18*	*7,19*	*7,78*
	Veneer TR	*6,06 ± 0,23*	*5,68*	*6,35*	*7,90 ± 0,26*	*7,37*	*8,24*
	Veneer WO	*8,43 ± 0,79*	*7,31*	*9,36*	*10,46 ± 1,03*	*9,16*	*12,40*

Graphic 34. Composite resin (A2) and ceramic samples cemented ΔE00₂ mean ± standard deviation, minimum and maximum Boxplot



An analysis of Table 74 reveals that for *IPS e.max®* ceramic bonded with *Universal TR* cement, the average $\Delta E_{00}2$ values increase from 4,35 ± 0,23 to 5,06 ± 0,11 as the ceramic thickness grows from 0,5mm to 0,8mm. In a similar manner, an increase in ceramic thickness from 0,5mm to 0,8mm results in a rise of average $\Delta E_{00}2$ values for *IPS e.max®* ceramic cemented with *Veneer TR* cement, moving from 4,79 ± 0,29 to 6,62 ± 0,83. Likewise, *IPS e.max®* ceramic bonded with *Veneer WO* cement also shows an enhancement in average $\Delta E_{00}2$ values, from 6,63 ± 0,76 to 8,66 ± 1,01, for the same change in thickness.

In the case of VitaBlocs® Mark II ceramic bonded with Universal TR cement, there is a increase in average ΔE002 values, from 5,92 ± 0,18 to 7,50 ± 0,18, as the ceramic thickness expands from 0,5mm to 0,8mm. VitaBlocs® Mark II ceramic cemented with Veneer TR cement displays a rise in average ΔE002 values, from 6,06 ± 0,23 to 7,90 ± 0,26, for the same alteration in ceramic thickness. Furthermore, when VitaBlocs® Mark II ceramic is bonded with Veneer WO cement, the average

ΔE002 values experience an increase, from 8,43 ± 0,79 to 10,46 ± 1,03, with the same change in ceramic thickness.

When examining *IPS e.max®* ceramic with a 0,5mm thickness, the average ΔE_{002} values reveal an ascending trend, displaying values of 4,35 ± 0,23, 4,79 ± 0,29, and 6,63 ± 0,76 for *Universal TR, Veneer TR,* and *Veneer WO* cements, respectively. On the other hand, the *VitaBlocs® Mark II* ceramic with the same thickness presents average ΔE_{002} values of 5,92 ± 0,18, 6,06 ± 0,23, and 8,43 ± 0,79 for *Universal TR, Veneer TR,* and *Veneer WO* cements, respectively.

Furthermore, an increase in average ΔE_{002} values is observed for *IPS e.max®* ceramic with a thickness of 0,8mm, showing values of 5,06 ± 0,11, 6,62 ± 0,83, and 8,66 ± 1,01 for *Universal TR, Veneer TR,* and *Veneer WO* cements, respectively. On the other hand, the *VitaBlocs® Mark II* ceramic with the same thickness exhibits a rise in average ΔE_{002} values, with values of 7,50 ± 0,18, 7,90 ± 0,26, and 10,46 ± 1,03 for *Universal TR, Veneer WO,* and *Veneer TR* cements, respectively.

While assessing a 0,5mm ceramic thickness with *Universal TR* cement, there is an increase in average ΔE_{002} values when moving from *IPS e.max®* ceramic to *VitaBlocs® Mark II*, with values changing from 4,35 ± 0,23 to 5,92 ± 0,18, respectively. Similarly, when using *Veneer TR* cement for the same ceramic thickness, a growth in average ΔE_{002} values is evident, shifting from 4,79 ± 0,29 to 6,06 ± 0,23 when transitioning from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Moreover, with *Veneer WO* cement, an increase in average ΔE_{002} values is observed when switching from *IPS e.max®* ceramic with a value of 6,63 ± 0,76 to *VitaBlocs® Mark II* ceramic with a value of 8,43 ± 0,79.

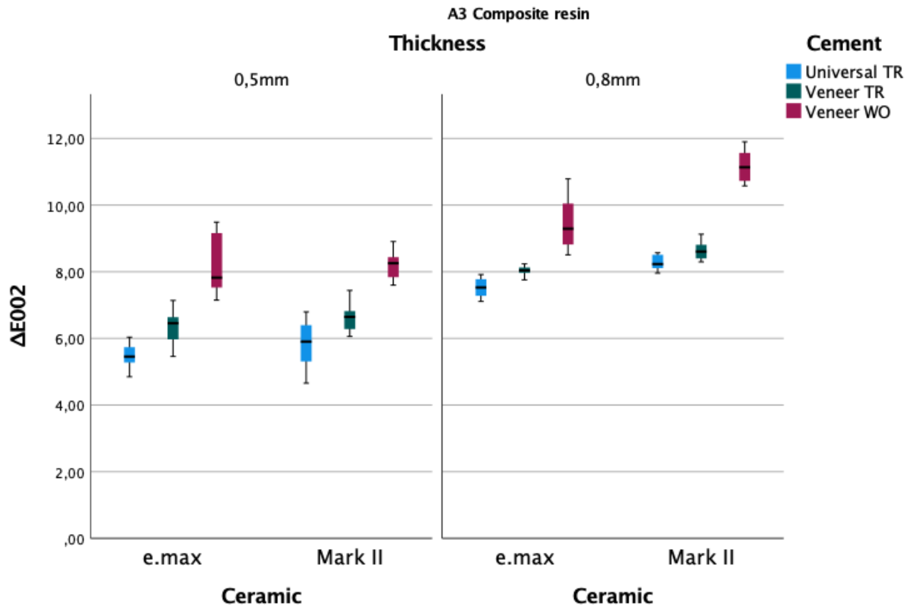
Regarding a 0,8mm ceramic thickness and the application of *Universal TR* cement, there is an elevation in average ΔE_{002} values from 5,06 ± 0,11 to 7,50 ± 0,18 when moving from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. Similarly, employing *Veneer TR* cement with the same thickness, an enhancement in average ΔE_{002} values can be seen, rising from 6,62 ± 0,83 to 7,90 ± 0,26 when transitioning from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Furthermore, using *Veneer WO* cement and maintaining the same ceramic thickness, the average ΔE_{002} values increased from 8,66 ± 1,01 for *IPS e.max®* ceramic to 10,46 ± 1,03 for *VitaBlocs® Mark II* ceramic.

The $\Delta E_{00}2$ mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A3 base are displayed in Table 75 and Graphic 35.

Table 75. Composite resin (A3) and ceramic samples cemented $\Delta E_{00}2$ mean ± standard deviation, minimum and maximum.

		Thickness					
		0,5mm			0,8mm		
Ceramic	Cement	Mean ± Std. Dev.	Min.	Max.	Mean ± Std. Dev	Min.	Max.
e.max®	Universal TR	5,44 ± 0,38	4,85	6,04	7,52 ± 0,31	7,11	7,92
	Veneer TR	6,33 ± 0,53	5,46	7,14	8,03 ± 0,16	7,76	8,24
	Veneer WO	8,14 ± 0,84	7,15	9,49	9,47 ± 0,79	8,51	10,79
Mark II	Universal TR	5,83 ± 0,67	4,66	6,80	8,28 ± 0,22	7,96	8,57
	Veneer TR	6,61 ± 0,42	6,06	7,44	8,61 ± 0,26	8,30	9,13
	Veneer WO	8,22 ± 0,42	7,60	8,91	11,16 ± 0,46	10,58	11,90

Graphic 35. Composite resin (A3) and ceramic samples cemented $\Delta E_{00}2$ mean ± standard deviation, minimum and maximum Boxplot



Examining Table 75, it becomes clear that for *IPS e.max®* ceramic bonded with *Universal TR* cement, the average ΔE_{002} values increased from 5,44 ± 0,38 to 7,52 ± 0,31 as the ceramic thickness increases from 0,5mm to 0,8mm. On the other hand, when the ceramic thickness grows from 0,5mm to 0,8mm, the average ΔE_{002} values for *IPS e.max®* ceramic cemented with *Veneer TR* cement rise from 6,33 ± 0,53 to 8,03 ± 0,16. Similarly, *IPS e.max®* ceramic bonded with *Veneer WO* cement exhibits an improvement in average ΔE_{002} values, from 8,14 ± 0,84 to 9,47 ± 0,79, with the same thickness change.

Regarding *VitaBlocs® Mark II* ceramic bonded with *Universal TR* cement, an increase in average ΔE_{002} values is observed, from 5,83 ± 0,67 to 8,28 ± 0,22, as the ceramic thickness extends from 0,5mm to 0,8mm. *VitaBlocs® Mark II* ceramic cemented with *Veneer TR* cement exhibits an increase in average ΔE_{002} values, from 6,61 ± 0,42 to 8,61 ± 0,26, for the same shift in ceramic thickness. Additionally, when *VitaBlocs® Mark II* ceramic is bonded with *Veneer WO* cement, the average ΔE_{002} values see an elevation, from 8,22 ± 0,42 to 11,16 ± 0,46, with the same alteration in ceramic thickness.

Upon inspecting *IPS e.max®* ceramic with a thickness of 0,5mm, the average ΔE_{002} values display an upward trajectory, presenting values of 5,44 ± 0,38, 6,33 ± 0,53 and 8,14 ± 0,84 for *Universal TR, Veneer TR,* and *Veneer WO* cements, respectively. In a similar manner, *VitaBlocs® Mark II* ceramic with the same thickness exhibits average ΔE_{002} values of 5,83 ± 0,67, 6,61 ± 0,42, and 8,22 ± 0,42 for *Universal TR, Veneer TR,* and *Veneer WO* cements, respectively.

Moreover, a growth in average ΔE_{002} values is noted for *IPS e.max®* ceramic with a thickness of 0,8mm, indicating values of 7,52 ± 0,31, 8,03 ± 0,16, and 9,47 ± 0,79 for *Universal TR, Veneer TR,* and *Veneer WO* cements, respectively. Likewise, *VitaBlocs® Mark II* ceramic with the same thickness demonstrates an increase in average ΔE_{002} values, with values of 8,28 ± 0,22, 8,61 ± 0,26, and 11,16 ± 0,46 for *Universal TR, Veneer TR,* and *Veneer WO* cements, respectively.

While evaluating a 0,5mm ceramic thickness alongside *Universal TR* cement, a rise in average ΔE_{002} values occurs when transitioning from *IPS e.max®* ceramic to *VitaBlocs® Mark II*, with values altering from 5,44 ± 0,38 to 5,83 ± 0,67, respectively. In the same vein, when employing *Veneer TR* cement for the same ceramic thickness, an increase in average ΔE_{002} values becomes apparent, moving from 6,33 ± 0,53 to 6,61 ± 0,42 when shifting from *IPS e.max®* to *VitaBlocs® Mark II* ceramic.

Additionally, with *Veneer WO* cement, a rise in average ΔE_{00^2} values is observed when changing from *IPS e.max®* ceramic with a value of 8,14 ± 0,84 to *VitaBlocs® Mark II* ceramic with a value of 8,22 ± 0,42.

In the context of a 0,8mm ceramic thickness and using *Universal TR* cement, an increase in average ΔE_{00^2} values is seen from 7,52 ± 0,31 to 8,28 ± 0,22 when progressing from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. Similarly, when applying *Veneer TR* cement with the same thickness, an improvement in average ΔE_{00^2} values is detected, advancing from 8,03 ± 0,16 to 8,61 ± 0,26 when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. Additionally, for the same ceramic thickness and *Veneer WO* cement, the average ΔE_{00^2} values rise from 9,47 ± 0,79 for *IPS e.max®* ceramic to 11,16 ± 0,46 for *VitaBlocs® Mark II* ceramic.

Table 76. Composite resin and ceramic samples cemented ΔE_{002} mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Same lowercase letters within the same column indicate a non-statistically significant differences between cements for each ceramic. The p-values below each column, for each base, represent differences for the same cement between different ceramics. Same capital letters within the same column indicate a non-statistically significant differences for the same cement between different ceramics.

			Thickness		
			0,5mm	0,8mm	
Composite	**Ceramic**	**Cement**	**Mean ± Std. Dev**	**Mean ± Std. Dev**	**p-values**
A2	**e.max®**	Universal TR	$4,35 \pm 0,23^{a}$	$5,06 \pm 0,11$	p=0,009$^{(*)}$
		Veneer TR	$4,79 \pm 0,29^{a}$	$6,62 \pm 0,83$	p<0,001$^{(*)}$
		Veneer WO	$6,63 \pm 0,76$	$8,66 \pm 1,01$	p<0,001$^{(*)}$
	Mark II	Universal TR	$5,92 \pm 0,18^{b}$	$7,50 \pm 0,18^{c}$	p<0,001$^{(*)}$
		Veneer TR	$6,06 \pm 0,23^{b}$	$7,90 \pm 0,26^{c}$	p<0,001$^{(*)}$
		Veneer WO	$8,43 \pm 0,79$	$10,46 \pm 1,03$	p<0,001$^{(*)}$
			p<0,001$^{(*)}$	p<0,001$^{(*)}$	
A3	**e.max®**	Universal TR	$5,44 \pm 0,38^{A}$	$7,52 \pm 0,31^{d}$	p<0,001$^{(*)}$
		Veneer TR	$6,33 \pm 0,53^{B}$	$8,03 \pm 0,16^{d}$	p<0,001$^{(*)}$
		Veneer WO	$8,14 \pm 0,84^{C}$	$9,47 \pm 0,79$	p<0,001$^{(*)}$
	Mark II	Universal TR	$5,83 \pm 0,67^{A}$	$8,28 \pm 0,22^{e}$	p<0,001$^{(*)}$
		Veneer TR	$6,61 \pm 0,42^{B}$	$8,61 \pm 0,26^{e}$	p<0,001$^{(*)}$
		Veneer WO	$8,22 \pm 0,42^{C}$	$11,16 \pm 0,46$	p<0,001$^{(*)}$
			p=0,080$^{(A)}$ p=0,209$^{(B)}$ p=0,709$^{(C)}$	p<0,001$^{(*)}$	

(*) Statistically significant differences for a 95% confidence interval

A four-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, ceramic thickness and cement on the colour variation (ΔE_{002}). The data was checked for potential outliers using boxplots, but none were detected (Graphic 34 and 35). The normality assumption was verified using the Shapiro-Wilk test, which indicated that both groups exhibited normal distribution (p>0,05). However, Levene's test revealed significant differences in variances between the groups (p<0,001). Henceforth, a decision was made to conduct a Split File of the composite resin independent variable, followed by a three-way ANOVA. To compare the studied groups across different composite resin bases, an independent samples t-test was performed. It is noteworthy to mention that the Levene´s test in this scenario continues to exhibit statistical significance (p<0,001). However, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and N > 15 among groups.

A significant three-way interaction was observed between ceramic type, ceramic thickness, and cement (p=0,006) for A3 composite resin base. Simple two-way interactions and simple simple main effects were also significant at the p<0,025 level. Simple two-way interactions were verified, which proved to be statistically significant for Mark II (p=0,016) and not statistically significant for e.max (p=0,062). There was a simple simple main effect of thickness in the other variables (p<0,001), and simple simple comparisons were made.

A non-significant three-way interaction was observed between ceramic type, ceramic thickness, and cement for A2 (p=0,260) composite resin base. Two-way interactions were verified between ceramic and cement (p=0,022) and between thickness and cement (p=0,004) for an A2 composite resin base, which proved to be statistically significant. The two-way interaction between ceramic and thickness proved to be non-significant (p=0,187). The simple main effect of cement is statistically significant for all combination of variables (p<0,001).

All pairwise comparisons were adjusted using the Bonferroni method. Comparing the thicknesses of *IPS e.max®* and *VitaBlocs® Mark II* ceramics cemented to A2 and A3 composite bases, we found that variations in ceramic thickness cause statistically significant changes in the ΔE_{00^2} variable when cemented with all studied cements (Table 76).

When considering the *IPS e.max®* ceramic samples with 0,5mm thickness, there were no statistically significant differences observed between the use of *Universal TR* and *Veneer TR* cements when cemented to an A2 composite base (p>0,05) and between the same cements to a *IPS e.max®* 0,8mm ceramic in a A3 camposite resin base. When considering the *VitaBlocs® Mark II* ceramic samples with 0,5mm and 0,8mm thickness, there were no statistically significant differences observed between the use of *Universal TR* and *Veneer TR* cements when cemented to an A2 composite base (p>0,05). When cemented to an A3 colour base, there were no statistically significant differences observed between the use of *Universal TR* and *Veneer TR* (p>0,05) for a 0,8mm *VitaBlocs® Mark II* ceramic (Table 76).

When cemented to an A2 colour base using any of the studied cements and for both thicknesses, statistically significant differences were observed when switching from *IPS e.max®*ceramic to *VitaBlocs® Mark II* ceramic (p<0,001). When cemented to an A3 colour base using any of the studied cements and for 0,8mm thickness, statistically significant differences were observed when switching from *IPS e.max®*ceramic to *VitaBlocs® Mark II* ceramic, but non-statistically significant differences were found for a 0,8mm thickness, in *Universal TR* (p=0,080), *Veneer TR* (p=0,209) and *Veneer WO* (p=0,709) (Table 76).

Table 77. ΔE_{00^2} independent samples t-test between A2 and A3 composite resin base for each ceramic and thickness and each cement

			Thickness	
			0,5mm	*0,8mm*
Composite	***Ceramic***	***Cement***	***p-values***	***p-values***
A2 vs. A3	***e.max®***	*Universal TR*	*p<0,001*(*)	*p<0,001*(*)
		Veneer TR	*p<0,001*(*)	*p<0,001*(*)
		Veneer WO	*p<0,001*(*)	*p=0,062*
	Mark II	*Universal TR*	*p=0,702*	*p<0,001*(*)
		Veneer TR	*p=0,002*(*)	*p<0,001*(*)
		Veneer WO	*p=0,473*	*p=0,066*

(*) Statistically significant differences for a 95% confidence interval

The utilization of *IPS e.max®* ceramic material with a thickness of 0,8mm and cemented using *Veneer WO* (p=0,062) while altering the base shade from A2 to A3 resulted in a non-statistically significant difference, according to an independent samples t-test (Table 77). The same trend was observed when the *VitaBlocs® Mark II* ceramic type with a thickness of 0,8mm was cemented using *Veneer WO* (p=0,066) and with a 0,5mm thickness when cemented with *Universal TR* (p=0,702) and *Veneer WO* (p=0,473).

5.1.3. Study of ΔE_{003}

The results concerning the colour variation (ΔE_{00}) between the composite resin samples attached to ceramic with glycerine and the composite resin samples cemented to ceramic using the studied cements (ΔE_{003}) are available in Table 78, 79 and 80. The maximum and minimum ΔE_{003} mean absolute values obtained were 5,93, corresponding to 0,8mm *VitaBlocs® Mark II* ceramic, cemented to A3 composite resin base with *Universal TR* cement, and 1,60, corresponding to 0,5mm *IPS e.max®* ceramic cemented to A3 composite resin base with *Veneer WO* cement, respectively.

The ΔE_{003} mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A2 base are displayed in Table 78 and Graphic 36.

Table 78. Composite resin (A2) and ceramic samples cemented ΔE_{003} mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			*0,8mm*		
Ceramic	***Cement***	*Mean ± Std. Dev.*	*Min.*	*Max.*	*Mean ± Std. Dev*	*Min.*	*Max.*
e.max®	*Universal TR*	*3,87 ± 0,21*	*3,44*	*4,06*	*4,38 ± 0,07*	*4,28*	*4,49*
	Veneer TR	*3,79 ± 0,25*	*3,49*	*4,32*	*4,45 ± 0,19*	*4,23*	*4,75*
	Veneer WO	*2,70 ± 0,43*	*2,06*	*3,43*	*2,71 ± 0,63*	*1,86*	*3,52*
Mark II	*Universal TR*	*4,09 ± 0,15*	*3,85*	*4,27*	*4,66 ± 0,18*	*4,41*	*4,91*
	Veneer TR	*4,23 ± 0,30*	*3,76*	*4,73*	*4,78 ± 0,28*	*4,23*	*5,15*
	Veneer WO	*2,55 ± 0,45*	*1,76*	*3,23*	*2,89 ± 0,48*	*2,20*	*3,77*

Graphic 36. Composite resin (A2) and ceramic samples cemented ΔE₀₀₃ mean ± standard deviation, minimum and maximum Boxplot

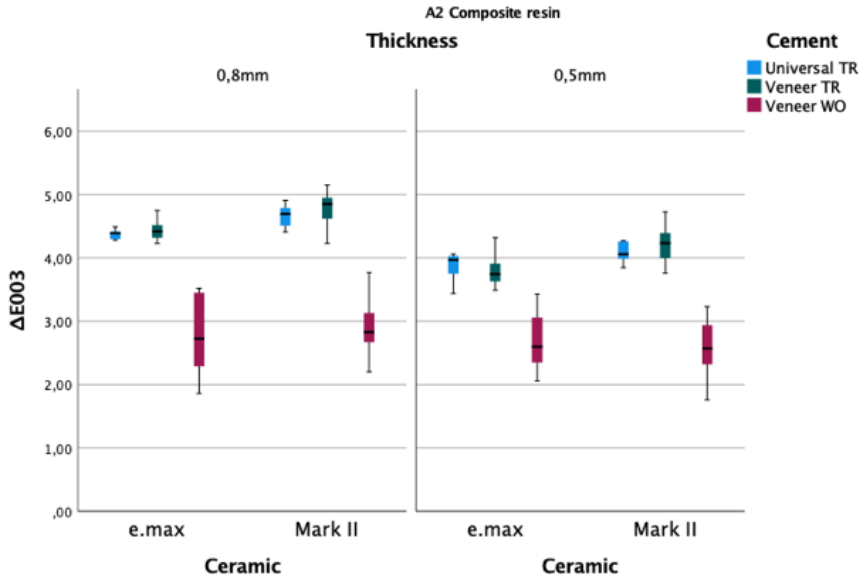


Table 78 demonstrates that for *IPS e.max®* ceramic, the average ΔE_{003} values climb as the ceramic thickness increases from 0,5mm to 0,8mm when cemented with *Universal TR*. In particular, the values rise from 3,87 ± 0,21 to 4,38 ± 0,07. A similar pattern is observed with *Veneer TR* cement, where the average ΔE_{003} values increase from 3,79 ± 0,25 to 4,45 ± 0,19 for the same change in thickness. Likewise, when *IPS e.max®* ceramic is bonded with *Veneer WO* cement, the average ΔE_{003} values show almost no change in values from 2,70 ± 0,43 to 2,71 ± 0,63 with the same alteration in thickness.

