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REVIEW

Bariatric-Metabolic Surgery is the Most Effective Intervention in Reducing Food Addiction Symptoms: A Systematic Review and Meta-Analysis

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Abstract

There are different treatments for food addiction (FA) symptomatology, but a comprehensive review with a meta-analysis to determine the most effective intervention is lacking. The aim of this review is to investigate the efficacy of pharmacological, behavioral, and bariatric-metabolic surgical interventions in reducing FA symptomatology. Meta-analyses including 15 studies in adults showed a significantly positive effect (std mean difference in FA symptoms before vs after intervention 0.72 (0.58–0.95)), with bariatric-metabolic surgical interventions showing the highest efficacy in improving FA symptoms (1.17 (0.58–1.76) before vs after intervention). The existing evidence suggests a beneficial effect of bariatric-metabolic surgical, pharmacological, and behavioral interventions, in that order, on FA symptomatology in people with overweight/obesity. Weight loss and behavioral and lifestyle changes after surgery may be determinants in improving FA symptomatology.

Keywords Food addiction · YFAS · Intervention · Treatment · Pharmacological, Surgical, Behavioral

Introduction

Eating disorders (EDs) are characterized by severe alterations in eating behavior and body weight that lead to multiple psychiatric and somatic complications and, in some cases, death. They are more common in adolescents and young adults, with a higher prevalence in women than in men [1]. EDs have shown rapid social expansion, with the prevalence increasing from 3.5% for the 2000–2006 period to 7.8% for the 2013–2018 period [1].

The Diagnostic and Statistical Manual of Mental Disorders (DSM-V-TR) describes various EDs, including classic disorders such as anorexia, bulimia, binge eating disorder, and eating disorders not otherwise specified [2]. However, there are new emerging forms of disordered eating, such as food addiction (FA), orthorexia [3], muscle dysmorphia (bigorexia) [4], or diabulimia [5], that have not yet been classified as ED. Food addiction is not recorded in the ICD-11 either; although, it is worth noting that ICD11 does identify caffeine addiction, which is, after all, a component of

Key Points
- Surgical intervention was the most effective intervention to reduce food addiction symptomatology.
- Pharmacological/behavioral interventions also improved food addiction symptomatology.
- Weight loss and lifestyle changes after surgery will determine this improvement.
- There is a lack of scientific evidence about the best therapeutic approach to reduce food addiction symptomatology on adolescents and normal weight people.

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many diets. Then, although food addiction is not yet recognized as an individual entity in the DSM-V-TR by the American Psychiatric Association [2], it is well-documented in scientific literature, and there is a growing body of evidence regarding its clinical significance. Currently, there is information about epidemiological data [6, 7], assessment tools [8, 9], associations with mental health symptomatology [10, 11], neurological overlaps with other addictions [12–14], and intervention studies [15] to support the relevance of food addiction. Furthermore, research has explored the connection between food addiction and other parameters such as lifestyle, sleep quality, cognitive functions, and more. These findings collectively emphasize the importance of studying food addiction within the context of obesity research.

FA often contributes to the development of obesity in the general population [16], and it is associated with the presence of mental health issues [11]. Available data show that the prevalence of food addiction is 19.9%, higher in adults aged > 35 years, females, and people with overweight/obesity. It is also higher in clinical samples compared to non-clinical counterparts [17]. Moreover, FA is elevated in specific clinical conditions like class III obesity (37%) [18] or classic ED [19] (anorexia nervosa, 61.5%; binge-eating/purging type, 87.9%; bulimia nervosa, 97.6%; and binge-eating disorder, 93.3%) [19].

Individuals with FA exhibit hallmark signs akin to those observed in substance use disorders [9]. Neuroimaging studies have revealed overlapping brain circuitry involved in reward, motivation, and craving in both food addiction and substance addiction [20, 21]. Foods with addictive potential are often highly processed, and individuals with FA may exhibit characteristics similar to those associated with drug addiction (e.g., tolerance, withdrawal) when they try to avoid those addictive foods [22], making it particularly challenging to adopt healthier eating habits [23, 24]. The elevation of reward thresholds in these cases was indicative of a reduced sensitivity, which suggests that excessive consumption of palatable foods leading to weight gain can potentially induce substantial impairments in the brain's reward system, akin to the effects observed with the overconsumption of addictive substances. On the other hand, there are individuals whose FA does not lead to obesity but still experience symptoms related to their addiction [25].

For physicians and other health professionals involved in the treatment of obesity, the detection of food addiction symptoms is of great interest, since individuals attempting to lose weight while combating symptoms of food addiction may be especially prone to eating-related pathologies, internalized weight bias, and body shame [26]. For example, recent studies have shown that postoperative, but not preoperative, loss of dietary control and bulimia are associated with worse weight outcomes after sleeve gastrectomy and Roux-en-Y gastric bypass surgery. Given the overlapping characteristics of food addiction and binge eating, postoperative food addiction may also be associated with poorer long-term weight outcomes after bariatric surgery [27]. Simultaneously, adhering to a strict dietary regimen, coupled with weight loss, may prove advantageous in mitigating these symptoms.

Considering the above comments, it seems clear that there is a need for appropriate treatments to mitigate the negative consequences of food addiction. Present treatments for food addiction include various types of interventions: behavioral, pharmacological, and surgical. Although these interventions have been partially reviewed in the past, no meta-analysis has been conducted to evaluate their efficacy in improving FA symptoms [15, 28]. It is particularly important to identify the most suitable intervention, especially for adolescents, as previous treatments for addiction-related pathology have not shown symptom improvement in this age group [15].

The aim of this review and meta-analysis is to investigate the efficacy of pharmacological, behavioral, and surgical interventions in reducing the symptomatology of food addiction, as assessed by the YFAS scale, in both adolescents and adults.

Methods

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were followed. The PRISMA checklist is provided as Table S1 in the Supporting Information online). The systematic review was registered on the PROSPERO database (registration no. CRD42023387124).

Data Sources and Literature Search

The PubMed database was searched for suitable articles published up to April 2023. The following MeSH (Medical Subject Headings) search terms were used: ("YFAS" OR "Food Addiction") AND ("intervention*" OR "treatment*" OR "therap*" OR "program*") AND ("human*"). Title, abstract, and keywords were carefully examined to identify relevant papers. A parallel search in the Web of Science database was performed to check for additional papers using the same terms. The same procedure was carried out in Scopus, APA, and the Psychology and Behavioral Sciences Collection. Reference lists of identified manuscripts and reviews were checked manually.

Eligibility Criteria

Table 1 shows the PICOS (participants, intervention, comparison, outcome, and study design) criteria used to define the research question. Studies that fulfilled the following criteria were eligible: interventional studies that reported FA symptomatology pre- and post-intervention, including clinical, preclinical, and other intervention studies, whether single-arm, non-randomized, or randomized studies. Observational, descriptive, and cross-sectional studies were excluded. FA symptomatology was reported as an outcome

Table 1 PICOS criteria for inclusion and exclusion of studies

Parameter	Description
Population	Humans with food addiction symptomatology
Intervention	Behavioral, surgical, and pharmacological
Comparison	Matching placebo, control group, or repeated measures
Outcome	Performance in YFAS test
Study design	Randomized controlled trials, crossover trials or non-controlled interventional studies

measure. Articles in English or Spanish were screened. There were no date limits on the publication date, so references identified up until the date of the last search (April 2023) were included.

Selection Process and Data Extraction

Two authors (J.J.H-M. and C.R.G.) independently reviewed the titles and abstracts of all retrieved articles to identify articles meeting the eligibility criteria. The full text of eligible studies was retrieved and independently reviewed by the same researchers. Differences were resolved through discussion and consensus. Covidence, a Cochrane technology platform, was used for data management [29].

All data included in the article were extracted by one author (J.J.H.M.) and checked by another author (C.R.G.). Information extracted included the study population, study design, and the tools and procedures used to measure cognitive outcomes. Differences were identified and resolved through discussion and consensus.

Quality Assessment

Two authors, C.R.G. and J.J.H-M assessed the quality of included studies twice using the Cochrane risk of bias tool and the Covidence systematic review software [29], and conflicts were resolved through discussion. The Risk of Bias tool assesses the following areas: sequence generation (selection bias), attribution confounding (selection bias), blinding of participants and staff (performance bias), blinding of outcome reviewers (detection bias), incomplete results data (attrition bias), selective results reporting (reporting bias), and other sources of distortion. Funnel plots were used to assess publication bias.

Synthesis of Results

Where possible, meta-analyses were carried out on those studies that reported YFAS scores before and after the intervention, overall, and by intervention type. Meta-analyses were conducted when at least two studies reported the same outcomes. Random-effects models were selected a priori considering the differences in study populations and methods used to evaluate outcomes. Standardized mean differences (SMDs) with 95% confidence intervals (CIs) were calculated and reported. The I^2 statistic was used to assess the statistical heterogeneity, and the strength of evidence was determined by the precision of the 95% CIs, which allowed for the identification of significant differences and the evaluation of heterogeneity. All the data used in the meta-analyses were extracted using the Review Manager (RevMan) software, version 5.3, developed by the Cochrane Community. Otherwise, the results were synthesized narratively.

Results

Search Results

Figure 1 shows the PRISMA flow diagram. The initial search yielded 1688 potentially appropriate publications. After removing duplicates (782), 906 studies were carefully reviewed. Finally, 22 manuscripts met the inclusion criteria to be included in this systematic review, of which 3 studies examined behavioral interventions for food addiction (FA) in adolescents and 19 studies focused on adults (12 behavioral, 4 surgical, and 3 pharmacological interventions, Fig. 1). A detailed overview of the studies that investigated different interventions in food addiction is provided in Table 2 and 3. Fifteen studies used the same outcomes and were included in the meta-analysis; however, none of them involved adolescent populations, so only adults were included in the meta-analysis.

The first interventions for FA were behavioral [39–41]. Later, pharmacological interventions [44] and surgical interventions [48] were included as potential therapeutic options. The 22 studies that examined FA interventions included a total of 1587 participants. Most participants were women, with a prevalence of FA ranging from 54 to 100% in the reviewed papers, and only one study based on a behavioral intervention was exclusively conducted in men [34]. Nineteen out of the 22 studies were carried out in adults (age range 18–52.7 years), and three studies included an adolescent population (age range 14–15.5 years).

All the studies focused on overweight/obese participants (BMI range 29 to 48), and therefore, no study specifically targeted individuals with normal weight and FA. Other clinical groups included individuals with male obesity secondary hypogonadism syndrome [34], binge eating disorder [37, 43], bulimia [39], or patients with class III–IV obesity [45–48].