In the case of *VitaBlocs® Mark II* ceramic, when bonded with *Universal TR* cement, the average ΔE_{003} values rise from 4,09 ± 0,15 to 4,66 ± 0,18 as the ceramic thickness expands from 0,5mm to 0,8mm. In a similar manner, the average ΔE_{003} values increase from 4,23 ± 0,30 to 4,78 ± 0,28 for the same thickness change when *VitaBlocs® Mark II* ceramic is bonded with *Veneer TR* cement. Furthermore, with *Veneer WO* cement, *VitaBlocs® Mark II* ceramic exhibits a growth in average ΔE_{003} values from 2,55 ± 0,45 to 2,89 ± 0,48 for the same change in thickness.

For the *IPS e.max®* ceramic with a 0,5mm thickness, an upward pattern in average ΔE_{003} values is observed, presenting values of 2,70 ± 0,43, 3,79 ± 0,25, and 3,87 ± 0,21 for *Veneer WO, Veneer TR*, and *Universal TR* cements, respectively. Conversely, the *VitaBlocs® Mark II* ceramic at the same thickness exhibits average ΔE_{003} values of 2,55 ± 0,45, 4,09 ± 0,15, and 4,23 ± 0,30 for *Veneer WO, Universal TR*, and *Veneer TR* cements, respectively.

Additionally, an increase in average ΔE_{003} values is observed for *IPS e.max®* ceramic with a thickness of 0,8mm, displaying values of 2,71 ± 0,63, 4,38 ± 0,07, and 4,45 ± 0,19 for *Veneer WO, Universal TR*, and *Veneer TR* cements, respectively. Similarly, the *VitaBlocs® Mark II* ceramic at the same thickness reveals a rise in average ΔE_{003} values, presenting values of 2,89 ± 0,48, 4,66 ± 0,18, and 4,78 ± 0,28 for *Veneer WO, Universal TR*, and *Veneer TR* cements, respectively.

When analysing a 0,5mm ceramic thickness and utilizing *Universal TR* cement, an upward shift in average ΔE_{003} values is seen when transitioning from *IPS e.max®* ceramic to *VitaBlocs® Mark II*, with values changing from 3,87 ± 0,21 to 4,09 ± 0,15, respectively. Similarly, when applying *Veneer TR* cement at the same ceramic thickness, an increase in average ΔE_{003} values is observed from 3,79 ± 0,25 to 4,23 ± 0,30 when switching from *IPS e.max®* to *VitaBlocs® Mark II* ceramic. However, with *Veneer WO* cement, a reduction in average ΔE_{003} values is found when moving from *IPS e.max®* ceramic (2,70 ± 0,43) to *VitaBlocs® Mark II* ceramic (2,55 ± 0,45).

With respect to a 0,8mm ceramic thickness and the use of *Universal TR* cement, a rise in average ΔE_{003} values is noted from 4,38 ± 0,07 to 4,66 ± 0,18 when transitioning from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. In a similar manner, when applying *Veneer TR* cement with the same thickness, average ΔE_{003} values increase from 4,45 ± 0,19 to 4,78 ± 0,28 when changing between ceramics. Additionally, for the same ceramic thickness and *Veneer WO* cement, the average ΔE_{003} values grew from 2,71 ± 0,63 for *IPS e.max®* ceramic to 2,89 ± 0,48 for *VitaBlocs® Mark II* ceramic.

The ΔE_{003} mean values and standard deviations for the samples cemented to *Filtek™ Supreme* A3 base are displayed in Table 79 and Graphic 37.

Table 79. Composite resin (A3) and ceramic samples cemented ΔE_{003} mean ± standard deviation, minimum and maximum

		Thickness					
		0,5mm			0,8mm		
Ceramic	**Cement**	Mean ± Std. Dev.	Min.	Max.	Mean ± Std. Dev	Min.	Max.
e.max®	Universal TR	5,00 ± 0,27	4,68	5,43	5,22 ± 0,18	4,81	5,42
	Veneer TR	4,64 ± 0,43	3,63	5,02	5,04 ± 0,28	4,48	5,38
	Veneer WO	3,10 ± 0,86	1,60	4,44	2,86 ± 0,67	1,92	3,74
Mark II	Universal TR	5,19 ± 0,22	4,75	5,60	5,37 ± 0,40	4,59	5,93
	Veneer TR	4,87 ± 0,31	4,44	5,38	5,42 ± 0,19	5,23	5,76
	Veneer WO	3,39 ± 0,23	3,11	3,73	3,33 ± 0,46	2,61	4,22

Graphic 37. Composite resin (A3) and ceramic samples cemented ΔE_{003} mean ± standard deviation, minimum and maximum Boxplot

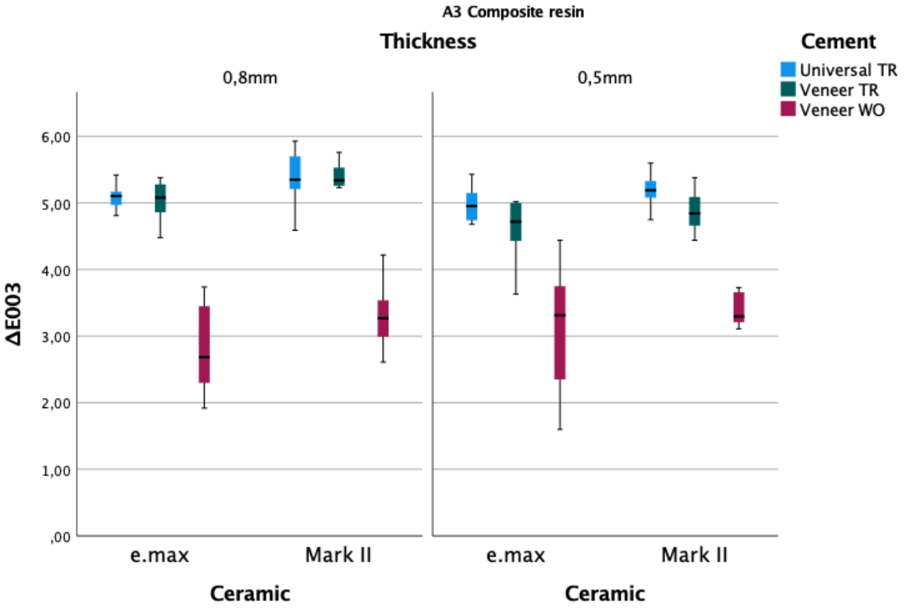


Table 79 illustrates that for *IPS e.max®* ceramic, the average ΔE_{003} values ascend as the ceramic thickness enlarges from 0,5mm to 0,8mm when cemented with *Universal TR*. Specifically, the values increase from 5,00 ± 0,27 to 5,22 ± 0,18. A comparable trend is noticed with *Veneer TR* cement, where the average ΔE_{003} values grow from 4,64 ± 0,43 to 5,04 ± 0,28 for the same alteration in thickness. Conversely, when *IPS e.max®* ceramic is bonded with *Veneer WO* cement, the average ΔE_{003} values decline from 3,10 ± 0,86 to 2,86 ± 0,67 with the same change in thickness.

Regarding *VitaBlocs® Mark II* ceramic, when bonded with *Universal TR* cement, the average ΔE_{003} values elevate from 5,19 ± 0,22 to 5,37 ± 0,40 as the ceramic thickness broadens from 0,5mm to 0,8mm. Similarly, the average ΔE_{003} values rise from 4,87 ± 0,31 to 5,42 ± 0,19 for the same thickness modification when *VitaBlocs® Mark II* ceramic is bonded with *Veneer TR* cement. On the other hand, with *Veneer WO* cement, *VitaBlocs® Mark II* ceramic displays a slight reduction in average ΔE_{003} values from 3,39 ± 0,23 to 3,33 ± 0,46 for the same change in thickness.

For the *IPS e.max®* ceramic with a 0,5mm thickness, a rising trend in average ΔE_{003} values is detected, showcasing values of 3,10 ± 0,86, 4,64 ± 0,43, and 5,00 ± 0,27 for *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively. In the same vein, the *VitaBlocs® Mark II* ceramic at the same thickness displays average ΔE_{003} values of 3,39 ± 0,23, 4,87 ± 0,31, and 5,19 ± 0,22 for *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively. Moreover, a growth in average ΔE_{003} values is noted for *IPS e.max®* ceramic with a thickness of 0,8mm, presenting values of 2,86 ± 0,67, 5,04 ± 0,28, and 5,22 ± 0,18 for *Veneer WO, Veneer TR,* and *Universal TR* cements, respectively. In contrast, the *VitaBlocs® Mark II* ceramic at the same thickness exhibits an increase in average ΔE_{003} values, showing values of 3,33 ± 0,46, 5,37 ± 0,40, and 5,42 ± 0,19 for *Veneer WO, Universal TR,* and *Veneer TR* cements, respectively.

Upon evaluating a 0,5mm ceramic thickness and using *Universal TR* cement, an upward movement in average ΔE_{003} values becomes apparent when shifting from *IPS e.max®* ceramic to *VitaBlocs® Mark II*, with values altering from 5,00 ± 0,27 to 5,19 ± 0,22, respectively. In a similar fashion, when employing *Veneer TR* cement for the same ceramic thickness, an increase in average ΔE_{003} values is noticeable, transitioning from 4,64 ± 0,43 to 4,87 ± 0,31 when changing between the studied ceramics. Concurrently, with *Veneer WO* cement, an increase in average ΔE_{003} values from 3,10 ± 0,86 to 3,39 ± 0,23 is observed when moving from *IPS e.max®* ceramic to *VitaBlocs® Mark II* ceramic, respectively.

Regarding a 0,8mm ceramic thickness and utilizing *Universal TR* cement, an elevation in average ΔE_{003} values is evident, going from 5,22 ± 0,18 to 5,37 ± 0,40 when transitioning from *IPS e.max®* ceramic to *VitaBlocs® Mark II*. In a similar vein, when applying *Veneer TR* cement with the same thickness, average ΔE_{003} values increase from 5,04 ± 0,28 to 5,42 ± 0,19 when switching between ceramics. Additionally, for the same ceramic thickness and *Veneer WO* cement, the average ΔE_{003} values grew from 2,86 ± 0,67 for *IPS e.max®* ceramic to 3,33 ± 0,46 for *VitaBlocs® Mark II* ceramic.

Table 80. Composite resin and ceramic samples cemented ΔE_{003} mean ± standard deviation and p-values (three-way ANOVA pairwise comparisons Bonferroni test). Same lowercase letters within the same column indicate a non-statistically significant differences between cements for each ceramic. The p-values below each column, for each base, represent differences for the same cement between different ceramics. Same capital letters within the same column indicate a non-statistically significant differences for the same cement between different ceramics

			Thickness		
			0,5mm	*0,8mm*	
Composite	***Ceramic***	***Cement***	***Mean ± Std. Dev***	***Mean ± Std. Dev***	***p-values***
A2	***e.max®***	*Universal TR*	*3,87 ± 0,21* $^{a\,A}$	*4,38 ± 0,07* $^{c\,C}$	*p<0,001*$^{(*)}$
		Veneer TR	*3,79 ± 0,25* ^{a}	*4,45 ± 0,19* ^{c}	*p<0,001*$^{(*)}$
		Veneer WO	*2,70 ± 0,43* ^{B}	*2,71 ± 0,63* ^{D}	*p=0,963*
	Mark II	*Universal TR*	*4,09 ± 0,15* $^{b\,A}$	*4,66 ± 0,18* $^{d\,C}$	*p<0,001*$^{(*)}$
		Veneer TR	*4,23 ± 0,30* ^{b}	*4,78 ± 0,28* ^{d}	*p<0,001*$^{(*)}$
		Veneer WO	*2,55 ± 0,45* ^{B}	*2,89 ± 0,48* ^{D}	*p=0,028*$^{(*)}$
			p=0,149$^{(A)}$ *p=0,324*$^{(B)}$	*p=0,064*$^{(C)}$ *p=0,237*$^{(D)}$	
A3	***e.max®***	*Universal TR*	*5,00 ± 0,27* $^{e\,E}$	*5,22 ± 0,18* $^{g\,H}$	*p=0,553*
		Veneer TR	*4,64 ± 0,43* $^{e\,F}$	*5,04 ± 0,28* ^{g}	*p=0,040*$^{(*)}$
		Veneer WO	*3,10 ± 0,86* ^{G}	*2,86 ± 0,67*	*p=0,213*
	Mark II	*Universal TR*	*5,19 ± 0,22* $^{f\,E}$	*5,37 ± 0,40* $^{h\,H}$	*p=0,340*
		Veneer TR	*4,87 ± 0,31* $^{f\,F}$	*5,42 ± 0,19* ^{h}	*p=0,005*$^{(*)}$
		Veneer WO	*3,39 ± 0,23* ^{G}	*3,33 ± 0,46*	*p=0,749*
			p=0,315$^{(E)}$ *p=0,233*$^{(F)}$ *p=0,126*$^{(G)}$	*p=0,172*$^{(H)}$	

(*) Statistically significant differences for a 95% confidence interval

A four-way analysis of variance (ANOVA) was conducted to explore the impact of composite resin, ceramic type, ceramic thickness and cement on the colour variation ($\Delta E_{00}3$). The data was checked for potential outliers using boxplots, but none were detected (Graphic 36 and 37). The normality assumption was verified using the Shapiro-Wilk test, which indicated that both groups exhibited normal distribution (p>0,05). However, Levene's test revealed significant differences in variances between the groups (p<0,001). Henceforth, a decision was made to conduct a Split File of the composite resin independent variable, followed by a three-way ANOVA. To compare the studied groups across different composite resin bases, an independent samples t-test was performed. It is noteworthy to mention that the Levene´s test in this scenario continues to exhibit statistical significance (p<0,001). However, the study design ensured robustness and allowed for the analysis to proceed with sufficient security, given the equal number of samples and N > 15 among groups.

A non-significant three-way interaction was observed between ceramic type, ceramic thickness and cement for A2 (p=0,337) and A3 (p=0,957) composite resin base. Two-way interactions were verified between thickness and cement (p<0,001) for an A2 (p=0,010) and A3 (p=0,006) composite resin base, which proved to be statistically significant. The simple main effect of cement is statistically significant for all combination of variables (p<0,001).

All pairwise comparisons were adjusted using the Bonferroni method. Comparing the thicknesses of *IPS e.max®* and *VitaBlocs® Mark II* ceramics cemented to A2 and A3 composite bases, we found that variations in ceramic thickness didn´t cause statistically significant changes in the $\Delta E_{00}3$ variable when cemented with *Veneer WO* between *IPS e.max®* and A2 composite resin base (p=0,963). The same situation occurred when cemented with *Universal TR* (p=0,553) and *Veneer WO* (p=0,213) between *IPS e.max®* and A3 composite resin base. When cemented with a *VitaBlocs® Mark II* ceramic, *Universal TR* (p=0,340) and *Veneer WO* (p=0,749) presented a non-statistically significant difference between thicknesses for a A3 composite resin base (Table 80).

When considering the *IPS e.max®* and *VitaBlocs® Mark II* ceramic samples with 0,5mm and 0,8mm thickness, there were no statistically significant differences observed between the use of *Universal TR* and *Veneer TR* cements when cemented to an A2 or A3 composite resin base (p>0,05) (Table 80).

When cemented to an A2 colour base using *Universal TR* (p=0,149) and *Veneer WO* (p=0,324) cements and for 0,5mm thickness, statistically significant differences were not observed when switching from *IPS e.max®*ceramic to *VitaBlocs® Mark II* ceramic. In the same conditions with a 0,8mm ceramic thickness statistically significant differences were not observed when using *Universal TR* (p=0,064) and *Veneer WO* (p=0,237). Additionally, when cemented to an A3 colour base using *Universal TR* (p=0,315), *Veneer TR* (p=0,233) and *Veneer WO* (p=0,126) cements for a 0,5mm thickness, statistically significant differences were not observed when switching from *IPS e.max®*ceramic to *VitaBlocs® Mark II* ceramic. Furthermore, with a 0,8mm thickness, statistically significant differences were also not observed when using *Universal TR* cement between ceramic types (p=0,172) (Table 80).

Table 81. ΔE_{003} independent samples t-test between A2 and A3 composite resin base for each ceramic and thickness and each cement

			Thickness	
			0,5mm	*0,8mm*
Composite	***Ceramic***	***Cement***	***p-values***	***p-values***
A2 vs. A3	***e.max®***	*Universal TR*	*p<0,001(*)*	*p<0,001(*)*
		Veneer TR	*p<0,001(*)*	*p<0,001(*)*
		Veneer WO	*p=0,215*	*p=0,608*
	Mark II	*Universal TR*	*p<0,001(*)*	*p<0,001(*)*
		Veneer TR	*p<0,001(*)*	*p<0,001(*)*
		Veneer WO	*p<0,001(*)*	*p=0,049(*)*

(*) Statistically significant differences for a 95% confidence interval

The use of *IPS e.max®* ceramic material with a thickness of 0,5mm (p=0,215) and 0,8mm (p=0,608) cemented with *Veneer WO* while varying the base shade from A2 to A3, resulted in a non-statistically significant difference according to an independent samples t-test (Table 81).

VI – DISCUSSION

VI -DISCUSSION

The present study aimed to analyse the colour changes of feldspathic ceramic and lithium disilicate ceramic when cemented with different cements: *RelyX™ Veneer Cement System* (3M ESPE, Minnesota, USA) in *Translucent (TR)* and *White Opaque (WO)* shades and *RelyX™ Universal Resin Cement* (3M ESPE, Minnesota, USA) in *Translucent (TR)* shade, varying the thickness of the ceramic (0,5mm and 0,8mm) and the colour of the substrate (A3 and A2).

6.1. DISCUSSION OF THE METHODOLOGY

In this study, two types of A1 shade ceramics were used: *VitaBlocs® Mark II* feldspathic ceramic (VITA Zahnfabrik, Bad Säckingen, Germany) and *IPS e.max® CAD* (HT) lithium disilicate ceramic (Ivoclar Vivadent, Schaan, Liechtenstein).

The feldspathic ceramic was selected due to its superior aesthetic quality and ability to match the optical properties of natural teeth (Conrad et al., 2007; Li et al., 2014; McLaren & Figueira, 2015; Sampaio et al., 2021). This type of ceramic remains mostly applied in dental veneers (Federizzi et al., 2016). Its translucency permits more light transmission through the material, presents a challenge to the colour stability of the final restoration, particularly when different cements and ceramic thicknesses are utilized (Igiel et al., 2018; Tamam et al., 2020).

Several authors have used the same type of feldspathic ceramic in their studies, such as Igiel et al. (2018), who used the *VitaBlocs® Mark II* ceramic (VITA Zahnfabrik, Bad Säckingen, Germany) in the A2 shade to evaluate the effect of ceramic thickness, cement colour, and substrate on the restoration's final colour. Carraba et al. (2020), who also utilized the same type of feldspathic ceramic, and Tamam et al. (2020), who used 10 different colours of the same type of ceramic in their study, conducted similar research (Carrabba et al., 2020; Igiel et al., 2018; Tamam et al., 2020).

The lithium disilicate ceramic was chosen not just for its superior visual qualities, but also for its remarkable biomechanical capabilities. Aesthetically, this ceramic closely resembles natural teeth, making it a great clinical alternative, particularly when paired with various resin cements. It is one of the most commonly utilized ceramics in different clinical settings, including veneers, due to its durability and versatility. (Conrad et al., 2007; Ho & Matinlinna, 2011; Kaur et al., 2022).

The *IPS e.max® CAD* (HT) ceramic (Ivoclar Vivadent, Schaan, Liechtenstein) was also used in previous studies. Turgut et al. (2014) in their study on the influence of surface treatments on the final colour of ceramic veneers, used several types of lithium disilicate ceramic from the same manufacturer in A1 colour (*IPS e.max® Press, IPS Empress® Esthetic*, *IPS e.max® Ceram* e *IPS Inline*), including the ceramic used in this study. Czigola et al. (2019) also used the same A1 colour ceramic with high and low translucency in their study. Later, Comba et al. (2020) used, in their study on the influence of cement and substrate colour, the *IPS e.max® CAD* ceramic but with low translucency and in the A2 colour. In the following year, in a similar study, Yildirim et al. (2021) used the same type and colour of ceramic used in this study (Comba et al., 2022; Czigola et al., 2019; Turgut et al., 2014; Yildirim et al., 2021).

The thickness of the ceramic appears to have a significant effect on the restoration's ultimate colour. When a ceramic is thinner, a greater proportion of light passes through its surface without being reflected. However, as the thickness of the ceramic increases, the amount of light that passes through its surface decreases proportionally, as does its translucency (Alayad et al., 2021; Baldissara et al., 2018; Chaiyabutr et al., 2011).

In this way, the thickness of the ceramic material is a significant issue to study, as it might affect the aesthetic outcome of these types of restorations (Talibi, Kaur, & Parmar (2022). In this regard, the present study utilized two different ceramic thicknesses, one with 0,5 mm, similar to the studies by Turgut & Bagis (2013), Tuzzolo Neto et al. (2018), Kandil et al. (2019), and Mihali et al. (2022), and another with 0,8 mm, similar to the studies by Archegas et al. (2011), Gugelmin et al. (2020), and Shadman et al. (2022) (Archegas et al., 2011; Gugelmin et al., 2020; Kandil et al., 2019; Mihali et al., 2022; Shadman et al., 2022; Turgut & Bagis, 2013; Tuzzolo Neto et al., 2018).

According to multiple authors, the minimum thickness of an anterior veneer should be 0,3 mm to prevent fracture. However, the ideal thickness of a ceramic crown depends on the type of ceramic used and the characteristics of the tooth to be restored (El-Mowafy et al., 2018; Farias-Neto et al., 2019; Sasse et al., 2015).

After cutting, the disilicate samples underwent a sintering process in a ceramic oven, in accordance with the manufacturer's instructions and similar to the study by Ramakrishnaiah et al. (2016) (Ramakrishnaiah et al., 2016).