Predominantly, pilot and preliminary studies were conducted (11 out of 22 selected). When excluding pilot studies and those without a control group, only three behavioral interventions [38, 40, 49], one pharmacological intervention [44], and two surgical studies remained [45, 46] and were identified as high-quality studies according to the

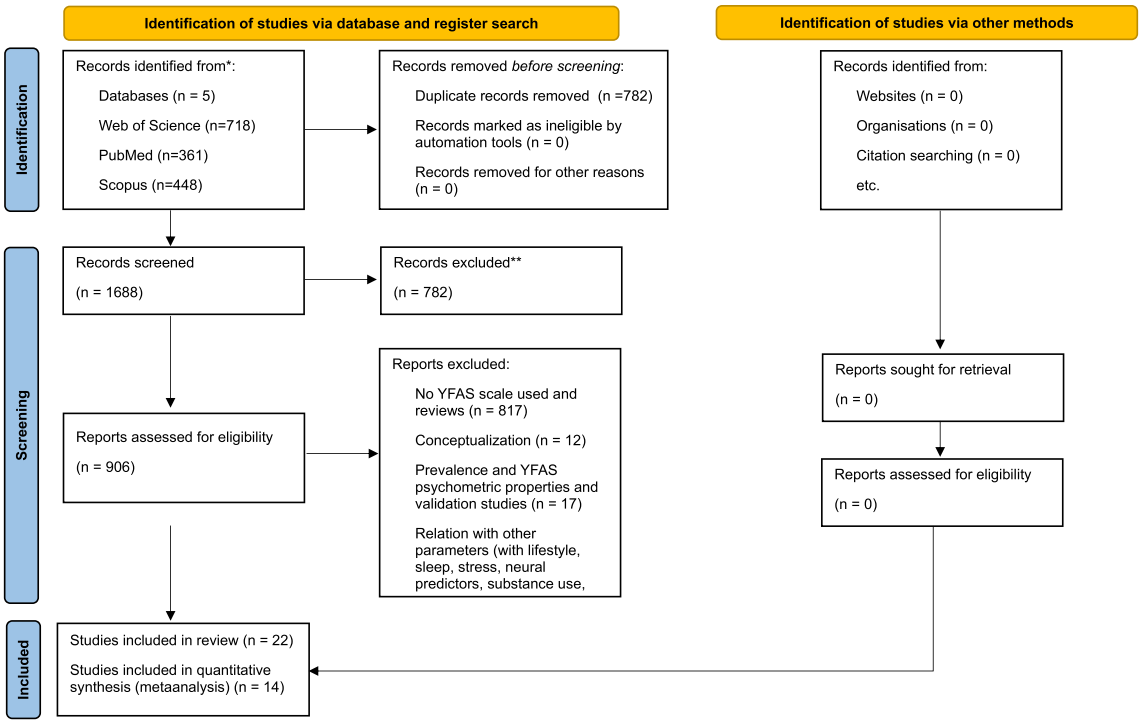

Fig. 1 PRISMA 2020 flow diagram of the literature search process

researchers' review process. Of these six high-quality studies, only one was conducted on adolescent participants [49].

Three studies followed a repeated measures pre/post-intervention design [33, 51, 52], two used a placebo comparison group [44, 45], while the other studies used different weight loss programs or different comparison groups.

All studies conducted on adult populations used the standard version of the Yale Food Addiction Scale (YFAS) to assess FA symptomatology, while the adolescent populations used the Children's YFAS (YFAS-C) version [49–51].

Types of Intervention

Regarding behavioral interventions, the retrieved studies referred to a wide range of interventions with durations between 2 weeks and 5 years. These interventions were based on lifestyle intervention programs, dietary modifications, increased physical activity, and other specific approaches such as mindfulness training, stress reduction programs, and therapy groups, among others (Table 4). Pharmacological interventions mainly included psychopharmacological drugs such as naltrexone, bupropion, pexacerfont, and vortioxetine, although one study also included lifestyle, diet, and physical activity modifications [43]. In surgical interventions, changes in YFAS scores before and after the operation and over time were assessed, and dietary guidance by the surgical team (doctor, dietitian, and psychologist) was incorporated, with follow-ups of up to 2 years [46]. In adolescents, behavioral instructions, changes in physical activity, and nutritional interventions were included. Additionally, two out of the three studies employed new technologies like smartphone apps [49, 50].

Before vs After Intervention Changes

The meta-analysis showed a significantly positive effect of the interventions regardless of type (SMD in FA symptoms before vs after intervention 0.72 (0.58–0.95). Surgical interventions were the most effective in reducing the symptoms of food addiction (SMD = 1.17; 95% CI, 0.58–1.7), especially due to the observed effect in the study by Carlos in [45] (24). Pharmacological treatment was also effective (SMD = 1.11; 95% CI, 0.48–1.74), particularly in the study by Epstein [44]. However, since there were only two drug-based studies included in the meta-analysis, these results are considered very preliminary. Behavioral interventions showed high variability, with certain studies not demonstrating a significant effect [31, 37, 38], while others showed even greater beneficial effects than pharmacological or surgical interventions [53], resulting in an overall benefit (SMD = 0.48; 95% CI, 0.26–0.69) (Fig. 2).

The remaining studies not included in the meta-analysis were based on behavioral interventions and were characterized by slight reductions in FA symptomatology, ranging from total to partial improvements, depending on the studies. However, some studies based on behavioral interventions

Table 2 Overview of studies investigating the effect of different treatments in adult participants with overweight/obesity