All specimens were polished for 15 seconds with sandpaper and deionized water using a 100rpm polisher. As was the case in the studies by Dede et al. (2017), Hernandes et al. (2016), and Hoorizad et al. (2021), the thickness of the specimens was subsequently measured with a digital calliper to account for variations in thickness and surface roughness (Dede et al., 2017; Hernandes et al., 2016; Hoorizad et al., 2021).

Samples of composite resin *Filtek™ Supreme XTE Universal Restorative Body* (3M ESPE, Minnesota, USA) in A2 and A3 shades, with a thickness of 1 mm, were fabricated for the purpose of simulating tooth structure and standardizing substrate colour. The matrix created for this purpose enabled standardization of sample size and thickness.

Previous studies simulated the dental substrate using composite resin samples from the same manufacturer. The thickness of the composite substrate, however, differs among authors. In their work, Dede et al. (2017) utilized a 3mm thick composite resin *Filtek™ Z250* in the colours A1, A2, A3, B2, and C2. Kandil et al. (2019), on the other hand, utilized a 4mm thick, C3-colored *Filtek™ Z250* resin. Similar to the present study, Pissaia et al. (2019) use a base of *Filtek™ Z350* in colour A2 and with a thickness of 1mm, while Comba et al. (2022) opted for *Filtek™ Supreme XTE* resin in A2 and A4 colours with a thickness of 2mm (Comba et al., 2022; Dede et al., 2017; Kandil et al., 2019; Pissaia et al., 2019).

The bonding protocol significantly influences the quality and durability of ceramic restorations. In order to ensure their long-term clinical success, it is crucial that the connection between the dental ceramic and the substrate is optimal (Aboushelib & Sleem, 2014; Turgut et al., 2014).

An effective adhesive protocol must consider the material's composition, the surface treatment, and the cement employed. Several studies suggest that etching with hydrofluoric acid is the optimal surface treatment for lithium disilicate ceramics and feldspathic ceramics with respect to bond strength (Colares et al., 2013; Iorizzo et al., 2014; Talibi et al., 2022).

In this study, lithium disilicate samples were treated with 5% hydrofluoric acid for 20 seconds, similar to the studies by Fonzar et al. (2020), Kalavacharla et al. (2015), and Araujo & Perdigo (2021), and feldspar ceramic samples were treated with 5% hydrofluoric acid for 60 seconds, similar to the study by Venturini et al. (2015) and the manufacturer's instructions (3M, 2021; Araujo & Perdigão, 2021; Fonzar et al., 2020; Kalavacharla et al., 2015; Venturini et al., 2015; VITA, 2022).

The samples were then washed for 60 seconds with a water syringe and dried with an air syringe for 20 seconds. According to the manufacturer's recommendations, the adhesive *Scotchbond™ Universal Plus* (3M ESPE, Minnesota, USA) was applied with a microbrush for 20 seconds and dried with an air syringe for 5 seconds, without light curing (3M, 2021; Araujo & Perdigão, 2021).

According to conventional adhesive protocol, silane must be applied before to adhesive. With the development of universal adhesives, however, the adhesion process has been simplified. This type of adhesive already contains silane and 10-MDP (methacryloyloxydecyl-dihydrogen phosphate), which enhances the chemical adhesion of the ceramic to the cement, consequently simplifying the method and shortening its execution time (Guimarães et al., 2018; Scotti et al., 2017).

However, despite the fact that several authors continue to advocate for the use of silane, even when a universal adhesive is employed (Araujo & Perdigão, 2021; Guimarães et al., 2018; Kalavacharla et al., 2015), there are still not many studies in the literature about the studied cement (*RelyX™ Universal Resin Cement* (3M ESPE, Minnesota, USA). Thus, in accordance with the manufacturer's instructions, in this study it was decided not to use any additional silane (3M, 2021).

Similar to the studies by Comba et al. (2022) and Porojan et al. (2022), the ceramic samples were initially attached to the composite resin samples using glycerine with the intention of analysing the influence of the cement on the colour of the final restoration (Comba et al., 2022; Porojan et al., 2022).

The samples were then bonded with the resin cements *RelyX™ Universal Resin Cement* (3M ESPE, Minnesota, USA) colour *Translucent* (*TR*) and *RelyX™ Veneer Cement System* (3M ESPE, Minnesota, USA) colour *Translucent* (*TR*) and

White Opaque (WO), according to the designated study groups. In accordance with prior research, they were placed between two glass plates and subjected to a weight of 2 kg for 60 seconds in order to standardize the cement's thickness (Carrabba et al., 2020; Hoorizad et al., 2021; Tabatabaian et al., 2020; Tomaselli et al., 2019) and subsequently light cured according to the manufacturer's instructions.

According to the research conducted by Hernandes et al. (2016), the optical properties of ceramics can be greatly affected by the cement thickness (Hernandes et al., 2016).

The use of resin cements for dental ceramic veneers is almost universally recommended by authors. In this investigation, several resin cements were utilized due to their superior optical characteristics, which allowed for exceptional aesthetics, opacity, and the capacity to cover the substrate. In contrast, they have excellent micromechanical qualities, which lend stability and fracture resistance to the restoration (Dede et al., 2017; Federizzi et al., 2016; Mizrahi, 2008; Spazzin et al., 2016; Xiaoping et al., 2014).

Several resin cements were utilized in previous research aimed at determining the influence of cement on the colour of the final ceramic restoration. Chen et al. (2015) investigates the influence of *Variolink Veneer* cement in five distinct colours, *Panavia* (light and brown) and *Relyx™ Veneer* WO, TR, and A3. Later, Kandil et al. (2019) and Comba et al. (2022) also utilize the *Relyx™ Veneer* cement in the shades A1 and WO in their respective studies (Chen et al., 2015; Comba et al., 2022; Kandil et al., 2019). As *Relyx™ Universal* cement is a new product on the market, a limited number of studies on it have been published.

Several methods for measuring colour are currently described in the scientific literature, including spectrophotometers, colorimeters, intraoral scanners, and, most recently, digital photography (Liberato et al., 2019; Sampaio et al., 2019). The use of the spectrophotometer remains the most used method by several authors, as it provides greater measurement accuracy and a simplified clinical application (Carrabba et al., 2020; Hoorizad et al., 2021; Lehmann et al., 2017; Liberato et al., 2019; Shadman et al., 2022).

Similar to the investigations of Czigola et al. (2019), Gugelmin et al. (2020), Sampaio et al. (2021), Sonza et al. (2021), and Tamam et al. (2020), this study's data were collected by reading samples using a spectrophotometer *EasyShade® V* (VITA

Zahnfabrik, Bad Säckingen, Germany) (Czigola et al., 2019; Gugelmin et al., 2020; Sampaio et al., 2021; Sonza et al., 2021; Tamam et al., 2020).

As in the study by Carraba et al. (2020) and in accordance with ISO/TR 28642:2016 specifications, readings were conducted under standardized conditions on a grey background (Carrabba et al., 2020; Comba et al., 2022; International Organization for Standardization [ISO], 2016).

Following the manufacturer's instructions, the spectrophotometer was calibrated between each reading to prevent measurement mistakes and was placed directly on each sample (Sampaio et al., 2021).

The L*, a*, and b* values obtained by the spectrophotometer allowed for the subsequent calculation of colour differences (ΔE) between the various samples through the calculation of ΔE_{ab} and ΔE_{00}, according to the CIELab and CIEDE2000 systems, respectively.

Despite the fact that the CIEDE2000 system is currently the most popular and recommended (Ghinea et al., 2010; Khosravani et al., 2022; Paravina et al., 2015), In this study, it was decided to analyse the results based on the two systems for comparison purposes, similarly to the study by Comba et al. (2022) (Comba et al., 2022).

Despite the fact that CIELab is regarded as an useful colour space measuring method, it is falling out of popularity due to the inaccuracy of its representation of the colours experienced by the human eye. Later, the CIEDE2000 system was created with the intention of enhancing the precision and non-uniformity of colour perception, promoting itself as a more sensitive and specific system (Ghinea et al., 2010; Luo et al., 2001; Perez et al., 2011).

After a number of practical applications of CIELab, a number of authors assumed that this system corresponds to a uniform colour space, necessitating the introduction of weighting factors to compensate for inaccuracies in the calculation of colour difference (Melgosa, 2000; Perez et al., 2011).

The CIEDE2000 system incorporates specific corrections (weighting functions: S_L, S_C, S_H) for the non-uniformity of the CIELab colour space, takes into account the interaction between differences in chroma and hue in the blue colour region (rotation function R_T), considers neutral colours, modifying the a* coordinate of the CIELab system, and incorporates parametric factors (K_L, K_C, K_H)

that take into account the influence of observation and lighting conditions when evaluating colour difference. These last parameters are usually adjusted to 1 (International Commission on Illumination [CIE], 2004; Luo et al., 2001; Perez et al., 2011).

However, the application of the CIEDE2000 formula is significantly more complicated than the previous formula (CIELab), as its multiple steps make it difficult to calculate. Currently, there are a variety of pre-defined online programs and tools that automatically calculate the ΔE_{00} value between two colour measurements, based on the L*, a*, and b* values (Colormine, n.d.; Lindbloom, 2001; Pereira, 2007).

To acquire the ΔE_{00} values in this investigation, a pre-defined Microsoft® Excel spreadsheet, available in the article by Sharma et al. (2005), was utilized (Sharma et al., 2005; Șoim et al., 2018).

The obtained ΔE_{ab} and ΔE_{00} values correspond to the colour differences between the various pairs of samples studied, that is, between the final samples and the initial samples. The greater the ΔE value, the greater the colour change between the two compared samples, and this colour difference may or may not be visible to the human eye. The determination of the colour difference (ΔE) is only of clinical interest after understanding the concepts of perceptibility and acceptability.

Perceptibility refers to the ability of the human eye to detect a colour difference between two objects. In dentistry, it refers to the ability to identify a colour difference between two restorations or between a restoration and the adjacent natural teeth. If this colour difference has a ΔE value lower than the perceptibility threshold, it will not be visible to the average observer (International Organization for Standardization [ISO], 2016).

Acceptability refers to the threshold of colour difference that is considered tolerable by the observer. Clinically, it refers to the magnitude of the colour difference between two surfaces that the patient or dentist considers aesthetically acceptable. However, acceptability thresholds can vary among observers, depending on their personal preferences, cultural and physiological factors (International Organization for Standardization [ISO], 2016).

Thus, the reference value of ΔE, according to which colour changes are considered perceivable or acceptable by the observer, is not consensual in the literature, varying quite a bit among authors and there is no determined value (J. D. Da Silva et al., 2008; Vichi et al., 2011). According to the study conducted by Douglas et al. (2007), the perceptibility reference value considered for 50% of observers was 2,6. According to Silva et al. (2008), the reference ΔE value considered was 2,69 and Chang et al. (2009) considered, in their study, a lower value of $\Delta E \leq 2$. Later, according to Chen et al. (2015) the reference ΔE value considered was 3,3 as well as in the study by Hoorizad et al. (2021) and Shadman et al. (2022) (Chang et al., 2009; Chen et al., 2015; Da Silva et al., 2008; Douglas et al., 2007; Hoorizad et al., 2021; Shadman et al., 2022).

In the present study and according to the study by Paravina et al. (2015) and Sampaio et al. (2021), it was considered that the 50:50% perceptibility threshold (PT) for CIELab corresponds to a ΔE_{ab} of 1,2 and the 50:50% acceptability threshold (AT) corresponds to a ΔE_{ab} of 2,7. The values considered for the CIEDE2000 system were $\Delta E_{00}=0,8$ and $\Delta E_{00}=1,8$, respectively for the perceptibility (PT) and acceptability (AT) thresholds (International Organization for Standardization [ISO], 2016; Paravina et al., 2015; Sampaio et al., 2021).

In addition to the study of colour difference (ΔE), this study also chose to study the differences between L*, a*, and b* coordinates between the various pairs of samples. That is, the differences in lightness (L*), the differences between green and red colour (a*), and the differences between blue and yellow colour (b*) between the various pairs of samples studied, similar to the studies by Comba et al. (2022), Tamam et al. (2020), and Rodrigues et al. (2017) (Comba et al., 2022; Rodrigues et al., 2017; Tamam et al., 2020).

However, the articles available in the literature are scarce regarding the separate study of L*, a*, and b* values since most of the available articles on the subject evaluate the colour difference (ΔE). It was chosen to analyse the tables provided by these authors regarding the L*, a*, and b* coordinates for possible comparison with the results of this study. There was some challenge in locating studies that employed the same methodology as the present investigation, both in terms of the calculation of the colour difference and the materials employed.

6.2. DISCUSSION OF THE RESULTS

6.2.1. L* Study

6.2.1.1. *Base variation*

Based on the findings of this study, it can be noted that the *Filtek™ Supreme* A2 composite resin base generally exhibits greater lightness in comparison to the *Filtek™ Supreme* A3 composite resin base.

When a ceramic is added to the composite base, regardless of whether it is *IPS e.max®* or *VitaBlocs® Mark II* and regardless of its thickness, the lightness of the composite and ceramic combination continues to be significantly higher in the presence of the A2 colour base, compared to the composite and ceramic combination with the A3 colour base, within the same ceramic type and thickness. From these results, it can be inferred that the colour of the composite resin base has a significant influence on the lightness of the final combination, even when a ceramic is applied. In other words, the lightness of the ceramic is not sufficient to mask the lightness of the base.

Additionally, when a cement is added to the composite resin base and ceramic, regardless of the cement type, that combination with A2 composite resin base continues to exhibit greater lightness compared to the same combinations with an A3 colour base for all the compared groups. This suggests that the lightness of the substrate significantly influences the lightness of the final restoration. In other words, the lightness of the cement and ceramic are not sufficient to a completely camouflage of the lightness of the base.

The observed differences in lightness between the two substrate shades could be attributed to several factors, such as differences in their chemical composition, filler content, and the size and distribution of filler particles. The pigments used in the manufacturing process could also affect the composite's optical properties, including lightness. While the specific pigments used in *Filtek™ Supreme* A2 and A3 composite resins are not publicly available, it can be assumed that the lightness differences between the two shades are due to pigments variations used in their composition (Klapdohr & Moszner, 2005; Lim et al., 2008).

The way the ceramics interact with the composite resins may also influence the lightness values. The combination of composite resins with different ceramics can lead to distinct optical effects due to differences in their refractive indices, light scattering, and absorption properties (Y. K. Lee, 2007).

These results are, in part, consistent with the study of Tamam et al. (2020), which, among other measurements, assessed the lightness (L*) of various shades of *Vita Simulate composite* (VITA North America, California, USA*)* (0M1S, 1M1S, 2M3S, 3M2S, 4M3S, and 5M3S) paired with 10 shades of *VitaBlocs® Mark II* ceramic (OM1C, 1M1C, 1M2C, 2M1C, 2M2C, 2M3C, 3M1C, 3M2C, 3M3C, and 4M2C) with thicknesses of 0,3mm, 0,5mm, 0,7mm, and 1mm, without using any cement. In that study, the L* values of the composite and ceramic assembly decreased when transitioning from a lighter base (1M1S) to a darker base (5M3S) for all ceramic shades and thicknesses, suggesting that the lightness of the ceramic when placed over a darker substrate, compared to a lighter substrate, indicates that the lightness of the base effectively influences the lightness of the assembly studied. This observation is also consistent with the findings of the present study between the A2 and A3 coloured bases (Tamam et al., 2020).

Similar to these findings, Comba et al. (2022) also assessed the differences in lightness (L*) between the same type of lithium disilicate ceramic with a 1.2mm thickness, *IPS e.max®* (Ivoclar Vivadent, Schaan, Liechtenstein) but in A2 shade and low translucency (LT), using *Filtek*™ *Supreme* composite resin in A2D and A4D shades as the substrate. Ceramic samples were bonded to the composite resin samples using glycerine (control group) and with *RelyX™ Veneer Cement System* (3M ESPE, Minnesota, USA) in the *Translucent (TR)* shade, as in the present study, and *Choice 2* (Bisco Dental, Schaumburg, IL, USA) in the *Milky Bright (MB)* shade. Observing the results of Comba et al. (2022), it is observed that, as in the present study, there is a significant increase in lightness associated with the lighter base (A2D) compared to the darker base (A4D) within the same type of cement/glycerine and ceramic, except when using an opaque cement (*Milky Bright (MB)*), where there is a non-statistically significant increase in lightness, which does not occur with the opaque cement used in the present study (*Veneer WO*). This difference in results may be due to differences in the cement brand itself and differences in the thickness and translucency of the ceramic used. However, as these results, the L* coordinate was significantly affected by the substrate colour for *Veneer TR* cement and glycerine (Comba et al., 2022).

6.2.1.2. *Ceramic variation*

According to the findings of this study, the lightness (L*) of the assembly increases significantly when a ceramic is applied over A2 and A3 composite base colours, regardless of whether *IPS e.max®* or *VitaBlocs® Mark II* ceramic is used for both thicknesses. The lightness is greater in the thicker ceramic (0,8mm) compared to the thinner (0,5mm) ceramic for both ceramic types, and in feldspathic ceramic compared to lithium disilicate ceramic for both thicknesses and base colours. According to these results, the lightness of the assembly appears to be affected by both the type of ceramic and its thickness.

When the ceramic is cemented with the composite resin-based cements under study, the results indicate that, given the same base, ceramic thickness, and cement, the lightness of the final assembly increases significantly when a *VitaBlocs® Mark II* ceramic is used as opposed to an *IPS e.max®* ceramic, thus maintaining the previously observed behaviour. In addition, it is possible to observe that, for both the A2 and A3 bases and when using a *VitaBlocs® Mark II* ceramic, the lightness of the final assembly increases significantly with increasing ceramic thickness for the three cements studied, except for *Universal TR* cement in the A3 base, where this increase is not significant. Regarding *IPS e.max®* ceramic, there is a significant increase in lightness as ceramic thickness increases for *Universal TR* and *Veneer WO* cements in the A3 base, whereas there are no significant differences when the same ceramic and base are cemented with *Veneer TR* cement. Concerning the A2 base, when the *IPS e.max®* ceramic is cemented with *Veneer TR* cement, the lightness decreases significantly with increasing ceramic thickness, whereas there are no significant differences when the ceramic is cemented with *Universal TR* and *Veneer WO* cements. In this instance, there appears to be a greater equilibrium between lightness values (L*) between thicknesses of 0,5mm and 0,8mm. This approximation of lightness, which sometimes corresponds to a decrease from 0,5mm to 0,8mm, is more pronounced in the *IPS e.max®* ceramic for either of the bases, thereby demonstrating a lower lightness behaviour of the *IPS e.max®* ceramic already manifested before cementation. It is essential to note that at this stage, the cement already has a greater impact on the ceramic, which should be viewed as a whole and not in isolation. This appears to be the reason why *VitaBlocs® Mark II* ceramics with *veneer WO* cement have the greatest lightness differences between thicknesses.

Pop-Ciutrila et al. (2021) assessed the colour compatibility between dental structures and three different types of ceramics with thicknesses of 1 mm and 2 mm. In addition to dental structure samples, a feldspathic ceramic, *Noritake Super Porcelain Ex-3* (Kuraray Noritake Dental, Tokyo, Japan), a disilicate ceramic reinforced with zirconia *Vita Suprinity* (Vita Zanhfabrik, Bad Säckingen, Germany), and a *Vita Enamic* (Vita Zanhfabrik, Bad Säckingen, Germany) were also included. The results indicate that the L* coordinate was significantly greater for the thickest sample (2mm) than for the thinnest sample (1mm), and that the feldspar ceramic obtained a higher luminosity (L*) than the zirconia-reinforced disilicate ceramic. Despite differences in the materials used between studies, these results corroborate the findings of the present study, since, as previously stated, the luminosity of the *VitaBlocs® Mark II* ceramic is greater than that of the *IPS e.max®*, and that of the 0,8mm ceramic is greater than that of the ceramics with a thickness of 0,5mm (Pop-Ciutrila et al., 2021).

6.2.1.3. ***Cement variation***

According to the results of this study and as mentioned earlier, the lightness increases in all groups with the addition of ceramics. However, when a cement is added to this set, the lightness decreases, approaching more of the values of the base's initial luminosity, regardless of the type of ceramics, the thickness and the base used for all the cements studied. These results imply that cement has a significant effect on the final restoration's lightness, as it is responsible for the reduction of the restoration's lightness and its approximation of its initial lightness.

This decrease in lightness was more pronounced when the *Universal TR* and *Veneer TR* cement was used, both for the A2 and A3 base, regardless of the ceramic and its thickness, and was less pronounced when using the *Veneer WO* cement, for the A2 and A3 base for both types of ceramics and thickness. These results suggest that the luminosity of the base continues to influence the final lightness in the restoration even when a cement is added, so translucent cements have less ability to maintain higher luminosity values assigned by the corresponding ceramics. On the other hand, opaque cement can camouflage the luminosity of the base, allowing ceramics to manifest more their luminosities regardless of their type.

Through these results it is also possible to verify that the lightness of the final set when using the *Veneer WO* cement is always higher, compared to the same set when used the *Universal TR* and *Veneer TR* cements for both types of ceramics, thickness, and base. This suggests that the opaquer cement gives greater luminosity to the final restoration, compared to other cements. On the other hand, it is possible to verify that the luminosity values of the final set between the *Veneer TR* and *Universal TR* cement are very close within the same type of ceramics, thickness, and base, which suggests that there are no major differences between the use of the two translucent cements.

The results also suggest that, as the thickness of the ceramics increases, the variation in luminosity values is more pronounced when no cement is present, and that this variation is reduced when cement is associated with either the A2 or A3 base. This suggests that the thickness of the ceramic continues to affect the final lightness but has a lesser effect on the presence of cement. The results also indicate that the *VitaBlocs® Mark II* ceramic is always brighter than the *IPS e.max®* ceramic for both bases, ceramic thicknesses, and each of the studied cements. Even when cement is added, the type of ceramics still affects the restoration's lightness, according to these findings.

Günal-Abduljalil & Ulusoy (2022) evaluated the influence of cement on the final colour of the ceramic restoration. Three types of ceramics in A2 shade were used, *Vita Enamic* (Vita Zahnfabrik, Bad Säckingen, Germany), *GC Cerasmart* (GC Dental Products Corp, Aichi, Japan) and *Lava Ultimate* (3M, ESPE, St. Paul, MN, USA) with thickness of 0,5mm and 1mm. Samples of resin cement with 0,1mm thickness, *Relyx Ultimate* resin cement (3M ESPE, St. Paul, MN, USA), in the colours A1, A3O, B05 and TR were also manufactured. The L* coordinate was measured for the ceramic samples bonded to the cement under study. The author concluded that, for a 1mm thick tile, the highest luminosity value (L*) corresponds to the opaquer cement (A3O), compared to the other cements, which corroborates the results of the present study. However, when a 0,5 mm thick ceramic is used, the opaquer cement (A3O) has lower luminosity compared to the other cements. These results contradict the results obtained in the present study. These differences in results can be explained by differences in methodology, namely by the fact that Günal-Abduljalil & Ulusoy (2022) did not consider the influence of base colour on final luminosity, as well as the different types of ceramics used in both studies (Günal-Abduljalil & Ulusoy, 2022).

Chen et al. (2015), in their study, evaluated the influence of various resin cements on the final colour of ceramic veneers. They used *IPS e.max® Press* LT (Ivoclar Vivadent, Schaan, Liechtenstein) disilicate ceramic samples in A3 colour with a thickness of 0,6mm. The ceramic samples were cemented to *Dentin* shade resin composite samples, *DC CORE PLUS* (Kuraray Medical Inc., Japan) with *Variolink Veneer* resin cements (Ivoclar Vivadent, Schaan, Liechtenstein) in five shades (LV-3, LV-2, MV, HV+2, HV+3), *Panavia F* (Kuraray Medical Inc., Japan) in light and brown shades, and *Relyx™ Veneer* (3M, ESPE, USA) in WO, TR, and A3 shades. Regarding the L* coordinate values obtained in the mentioned study, the results indicated that samples cemented with the WO cement had higher L* values compared to the TR cement, similar to the present study (X.-D. Chen et al., 2015).

Önöral et al. (2021), evaluated the influence of cement colour and substrate colour on the final shade of resin matrix ceramics. They used three types of A2 colour ceramics with a 1mm thickness, *Vita Enamic* (Vita, Zahnfabrik), *Lava Ultimate* (3M ESPE, USA), and *Cerasmart* (GC Corp). The ceramics were cemented to composite resin bases in *white* and *dentin* colours, *Clearfil DC Core Plus* (Kuraray) with *G-CEM Link Force* resin cements (GC Corp) in *universal* (A2), *opaque* (OP), and *translucent* (*TR*) shades. The results of the previous study are consistent with the findings of the present study, as the L* coordinate values were higher when the *opaque* (OP) cement was used, compared to the *translucent* (*TR*) cement, regardless of the type of ceramic and base colour used (Önöral et al., 2021).

6.2.2. $a*$ Study

6.2.2.1. Base variation

The results suggest that the A2 composite resin has a more reddish colour compared to the A3 composite resin. These findings suggest that there is a noticeable difference in the redness of the two composite materials.

When a ceramic is added, the a* coordinate values for the *Filtek™ Supreme* A2 base are more negative (greenish) than those for the *Filtek™ Supreme* A3 base when paired with any ceramic type and thickness. In other words, the a* values increase significantly from the A2 base to the A3 base, meaning the combination (composite + ceramic) becomes less greenish within the same type and ceramic thickness when an A3 base is used, except for the 0,8mm thick *IPS e.max®* ceramic, where this decrease is not significant. These results suggest that the colour of the base significantly influence the a* coordinate of the pair. In the case of the thicker lithium disilicate ceramic, it is not only less translucent than the feldspathic ceramic, but its greater thickness also seems to have a higher capacity to camouflage the base's a* value compared to the other studied pairs.

Additionally, when the ceramic is cemented to the composite with the cements under study, it can be also observed that the a* values of the cemented group are more negative (greenish) when using an A2 colour base compared to an A3 colour base, using the same cement and the same ceramic type and thickness for all the groups studied. In other words, the a* values of the assembly (composite + cement + ceramic) increase significantly from an A2 base to an A3 base. These results suggest that the composite resin base influences the a* coordinate (green-red variation) of the final restoration.

Similarly to lightness (L*), the observed differences in a* values between the two substrate shades could be attributed to several factors such as the composition of composite resins, including the type and concentration of pigments and fillers that can influence their a* values. Different pigments and fillers can result in varying green-red hues in the composite resins. The type and composition of the polymer matrix used in composite resins can also affect their a* values. Different monomers or polymer matrices can lead to variations in the green-red hue of the material (Arikawa et al., 2007; Klapdohr & Moszner, 2005).

Contrary to the results of this study, Pecho et al. (2016) found in their study that the a* coordinate values for the same type of *Filtek™ Supreme* A2 composite resin, also using a 1mm thickness, are lower (more greenish) compared to the *Filtek™ Supreme* A3 base. The differences between the results may be due to differences in the measurement background (black and white) and the chosen measurement instrument (spectroradiometer) (Pecho et al., 2016).

The results of the study by Tamam et al. (2020), previously mentioned, support the findings of this study in that the a* values for the combination (composite + ceramic) within the same type and thickness of ceramic increase from a lighter substrate to a darker substrate (Tamam et al., 2020).

Additionally, Comba et al. (2022), in their study, suggest that changing the colour of the base from A2D to A4D does not cause statistically significant alterations in the a* values for the same ceramic set and thickness, either for the control group (glycerine) or for any of the studied cements (TR or MB). These results partly align with the findings of this study, where the differences in a* values between the A2 and A3 bases are not significant when using a 0,8mm *IPS e.max®* ceramic adhered to the composite with glycerine, which also suggests that for this group, the composite resin base does not influence the a* coordinate of the combination. On the other hand, the results of this study contradict the findings of Comba et al. (2022), as for the remaining samples paired with glycerine, there seems to be a significant influence of the base colour on the a* values of the composite + ceramic combination. The same occurs when any of the studied cements are added, suggesting that the base colour significantly influences the a* values of the final restoration, contrary to the previously mentioned study. The differences between these results may be due to differences in colour shades, thickness, and brands of the materials tested in both studies, which may influence the a* coordinate differently (Comba et al., 2022).

6.2.2.2. ***Ceramic variation***

According to the results of this study, it can be inferred that when a ceramic is added to the composite base, the a* values of the combination decrease significantly, meaning that its green coloration increases, both for the A2 base and the A3 base, regardless of the type of ceramic and thickness. This decrease is more pronounced in the thicker ceramic (0,8mm) compared to the thinner ceramic (0,5mm) for both types of ceramics and is more pronounced in the disilicate ceramic compared to the feldspathic ceramic. These results suggest that both the type of ceramic and its thickness seem to influence the a* coordinate of the combination, making it greener.

Additionally, when the ceramic is cemented to the composite resin base with the resin cements studied, the results suggest that, for both bases and considering the 0,8mm thickness, the a* values are lower in the *VitaBlocs® Mark II* ceramic compared to the *IPS e.max®* ceramic within the same cement. These results suggest that the type of ceramic and its thickness continue to influence the a* coordinate of the restoration after the cement has been added.

On the other hand, at the 0,5mm thickness, the a* values do not change significantly when the type of ceramic is changed from *IPS e.max®* to *VitaBlocs® Mark II* for the same cement and base colour, except for the *Universal TR* and *Veneer TR* cements on the A2 base, where the *IPS e.max®* ceramic has lower a* values compared to the *VitaBlocs® Mark II* ceramic. These results suggest that when a thinner ceramic is used, the type of ceramic does not have a significant influence on the a* coordinate of the restoration and does not have enough capacity to mask the colour of the cement and the underlying base.

Additionally, it is possible to observe that as the ceramic thickness increases, the a* values decrease, meaning that the green shade is greater the thicker the ceramic is for the same base, ceramic, and cement. These results suggest that the ceramic thickness has an influence on the a* coordinate of the final restoration. This is an exception in the A2 base, with the *IPS e.max®* ceramic when using the *Universal TR* and *Veneer TR* cements, where the change in ceramic thickness does not significantly influence the a* coordinate of the final combination. This suggests that the a* values of the A2 base and the *IPS e.max®* A1 ceramic are also similar, therefore justifying the lack of change with the increase in thickness.

However, these differences in the a* values are not perceptible, as they are below the threshold proposed by Lindsay et al. (2007) of 1,25. This suggests that there are no noticeable differences between the use of the two types of ceramics and between the two thicknesses for the same base colour and cement used. Therefore, all the reported exceptions may not have an influence on the interpretation of the data, as the a* coordinate seems to show very close values after cementing the samples (Lindsey & Wee, 2010; Skyllouriotis et al., 2017).

Pop-Ciutrila et al. (2021), in their study mentioned earlier, observed an increase in the a* coordinate values with the increase in ceramic thickness, which contradicts the results obtained in the present study. However, Pop-Ciutrila et al. (2021) indicate that, among ceramics, the feldspathic ceramic presents higher a* coordinate values (redder) compared to the disilicate ceramic, similar to the present study. These differences in the results may be due to the fact that the author did not take into account the influence of the base on the a* coordinate (Pop-Ciutrila et al., 2021).

Tamam et al. (2020), in their previously described study, found that the a* coordinate values showed a decrease with the increase in feldspathic ceramic thickness. These results are in line with the findings of the present study (Tamam et al., 2020).

6.2.2.3. ***Cement variation***

According to the results of this study and as mentioned earlier, the a* values decreased in all groups with the addition of the ceramic. However, when a cement is added to this combination, the a* values increase again, regardless of the type of ceramic, thickness, and base used for all the studied cements. These results suggest that the cement has a significant influence on the a* coordinate of the final restoration and is responsible for reducing its green coloration.

The cement with the lowest a* values, meaning the one that provides a greater green coloration, is the *Veneer WO* cement for a thickness of 0,8mm for both ceramics and base colours. This suggests that a greater ceramic thickness, combined with the opaquer cement, has a greater capacity to mask the reddish coloration of the base, highlighting the green colour more.

However, when using a smaller ceramic thickness (0,5mm), the a* values modified by the addition of the cement do not show a similar behaviour. For the 0,5mm *IPS e.max®* ceramic, the lowest a* values correspond to the *Veneer TR* cement, while for the *VitaBlocs® Mark II* ceramic, the a* values between the *Universal TR* and *Veneer TR* cements are similar in the A2 base. When evaluating the A3 base, the cement with the lowest a* values is the *Veneer WO* cement for the *IPS e.max®* ceramic, but for the *VitaBlocs® Mark II* ceramic, this decrease is attributed to the *Veneer TR* cement.

However, these differences in the a* values are not perceptible, as they are below the threshold proposed by Lindsay et al. (2007) of 1,25. This suggests that there are no noticeable differences between the use of the various cements, regardless of the type and thickness of the ceramic and the base used for the a* coordinate (Lindsey & Wee, 2010).

According to the results obtained by Turgut & Bagis (2013), the a* values for the A1 colour ceramic samples of *IPS Empress Esthetic* (Ivoclar Vivadent, Schaan, Liechtenstein) in the two thicknesses analysed (0,5mm and 1mm) are very similar between the *opaque* and *translucent* cements analysed, *Variolink II* (Ivoclar Vivadent, Schaan, Liechtenstein). This is in line with the results obtained in the present study, suggesting that there are no significant differences between the use of the two cements, regardless of the ceramic thickness used, in the a* coordinate (Turgut & Bagis, 2013).

6.2.3. $b*$ Study

6.2.3.1. *Base variation*

The results suggest that the A3 composite resin has a more yellowish colour compared to the A2 composite resin, as expected. These findings indicate that there is a noticeable difference in the yellowness of the two composite materials.

When evaluating the composite + ceramic set, it is possible to observe that the A3 base continues to exhibit more yellowish b* values compared to the A2 base. In other words, there is a significant increase from the A2 base to the A3 base within the same ceramic and thickness, suggesting that the base colour has an influence on the b* coordinate of the composite + ceramic set.

When a cement is added, the b* values for the composite + cement + ceramic set continue to show more yellowish values for the A3 base compared to the same set with the A2 base within the same cement, type, and thickness of ceramic. These results suggest that the base colour has a significant influence on the b* coordinate of the final restoration.

Differences in the b* coordinate between different shades of composite resins exist also due to variations in the composition and pigmentation of the materials used to create them. Composite resins are made of a combination of organic resins, inorganic fillers, and pigments that provide the desired colour and translucency for dental restorations. Minimal quantities of inorganic oxides, like ferrous oxide (for red hues) and ferric hydroxide (for yellow tones), are frequently incorporated into dental composites to achieve colours that closely resemble natural tooth shades (Klapdohr & Moszner, 2005; Pecho et al., 2016).

Previous studies support the findings of this research, such as the study by Pecho et al. (2016), which showed that the b* coordinate values are higher for the A3 composite resin base compared to the A2 base, using the same brand and shades of composite as those used in this study (Pecho et al., 2016).

On the other hand, Comba et al. (2022), in their study, indicated that higher values of the b* coordinate (more yellow), for the same ceramic, are higher when using a lighter base (A2), compared to a darker base (A4), for the Veneer TR cement and the control group (glycerine), with no significant difference, which contradicts the results of this study, since it was found that a darker base (A3) has significantly higher b* values. Regarding the opaque cement (MB), Comba et al. (2022) found that higher values of the b* coordinate correspond to the darker base (A4), similar to the results obtained in this study, suggesting that the base colours have a significant influence on the final colour of the restoration. These differences in the results may be due to differences in the thickness and colour of the ceramic, as well as differences in the composite colour used (Comba et al., 2022).

6.2.3.2. ***Ceramic variation***

According to the results of this study, it can be inferred that when a ceramic is added to a composite base, the b* values of the combination decrease significantly, meaning the yellow coloration decreases, for both the A2 and A3 bases, and regardless of the type of ceramic and its thickness. These results suggest that both the type of ceramic and its thickness seem to influence the b* coordinate of the combination, making it less yellow and masking the yellowish hue of the base.

When a smaller thickness is applied, the ceramic that shows more yellow b* values is the more translucent ceramic (*VitaBlocs® Mark II*), for both bases, suggesting that it reveals more of the base colour compared to the *IPS e.max®*. When a greater ceramic thickness is applied, the ceramic that shows more yellow b* values is the *IPS e.max®* ceramic, suggesting that the *IPS e.max®* ceramic has a more yellow hue compared to the *VitaBlocs® Mark II*, but it is only evident when its thickness is greater. In other words, when the thickness is increased, the *IPS e.max®* presents higher b* values compared to the *VitaBlocs® Mark II*.

These results suggest that both the thickness and the type of ceramic used have an influence on the yellow hue of the composite + ceramic combination. The greater the thickness, the greater the influence of the ceramic on the b* value.

When comparing between thicknesses, when using an A3 base for both ceramics, the b* values decrease from 0,5mm to 0,8mm thickness. The same happens with the A2 base and *VitaBlocs® Mark II* ceramic. This suggests that the ceramic thickness influences the b* coordinate, masking the yellowish colour of the base. On the other hand, when using the A2 base with the *IPS e.max®* ceramic, the b* values between thicknesses are very similar, showing a slight increase with increasing thickness, suggesting that the *IPS e.max®* A1 ceramic exhibits the same behaviour described earlier. The *IPS e.max®* presents higher b* values as its thickness increases, and therefore, over an A2 base, there is a slight increase in yellowness. On the other hand, there is a decrease in the same over an A3 base since at its smaller thickness, there is a significant influence of the base on the b* value.

Pop-Ciutrila et al. (2021), in their study described earlier, found an increase in the b* coordinate values with the increase in ceramic thickness. They also found that the b* values were higher for the feldspathic ceramic compared to the disilicate ceramic. These results contradict the findings of the present study. The differences in the results may be due to the fact that the author did not take into account the influence of the base on the b* coordinate (Pop-Ciutrila et al., 2021). Furthermore, it is essential to recognize that variations in experimental designs, materials, and other variables can result in varying research findings.

Tamam et al. (2020), in their previously described study, found that the b* values showed a decrease with the increase of feldspathic ceramic thickness, similar to the results obtained in the present study (Tamam et al., 2020).

6.2.3.3. ***Cement variation***

According to the results of this study, as mentioned before, the b* values decreased in all groups with the addition of ceramic. However, when a cement is added to this set, the b* values slightly increase, regardless of the type of ceramic, thickness, and base used for all the studied cements. These results suggest that the cement has a significant influence on the b* coordinate of the final restoration, responsible for the increase in yellow colour.

Between types of ceramics, but for the same thickness, it is possible to observe that the values of b* are higher for *IPS e.max®* ceramic, compared to *VitaBlocs® Mark II* ceramic, when evaluating the A2 base, within the same cement and for both thicknesses. This suggests that the yellowish tone of *IPS e.max®* ceramic becomes predominant in relation to *VitaBlocs® Mark II* ceramic.

When evaluating base A3, it is possible to verify that the values of b* are also higher in the *IPS e.max®* ceramic, except for the *Universal TR* and *Veneer TR* cements with a thickness of 0,5mm, where the values of b* are higher in the *VitaBlocs® Mark II* ceramic, suggesting that the more translucent *VitaBlocs® Mark II* ceramic allows for the observation of the greater yellowish tone of the A3 base in relation to the yellowish tone of the *IPS e.max®* ceramic.

The thicker the ceramic, the smaller the increase in b* values after cementation, regardless of the cement used. When using *Veneer WO* cement, the increase will always be smaller compared to *Universal TR* and *Veneer TR* cements. This behaviour is so observed that when using *Veneer WO* cement for *VitaBlocs® Mark II* ceramic of 0,8mm, in bases A2 and A3, there is a decrease in b* values, in other words, the thicker *VitaBlocs® Mark II* ceramic in combination with the opaque cement causes a decrease in b* value after cementation. This suggests that this cement, being opaque, has a greater ability to camouflage the yellowish tone of the base and confer a bluer tone, compared to translucent cements, regardless of the A2 or A3 base and the ceramic used.

These results also show that the b* values of the final assembly when using the *Universal TR* cement are always higher compared to the same assembly when using *Veneer TR* and *Veneer WO* cements, for both types of ceramic, thickness, and base. The differences between the translucent cements (*Universal TR* and *Veneer TR*) are not significant. This suggests that more translucent cements allow the colour of the base to show through, giving the final assembly a more yellowish hue. However, the differences in b* values between the translucent cements for the *VitaBlocs® Mark II* ceramic with 0,5mm thickness and base A3 are significant, suggesting that the more translucent and thinner ceramic has less ability to conceal the colour of the cement and base.

Chen et al. (2015), in their previously described study, also evaluated the behaviour of the cement in the b* coordinate, finding that b* values are lower (less yellow) for samples cemented with *WO* cement, compared to *TR* cement. These results are in line with the present study (X.-D. Chen et al., 2015).

However, Önöral et al. (2021), in their previously described study, observed that the b* values corresponding to the samples cemented with the opaque cement (OP) are higher (more yellowish) compared to the samples cemented with the translucent cement (*TR*), contrary to the results obtained in this study. These differences in results may be due to differences in methodology, particularly the types of materials used (Önöral et al., 2021).

6.2.4. Study of ΔE_{ab}

According to the results obtained in this study, it is possible to verify that the colour difference (ΔE_{ab1}) between the initial composite resin sample and the same sample when a ceramic is added is always perceptible (>1,2) and unacceptable (>2,7), regardless of the colour of the base, type of ceramic and thickness used. Subsequently, when a cement is added to the previous set, regardless of the type of cement, the colour difference (ΔE_{ab3}) caused by its addition is always perceptible (>1,2) and unacceptable (>2,7), for both bases, types of ceramics and thicknesses used.

According to the results obtained in this study, it is possible to verify that, when adding a ceramic to the composite resin base, regardless of the type of ceramic and its thickness, the observed colour difference (ΔE) is always greater when using an A3 base, compared to an A2 base, suggesting that the base colour influences the final colour of the composite + ceramic set, that is, from a darker base, there is a greater colour change for the same type of ceramic and thickness added. The same behaviour is observed when a cement is added to the set, regardless of the type of cement used.

The optical properties and colour of composite resins are defined by the composition of the resin matrix, filler components, and additional substances such as pigments and photo inhibitors (Y. K. Lee, 2007; Ota et al., 2012).

Previous studies have also sought to evaluate the influence of substrate colour, type and thickness of ceramic, and type of cement on the colour of the final restoration using the CIELab system.

Igiel et al. (2018), in their study, evaluated the influence of the colour of different substrates on the final colour of ceramic restorations. The authors used six colours of composite resin substrate, *Vita VM LC Base Dentine* (Vita, Zahnfabrik), different (1M1, 1M2, 2M2, 3M2, 4M2, and 5M2), to which samples of feldspathic ceramic *VitaBlocs® Mark II* (Vita, Zahnfabrik) with 0,4mm, 0,7mm, and 1mm thickness were cemented with six different try-in paste colours. It was found that, regardless of the ceramic thickness and cement colour used, the variation from a lighter to a darker substrate resulted in an increase in ΔE values, respectively, suggesting that the substrate colour influences the final restoration colour and that this situation is more noticeable for darker substrates compared to lighter ones, which is consistent with the results obtained in this study (Igiel et al., 2018).

Leevailoj & Sethakamnerd (2017) also sought to evaluate the influence of substrate colour on the masking ability of different types of ceramics. Three types of ceramics with thicknesses of 0,5mm and 1mm, *IPS e.max® Press HO* (Ivoclar Vivadent, Schaan, Liechtenstein), *Lava Plus* (3M ESPE, St. Paul, MN, USA) and *Lava Plus/Liner shade MO W2* (3M ESPE) were used, along with six different substrates: white, black, metal, and composite resin (*Filtek Z350*, 3M ESPE) in colours A2, A3, and C4, using white substrate as a control group initially and subsequently the A2 resin substrate. Even considering the differences in methodology and materials used, the results of Leevailoj & Sethakamnerd (2017) support the results of this study, since the authors suggests that the observed colour differences were influenced by the colour of the substrate. In other words, the use of a darker substrate was associated with lower ceramic masking ability, compared to a lighter substrate (Leevailoj & Sethakamnerd, 2017).