Reference	Design	Population characteristics	Retention rate	Intervention and duration	Results
Behavioral intervention					
Burrows et al. [30]	Control (without intervention) Pilot study	$N=52$ (94% female); (43.6 ± 12.2 years); BMI (36.7 ± 6.8)	$N=33$	A personality-targeted motivational interviewing intervention (Food-Fix). 3 months; 3 sessions	YFAS symptoms Control group (T0, 8.1 ± 2.5; T1, 6.9 ± 3.7) Intervention group (T0, 8.0 ± 2.7; T1, 6.5 ± 3.8) Significant reductions in FA; however, these changes were not significantly different between groups
Rostanzo et al. [31]	Control (no) Pilot study	$N=5$ (100% female), 4 with FA; (36.4 ± 4.9 years); BMI (31.1 ± 0.9)	$N=5$	Very low-calorie ketogenic diet with protein replacement for 5–7 weeks (T1) and a low-calorie diet for 11–21 weeks (T2)	80% of participants met the criteria for FA YFAS symptoms (T0, 6 ± 1.7; T1, 1.2 ± 0.6; T2, 0.5 ± 0.3)
Gordon et al. [32]	Control (no)	$N=182$ (84.6% female); (55.4 ± 9.9 years); BMI (36.6 ± 3.6)	$N=177$	Behavioral weight-loss program. 4-month in-person intervention (T1), 12-month extended care (T3), and 6-month follow-up (T4)	YFAS symptoms T0, 2.39 ± 1.58; T1 (month 4), 1.56 ± 1.10; T2 (month 10) 1.60 ± 1.29; T3 (month 16), 1.79 ± 1.46; T4 (month 22), 1.92 ± 1.51) FA decreased over time ps < 0.05
Chao et al. [33]	Control (no) Pre/post	$N=178$ (87.6% female); (44.2 ± 11.2 years); BMI (40.9 ± 5.9)	$N=138$	Lifestyle intervention program that used meal replacements and increased physical activity; 3 ± 1 months	6.7% of participants met the criteria for FA YFAS symptoms Pre 2.2 ± 1.6; post 1.9 ± 1.2; $p=0.02$
De Lorenzo et al. [34]	Control (no) Pilot study	$N=14$ (100% MOSH syndrome males and FA); (46.6 ± 14 years); BMI (36.2 ± 7.6)	$N=12$	Dietary intervention and physical activity and probiotic supplementation; 3 ± 1 months	YFAS (54.5% baseline prevalence; 9.1% following a 10% weight reduction); $p=0.063$
Webber et al. [35]	Control (compared two active interventions) Pilot study	$N=33$ (69% females); (52.7 ± 10.7 years); BMI (35.8 ± 3.8); EBT group (pre), $N=16$; IE group (pre), $N=17$	$N=26$; EBT group (post), $N=12$; IE group (post), $N=14$	Intuitive eating program (IE) or stress reduction program (EBT). T1, 7 weeks; T2, 14 weeks	YFAS symptoms T0 EBT, 3.31 ± 1.5; T1 EBT, − 1.25 ± 1.55; T2 EBT, − 0.75 ± 1.66 T0 IE, 3.35 ± 2.2; T1 IE, − 1.15 ± 2.34; T2 IE, − 0.43 ± 2.10 The stress reduction group (EBT) reported decreased FA at week 7; $p=0.02$
Miller-Matero et al. [36]	Control (no) Pilot study	$N=51$ (80.4% female); (48.9 ± 11.70 years); BMI (47.6 ± 9.1)	$N=17$	Integrative psychological weight management group; 6 weeks	YFAS symptoms Pre, 4.00 ± 1.41; post 1–2 years after, 2.70 ± 2.16; $p=0.05$
Giel et al. [37]	Control (no restrictions) Pilot study	$N=26$ (100% female with binge eating disorder); (36.6 ± 11.9 years); BMI (29.6 ± 6.3)	$N=20$	A food-specific inhibition training in three sessions; 2 weeks	YFAS symptoms Control group (T0, 3.4 ± 1.4; T1, 3.5 ± 1.8); FIT group (T0, 3.4 ± 1.8; T1, 3.4 ± 1.3); $p=0.83$

Table 2 (continued)

Reference	Design	Population characteristics	Retention rate	Intervention and duration	Results
Sawamoto et al. [38]	Control (weight maintenance intervention)	$N=119$ (100% female); (48.1 ± 11.3 years)	$N=86$; successful weight loss, $N=34$; unsuccessful weight loss, $N=52$	Weight loss intervention with or without a program to increase exercise adherence; 7 months	YFAS symptoms Successful weight loss (pre), 1.9 ± 1.5; T1 (12 months), 1.7 ± 0.97; T2 (24 months) 1.8 ± 1.1 Unsuccessful weight loss (pre) 2.2 ± 1.4; T1 (12 months), 2.7 ± 1.6; T2 (24 months), 2.5 ± 1.6; $p<0.05$
Hilker et al. [39]	Control (no)	$N=66$, (100% female with bulimia nervosa); (29.2 ± 9.2 years)	$N=55$; good responders, $N=42$; bad responders, $N=13$	Intervention for bulimia nervosa; 6 weeks	YFAS symptoms Good responders (pre, 6.02 ± 1.27; post, 4.78 ± 2.04) Bad responders (pre, 6.58 ± 0.51; post, 6.09 ± 1.04; $p=0.01$)
Mason et al. [40]	Control (standard weight loss program)	$N=88$ (100% females); (46.7 ± 13.2 years); BMI (35.8 ± 3.8)	$N=88$; mindfulness, $N=45$; active control, $N=43$	Weight loss intervention with or without mindfulness training; 5.5 months	Among participants with naltrexone-induced cortisol increases, mindfulness participants reported greater reductions in FA symptoms; $p=0.02$
Weinstein et al. [41]	Control (no) Comparing 3 groups	$N=60$ (100% female); (52 ± 7.61 years)	Gr. 1 (beginning of treatment), $N=21$; Gr. 2 (1 year), $N=17$; Gr. 3 (5 years), $N=22$	Compulsive eating anonymous self-help group using the 12-step program to handle compulsive eating; 60 months	YFAS total (group 1, 36.0 ± 18.7; group 2, 20 ± 11.8; group 3, 26 ± 20.36) FA is lower among participants attending the program for 1 year, $p<0.01$; but not 5 years, $p=0.06$
Pharmacological intervention					
Segura-García et al. [42]	Control (no) Pilot study	$N=35$ (87% female); (33.1 ± 12.8 years); BMI (38.8)	$N=30$	Vortioxetina (VTX) ± 5 mg/day. Without modifying either their eating habits or physical activity during the 24 weeks	YFAS symptoms ($p=0.039$); BMI = 33.6 ($p=0.03$)
Carbone et al. [43]	Control: individuals with non-BED and obesity Pilot study	$N=43$ (67.6% females); age range 18–65 years; BMI ≥ 30 (41.4 ± 8.7) Group 1 (individuals with obesity and BED), $N=23$; Group 2 (individuals with obesity and non-BED), $N=20$	$N=34$; Gr. 1 (individuals with obesity and BED), $N=19$; Gr. 2 (individuals with obesity and non-BED), $N=15$	Naltrexone + bupropion + lifestyle modification—hypo-caloric diet (reducing daily calorie intake of about 500 kcal), behavioral counseling, and moderate aerobic physical activity (i.e., 20-min walk every day); 16 weeks	YFAS symptoms Group 1 (T0, 6.5 ± 3.5; T1, 3.4 ± 3.6); Group 2 (T0, 3.4 ± 2.5; T1, 2.9 ± 3.0); $p=0.03$
Epstein et al. [44]	Control (placebo)	$N=31$ (80.6% female); (31.8 ± 9.5 years); BMI (34.7 ± 9.8)	$N=25$	Pexacerfont (300 mg/day for 7 days then 100 mg/day for 21 days)	YFAS symptoms treatment group (pre, 6.5 ± 4.3; post, 1.59 ± 0.30); placebo group (pre, 7.8 ± 4.2; post, 2.49 ± 0.27); $p<0.04$ Problems/preoccupation on the YFAS were lower in participants randomized to pexacerfont than in those randomized to placebo. This group difference was present from the first day of capsule ingestion