In the same year, Skyllouriotis et al. (2017) evaluated the ability of various types of ceramics to mask the colour of the substrate. The author compared six different types of ceramics, including *VitaBlocs® Mark II* and *IPS e.max® CAD* HT ceramics, both in 0,5mm thickness and A2 colour, similar to this study. For substrate simulation, the author used acrylic resin samples in colours A2 (control group), A3,5, A4, and B4. Analysing within the same hue used in this study (A3,5 and A4), the results indicated that, similar to the present study, the colour difference (ΔE) was greater when using the darker substrate (A4), compared to the lighter one (A3,5), regardless of the ceramic used. However, the ΔE values for the B4 base were lower compared to the other two bases (A3,5 and A4), which seems counterintuitive at first. In order to justify these results, the author separately analysed the L*, a*, and b* values, finding that the L* values corresponding to the B4 material were much higher compared to the A3,5 and A4 bases. The same was true for the a* and b* values, suggesting that, despite the B4 base having higher luminosity (L*) and also higher a* and b* values, it does not seem to affect the final colour of the restoration, suggesting that the substrate's luminosity L* is the coordinate that most affects the final colour of ceramic restorations (Skyllouriotis et al., 2017).

It is worth noting that the results obtained by Dozic et al. (2010) were also in line with the results obtained in this study, suggesting that neither the ceramic nor the cement used were able to mask the colour of any of the substrates used, and that the colour difference analysed was always greater in the darker substrate, compared to the lighter substrate. In this study, the author used *IPS Empress Esthetic* HO ceramic samples (Ivoclar Vivadent, Schaan, Liechtenstein) in colour A1 with 0,6mm thickness, which were cemented to nine different dentin composite resin substrates (ND1, ND2, ND3, ND4, ND5, ND6, ND7, ND8, ND9) with six different resin cements, *Variolink Veneer* (Ivoclar Vivadent, Schaan, Liechtenstein) (Dozic et al., 2010).

Additionally, when both types of ceramics are added to the base with different thicknesses, it is possible to verify that, regardless of the base, a *VitaBlocs® Mark II* ceramic always presents a greater colour change when compared to an *IPS e.max®* ceramic, regardless of its thickness, as well as a ceramic with a greater thickness (0,8mm) also presents a greater colour change relative to a ceramic with a smaller thickness (0,5mm), within the same type of ceramic. This behaviour is maintained after the cementation of the samples, so it can be inferred that *VitaBlocs® Mark II* ceramic has a greater ability to mask the colour of the base, as well as ceramics with a thickness of 0,8mm, regardless of the cement used and for both bases.

These differences in results may be due to the fact that *VitaBlocs® Mark II* and *IPS e.max®* ceramics have distinct optical properties that can influence how light interacts with the ceramic and, consequently, the colour change. The greater colour change observed in *VitaBlocs® Mark II* ceramic can be attributed to greater light scattering or absorption in that specific combination of materials compared to *IPS e.max®* ceramic (Oh et al., 2018).

The results indicate that the thickness of the ceramic influences the final colour of the restoration, which may be due to differences in the translucency of the ceramic depending on its thickness. A thicker ceramic is less translucent and therefore allows less light to pass through it. On the other hand, a thinner ceramic allows greater light transmission, being more translucent and allowing the colour of the substrate to show through more (Omar et al., 2010).

Sari et al. (2018), in their study, among other variables, evaluated the influence of ceramic thickness on the final colour of the restoration. They used samples of *VitaBlocs® Mark II* ceramic (Vita Zahnfabrik) in the colour 2M2 with thicknesses of 0,3mm, 0,5mm, 0,7mm, and 1,5mm, joined to six different colours of resin composite substrate *Vita Simulate Preparation Material Kit* (Vita Zahnfabrik) with a thickness of 2mm, concluding that varying the ceramic thickness significantly influences the final colour of the restoration. These results corroborate the results obtained in this study, suggesting that a thinner ceramic has less ability to mask the substrate colour compared to a thicker ceramic, regardless of the substrate colour used (Sari et al., 2018).

Begum et al. (2014), with the aim of evaluating the influence of ceramic thickness on the final colour of the restoration, like this study, also calculated the colour differences between the composite resin base and after its cementation to the ceramic. The author used two types of ceramics, *IPS e.max®* (Ivoclar Vivadent) and *Cergo* (Dentisply), with thicknesses of 0,5mm, 1mm, and 1,5mm, which were cemented to the *C3 Tetric N-Ceram* composite resin base (Ivoclar Vivadent, Schaan, Liechtenstein) with two resin cements, *Relyx™ Veneer translucent* and *opaque*. The results presented are consistent with the results of this study, since the colour difference (ΔE) values also increase with the increase in ceramic thickness, suggesting that it has an influence on the final colour of the restoration and that a greater thickness has a greater ability to camouflage the substrate, compared to a lesser thickness, regardless of the type of ceramic and cement used (Begum et al., 2014).

The study by Calgaro et al. (2014) also concluded that using a thicker ceramic has a greater ability to mask the colour of the substrate compared to a thinner ceramic, regardless of the colour of the cement used. In this study, a leucite-reinforced glass ceramic *IPS Classic* (Ivoclar Vivadent, Schaan, Liechtenstein) in the colour A1 with thicknesses of 0,5mm, 0,7mm, and 1mm was tested, cemented to a base of *Adoro* composite resin (Ivoclar Vivadent, Schaan, Liechtenstein) in the dentin colour A3,5 with the resin cement *Variolink II* (Ivoclar Vivadent, Schaan, Liechtenstein) in the colours A1, bleach, opaque, and transparent (Calgaro et al., 2014).

Shono & Nahedh (2012), evaluated the influence of the type of ceramic and its thickness on its masking ability. They used three types of A2-colored ceramics with 1mm and 1,5mm thickness: lithium disilicate *IPS e.max® Press* (Ivoclar Vivadent, Schaan, Liechtenstein), feldspathic *Vita VM7* (VITA Zahnfabrik, Bad Säckingen, Germany) and alumina-reinforced *Nobel Rondo Press Alumina: Solo NRPA* (Nobel Biocare, Zurich-Flughafen, Switzerland). Similar to this study, the author concluded that both the thickness and type of ceramic used influence the final colour of the restoration and therefore its masking ability. However, when comparing the disilicate and feldspathic ceramics, contrary to the results of this study, the highest ΔE values corresponded to the disilicate ceramic at 1mm thickness, but at 1,5mm thickness, the highest ΔE values were represented by the feldspathic ceramic, as occurred in this study, although in both thicknesses of ceramic. These differences in results may be due to differences in the brands of ceramics used, as well as the fact that the author did not use any substrate or cement, or even that the ΔE measurement was performed on a black and white background, contrary to the methodology of this study (Shono & Nahedh, 2012).

Based on the results obtained, it is also possible to observe that the cement that causes the greatest colour change to the base is *Veneer WO*, compared to the other two studied cements, regardless of the colour of the base, type of ceramic and thickness used. These results suggest that the opaquer cement has a greater ability to mask the colour of the base, compared to the other two evaluated cements.

When comparing the colour differences (ΔE_{ab3}) caused by *Universal TR* and *Veneer TR* cements, they are not significant, suggesting that the colour change they cause is very similar to each other.

Indeed, opaque cements mask the underlying base colour more effectively than translucent cements due to their optical properties and composition. An opaque cement contains a higher amount of pigments and/or fillers in its composition, resulting in a lower transmission of light through the material. Thus, an opaque cement can block or reflect light more efficiently, preventing it from passing through the material and interacting with the underlying base colour. This makes the base colour less noticeable and, therefore, more camouflaged by the opaque cement. On the other hand, a translucent cement allows more light to pass through, enabling the light to interact more with the base colour. As a result, the base colour has a greater influence on the final appearance of the restoration, being less masked by the translucent cement (Carrabba et al., 2020; Pissaia et al., 2019; Zhou et al., 2022).

Hernandes et al. (2016), in their study, evaluated the influence of cement colour on the final colour of ceramic restorations, using samples of *IPS e.max® Press* (Ivoclar Vivadent, Schaan, Liechtenstein) lithium disilicate ceramic in A2 shade with 1mm thickness and *Variolink II* low viscosity cement (Ivoclar Vivadent, Schaan, Liechtenstein) in A1 and A3 shades. Colour measurements were taken before and after cementation. The author concluded that the use of a darker cement (A3), compared to a lighter cement (A1), caused more pronounced colour changes in the final colour of the ceramic, regardless of its translucency. These results are consistent with the results obtained in the present study, since the values of ΔE were higher when the more opaque cement (*Veneer WO*) was applied, compared to the translucent cements (Hernandes et al., 2016).

Kandil et al. (2019) evaluated the influence of cement colour on the ability to mask the substrate of a ceramic restoration. In their study, the authors used two different types of ceramics with 0,5mm thickness, *Vita Enamic* (Vita Zahnfabrik, Bad Säckingen, Germany) in colour 1M2 and *Vita Suprinity* (Vita Zahnfabrik, Bad Säckingen, Germany) in colour A1 with HT and T translucency. The ceramics were cemented to composite resin bases with 4mm thickness, *Filtek™ Z250* (3M ESPE, Minnesota, USA) in colour C3 with *Relyx™ Veneer* (3M ESPE, Minnesota, USA) cement in colours A1 and *WO*. The colour differences were analysed between the A1 reference samples and the cemented samples. Kandil et al. (2019) concluded in their study that regardless of the type of ceramic used, the resin cement has an influence on the final colour of the restoration. Specifically, the use of an opaquer cement (*WO*), compared to A1 cement, resulted in lower ΔE values, meaning that the colour difference compared to the A1 reference colour was smaller with the opaque cement, suggesting that more opaque cements have greater ability to mask the substrate. These results corroborate the results of the present study (Kandil et al., 2019).

In Begum et al.'s (2014) study, which was described earlier, the author also evaluated the influence of cement on the final colour of ceramic restoration, comparing the colour difference between the substrate and the final restoration, similar to the present study. Using the same cements used in this study, *Relyx™ Veneer translucent* and *opaque*, the author concluded that the colour of the cement also influences the ability to mask the substrate of the restoration, and that the use of an *opaque* cement (*WO*) resulted in a greater colour difference (ΔE) compared to the *translucent* cement, suggesting that opaque cements have a greater ability to mask the substrate, which is consistent with the results obtained in the present study (Begum et al., 2014).

6.2.5. Study of $\Delta \boldsymbol{E}_{00}$

When evaluating the results using the CIEDE2000 system, the materials, in general, follow the same behaviour, as expected.

Based on the results obtained in this study, it is possible to verify that the colour difference (ΔE_{001}) between the initial composite resin sample and the same sample, when a ceramic is added to it, is always perceptible (>1,2) and not acceptable (>2,7), regardless of the colour of the base, type of ceramic, and thickness used. Subsequently, when a cement is added to the previous set, regardless of the type of cement, the colour difference (ΔE_{003}) caused by its addition is always perceptible (>1,2) and not acceptable (>2,7) for both bases, types of ceramic, and thicknesses used.

These results suggest that when adding ceramic to a composite resin base, regardless of the type of ceramic and its thickness, the observed colour difference (ΔE_{00}) is always greater when using an A3 base compared to an A2 base, indicating that the colour of the base influences the final colour of the composite + ceramic set, in other words, starting from a darker base leads to a greater colour change for the same type of added ceramic and thickness. When the samples are cemented, the colour variation (ΔE_{002}) between the initial and cemented samples remains consistent with the bases, except when adding a *VitaBlocs® Mark II* ceramic with a thickness of 0,5mm using the *Universal TR* and *Veneer WO* cements, when adding the same ceramic with a thickness of 0,8mm using the *Veneer WO* cement, and when adding an *IPS e.max®* ceramic with a thickness of 0,8mm using the *Veneer WO* cement, where the different base colours do not show significant changes in the restoration when comparing them for the same type of ceramic, thickness, and cement. This result suggests that the more opaque cement, together with a greater thickness of ceramic, seems to better mask the colour of the base compared to the other materials. This result may also reflect the fact that this variation (ΔE_{002}) corresponds to the influence of the ceramic in conjunction with the cement, so the different bases may have less influence on the final colour of the samples.

Previous studies have also sought to evaluate the influence of substrate colour, ceramic type and thickness, and cement type on the final restoration colour, using the CIEDE2000 system.

Comba et al. (2022) aimed to evaluate the influence of the substrate colour on the final colour of ceramic restorations. In their study, they used a lithium disilicate ceramic, *IPS e.max® CAD* (Ivoclar Vivadent, Schaan, Liechtenstein) LT in colour A2, and a *Katana* zirconia (Kuraray Noritake Dental, Tokyo, Japan) in colour HT12, both with a thickness of 1,2mm. The ceramics were cemented to *Filtek™ Supreme* composite resin (3M ESPE, St. Paul, MN, USA) in colours A2D and A4D, with *RelyX™ Veneer Cement System* (3M ESPE, Minnesota, USA) in *Translucent* (*TR*), *Choice 2* (Bisco Dental, Schaumburg, IL, USA) in *Milky Bright* (MB) resin cements, and with glycerine (control group) as in the present study. The author concluded that the final colour of ceramic restorations can be significantly affected by the colour of the substrate used, regardless of the type of ceramic and cement used, as in the present study. However, when specifically comparing the results between studies, it is found that in the study by Comba et al. (2022), the colour difference values (ΔE_{00}) between the control group and the cemented samples are higher for the lighter base (A2D) compared to the darker base (A4D) for both types of ceramic and cements. These results contradict the results obtained in the present study, where it was found that the colour difference (ΔE_{003}) is higher when considering the darker base (A3), compared to the lighter base (A2), regardless of the ceramic and cement used. These differences in results may be due to differences in methodology, such as different substrate colours, different lithium disilicate ceramic colours used, different brands of opaque cement, and even differences in the colour of the measuring backgrounds (black and white) (Comba et al., 2022).

Șoim et al. (2018) also analysed the influence of the substrate on the final colour of two different ceramics. The author used two pressable ceramics with 1mm thickness, one feldspathic, *VITA PM9* (Vita Zahnfabrik, Germany), with different colours (1M1 T and HT, 1M2 T and HT, and 2M2 T), and one lithium disilicate, *IPS e.max® Press* (Ivoclar Vivadent, Shaan, Liechtenstein), also with different colours (A1 LT, A1 HT, A2HT, B1LT, B1HT). The ceramics were placed on different substrates of *Universal* composite resin (Quadrant Universal LC, Cavex, Holland), in colours A1 and A2 (control group depending on the colour of the ceramic) and A3, A3.5, and A4 (test groups). Colour differences were measured between the ceramic samples on the control bases and the same samples on the test bases. The results obtained in this study suggest that, regardless of the type of ceramic, the greatest colour change (ΔE_{00}) always corresponded to the darker base (A4), compared to the lighter base (A3), which is consistent with the results presented in this study, suggesting that the darker the colour of the base, the greater the influence on the final colour of the ceramic restoration, for both types of ceramics studied (Șoim et al., 2018).

Dede et al. (2017) conducted a study to evaluate the effect of the substrate on the final colour of lithium disilicate restorations. They used *IPS e.max® Press* lithium disilicate ceramic (Ivoclar Vivadent AG) in A2 MO and HT shades, with a thickness of 1,5mm, cemented to five different *Filtek™ Z250* resin composite substrate colours (A1, A2, A3, B2, and C2) with *Crearfil esthetic* cement (Kuraray Medical Inc) in *Translucent* (*TR*), *Universal/A2* (*UN*), and *White Opaque* (*WO*) shades. Colour differences were calculated between the control group (A2 cement and A2 substrate) and the other groups. The author concluded that the substrate colour significantly influences the final colour of ceramic restorations, regardless of the ceramic and cement used and for all substrate colours tested, similar to the results of the present study. However, when comparing the different substrate colours, it was found that there were no significant differences between TR and UN cements. These results partially contradict the results of the present study, as it was found that there are significant differences between using an A2 and A3 base. These differences in results may be due to the fact that Dede et al. (2017) used a much thicker ceramic layer of 1,5mm, which may have camouflaged the substrate colour more, as well as differences in the materials used (Dede et al., 2017).

When comparing the two types of ceramics added to the base, with different thicknesses, it is possible to verify that, regardless of the base, a *VitaBlocs® Mark II* ceramic always shows a greater colour change when compared to an *IPS e.max®* ceramic, regardless of its thickness. Moreover, a ceramic with a greater thickness (0,8mm) also shows a greater colour change compared to a ceramic with a lower thickness (0,5mm), within the same type of ceramic. This behaviour is maintained after cementation, so it can be inferred that the *VitaBlocs® Mark II* ceramic has a greater ability to mask the colour of the base, as well as ceramics with a thickness of 0,8mm, regardless of the cement used and the base. It is important to note that for an A3 base, using the same cement, although the variation between ceramics increases as indicated above in favour of the *VitaBlocs® Mark II* ceramic, these are not statistically significant, suggesting that the A3 base may be creating a balance between the effect of the two ceramics.

Fachinetto et al. (2023) evaluated the influence of the type and thickness of the ceramic on the final colour of the restoration. They used six different types of ceramics in the A1 colour, with thicknesses of 0,5mm, 1mm, and 1,5mm, including the *IPS e.max® CAD* (Ivoclar Vivadent, Schaan, Liechtenstein) HT lithium disilicate ceramic, similar to the present study, and the feldspathic ceramic *CEREC Bloc* (Dentsplay Sirona). The ceramic samples were cemented to different samples of *Filtek™ Z350XT Dentin* (3M, ESPE, MN, USA) composite resin substrate in the A1 (reference), B2, B3, A3, C2, and C3 colours, with try-in pastes in the White Opaque and A1 colours. The results of this study are in line with the results presented in this study, concluding that both the type of ceramic and its thickness have an influence on the final colour of the ceramic restoration (Fachinetto et al., 2023).

Bacchi et al. (2019) also studied the influence of ceramic type on the ability to mask the substrate of ceramic restorations. In their study, they used various ceramics in the A1 shade with a thickness of 1,8mm. Within the group of monolithic ceramics, among others, they used a feldspathic ceramic *CEREC Block* (Vita Zahnfabrik) and a lithium disilicate ceramic *IPS e.max® CAD* LT (Ivoclar Vivadent). The calculation of the colour difference was performed between the ceramic samples bonded with glycerine and between the cemented ceramic samples with try-in pastes in the *White Opaque* (*WO*) shade to *Filtek™ Z350XT Dentin* composite resin bases (3M ESPE, St. Paul, MN, USA) in the A3,5 and A4 shades. Metal bases were also used. Similar to the results obtained in this study, Bacchi et al. (2019)

concluded that the type of ceramic used has an influence on the final colour of the restoration. Furthermore, when analysing the two types of ceramics, it is possible to verify that the feldspathic ceramic presents a greater colour difference (ΔE_{00}), compared to the lithium disilicate ceramic, regardless of the substrate used. These results are in line with the results obtained in this study (Bacchi et al., 2019).

Leevailoj & Sethakamnerd (2017), previously mentioned, also sought to evaluate the influence of the thickness of the lithium disilicate ceramic, among others, on the final colour of the restoration. The author concluded that the thickness of the ceramic has an influence on the final colour of the restoration, regardless of the type of ceramic and base used, suggesting that the masking ability of the ceramic is significantly related to its thickness. These results corroborate the results of the present study (Leevailoj & Sethakamnerd, 2017).

Pires et al. (2017) also evaluated the influence of ceramic thickness on the final colour of the restoration. In their study, they used an *IPS e.max® Press* (Ivoclar Vivadent AG) LT lithium disilicate ceramic in A2 colour with thicknesses of 1,5mm and 2mm. To simulate two different clinical situations, they used an A2 composite resin base and a metal base. The samples were cemented with *Variolink II* cement (Ivoclar Vivadent AG) in *translucent* shade, and colour differences were evaluated between the initial ceramic samples and the ceramic samples joined to the substrates and after cementation. The previous study concluded that ceramic thickness has a significant influence on the final colour of the restoration, suggesting that increasing the thickness may minimize the influence of the base colour. These results are consistent with the results of the present study, in which the ceramic with greater thickness (0,8mm) also demonstrated greater ability to mask the substrate, compared to a smaller thickness (0,5mm) (Pires et al., 2017).

Based on the results obtained, it is possible to see that the cement that causes the greatest colour change to the base is *Veneer WO*, compared to the other two cements studied, regardless of the colour of the base, type of ceramic, and thickness used. These results suggest that the more opaque cement has a greater ability to mask the colour of the base compared to the other two cements evaluated. When comparing the colour differences (ΔE_{003}) caused by *Universal TR* and *Veneer TR* cements, they are not significant, indicating that the colour changes they produce are nearly identical.

Günal-Abduljalil & Ulusoy (2022) evaluated the influence of cement on the final colour of ceramic restorations. They used three different types of A2-colored ceramics, *Vita Enamic* (Vita Zahnfabrik, Bad Säckingen, Germany), *GC Cerasmart* (GC Dental Products Corp, Aichi, Japan), and *Lava Ultimate* (3M, ESPE, St. Paul, MN, USA), with thicknesses of 0,5mm and 1mm. They also fabricated resin cement samples with a thickness of 0,1mm using *Relyx^{TM} Ultimate* resin cement (3M ESPE, St. Paul, MN, USA) in the colours A1, A3O, B05, and TR. The colour differences (ΔE_{00}) were measured between the initial ceramic samples and the ceramic samples bonded with different cements. The results of this study showed that the final colour of ceramic restorations, regardless of the type of ceramic used, was significantly affected by the colour of the cement. Furthermore, the cement that caused the greatest colour alteration (ΔE_{00}) was the more opaque A3O cement, compared to the other cements studied, for all types of ceramics. These results are consistent with those obtained in the present study, as the cement that caused the greatest colour alteration was the *Veneer WO* cement (Günal-Abduljalil & Ulusoy, 2022).

Comba et al. (2022), in their study mentioned above, also aimed to evaluate the effect of cement colour on the final restoration by comparing a *translucent* cement (*TR*) and an *opaque* cement (*MB*). Similar to the results obtained in this study, Comba et al. (2022) also showed that the opaquer cement (*MB*) had a greater influence on the colour change of the final restoration compared to the *translucent* cement (*TR*), regardless of the type of ceramic and colour of the substrate used. This suggests that the cement colour significantly influences the final aesthetic outcome of the restoration and that the more opaque cement has a greater ability to mask the substrate colour (Comba et al., 2022).

According to Carrabba et al. (2020), the influence of the cement on the final colour of the restoration was also studied. They used a *VitaBlocs$^{®}$ Mark II* feldspar ceramic (Vita Zahnfabrik, Bad Säckingen, Germany) in the colour 2M2 with thicknesses of 0,5mm, 1mm, 1,5mm and 2mm. The ceramic samples were cemented to *Herculite XRV Ultra Dentine* composite resin samples (Kerr Italia s.r.l., Scafati SA, Italy) in the colour A2 with *Maxcem Elite* resin cements (Kerr Italia s.r.l., Scafati SA, Italy) in five different colours (clear, white, yellow, brown and white opaque). The colour difference (ΔE_{00}) was analysed between the samples bonded with glycerine and the samples cemented with the different cements. The results of this study suggest that the cement significantly influences the final restoration colour, and the more opaque cement (white opaque) causes greater colour change (ΔE_{00}) compared to the other cements studied, which corroborates the results presented in this study. Carrabba et al. (2020) also suggest that the use of an opaquer cement seems to be a good option for restorations where there is a large difference between the desired final colour and the initial colour, having a greater capacity to camouflage the colour of the base, compared to a translucent cement (Carrabba et al., 2020).

The most opaque layer of these types of cements appears to influence the light that is transmitted through the restoration, reflecting mostly its spectral composition (Carrabba et al., 2020).

Although the studies by Carrabba et al. (2020) and Comba et al. (2022) identified the opaque cement as the one that causes the greatest colour alteration, when evaluating the data presented by the authors, the colour alteration value is higher than that of the translucent cements, which does not match the results obtained in the present study. The authors' results do not specifically specify the path of the L*a*b* coordinates along the applied transformations, making direct comparison between the studies complex. In the present study, the colour alteration values of the ceramic with glycerine on the base for the cemented samples revealed a lower colour alteration value for the more opaque cement. However, this cement from the starting point of the base to the cemented sample presented the greatest colour alteration. This behaviour is justified by the fact that the L*a*b* coordinates are closer between samples with glycerine and cemented samples, that is, the coordinates associated with the more opaque cement are three-dimensionally higher than the coordinates of the translucent cements, thus manifesting greater alteration to the base.

Table 82. General framework of the results and considerations obtained

		Base	Ceramic	Thickness	Cement
L^*	**highest**	A2	VitaBlocs® Mark II	0,8mm	Veneer WO
	lowest	A3	IPS e.max®	0,5mm	Universal TR
a^*	**reddish**	A3	IPS e.max®	0,5mm	Universal TR
	greenish	A2	VitaBlocs® Mark II	0,8mm	Veneer WO
b^*	**yellowish**	A3	IPS e.max®	0,5mm	Universal TR
	blueish	A2	VitaBlocs® Mark II	0,8mm	Veneer WO
ΔE_{ab}	**highest**	A3	VitaBlocs® Mark II	0,8mm	Veneer WO
	lowest	A2	IPS e.max®	0,5mm	Universal TR
ΔE_{00}	**highest**	A3	VitaBlocs® Mark II	0,8mm	Veneer WO
	lowest	A2	IPS e.max®	0,5mm	Universal TR

After discussing the outcomes of L*a*b* and ΔE, it is necessary to provide an overview of the work, necessary to transform this *in vitro* study into clinical practice guidelines. In this way, evaluating the different characteristics of the studied variables and observing Table 82, it is possible to conclude that greater luminosity will always be achieved on a lighter base (A2) to the detriment of a darker one, and by applying a thicker (0,8mm) feldspathic ceramic (*VitaBlocs® Mark II*) with an opaquer cement (*Veneer WO*). To achieve more reddish and yellowish tones, the optimal base is always the darkest (A3) with a thinner (0,5mm) lithium disilicate ceramic (*IPS e.max®*) and more translucent cement (*Universal TR*). If the objective is a less reddish and more bluish tone, however, a lighter base (A2) should ideally be used (or the existing base should be clinically transformed through bleaching), along with a thicker (0,8mm) feldspathic ceramic (*VitaBlocs® Mark II*) and an opaquer cement (*Veneer WO*). Regarding the colour change caused by ceramics and cements studied, the feldspathic (*VitaBlocs® Mark II*) ceramic with a greater thickness (0,8mm) and cemented with an opaquer cement (*Veneer WO*) causes the greatest colour change. Considering the results of the study, lightness (L*) has a greater impact on colour change as considered by Skyllouriotis et al. (2017) and Rafael et al. (2017) (Rafael et al., 2017; Skyllouriotis et al., 2017).

The experiment results provide sufficient evidence to reject the null hypothesis (H_0) that "the aesthetic outcome of the studied glass ceramics is not influenced by the cement, the ceramic type and thickness, and the substrate colour". Therefore, we can accept with confidence the alternative hypothesis ($H1_1$) that "the aesthetic outcome of the studied glass ceramics is influenced by the cement, the ceramic type and thickness, and the substrate colour" and proceed with further research in this area.

VII – CONCLUSIONS

VII - CONCLUSIONS

The objective of this study was to investigate the aesthetic outcome of glass ceramic restorations of various thicknesses cemented to composite resin substrates of different shades with multiple cements. The results of this research have important implications for the field of restorative dentistry, as they shed light on the factors that affect the aesthetic outcome of glass ceramic restorations. It contributes to the understanding of the complex relationship between material properties, shade matching, and cement selection in achieving optimal aesthetic outcomes in dental restorations. In this way, it can be concluded that:

1. The aesthetic outcome of glass ceramic restorations can be influenced by a variety of factors, including the ceramic type and thickness, the cement colour used, and the shade of the substrate.

2. In order to achieve absolute success in an aesthetic case, it is important to correctly understand and evaluate the base colour of the teeth used as a substrate since this has an influence on the choice of ceramic type, thickness, and cements to be used.

3. The choice to use a *VitaBlocs® Mark II* or *IPS e.max®* ceramic will depend on the final aesthetic effect that the clinician intends to achieve based on the patient's expectations. Both of ceramics have excellent optical properties and the capacity to mask a substrate. The *VitaBlocs® Mark II* seems to have better masking ability and higher luminosity.

4. Whether *VitaBlocs® Mark II* or *IPS e.max®*, the greater the thickness of the ceramic, the greater its ability to exhibit its optical properties and thus optimise its performance. A 0,8mm thickness provides better masking ability and higher

luminosity in any of the studied ceramics, with *VitaBlocs® Mark II* showing proportionally greater performance.

5. Cement selection is a crucial clinical decision that has a significant impact on the treatment's final success. It must be based on the substrate colour, the type of ceramic employed, and the required thickness, as well as the clinician's preparation. When the objective is to mask the substrate, emphasizing the characteristics of the ceramics placed, *Veneer WO* cement will be a better solution. *Universal TR* and *Veneer TR* are excellent options when the aesthetic challenge is not so demanding. Furthermore, *Veneer WO* cement also exhibit higher luminosity compared to *Universal TR* and *Veneer TR* cements.

6. Although its optical properties are similar to *Veneer TR*, the new *Universal TR* cement appears to be a good clinical option.

VIII – LIMITATIONS AND FUTURE WORK

VIII - LIMITATIONS AND FUTURE WORK

8.1. LIMITATIONS

This study has limitations that must be taken into account for a comprehensive and correct understanding of the findings.

First, as an *in vitro* study, despite having control over the majority of experimental factors, it cannot fully replicate the oral cavity conditions and patient-specific requirements to which ceramic restorations are subjected on a daily basis. Therefore, the results obtained in an *in vivo* environment may differ.

This investigation was limited to the examination of two types of ceramics (*VitaBlocs® Mark II* and *IPS e.max®*) and three distinct cements. It is not possible to generalize the findings to all available materials because there are numerous more varieties and hues of cements on the market, as well as different types of ceramics that may not exhibit the same outcomes as those found in this study.

Also, the number of samples and dental materials used in this study, even though sufficient for a statistical analysis, may not be representative of the numerous existing clinical situations and different scenarios found in clinical practice.

The fact that a control group was not used, such as a predefined colour objective, limits the evaluation of the results between the samples and not comparatively to the objective colour. This allows understanding the differences between the various materials used but does not offer a concrete clinical answer to reach a concrete objective in terms of colour.

The fact that long-term colour stability was not evaluated lacks information about the behaviour of materials over their lifetime, offering only results relative to their immediate behaviour. Factors such as deterioration, pigmentation, and patient satisfaction over time can influence the aesthetic success of the restoration.

Finally, the use of a single measurement method also limits the results obtained, as it provides a restricted measurement technique, generalized to the measurement instrument itself and considering its inherent limitations. Each method has its own set of limitations, by using a single method, the results are limited by its technical constraints. The use of multiple methods can help ensure that the results are robust and applicable in a variety of settings.

8.2. FUTURE WORK

The results obtained in the present study, through the analysis of the aesthetic outcome of ceramic restorations, provided a solid foundation for future studies in the field of restorative dentistry. Dental aesthetics is one of the most sought-after topics today, both by health professionals and patients who are increasingly seeking to achieve an ideal aesthetic result. Based on the conclusions obtained in this study, it is relevant to mention some of its future perspectives:

1. **Ceramic Type and Thickness:** Future studies may investigate the optical properties of other types of ceramics used in aesthetic restorations, as well as different thicknesses. This could lead to a more detailed understanding of the influence of the ceramic on the final aesthetic outcome.
2. **Substrate Colour:** The present study highlighted the influence of the initial substrate colour on the final colour of the ceramic restoration. Future studies may focus on the development or refinement of techniques for assessing substrate colour, which could lead to a more precise selection of ceramics and cement, improving the final aesthetic outcome. Future studies could also study the influence of different base colours in obtaining the desired final colour, initially defined, understanding the necessary cement and ceramic colour to achieve the target colour, which will become an added value at the clinical level.
3. **Dental Cements:** New studies could be done to cover other types, colours, and brands of cements available on the market, as well as new cements that continue to be manufactured, deepening the study of their optical

properties. Future studies could also be done to assess the influence of the cement alone, understanding its influence on the final aesthetic outcome.

4. **Patient-adapted dental aesthetics:** Future studies may focus on more specific patient groups, divided by various factors such as age, lifestyle, cultural aspects, and personal preferences, creating a personalized aesthetic guide for each type of patient to achieve an individualized aesthetic result.
5. **Technological Advances:** Considering the rapid technological advances, future studies should consider the new digital resources available on the market. This could include digital shade matching, CAD/CAM technology, and virtual simulations that may aid in achieving better aesthetic results. Nowadays, there are some cement brands that provide try-in pastes to improve clinical decision-making in achieving a target colour. In light of the above considerations, it would be of clinical interest to conceptualize and develop an innovative device. This apparatus, guided by a user-specified target colour, would be designed with the capacity to systematically determine the most suitable type of ceramic and cement to apply in order to achieve the pre-determined colour. Such an advancement could significantly enhance the precision and efficacy of colour matching in diverse applications, potentially introducing a paradigm shift in the field.
6. **Longitudinal Studies:** Longitudinal studies could help to understand the durability and longevity of different ceramics, cements, and techniques over time. This would provide a clearer picture of long-term aesthetic success and patient satisfaction.
7. **Optical Properties:** Lastly, future studies may also focus on evaluating different optical properties such as translucency, opalescence, and fluorescence which will deepen the study and achievement of an improved aesthetic outcome of ceramic restorations.

Summary, this study has created a few avenues for future research, which promises to significantly advance the field of aesthetic restorative dentistry. With the goal of enhancing patient outcomes and satisfaction, the potential for new discoveries and breakthroughs is vast and exciting.

IX – BIBLIOGRAPHICAL REFERENCES

IX - BIBLIOGRAPHICAL REFERENCES

3M. (2021). *STEP-BY-STEP 3M ™ RelyX ™ Universal Resin Cement [Brochure].* https://www.3m.com.pt/3M/pt_PT/dental-pt/produtos/cimentos/relyx-universal/

Aboushelib, M. N., & Sleem, D. (2014). Microtensile bond strength of lithium disilicate ceramics to resin adhesives. *The Journal of Adhesive Dentistry*, *16*(6), 547–552. https://doi.org/10.3290/j.jad.a33249

Ahn, J.-S., & Lee, Y.-K. (2008). Color distribution of a shade guide in the value, chroma, and hue scale. *The Journal of Prosthetic Dentistry*, *100*(1), 18–28. https://doi.org/10.1016/S0022-3913(08)60129-8

Alayad, A. S., Alqhatani, A., Alkatheeri, M. S., Alshehri, M., AlQahtani, M. A., Osseil, A. E. Bin, & Almusallam, R. A. (2021). Effects of CAD/CAM ceramics and thicknesses on translucency and color masking of substrates. *The Saudi Dental Journal*, *33*(7), 761–768. https://doi.org/10.1016/j.sdentj.2020.03.011

Alghazzawi, T. F., Lemons, J., Liu, P.-R., Essig, M. E., & Janowski, G. M. (2012). Evaluation of the optical properties of CAD-CAM generated yttria-stabilized zirconia and glass-ceramic laminate veneers. *The Journal of Prosthetic Dentistry*, *107*(5), 300–308. https://doi.org/10.1016/S0022-3913(12)60079-1

Alla, R. (2013). *Dental Materials Science*. Jaypee Brothers Medical Publishers (P) Ltd. https://doi.org/10.5005/jp/books/12018

Al-Wahadni, A. (1999). The Roots of Dental Porcelain: a Brief Historical Perspective. *Dental News*, *6*(2), 43–44.

Anusavice, K. J., Shen, C., & Rawls, H. R. (2013). *Philips' science of dental materials* (12th ed.). Saunders.

Araujo, E., & Perdigão, J. (2021). Anterior Veneer Restorations - An Evidence-based Minimal-Intervention Perspective. *The Journal of Adhesive Dentistry*, *23*(2), 91–110. https://doi.org/10.3290/j.jad.b1079529

Archegas, L. R. P., Freire, A., Vieira, S., Caldas, D. B. de M., & Souza, E. M. (2011). Colour stability and opacity of resin cements and flowable composites for ceramic veneer luting after accelerated ageing. *Journal of Dentistry*, *39*(11), 804–810. https://doi.org/10.1016/j.jdent.2011.08.013

Arikawa, H., Kanie, T., Fujii, K., takahashi, H., & Ban, S. (2007). Effect of Filler Properties in Composite Resins on Light Transmittance Characteristics and Color. *Dental Materials Journal*, *26*(1), 38–44. https://doi.org/10.4012/dmj.26.38

Azer, S. S., Rosenstiel, S. F., Seghi, R. R., & Johnston, W. M. (2011). Effect of substrate shades on the color of ceramic laminate veneers. *The Journal of Prosthetic Dentistry*, *106*(3), 179–183. https://doi.org/10.1016/S0022-3913(11)60117-0

Babu, P. J., Alla, R. K., Alluri, V. R., Datla, S. R., & Konakanchi, A. (2015). Dental Ceramics: Part I – An Overview of Composition, Structure and Properties. *American Journal of Materials Engineering and Technology*, *3*(1), 13–18. https://doi.org/10.12691/materials-3-1-3

Bacchi, A., Boccardi, S., Alessandretti, R., & Pereira, G. K. R. (2019). Substrate masking ability of bilayer and monolithic ceramics used for complete crowns and the effect of association with an opaque resin-based luting agent. *Journal of Prosthodontic Research*, *63*(3), 321–326. https://doi.org/10.1016/j.jpor.2019.01.005

Bacchi, A., & Cesar, P. F. (2022). Advances in Ceramics for Dental Applications. *Dental Clinics of North America*, *66*(4), 591–602. https://doi.org/10.1016/j.cden.2022.05.007

Bahannan, S. A. (2014). Shade matching quality among dental students using visual and instrumental methods. *Journal of Dentistry*, *42*(1), 48–52. https://doi.org/10.1016/j.jdent.2013.11.001

Baldissara, P., Wandscher, V. F., Marchionatti, A. M. E., Parisi, C., Monaco, C., & Ciocca, L. (2018). Translucency of IPS e.max and cubic zirconia monolithic crowns. *Journal of Prosthetic Dentistry*, *120*(2), 269–275. https://doi.org/10.1016/j.prosdent.2017.09.007

Barbon, F. J., Moraes, R. R., Isolan, C. P., Spazzin, A. O., & Boscato, N. (2019). Influence of inorganic filler content of resin luting agents and use of adhesive on the performance of bonded ceramic. *The Journal of Prosthetic Dentistry*, *122*(6), 566.e1-566.e11. https://doi.org/10.1016/j.prosdent.2019.09.013

Baroudi, K., & Ibraheem, S. N. (2015). Assessment of Chair-side Computer-Aided Design and Computer-Aided Manufacturing Restorations: A Review of the Literature. *Journal of International Oral Health : JIOH*, *7*(4), 96–104.

Battersby, P. D., & Battersby, S. J. (2015). Measurements and modelling of the influence of dentine colour and enamel on tooth colour. *Journal of Dentistry*, *43*(3), 373–381. https://doi.org/10.1016/j.jdent.2014.11.003

Beckman, A. O., Gallaway, W. S., Kaye, W., & Ulrich, W. F. (1977). History of spectrophotometry at Beckman Instruments, Inc. *Analytical Chemistry*, *49*(3), 280A-300A. https://doi.org/10.1021/ac50011a001

Begum, Z., Chheda, P., Shruthi, C. S., & Sonika, R. (2014). Effect of Ceramic Thickness and Luting Agent Shade on the Color Masking Ability of Laminate Veneers. *The Journal of Indian Prosthodontic Society*, *14*(S1), 46–50. https://doi.org/10.1007/s13191-014-0362-2

Burgess, J. O. (2018). Zirconia: The Material, Its Evolution, and Composition. *Compendium of Continuing Education in Dentistry (Jamesburg, N.J. : 1995)*, *39*(suppl 4), 4–8.

Byeon, S.-M., & Song, J.-J. (2018). Mechanical Properties and Microstructure of the Leucite-Reinforced Glass-Ceramics for Dental CAD/CAM. *Journal of Dental Hygiene Science*, *18*(1), 42–49. https://doi.org/10.17135/jdhs.2018.18.1.42

Calgaro, P. A. M., Furuse, A. Y., Correr, G. M., Ornaghi, B. P., & Gonzaga, C. C. (2014). Post-cementation colorimetric evaluation of the interaction between the thickness of ceramic veneers and the shade of resin cement. *American Journal of Dentistry*, *27*(4), 191–194. http://www.ncbi.nlm.nih.gov/pubmed/25831601

Cardenas, A. M., Siqueira, F., Hass, V., Malaquias, P., Gutierrez, M. F., Reis, A., Perdigão, J., & Loguercio, A. (2017). Effect of MDP-containing Silane and Adhesive Used Alone or in Combination on the Long-term Bond Strength and Chemical Interaction with Lithium Disilicate Ceramics. *The Journal of Adhesive Dentistry*, *19*(3), 203–212. https://doi.org/10.3290/j.jad.a38414

Carrabba, M., Vichi, A., Tozzi, G., Louca, C., & Ferrari, M. (2020). Cement opacity and color as influencing factors on the final shade of metal-free ceramic restorations. *Journal of Esthetic and Restorative Dentistry*, *34*(2), 423–429. https://doi.org/10.1111/jerd.12587

Catelan, A., Guedes, A. P. A., Suzuki, T. Y. U., Takahashi, M. K., De Souza, E. M., Briso, A. L. F., & Dos Santos, P. H. (2015). Fluorescence intensity of composite layering combined with surface sealant submitted to staining solutions. *Journal of Esthetic and Restorative Dentistry*, *27*(S1), S33–S40. https://doi.org/10.1111/jerd.12139

Çelik, E., Sahin, S. C., & Dede, D. Ö. (2018). Shear Bond Strength of Nanohybrid Composite to the Resin Matrix Ceramics After Different Surface Treatments. *Photomedicine and Laser Surgery*, *36*(8), 424–430. https://doi.org/10.1089/pho.2018.4467

Chaiyabutr, Y., Kois, J. C., Lebeau, D., & Nunokawa, G. (2011). Effect of abutment tooth color, cement color, and ceramic thickness on the resulting optical color of a CAD/CAM glass-ceramic lithium disilicate-reinforced crown. *The Journal of Prosthetic Dentistry*, *105*(2), 83–90. https://doi.org/10.1016/S0022-3913(11)60004-8

Chang, J., Da Silva, J. D., Sakai, M., Kristiansen, J., & Ishikawa-Nagai, S. (2009). The optical effect of composite luting cement on all ceramic crowns. *Journal of Dentistry*, *37*(12), 937–943. https://doi.org/10.1016/j.jdent.2009.07.009

Chen, H., Huang, J., Dong, X., Qian, J., He, J., Qu, X., & Lu, E. (2012). A systematic review of visual and instrumental measurements for tooth shade matching. *Quintessence International (Berlin, Germany : 1985)*, *43*(8), 649–659.

Chen, X.-D., Hong, G., Xing, W.-Z., & Wang, Y.-N. (2015). The influence of resin cements on the final color of ceramic veneers. *Journal of Prosthodontic Research*, *59*(3), 172–177. https://doi.org/10.1016/j.jpor.2015.03.001

Chen, Y.-M., Smales, R. J., Yip, K. H.-K., & Sung, W.-J. (2008). Translucency and biaxial flexural strength of four ceramic core materials. *Dental Materials*, *24*(11), 1506–1511. https://doi.org/10.1016/j.dental.2008.03.010

Chu, S., & Ahmad, I. (2005). A historical perspective of synthetic ceramic and traditional feldspathic porcelain. *Practical Procedures & Aesthetic Dentistry : PPAD*, *17*(9), 593–598; quiz 600.