Table 2 (continued)

Reference	Design	Population characteristics	Retention rate	Intervention and duration	Results
Metabolic-bariatric surgical intervention					
Carlos et al. [45]	Control (placebo)	$N=101$ (87.3% female); (40 ± 11.25 years); BMI (43.2 ± 5.4) in subjects after Roux-en-Y gastric bypass surgery	Control group (T0, $N=33$; T1, $N=32$; T2, $N=22$) Intervention group (T0, $N=38$; T1, $N=37$; T2, $N=22$)	Probiotic supplementation (*Lactobacillus acidophilus* NCFM y *Bifidobacterium lactis* Bi-07) dietary orientations by the surgical team (i.e., doctor, dietitian, and psychologist); 3 months	10 days before surgery (T0), at 90 days (T1), and 1 year (T2) after surgery YFAS symptoms Control group (T0, 2.94 ± 2.01; T1, 0.87 ± 1.24; T2, 1.27 ± 1.16) Intervention group (T0, 3.89 ± 1.90; T1, 0.70 ± 0.97; T2, 0.82 ± 1.01) T0, $p=0.025$; T1, $p=0.076$; T2, $p=0.141$
Chiappetta et al. [46]	Control (SG or GB)	$N=113$ underwent sleeve gastrectomy and gastric bypass (68% female); (44.2 ± 9.9 years); BMI pre-surgical (51.7 ± 9.8)	T1, $N=69$; T2, $N=50$	Underwent sleeve gastrectomy and gastric bypass; 24 months	T0 before operation (all, 3.52 ± 1.95; SG, 3.51 ± 1.90; GB 3.53 ± 2.03) T1 6 months postoperatively (all, 1.97 ± 1.54; SG, 2.21 ± 1.64; GB, 1.59 ± 1.31) T2 24 months postoperatively (all, 1.26 ± 0.99; SG, 1.11 ± 0.75; GB, 1.43 ± 1.20); $p<0.0001$; these values did not differ between the surgical groups ($p=0.78$). T0 69% FA–T2 10% FA
Murray et al. [47]	Control (no treatment) Pilot study	$N=27$ (93% female); (32.7 ± 7.6 years); BMI (44.3 ± 4.4)	$N=27$	Weight loss surgery (underwent RYGB and underwent SG); T1, 4 months follow-up; T2, 24 months follow-up	YFAS (33.3% baseline prevalence) YFAS scores decreased in 24 months ($p=0.006$)
Sevinçer et al. [48]	Control (no) Pre/post	$N=166$ underwent sleeve gastrectomy and gastric bypass (77.1% female); (35.6 ± 9.8 years); BMI pre-surgical (47.0 ± 7.1)	$N=158$	Underwent sleeve gastrectomy and gastric bypass; 12 months	T0 (before operation), 3.76 ± 1.45; T1 (6 months after surgery), 2.76 ± 1.01; T2 (12 months after surgery), 2.06 ± 1.25; $p<0.01$ at 6 and 12 months

Table 3 Overview of studies investigating the effect of different treatments in adolescent participants with overweight/obesity

Adolescents behavioral intervention					
Reference	Design	Population characteristics	Retention rate	Intervention and duration	Results
Vidmar et al. [49]	Control (usual care). Multidisciplinary program delivered by a health educator, a registered dietician, and a physician	$N=117$ (65% female); (15.5 ± 1.3 years); with obesity	Control group, $N=23$; Appcoach group, $N=39$; AppAlone, $N=18$	Movil health incorporating elements of addiction medicine; 24 weeks	YFAS symptoms (T0, 3; T1, median change, −0.3); 57% showed a decrease in symptom count in YFAS-C scores after the intervention; $p=0.045$
Vidmar et al. [50]	Control (usual care) Pilot study	$N=54$; 93% FA (60% female); (14.4 ± 1.7 years); with obesity	$N=35$	Mobile health weight loss intervention; 6 months	YFAS symptoms (pre, 4.22 ± 1.35; post, 3.78 ± 1.48); 17% of app participants had negative YFAS-C scores upon completion of the intervention; $p=0.52$
Tompkins et al. [51]	Control (no) Pre/post Pilot study	$N=26$ (53.8% female); (14.0 ± 1.9 years); BMI (33.0 ± 6.3)	$N=13$	Physical activity and nutrition instruction as well as behavioral instruction derived from social cognitive theory; 12 weeks	T0, 50% reported ≥ 3 symptoms; YFAS symptoms (pre, 2.08 ± 1.6; post, 1.00 ± 0.9); there were no statistically significant changes