Chu, S. J., Trushkowsky, R. D., & Paravina, R. D. (2010). Dental color matching instruments and systems. Review of clinical and research aspects. *Journal of Dentistry*, *38*(SUPPL. 2). https://doi.org/10.1016/j.jdent.2010.07.001

Colares, R. C. R., Neri, J. R., Souza, A. M. B. de, Pontes, K. M. de F., Mendonca, J. S., & Santiago, S. L. (2013). Effect of Surface Pretreatments on the Microtensile Bond Strength of Lithium-Disilicate Ceramic Repaired with Composite Resin. *Brazilian Dental Journal*, *24*(4), 349–352. https://doi.org/10.1590/0103-6440201301960

Colormine. (n.d.). *CIE2000 Calculator [Computer Software]*. Retrieved March 5, 2023, from http://colormine.org/delta-e-calculator/cie2000

Comba, A., Paolone, G., Baldi, A., Vichi, A., Goracci, C., Bertozzi, G., & Scotti, N. (2022). Effects of Substrate and Cement Shade on the Translucency and Color of CAD/CAM Lithium-Disilicate and Zirconia Ceramic Materials. *Polymers*, *14*(9), 1778. https://doi.org/10.3390/polym14091778

Conrad, H. J., Seong, W.-J., & Pesun, I. J. (2007). Current ceramic materials and systems with clinical recommendations: A systematic review. *The Journal of Prosthetic Dentistry*, *98*(5), 389–404. https://doi.org/10.1016/S0022-3913(07)60124-3

Cuevas-Suárez, C. E., de Oliveira da Rosa, W. L., Vitti, R. P., da Silva, A. F., & Piva, E. (2020). Bonding Strength of Universal Adhesives to Indirect Substrates: A Meta-Analysis of in Vitro Studies. *Journal of Prosthodontics*, *29*(4), 298–308. https://doi.org/10.1111/jopr.13147

Czigola, A., Abram, E., Kovacs, Z. I., Marton, K., Hermann, P., & Borbely, J. (2019). Effects of substrate, ceramic thickness, translucency, and cement shade on the color of CAD/CAM lithium-disilicate crowns. *Journal of Esthetic and Restorative Dentistry*, *31*(5), 457–464. https://doi.org/10.1111/jerd.12470

Rosa, L. S., Dapieve, K. S., Dalla-Nora, F., Rippe, M. P., Valandro, L. F., Sarkis-Onofre, R., & Pereira, G. K. R. (2022). Does Adhesive Luting Reinforce the Mechanical Properties of Dental Ceramics Used as Restorative Materials? A Systematic Review and Meta-Analysis. *The Journal of Adhesive Dentistry*, *24*(1), 209–222. https://doi.org/10.3290/j.jad.b2916469

Da Silva, J. D., Park, S. E., Weber, H.-P., & Ishikawa-Nagai, S. (2008). Clinical performance of a newly developed spectrophotometric system on tooth color reproduction. *The Journal of Prosthetic Dentistry*, *99*(5), 361–368. https://doi.org/10.1016/S0022-3913(08)60083-9

Dapieve, K. S., Pilecco, R. O., Temp, R. W., Villetti, M. A., Pereira, G. K. R., & Valandro, L. F. (2023). Adhesion to lithium disilicate glass-ceramics after aging: Resin viscosity and ceramic surface treatment effects. *Journal of the Mechanical Behavior of Biomedical Materials*, *142*, 105819. https://doi.org/10.1016/j.jmbbm.2023.105819

Dede, D. Ö., Ceylan, G., & Yilmaz, B. (2017). Effect of brand and shade of resin cements on the final color of lithium disilicate ceramic. *The Journal of Prosthetic Dentistry*, *117*(4), 539–544. https://doi.org/10.1016/j.prosdent.2016.07.014

Deubener, J., Allix, M., Davis, M. J., Duran, A., Höche, T., Honma, T., Komatsu, T., Krüger, S., Mitra, I., Müller, R., Nakane, S., Pascual, M. J., Schmelzer, J. W. P., Zanotto, E. D., & Zhou, S. (2018). Updated definition of glass-ceramics. *Journal of Non-Crystalline Solids*, *501*, 3–10. https://doi.org/10.1016/j.jnoncrysol.2018.01.033

Douglas, R. D., Steinhauer, T. J., & Wee, A. G. (2007). Intraoral determination of the tolerance of dentists for perceptibility and acceptability of shade mismatch. *The Journal of Prosthetic Dentistry*, *97*(4), 200–208. https://doi.org/10.1016/j.prosdent.2007.02.012

Dozic, A., Tsagkari, M., Khashayar, G., & Aboushelib, M. (2010). Color management of porcelain veneers: influence of dentin and resin cement colors. *Quintessence International (Berlin, Germany : 1985)*, *41*(7), 567–573. http://www.ncbi.nlm.nih.gov/pubmed/20614043

El-Damanhoury, H. M., & Gaintantzopoulou, M. D. (2018). Self-etching ceramic primer versus hydrofluoric acid etching: Etching efficacy and bonding performance. *Journal of Prosthodontic Research*, *62*(1), 75–83. https://doi.org/10.1016/j.jpor.2017.06.002

El-Mowafy, O., El-Aawar, N., & El-Mowafy, N. (2018). Porcelain veneers: An update. *Dental and Medical Problems*, *55*(2), 207–211. https://doi.org/10.17219/dmp/90729

Fachinetto, E., Chiapinotto, G., Barreto, V., Pereira, G., & Bacchi, A. (2023). Masking ability of CAD-CAM monolithic ceramics: effect of ceramic type and thickness, and try-in paste shade. *Quintessence Int*. https://doi.org/10.3290/j.qi.b3964073

Farias-Neto, A., de Medeiros, F. C. D., Vilanova, L., Simonetti Chaves, M., & Freire Batista de Araújo, J. J. (2019). Tooth preparation for ceramic veneers: when less is more. *The International Journal of Esthetic Dentistry*, *14*(2), 156–164. http://www.ncbi.nlm.nih.gov/pubmed/31061996

Federizzi, L., Gomes, É. A., Báratro, S. S. P., Baratto-Filho, F., Bacchi, A., & Spazzin, A. O. (2016). Use of Feldspathic Porcelain Veneers to Improve Smile Harmony: A 3-Year Follow-up Report. *Brazilian Dental Journal*, *27*(6), 767–774. https://doi.org/10.1590/0103-6440201602453

Ferracane, J. L., Stansbury, J. W., & Burke, F. J. T. (2011). Self-adhesive resin cements - chemistry, properties and clinical considerations. *Journal of Oral Rehabilitation*, *38*(4), 295–314. https://doi.org/10.1111/j.1365-2842.2010.02148.x

Fleming, G. J. P., & Addison, O. (2009). Adhesive Cementation and the Strengthening of All-Ceramic Dental Restorations. *Journal of Adhesion Science and Technology*, *23*(7–8), 945–959. https://doi.org/10.1163/156856109X440119

Fonzar, R. F., Goracci, C., Carrabba, M., Louca, C., Ferrari, M., & Vichi, A. (2020). Influence of Acid Concentration and Etching Time on Composite Cement Adhesion to Lithium-silicate Glass Ceramics. *The Journal of Adhesive Dentistry*, *22*(2), 175–182. https://doi.org/10.3290/j.jad.a44282

Ghinea, R., Pérez, M. M., Herrera, L. J., Rivas, M. J., Yebra, A., & Paravina, R. D. (2010). Color difference thresholds in dental ceramics. *Journal of Dentistry*, *38*, e57–e64. https://doi.org/10.1016/j.jdent.2010.07.008

Giordano, R. (2022). Ceramics overview. *British Dental Journal*, *232*(9), 658–663. https://doi.org/10.1038/s41415-022-4242-6

Giordano, R., & McLaren, E. A. (2010). Ceramics overview: classification by microstructure and processing methods. *Compendium of Continuing Education in Dentistry*, *31*(9), 682–697. http://www.ncbi.nlm.nih.gov/pubmed/21197937

Gomes, E. A., Assunção, W. G., Rocha, E. P., & Santos, P. H. (2008). Cerâmicas odontológicas: o estado atual. *Cerâmica*, *54*(331), 319–325. https://doi.org/10.1590/S0366-69132008000300008

Gracis, S., Thompson, V., Ferencz, J., Silva, N., & Bonfante, E. (2015). A New Classification System for All-Ceramic and Ceramic-like Restorative Materials. *The International Journal of Prosthodontics*, *28*(3), 227–235. https://doi.org/10.11607/ijp.4244

Gugelmin, B. P., Miguel, L. C. M., Baratto Filho, F., Cunha, L. F. da, Correr, G. M., & Gonzaga, C. C. (2020). Color Stability of Ceramic Veneers Luted With Resin Cements and Pre-Heated Composites: 12 Months Follow-Up. *Brazilian Dental Journal*, *31*(1), 69–77. https://doi.org/10.1590/0103-6440202002842

Guimarães, H. A. B., Cardoso, P. C., Decurcio, R. A., Monteiro, L. J. E., de Almeida, L. N., Martins, W. F., & Magalhães, A. P. R. (2018). Simplified Surface Treatments for Ceramic Cementation: Use of Universal Adhesive and Self-Etching Ceramic Primer. *International Journal of Biomaterials*, *2018*, 1–7. https://doi.org/10.1155/2018/2598073

Günal-Abduljalil, B., & Ulusoy, M. M. (2022). The effect of resin cement shade and restorative material type and thickness on the final color of resin-matrix ceramics. *Journal of Prosthodontic Research*, *66*(1), JPR_D_20_00138. https://doi.org/10.2186/jpr.JPR_D_20_00138

Heboyan, A., Vardanyan, A., Karobari, M. I., Marya, A., Avagyan, T., Tebyaniyan, H., Mustafa, M., Rokaya, D., & Avetisyan, A. (2023). Dental Luting Cements: An Updated Comprehensive Review. *Molecules*, *28*(4), 1619. https://doi.org/10.3390/molecules28041619

Heintze, S. D., Rousson, V., & Mahn, E. (2015). Bond strength tests of dental adhesive systems and their correlation with clinical results - A meta-analysis. *Dental Materials*, *31*(4), 423–434. https://doi.org/10.1016/j.dental.2015.01.011

Helvey, G. (2010). Ceramics. *Compendium of Continuing Education in Dentistry (Jamesburg, N.J. : 1995)*, *31*(4), 309–311.

Hernandes, D. K. L., Arrais, C. A. G., Lima, E. de, Cesar, P. F., & Rodrigues, J. A. (2016). Influence of resin cement shade on the color and translucency of ceramic veneers. *Journal of Applied Oral Science*, *24*(4), 391–396. https://doi.org/10.1590/1678-775720150550

Heymann, H., Swift, E. J., Ritter, A. V, & Sturdevant, C. M. (2013). *Sturdevant's art and science of operative dentistry*. Elsevier .

Hilton, T. J., Ferracane, J. L., & Broome, J. (2013). *Fundamentals of Operative Dentistry: A Contemporary Approach*. Quintessence Publishing Co. Inc.

Ho, G. W., & Matinlinna, J. P. (2011). Insights on Ceramics as Dental Materials. Part I: Ceramic Material Types in Dentistry. *Silicon*, *3*(3), 109–115. https://doi.org/10.1007/s12633-011-9078-7

Hoorizad, M., Valizadeh, S., Heshmat, H., Tabatabaei, S. F., & Shakeri, T. (2021). Influence of resin cement on color stability of ceramic veneers: in vitro study . *Biomaterial Investigations in Dentistry*, *8*(1), 11–17. https://doi.org/10.1080/26415275.2020.1855077

Igiel, C., Weyhrauch, M., Mayer, B., Scheller, H., & Lehmann, K. M. (2018). Effects of ceramic layer thickness, cement color, and abutment tooth color on color reproduction of feldspathic veneers. *The International Journal of Esthetic Dentistry*, *13*(1), 110–119. http://www.ncbi.nlm.nih.gov/pubmed/29379907

International Commission on Illumination [CIE]. (2001). *CIE 142: Improvement to Industrial Colour-Difference evaluation*.

International Commission on Illumination [CIE]. (2004). *CIE 15: Technical Report: Colorimetry, 3rd edition*. Commission Internationale de l'Eclairage.

International Organization for Standardization [ISO]. (2015). *ISO 6872:2015 Dentistry - Ceramic Materials*. https://www.iso.org/standard/59936.html

International Organization for Standardization [ISO]. (2016). *ISO/TR 28642:2016 Dentistry — Guidance on colour measurement*. www.iso.org

International Organization for Standardization [ISO]. (2022). *ISO/CIE 11664-6 Colorimetry-Part 6: CIEDE2000 colour-difference formula*.

Iorizzo, G. M., Prete, F., Mazzanti, B., Timellini, G., Scotti, R., & Baldissara, P. (2014). Effects of hydrofluoric acid etching on lithium disilicate. *Dental Materials*, *30*, e24. https://doi.org/10.1016/j.dental.2014.08.049

Johnston, W. M. (2009). Color measurement in dentistry. *Journal of Dentistry*, *37*(SUPPL. 1), e2–e6. https://doi.org/10.1016/j.jdent.2009.03.011

Johnston, W. M., Hesse, N. S., Davis1, B. K., & Seghi, R. R. (1996). Analysis of Edge-losses in Reflectance Measurements of Pigmented Maxillofacial Elastomer. In *J Dent Res* (Vol. 75, Issue 2).

Joiner, A. (2004). Tooth colour: a review of the literature. *Journal of Dentistry*, *32 Suppl 1*(SUPPL.), 3–12. https://doi.org/10.1016/j.jdent.2003.10.013

Joiner, A., & Luo, W. (2017). Tooth colour and whiteness: A review. *Journal of Dentistry*, *67*, S3–S10. https://doi.org/10.1016/j.jdent.2017.09.006

Kalavacharla, V., Lawson, N., Ramp, L., & Burgess, J. (2015). Influence of Etching Protocol and Silane Treatment with a Universal Adhesive on Lithium

Disilicate Bond Strength. *Operative Dentistry, 40*(4), 372–378. https://doi.org/10.2341/14-116-L

Kandil, B. S. M., Hamdy, A. M., Aboelfadl, A. K., & El-Anwar, M. I. (2019). Effect of ceramic translucency and luting cement shade on the color masking ability of laminate veneers. *Dental Research Journal, 16*(3), 193–199. http://www.ncbi.nlm.nih.gov/pubmed/31040876

Kaur, K., Talibi, M., & Parmar, H. (2022a). Do you know your ceramics? Part 3: lithium disilicate. *British Dental Journal, 232*(3), 147–150. https://doi.org/10.1038/s41415-022-3882-x

Kaur, K., Talibi, M., & Parmar, H. (2022b). Do you know your ceramics? Part 4: alumina. *British Dental Journal, 232*(4), 221–223. https://doi.org/10.1038/s41415-022-3937-z

Kelly, J. R., & Benetti, P. (2011). Ceramic materials in dentistry: historical evolution and current practice. *Australian Dental Journal, 56 Suppl 1*(SUPPL. 1), 84–96. https://doi.org/10.1111/j.1834-7819.2010.01299.x

Khosravani, S. R., Kahnamoui, M. A., Kimyai, S., Navimipour, E. J., Mahounak, F. S., & Azar, F. P. (2022). Final Colour of Ultratranslucent Multilayered Zirconia Veneers, Effect of Thickness, and Resin Cement Shade. *BioMed Research International, 2022*, 1–7. https://doi.org/10.1155/2022/2555797

Kilinc, E., Antonson, S. A., Hardigan, P. C., & Kesercioglu, A. (2011). Resin cement color stability and its influence on the final shade of all-ceramics. *Journal of Dentistry, 39*(SUPPL. 1), e30–e36. https://doi.org/10.1016/j.jdent.2011.01.005

Klapdohr, S., & Moszner, N. (2005). New Inorganic Components for Dental Filling Composites. *Monatshefte F🐦r Chemie - Chemical Monthly, 136*(1), 21–45. https://doi.org/10.1007/s00706-004-0254-y

Lee, Y. K. (2007). Influence of scattering/absorption characteristics on the color of resin composites. *Dental Materials, 23*(1), 124–131. https://doi.org/10.1016/j.dental.2006.01.007

Lee, Y. K., Lu, H., & Powers, J. M. (2005). Measurement of opalescence of resin composites. *Dental Materials, 21*(11), 1068–1074. https://doi.org/10.1016/j.dental.2005.03.015

Lee, Y. K., Yu, B., & Lim, H. N. (2010). Lightness, chroma, and hue distributions of a shade guide as measured by a spectroradiometer. *Journal of Prosthetic Dentistry*, *104*(3), 173–181. https://doi.org/10.1016/S0022-3913(10)60116-3

Lee, Y.-K. (2016). Opalescence of human teeth and dental esthetic restorative materials. *Dental Materials Journal*, *35*(6), 845–854. https://doi.org/10.4012/dmj.2016-091

Leevailoj, C., & Sethakamnerd, P. (2017). Masking ability of lithium disilicate and high-translucent zirconia with liner on colored substrates. *IP Annals of Prosthodontics & Restorative Dentistry*, *3*(3), 94–100. https://doi.org/10.18231/2455-8486.2017.0022

Lehmann, K., Devigus, A., Wentaschek, S., Igiel, C., Scheller, H., & Paravina, R. (2017). Comparison of visual shade matching and electronic color measurement device. *The International Journal of Esthetic Dentistry*, *12*(3), 396–404. http://www.ncbi.nlm.nih.gov/pubmed/28717795

Li, R. W. K., Chow, T. W., & Matinlinna, J. P. (2014). Ceramic dental biomaterials and CAD/CAM technology: State of the art. *Journal of Prosthodontic Research*, *58*(4), 208–216. https://doi.org/10.1016/j.jpor.2014.07.003

Liberato, W. F., Barreto, I. C., Costa, P. P., de Almeida, C. C., Pimentel, W., & Tiossi, R. (2019). A comparison between visual, intraoral scanner, and spectrophotometer shade matching: A clinical study. *The Journal of Prosthetic Dentistry*, *121*(2), 271–275. https://doi.org/10.1016/j.prosdent.2018.05.004

Lien, W., Roberts, H. W., Platt, J. A., Vandewalle, K. S., Hill, T. J., & Chu, T.-M. G. (2015). Microstructural evolution and physical behavior of a lithium disilicate glass–ceramic. *Dental Materials*, *31*(8), 928–940. https://doi.org/10.1016/j.dental.2015.05.003

Lim, Y.-K., Lee, Y.-K., Lim, B.-S., Rhee, S.-H., & Yang, H.-C. (2008). Influence of filler distribution on the color parameters of experimental resin composites. *Dental Materials*, *24*(1), 67–73. https://doi.org/10.1016/j.dental.2007.02.007

Lima, R. B. W., Muniz, I. de A. F., Campos, D. e S., Murillo-Gómez, F., Andrade, A. K. M. de, Duarte, R. M., & de Souza, G. M. (2022). Effect of universal adhesives and self-etch ceramic primers on bond strength to glass ceramics: A systematic review and meta-analysis of in vitro studies. *The Journal of Prosthetic Dentistry*. https://doi.org/10.1016/j.prosdent.2022.01.011

Lindbloom, B. J. (2001). *Color Difference Calculator [Computer Software]*. http://www.brucelindbloom.com/

Lindsey, D. T., & Wee, A. G. (2010). Assessing Tooth Color Differences in Digital Facial Portraits. *Journal of Dental Research*, *89*(11), 1254–1258. https://doi.org/10.1177/0022034510376772

Lopes, C. de C. A., Rodrigues, R. B., Silva, A. L. F. e, Simamoto Júnior, P. C., Soares, C. J., & Novais, V. R. (2015). Degree of Conversion and Mechanical Properties of Resin Cements Cured Through Different All-Ceramic Systems. *Brazilian Dental Journal*, *26*(5), 484–489. https://doi.org/10.1590/0103-6440201300180

Luo, M. R., Cui, G., & Rigg, B. (2001). The development of the CIE 2000 colour-difference formula: CIEDE2000. *Color Research & Application*, *26*(5), 340–350. https://doi.org/10.1002/col.1049

Makhija, S. K., Lawson, N. C., Gilbert, G. H., Litaker, M. S., McClelland, J. A., Louis, D. R., Gordan, V. V., Pihlstrom, D. J., Meyerowitz, C., Mungia, R., & McCracken, M. S. (2016). Dentist material selection for single-unit crowns: Findings from the National Dental Practice-Based Research Network. *Journal of Dentistry*, *55*, 40–47. https://doi.org/10.1016/j.jdent.2016.09.010

Malkondu, O., Tinastepe, N., & Kazazoglu, E. (2016). Influence of type of cement on the color and translucency of monolithic zirconia. *The Journal of Prosthetic Dentistry*, *116*(6), 902–908. https://doi.org/10.1016/j.prosdent.2016.05.001

Marcondes, R. L., Lima, V. P., Barbon, F. J., Isolan, C. P., Carvalho, M. A., Salvador, M. V., Lima, A. F., & Moraes, R. R. (2020). Viscosity and thermal kinetics of 10 preheated restorative resin composites and effect of ultrasound energy on film thickness. *Dental Materials*, *36*(10), 1356–1364. https://doi.org/10.1016/j.dental.2020.08.004

Matos, J. D. M. de, Nakano, L. J. N., Bottino, M. A., Jesus, R. H. de, & Maciel, L. C. (2020). Current Considerations for Dental Ceramics and Their Respective Union Systems. *Revista Brasileira de Odontologia*, *77*, 1. https://doi.org/10.18363/rbo.v77.2020.e1768

McLaren, E. A., & Figueira, J. (2015). Updating Classifications of Ceramic Dental Materials: A Guide to Material Selection. *Compendium of Continuing Education in Dentistry*, *36*(6), 400–405. http://www.ncbi.nlm.nih.gov/pubmed/26053778

Melgosa, M. (2000). Testing CIELAB-based color-difference formulas. *Color Research & Application*, *25*(1), 49–55. https://doi.org/10.1002/(SICI)1520-6378(200002)25:1<49::AID-COL7>3.3.CO;2-W

Mihali, S. G., Lolos, D., Popa, G., Tudor, A., & Bratu, D. C. (2022). Retrospective Long-Term Clinical Outcome of Feldspathic Ceramic Veneers. *Materials*, *15*(6). https://doi.org/10.3390/ma15062150

Mizrahi, B. (2008). The anterior all-ceramic crown: a rationale for the choice of ceramic and cement. *British Dental Journal*, *205*(5), 251–255. https://doi.org/10.1038/sj.bdj.2008.735

Mortazavi, H., Baharvand, M., & Khodadoustan, A. (2014). Colors in tooth discoloration: a new classification and literature review. *International Journal of Clinical Dentistry*, *7*(1), 17–28.

Naji, A.-H. G., Anita Omar, R., & Yahya, R. (2018). An Overview of the Development and Strengthening of All-Ceramic Dental Materials. *Biomedical and Pharmacology Journal*, *11*(3), 1553–1563. https://doi.org/10.13005/bpj/1522

Neis, C. A., Albuquerque, N. L. G., Albuquerque, I. de S., Gomes, E. A., Souza-Filho, C. B. de, Feitosa, V. P., Spazzin, A. O., & Bacchi, A. (2015). Surface Treatments for Repair of Feldspathic, Leucite - and Lithium Disilicate-Reinforced Glass Ceramics Using Composite Resin. *Brazilian Dental Journal*, *26*(2), 152–155. https://doi.org/10.1590/0103-6440201302447

Noda, Y., Nakajima, M., Takahashi, M., Mamanee, T., Hosaka, K., Takagaki, T., Ikeda, M., Foxton, R. M., & Tagami, J. (2017). The effect of five kinds of surface treatment agents on the bond strength to various ceramics with thermocycle aging. *Dental Materials Journal*, *36*(6), 755–761. https://doi.org/10.4012/dmj.2016-383

Oh, S., Shin, S.-M., Kim, H.-J., Paek, J., Kim, S.-J., Yoon, T. H., & Kim, S.-Y. (2018). Influence of glass-based dental ceramic type and thickness with identical shade on the light transmittance and the degree of conversion of resin cement. *International Journal of Oral Science*, *10*(1), 5. https://doi.org/10.1038/s41368-017-0005-7

Omar, H., Atta, O., El-Mowafy, O., & Khan, S. A. (2010). Effect of CAD–CAM porcelain veneers thickness on their cemented color. *Journal of Dentistry*, *38*, e95–e99. https://doi.org/10.1016/j.jdent.2010.05.006

Önöral, Ö., Günal-Abduljalil, B., & Ongun, S. (2021). Effect of color of the cement and the composite resin foundation on the resultant color of resin-matrix ceramics. *The Journal of Prosthetic Dentistry, 125*(2), 351.e1-351.e7. https://doi.org/10.1016/j.prosdent.2020.09.021

Ota, M., Ando, S., Endo, H., Ogura, Y., Miyazaki, M., & Hosoya, Y. (2012). Influence of refractive index on optical parameters of experimental resin composites. *Acta Odontologica Scandinavica, 70*(5), 362–367. https://doi.org/10.3109/00016357.2011.600724

Öztürk, E., Bolay, Ş., Hickel, R., & Ilie, N. (2013). Shear bond strength of porcelain laminate veneers to enamel, dentine and enamel–dentine complex bonded with different adhesive luting systems. *Journal of Dentistry, 41*(2), 97–105. https://doi.org/10.1016/j.jdent.2012.04.005

Pameijer, C. H. (2012). A Review of Luting Agents. *International Journal of Dentistry, 2012*, 1–7. https://doi.org/10.1155/2012/752861

Paravina, R. D., Ghinea, R., Herrera, L. J., Bona, A. D., Igiel, C., Linninger, M., Sakai, M., Takahashi, H., Tashkandi, E., & Mar Perez, M. del. (2015). Color Difference Thresholds in Dentistry. *Journal of Esthetic and Restorative Dentistry, 27*(S1), S1–S9. https://doi.org/10.1111/jerd.12149

Paravina, R. D., Pérez, M. M., & Ghinea, R. (2019). Acceptability and perceptibility thresholds in dentistry: A comprehensive review of clinical and research applications. *Journal of Esthetic and Restorative Dentistry, 31*(2), 103–112. https://doi.org/10.1111/jerd.12465

Pecho, O. E., Ghinea, R., Amaral, E. A. N. do, Cardona, J. C., Della Bona, A., & Pérez, M. M. (2016). Relevant optical properties for direct restorative materials. *Dental Materials, 32*(5), e105–e112. https://doi.org/10.1016/j.dental.2016.02.008

Pereira, J. (2007). *Delta E Calculator for Mac OS X (Versão 2.0) [Computer Software].* http://www.jpereira.net/download-delta-e-calculator-for-mac-os-x

Perez, M. del M., Ghinea, R., Herrera, L. J., Ionescu, A. M., Pomares, H., Pulgar, R., & Paravina, R. D. (2011). Dental ceramics: A CIEDE2000 acceptability thresholds for lightness, chroma and hue differences. *Journal of Dentistry, 39*(SUPPL. 3), e37–e44. https://doi.org/10.1016/j.jdent.2011.09.007

Peumans, M., Van Meerbeek, B., Lambrechts, P., & Vanherle, G. (2000). Porcelain veneers: a review of the literature. *Journal of Dentistry*, *28*(3), 163–177. https://doi.org/10.1016/S0300-5712(99)00066-4

Pires, L. A., Novais, P. M. R., Araújo, V. D., & Pegoraro, L. F. (2017). Effects of the type and thickness of ceramic, substrate, and cement on the optical color of a lithium disilicate ceramic. *Journal of Prosthetic Dentistry*, *117*(1), 144–149. https://doi.org/10.1016/j.prosdent.2016.04.003

Pissaia, J. F., Guanaes, B. K. de A., Kintopp, C. C. de A., Correr, G. M., da Cunha, L. F., & Gonzaga, C. C. (2019). Color stability of ceramic veneers as a function of resin cement curing mode and shade: 3-year follow-up. *PloS One*, *14*(7), e0219183. https://doi.org/10.1371/journal.pone.0219183

Pop-Ciutrila, I.-S., Ghinea, R., Colosi, H. A., Ruiz-López, J., Perez, M. M., Paravina, R. D., & Dudea, D. (2021). Color compatibility between dental structures and three different types of ceramic systems. *BMC Oral Health*, *21*(1), 75. https://doi.org/10.1186/s12903-021-01404-7

Porojan, L., Vasiliu, R. D., & Porojan, S. D. (2022). Masking Abilities of Dental Cad/Cam Resin Composite Materials Related to Substrate and Luting Material. *Polymers*, *14*(3), 364. https://doi.org/10.3390/polym14030364

Poticny, D. J., & Klim, J. (2010). CAD/CAM in-office technology: innovations after 25 years for predictable, esthetic outcomes. *Journal of the American Dental Association (1939)*, *141*(2), 5S-9S. https://doi.org/10.14219/jada.archive.2010.0356

Pyo, S.-W., Kim, D.-J., Han, J.-S., & Yeo, I.-S. L. (2020). Ceramic Materials and Technologies Applied to Digital Works in Implant-Supported Restorative Dentistry. *Materials (Basel, Switzerland)*, *13*(8). https://doi.org/10.3390/ma13081964

Rafael, C. F., Güth, J. F., Kauling, A. E. C., Cesar, P. F., Volpato, C. A. M., & Liebermann, A. (2017). Impact of background on color, transmittance, and fluorescence of leucite based ceramics. *Dental Materials Journal*, *36*(4), 394–401. https://doi.org/10.4012/dmj.2016-322

Ramakrishnaiah, R., Alkheraif, A., Divakar, D., Matinlinna, J., & Vallittu, P. (2016). The Effect of Hydrofluoric Acid Etching Duration on the Surface Micromorphology, Roughness, and Wettability of Dental Ceramics.

International Journal of Molecular Sciences, *17*(6), 822. https://doi.org/10.3390/ijms17060822

Ramaraju, D. S., Krishna Alla, R., Ramaraju Alluri, V., & MAKV, R. (2014). A Review of Conventional and Contemporary Luting Agents Used in Dentistry. *American Journal of Materials Science and Engineering*, *2*(3), 28–35. https://doi.org/10.12691/ajmse-2-3-1

Ramsey, P. H. (1980). Exact Type 1 Error Rates for Robustness of Student's *t* Test with Unequal Variances. *Journal of Educational Statistics*, *5*(4), 337–349. https://doi.org/10.3102/10769986005004337

Rodrigues, R. B., Lima, E. de, Roscoe, M. G., Soares, C. J., Cesar, P. F., & Novais, V. R. (2017). Influence of Resin Cements on Color Stability of Different Ceramic Systems. *Brazilian Dental Journal*, *28*(2), 191–195. https://doi.org/10.1590/0103-644020170

Romanini-Junior, J. C., Kumagai, R. Y., Ortega, L. F., Rodrigues, J. A., Cassoni, A., Hirata, R., & Reis, A. F. (2018). Adhesive/silane application effects on bond strength durability to a lithium disilicate ceramic. *Journal of Esthetic and Restorative Dentistry*, *30*(4), 346–351. https://doi.org/10.1111/jerd.12387

Rosenblum, M. A., & Schulman, A. (1997). A review of all-ceramic restorations. *Journal of the American Dental Association (1939)*, *128*(3), 297–307. https://doi.org/10.14219/jada.archive.1997.0193

Salas, M., Lucena, C., Herrera, L. J., Yebra, A., Della Bona, A., & Pérez, M. M. (2018). Translucency thresholds for dental materials. *Dental Materials*, *34*(8), 1168–1174. https://doi.org/10.1016/j.dental.2018.05.001

Sampaio, C. S., Atria, P. J., Hirata, R., & Jorquera, G. (2019). Variability of color matching with different digital photography techniques and a gray reference card. *The Journal of Prosthetic Dentistry*, *121*(2), 333–339. https://doi.org/10.1016/j.prosdent.2018.03.009

Sampaio, C. S., Belfus, J., Avila, A., Cordero, C., Freitte, M., Ferrari, V., Atria, P. J., & Jorquera, G. (2021). Effect of different fabrication steps on color and translucency of a CAD-CAM feldspathic ceramic. *Journal of Esthetic and Restorative Dentistry*, *33*(7), 1038–1044. https://doi.org/10.1111/jerd.12789

Santos, G., Santos, M., & Rizkalla, A. (2010). Cementation basics for etchable ceramic restorations. *Dental Abstracts*, *55*(1), 20–23. https://doi.org/10.1016/j.denabs.2009.08.046

Sari, T., Ural, C., Yüzbasioglu, E., Duran, I., Cengiz, S., & Kavut, I. (2018). Color match of a feldspathic ceramic CAD-CAM material for ultrathin laminate veneers as a function of substrate shade, restoration color, and thickness. *The Journal of Prosthetic Dentistry*, *119*(3), 455–460. https://doi.org/10.1016/j.prosdent.2017.02.022

Sasse, M., Krummel, A., Klosa, K., & Kern, M. (2015). Influence of restoration thickness and dental bonding surface on the fracture resistance of full-coverage occlusal veneers made from lithium disilicate ceramic. *Dental Materials : Official Publication of the Academy of Dental Materials*, *31*(8), 907–915. https://doi.org/10.1016/j.dental.2015.04.017

Scotti, N., Cavalli, G., Gagliani, M., & Breschi, L. (2017). New adhesives and bonding techniques. Why and when? *The International Journal of Esthetic Dentistry*, *12*(4), 524–535. http://www.ncbi.nlm.nih.gov/pubmed/28983535

Shadman, N., Ebrahimi, S. F., Shoul, M. A., Kandi, S. G., & Rostami, S. (2022). The minimum thickness of a multilayer ceramic restoration required for masking dark background. *Dental Research Journal*, *19*, 31. http://www.ncbi.nlm.nih.gov/pubmed/35669605

Shammas, M., & Krishna Alla, R. (2011). Color and Shade Matching in Dentistry. In *Trends Biomater. Artif. Organs* (Vol. 25, Issue 4). http://www.sbaoi.org

Sharma, G., Wu, W., & Dalal, E. N. (2005). The CIEDE2000 color-difference formula: Implementation notes, supplementary test data, and mathematical observations. *Color Research & Application*, *30*(1), 21–30. https://doi.org/10.1002/col.20070

Sharma, S., Pandit, S. K., Das, R., Sinha, M., Sahu, R., & Trivedi, P. (2022). Comparison of Bond Strength of Metal and Ceramic Brackets with or without Primer. *Journal of Pharmacy & Bioallied Sciences*, *14*(Suppl 1), S225–S228. https://doi.org/10.4103/jpbs.jpbs_143_22

Shen, J., & Kosmac, T. (2013). *Advanced Ceramics for Dentistry* (1st ed.). Butterworth-Heinemann.

Shono, N., & Nahedh, H. Al. (2012). Contrast Ratio and Masking Ability of Three Ceramic Veneering Materials. *Operative Dentistry*, *37*(4), 406–416. https://doi.org/10.2341/10-237-L

Silva, L. H. da, Lima, E. de, Miranda, R. B. de P., Favero, S. S., Lohbauer, U., & Cesar, P. F. (2017). Dental ceramics: a review of new materials and processing methods. *Brazilian Oral Research*, *31*(suppl 1), 133–146. https://doi.org/10.1590/1807-3107bor-2017.vol31.0058

Skyllouriotis, A. L., Yamamoto, H. L., & Nathanson, D. (2017). Masking properties of ceramics for veneer restorations. *The Journal of Prosthetic Dentistry*, *118*(4), 517–523. https://doi.org/10.1016/j.prosdent.2016.12.003

Soares, C. J., Soares, P. V., Pereira, J. C., & Fonseca, R. B. (2005). Surface Treatment Protocols in the Cementation Process of Ceramic and Laboratory-Processed Composite Restorations: A Literature Review. *Journal of Esthetic and Restorative Dentistry*, *17*(4), 224–235. https://doi.org/10.1111/j.1708-8240.2005.tb00119.x

Șoim, A., Strîmbu, M., Burde, A. V., Culic, B., Dudea, D., & Gasparik, C. (2018). Translucency and masking properties of two ceramic materials for heat-press technology. *Journal of Esthetic and Restorative Dentistry*, *30*(2), E18–E23. https://doi.org/10.1111/jerd.12358

Sonza, Q. N., Della Bona, A., Pecho, O. E., & Borba, M. (2021). Effect of substrate and cement on the final color of zirconia-based all-ceramic crowns. *Journal of Esthetic and Restorative Dentistry : Official Publication of the American Academy of Esthetic Dentistry ... [et Al.]*, *33*(6), 891–898. https://doi.org/10.1111/jerd.12632

Spazzin, A. O., Guarda, G. B., Oliveira-Ogliari, A., Leal, F. B., Correr-Sobrinho, L., & Moraes, R. R. (2016). Strengthening of Porcelain Provided by Resin Cements and Flowable Composites. *Operative Dentistry*, *41*(2), 179–188. https://doi.org/10.2341/15-025-L

Subaşı, M. G., Alp, G., Johnston, W. M., & Yilmaz, B. (2018). Effect of thickness on optical properties of monolithic CAD-CAM ceramics. *Journal of Dentistry*, *71*, 38–42. https://doi.org/10.1016/j.jdent.2018.01.010

Tabatabaian, F. (2019). Color Aspect of Monolithic Zirconia Restorations: A Review of the Literature. *Journal of Prosthodontics*, *28*(3), 276–287. https://doi.org/10.1111/jopr.12906

Tabatabaian, F., Bakhshaei, D., & Namdari, M. (2020). Effect of Resin Cement Brand on the Color of Zirconia-Based Restorations. *Journal of Prosthodontics : Official Journal of the American College of Prosthodontists, 29*(4), 350–355. https://doi.org/10.1111/jopr.12953

Tabatabaian, F., Beyabanaki, E., Alirezaei, P., & Epakchi, S. (2021). Visual and digital tooth shade selection methods, related effective factors and conditions, and their accuracy and precision: A literature review. In *Journal of Esthetic and Restorative Dentistry* (Vol. 33, Issue 8, pp. 1084–1104). John Wiley and Sons Inc. https://doi.org/10.1111/jerd.12816

Talibi, M., Kaur, K., & Parmar, H. (2022a). Do you know your ceramics? Part 2: feldspathic ceramics. *British Dental Journal, 232*(2), 80–83. https://doi.org/10.1038/s41415-022-3874-x

Talibi, M., Kaur, K., & Parmar, H. (2022b). Do you know your ceramics? Part 5: zirconia. *British Dental Journal, 232*(5), 311–316. https://doi.org/10.1038/s41415-022-3997-0

Talibi, M., Kaur, K., Patanwala, H. S., & Parmar, H. (2022). Do you know your ceramics? Part 1: classification. *British Dental Journal, 232*(1), 27–32. https://doi.org/10.1038/s41415-021-3818-x

Tamam, E., Güngör, M., & Nemli, S. (2020). How are the color parameters of a CAD/CAM feldspathic ceramic of the material affected by its thickness, shade, and color of the substructure? *Nigerian Journal of Clinical Practice, 23*(4), 523–533. https://doi.org/10.4103/njcp.njcp_517_19

Thilagar, P., Sampathkumar, J., Krishnan, C., Ramakrishnan, H., Ramasubramanian, H., & Azhagarasan, N. (2019). Comparative evaluation of the masking ability of lithium disilicate ceramic with different core thickness on the shade match of indirect restorations over metallic substrate: An in vitro study. *Contemporary Clinical Dentistry, 10*(1), 56–63. https://doi.org/10.4103/ccd.ccd_301_18

Tian, T., Tsoi, J. K.-H., Matinlinna, J. P., & Burrow, M. F. (2014). Aspects of bonding between resin luting cements and glass ceramic materials. *Dental Materials, 30*(7), e147–e162. https://doi.org/10.1016/j.dental.2014.01.017

Tomaselli, L. de O., de Oliveira, D. C. R. S., Favarão, J., da Silva, A. F., Pires-De-Souza, F. de C. P., Geraldeli, S., & Sinhoreti, M. A. C. (2019). Influence of preheating regular resin composites and flowable composites on luting ceramic veneers with different thicknesses. *Brazilian Dental Journal*, *30*(5), 459–466. https://doi.org/10.1590/0103-6440201902513

Turgut, S., & Bagis, B. (2011). Colour stability of laminate veneers: An in vitro study. *Journal of Dentistry*, *39*, e57–e64. https://doi.org/10.1016/j.jdent.2011.11.006

Turgut, S., & Bagis, B. (2013). Effect of resin cement and ceramic thickness on final color of laminate veneers: An in vitro study. *The Journal of Prosthetic Dentistry*, *109*(3), 179–186. https://doi.org/10.1016/S0022-3913(13)60039-6

Turgut, S., Bağış, B., Korkmaz, F. M., & Tamam, E. (2014). Do surface treatments affect the optical properties of ceramic veneers? *The Journal of Prosthetic Dentistry*, *112*(3), 618–624. https://doi.org/10.1016/j.prosdent.2014.04.001

Tuzzolo Neto, H., do Nascimento, W. F., Erly, L., Ribeiro, R. A., Barbosa, J. de S., Zambrana, J. M., Raimundo, L. B., Mendes, C. da S., da Silva, I. P., Mesquita, A. M. M., Salgado, D. M. R. de A., & Costa, C. (2018). Laminated Veneers with Stratified Feldspathic Ceramics. *Case Reports in Dentistry*, *2018*, 5368939. https://doi.org/10.1155/2018/5368939

Venturini, A. B., Prochnow, C., May, L. G., Bottino, M. C., & Felipe Valandro, L. (2015). Influence of hydrofluoric acid concentration on the flexural strength of a feldspathic ceramic. *Journal of the Mechanical Behavior of Biomedical Materials*, *48*, 241–248. https://doi.org/10.1016/j.jmbbm.2015.03.025

Vichi, A., Louca, C., Corciolani, G., & Ferrari, M. (2011). Color related to ceramic and zirconia restorations: A review. *Dental Materials*, *27*(1), 97–108. https://doi.org/10.1016/j.dental.2010.10.018

VITA. (2022). *VITABLOCS® Instructions for use [Brochure]*. https://www.vita-zahnfabrik.com/VITABLOCS_lp_en,,,detail.print

Volpato, C., Monteiro, J. S., Deandrada, M., Fredel, M., & Petter, C. (2009). Optical influence of the type of illuminant, substrates and thickness of ceramic materials. *Dental Materials*, *25*(1), 87–93. https://doi.org/10.1016/j.dental.2008.04.013

Warreth, A., & Elkareimi, Y. (2020). All-ceramic restorations: A review of the literature. In *Saudi Dental Journal* (Vol. 32, Issue 8, pp. 365–372). Elsevier B.V. https://doi.org/10.1016/j.sdentj.2020.05.004

Willard, A., & Chu, G. T.-M. (2018). The science and application of IPS e.Max dental ceramic. *The Kaohsiung Journal of Medical Sciences*, *34*(4), 238–242. https://doi.org/10.1016/j.kjms.2018.01.012

Xiaoping, L., Dongfeng, R., & Silikas, N. (2014). Effect of etching time and resin bond on the flexural strength of IPS e.max Press glass ceramic. *Dental Materials : Official Publication of the Academy of Dental Materials*, *30*(12), e330-6. https://doi.org/10.1016/j.dental.2014.08.373

Xing, W., Chen, X., Ren, D., Zhan, K., & Wang, Y. (2017). The effect of ceramic thickness and resin cement shades on the color matching of ceramic veneers in discolored teeth. *Odontology*, *105*(4), 460–466. https://doi.org/10.1007/s10266-016-0287-9

Yildirim, B., Recen, D., & Tekeli Simsek, A. (2021). Effect of cement color and tooth-shaded background on the final color of lithium disilicate and zirconia-reinforced lithium silicate ceramics: An in vitro study. *Journal of Esthetic and Restorative Dentistry*, *33*(2), 380–386. https://doi.org/10.1111/jerd.12611

Yu, H., Zheng, M., Chen, R., & Cheng, H. (2014). Proper selection of contemporary dental cements. *Oral Health and Dental Management*, *13*(1), 54–59. http://www.ncbi.nlm.nih.gov/pubmed/24603917

Zaghloul, H., Elkassas, D. W., & Haridy, M. F. (2014). Effect of incorporation of silane in the bonding agent on the repair potential of machinable esthetic blocks. *European Journal of Dentistry*, *08*(01), 044–052. https://doi.org/10.4103/1305-7456.126240

Zhang, Y., & Kelly, J. R. (2017). Dental Ceramics for Restoration and Metal Veneering. *Dental Clinics of North America*, *61*(4), 797–819. https://doi.org/10.1016/j.cden.2017.06.005

Zhou, W., Liao, Z. X., Chen, J. H., Qiu, B. Y., Zhang, Y., & Zhang, L. (2022). Color change of glass ceramic restorations cemented by four types of dual-cured resin luting agents with different initiator systems. *Dental Materials Journal*, *41*(6), 833–842. https://doi.org/10.4012/dmj.2022-044