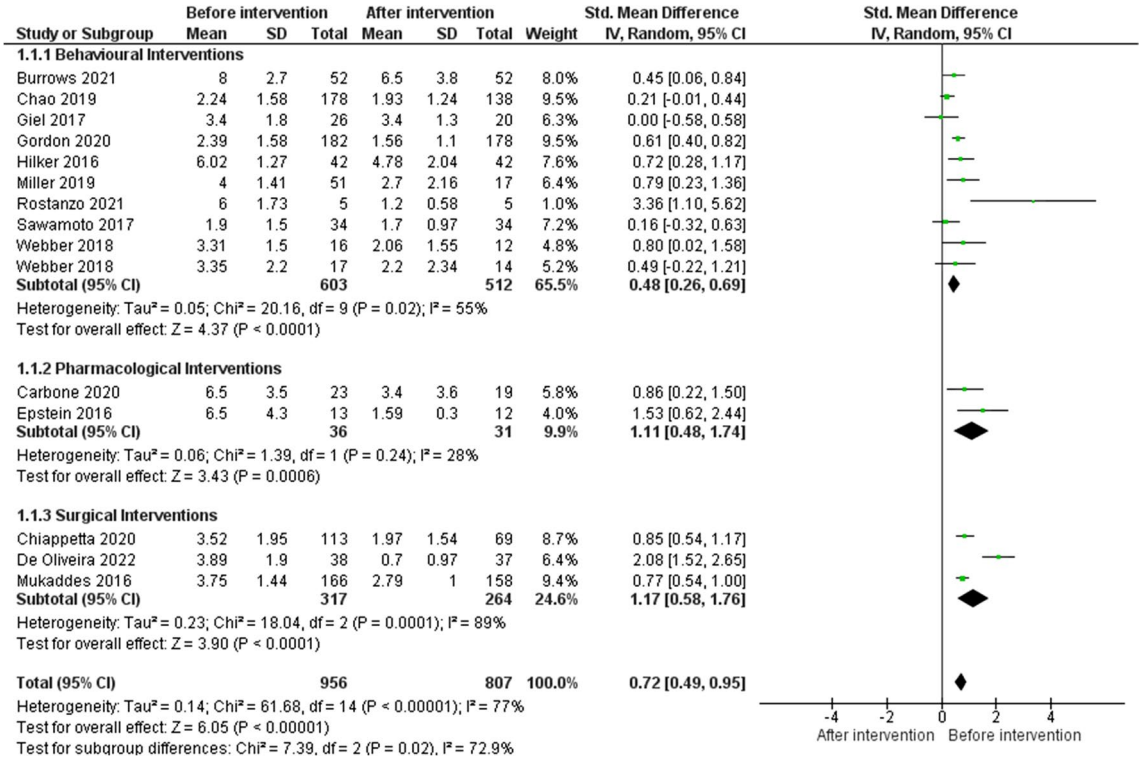

Fig. 2 Random-effects meta-analysis of standard mean differences (SMDs) and 95% CIs for studies included before/after the intervention information on YFAS scores. Meta-analysis categories included (1.1.1) behavioral, (1.1.2) pharmacological, and (1.1.3) surgical interventions. Pooled summary data for each group represent the SMD and 95% CI. The size of the data markers indicates the weight assigned to each study in the meta-analysis. Squares represent the SMD, bars represent the 95% CI, and diamonds represent the pooled analysis

found no significant differences [34], or the efficacy was not sustained over time [41]. All the studies that carried out pharmacological interventions found significant reductions in FA symptomatology, as did the studies testing surgical interventions. On the other hand, two of the studies conducted on adolescent populations did not show significant reductions in FA symptomatology, and only the work of Vidmar et al. [49], which employed a smartphone app with elements of addiction medicine, was able to significantly reduce FA symptoms in adolescents.

Weight-Related Changes

Considering that all the studies were conducted in individuals with overweight/obesity and that, in most studies, weight loss was reported as a secondary outcome, we also evaluated the efficacy of the interventions regarding weight loss outcomes (Table 4). Many of the psychological and pharmacological intervention studies in adults treated FA as a secondary outcome. Two of these studies reported associations between weight loss and changes in FA symptomatology [33, 38]. However, none of the psychological interventions in adolescents were associated with weight loss. All the surgical intervention studies used FA as the main outcome and generally reported a significant amount of weight loss.

Heterogeneity of the Reported Outcomes

In the meta-analysis of behavioral interventions, there was a medium degree of heterogeneity ($\chi^2 = 20.16$; $p = 0.02$; $I^2 = 55\%$), mainly as a consequence of the extreme variability of the study of Rostanzo et al. [31]. Regarding pharmacological interventions, there was lower heterogeneity ($\chi^2 = 1.39$; $p = 0.24$; $I^2 = 28\%$), a situation probably derived from the reduced number of studies in this kind of intervention. In contrast, heterogeneity for the bariatric-metabolic surgical intervention was very high ($\chi^2 = 18.04$; $p = 0.0001$; $I^2 = 89\%$), fully due to the higher effect observed in the study of Carlos et al. [45]. In fact, when a sensitivity analysis was performed removing this work, the heterogeneity of the bariatric-metabolic surgery studies disappeared ($\chi^2 = 0.19$; $p = 0.66$; $I^2 = 0\%$, see supplementary Fig. S1).

Table 4 Outcome measures in weight loss intervention programs

Reference	Retention rate and BMI	Duration	Weight intervention	Results	FA outcome
Behavioral intervention					
Rostanzo et al. [31]	$N=5$; BMI (31.1 ± 0.9)	5–7 weeks (T1),11–21 weeks (T2)	Very low-calorie ketogenic diet with protein replacement (T1) or low-calorie diet (T2)	Weight (T0, 83 ± 1.52; T1, 76.2 ± 1.01, $p<0.001$; T2, 75.75 ± 0.85, $p<0.001$)	Primary
Gordon et al. [32]	$N=177$; BMI (36.6 ± 3.6)	4 (T1), 10 (T2), 16 (T3), and 22 (T4) months	Behavioral weight loss program	Weight (T0, 99.6 ± 13.9; T1, 90.74 ± 13.56, $p=0.05$*; T2, 89.90 ± 14.8, $p=0.05$*; T3, 91.65 ± 15.38, $p=0.05$*; T4, 93.67 ± 15.38, $p=0.05$*)	Primary and is not associated with weight loss
Miller et al. (2019)	$N=17$; BMI (47.6 ± 9.1)	6 weeks	Integrative psychological weight management group	Pre/post group BMI, $t=7.04$, $p<0.001$	Primary
Chao et al. [33]	$N=138$; BMI (40.9 ± 5.9)	14 weeks	Lifestyle intervention program that used meal replacements and increased physical activity	Weight (T0 = 114.6 ± 22.5; T1 = 104.1 ± 20.8; $p=0.001$); FA changes were not associated with weight loss $p=0.80$	Secondary and predictor of weight loss
De Lorenzo et al. [34]	$N=12$; BMI (36.2 ± 7.6)	3 ± 1 months	Dietary intervention, physical activity, and probiotic supplementation	Weight (T0 = 109.3 ± 20.5; T1 = 100.8 ± 19.6; $p=0.0001$)	Secondary
Webber et al. [35]	N = 26; BMI (35.8 ± 3.8)	7 weeks follow up; 14 weeks	Intuitive eating program (IE) or stress reduction program (EBT)	Weight loss (lb) EBT to 7 weeks. − 2.9 ± 4.6, $p=0.05$*; EBT to 14 weeks − 4.4 ± 6.7, $p=0.05$*; IE to 7 weeks − 1.59 ± 3.3, $p=0.12$; IE to 14 weeks − 1.03 ± 6.10, $p=0.54$	Secondary
Sawamoto et al. [38]	$N=86$	7 months	Weight loss intervention with or without a program to increase exercise adherence	BMI change Successful weight loss (pre, 30.7 ± 4.9; T1 (12 months), − 13.3 ± 5.6; T2 (24 months), − 13.3 ± 5.7) Unsuccessful weight loss (pre, 31.6 ± 4.7; T1 (12 months), − 8.4 ± 2.6; T2 (24 months), − 9.2 ± 3.6)	Secondary and predictor of weight loss

Table 4 (continued)

Reference	Retention rate and BMI	Duration	Weight intervention	Results	FA outcome
Pharmacological intervention					
Segura-García et al. [42]	$N=30$; BMI (38.8)	24 weeks	Vortioxetina (VTX) ± 5 mg/day. Without modifying either their eating habits or physical activity	BMI change; T0 = 38.8; T1 = 38.4; T2 = 35.9; T3 = 34.8; T4 = 33.6; ($p=0.039$)	Secondary
Carbone et al. [43]	$N=34$; BMI ≥ 30 (41.4 ± 8.7)	16 weeks	Naltrexone + bupropion + lifestyle modification: hypocaloric diet (reducing daily calorie intake of about 500 kcal), behavioral counseling, and moderate aerobic physical activity (i.e., 20-min walk every day)	BMI change; Group 1 (T0, 39.0 ± 7.8; T1, 35.8 ± 6.8); Group 2 (T0, 43.8 ± 9.6; T1, 40.3 ± 8.8); $p=0.101$	Secondary and associated with weight loss
Epstein et al. [44]	$N=25$; BMI (34.7 ± 9.8)	Pexacerfont (300 mg/day for 7 days then 100 mg/day for 21 days)	Pexacerfont (300 mg/day for 7 days then 100 mg/day for 21 days)	Baseline BMI; treatment group, 33.0 ± 11.4; placebo group, 36.4 ± 8.3	Primary
Surgical intervention					
Carlos et al. [45]	Control group (T0, $N=33$; T1, $N=32$; T2, $N=22$) Intervention group (T0, $N=38$; T1, $N=37$; T2, $N=22$) BMI (43.2 ± 5.4) in subjects after Roux-en-Y gastric bypass surgery	3 months	Probiotic supplementation (*Lactobacillus acidophilus* NCFM y *Bifidobacterium lactis* Bi-07); dietary orientations by the surgical team (i.e., doctor, dietitian, and psychologist)	10 days before surgery (T0), at 90 days (T1), and 1 year (T2) after surgery Weight: control group (T0, 111.21 ± 17.57; T1, 87.72 ± 13.81; T2, 74.39 ± 13.34); intervention group (T0, 113.61 ± 23.21; T1, 91.31 ± 19.21; T2, 73.18 ± 21.12); between groups (T0, $p=0.95$; T1, $p=0.71$; T2, $p=0.34$)	Primary and associated with weight loss
Chiappetta et al. [46]	T1, $N=69$; T2, $N=50$; BMI pre-surgical (51.7 ± 9.8)	24 months	Underwent sleeve gastrectomy and gastric bypass	Weight loss; baseline weight 146.5 ± 31.2; % of total body weight loss at 24 months, 32.0 ± 13.4	Primary and associated with weight loss

Table 4 (continued)

Reference	Retention rate and BMI	Duration	Weight intervention	Results	FA outcome
Murray et al. [47]	$N=27$; BMI (44.3 ± 4.4)	T1, 4; T2, 24 month follow-up	Weight loss surgery (underwent RYGB and SG)	Significant reductions in BMI in all groups after 4 months ($p<0.050$ in all groups) When comparing baseline at 24 months, within each group, BMI declined significantly in the surgery group only ($p<0.001$)	Primary and associated with weight loss in surgical group
Sevinçer et al. [48]	$N=166$; BMI pre-surgical (47.0 ± 7.1)	12 months	Underwent sleeve gastrectomy and gastric bypass	Baseline BMI LSG group, 47.0 ± 7.1; T1, 6 months after LSG surgery (35.1 ± 5.90); T2, 12 months after LSG surgery (30.88 ± 6.07) Baseline BMI MGB group, 45.61 ± 6.07; T1, 6 months after MGB surgery (33.92 ± 5.39); T2, 12 months after MGB surgery (27.98 ± 4.67) Between groups $p=0.051$ There were no statistical differences between surgical interventions with regard to BMI at the 12-month follow-up	Primary and associated with weight loss
Adolescents behavioral intervention					
Vidmar et al. [49]	Control group, $N=23$; Appcoach group $N=39$; AppAlone, $N=18$; with obesity	24 weeks	Movil Health incorporating elements of addiction medicine	%BMIp95 (excess percent over the 95th percentile) Median (min–max): control group (pre 125.43 (101.56–197.93)); App group (pre, 129.53 (104.61–193.47)) There was no association with change in weight ($p=0.3$)	Primary and does not associate with weight loss

Table 4 (continued)

Reference	Retention rate and BMI	Duration	Weight intervention	Results	FA outcome
Vidmar et al. [50]	$N=35$; with obesity	6 month	Mobile health weight loss intervention	%BMIp95 (excess percent over the 95th percentile) App group (baseline = 127.17 ± 21.10; 3 months = 119.44 ± 21.31; 6 months = 118.83 ± 22.73); EMPOWER group (baseline = 136.45 ± 22.76; 3 months = 132.08 ± 20.91; 6 months = 132.20 ± 22.49) No significant relationship between the change in zBMI at 6 months and the YFAS-C score at baseline (coef = 0, 01; 95% CI = −0.02, 0.04; $p=0.52$)	Secondary and doesn´t associated with weight loss
Tompkins et al. [51]	$N=13$; BMI (33.0 ± 6.3)	12 weeks	Physical activity and nutrition instruction, as well as behavioral instruction derived from social cognitive theory	Weight (pre, 83.1 ± 12.8; post, 83.8 ± 12.3); BMI (pre, 30.7 ± 4.2; post, 30.4 ± 4.1) There were no statistically significant changes	Primary and is not associated with weight loss

Risk of Bias

More than half of the studies were found to be at high risk of bias for the following domains: sources of bias (80%), blinding of assessors (72%) and participants (66%), allocation concealment (58%), and selective outcome reporting (55%) (Fig. 3). The lowest risk of bias was observed in sequence generation. Overall, the quality of the studies was average, and only six of the 15 studies could be considered of high quality. Bariatric-metabolic surgery works were those that showed the lowest risk of bias, according to the assessment tool.

Discussion

This systematic review and meta-analysis aimed to investigate the effectiveness of behavioral, pharmacological, and surgical interventions in reducing the symptomatology of Food Addiction (FA) evaluated with the Yale Food Addiction Scale (YFAS) in human populations. The reviewed evidence, although limited and with a high risk of bias in most domains, suggests a beneficial effect of surgical, pharmacological, and behavioral interventions, in that order, on FA symptomatology in people with overweight/obesity. Despite searching multiple databases, limited evidence regarding therapeutic interventions against FA was found, especially for adolescents, where only three psychological interventions were retrieved. Furthermore, in this age group, no intervention appeared to improve symptoms related to FA. It is important to note that most eating disorders originate in adolescence, so the lack of effective interventions in this age group poses a problem in addressing addictions early and preventing psychiatric and physical comorbidity in adulthood.

This review also highlighted the absence of FA intervention studies conducted in individuals without overweight or obesity, which is of great relevance since there are individuals in whom FA does not lead to the development of obesity [53]. However, FA is associated with factors that may increase the risk of obesity, such as higher binge eating levels, greater emotional dysregulation and nonacceptance of negative feelings, lack of goal-oriented behavior, little impulse control, difficulty in emotion recognition and attentional impulsivity, inability to concentrate, and lack of inhibitory control behavior [54]. Some studies included in this review measured FA as a secondary outcome (36%) and/or associated it with or without weight loss. In adults, weight changes and reductions in FA symptoms were observed in all types of interventions, particularly in surgical interventions. Weight loss, along with other lifestyle changes after surgery, appears to be the determining factor in improving FA symptomatology in adults. However, all of the psychological interventions in adolescents and one of the adults [32] were not associated with weight loss.

This review found that surgical interventions (including lifestyle, diet, and/or behavior modifications) and pharmacological interventions (one of which also included lifestyle, diet, and physical activity modifications) significantly reduce self-reported FA symptoms in adults post-intervention. However, not all behavioral interventions (including lifestyle intervention programs, dietary modifications, increased physical activity, and more specific interventions such as mindfulness training, stress reduction programs, and therapy groups) included in this review reduced symptomatology. Some of them only had partial effects, were not significant, or were not sustained over time.

Fifteen behavioral, four surgical, and three pharmacological interventions were studied in this review. However, the limited number of interventions prevents drawing too strong conclusions, particularly regarding pharmacological and surgical interventions. In the case of psychological interventions, following the meta-analysis, the study by Rostanzo et al. [31] with four subjects with FA, using a very low-calorie

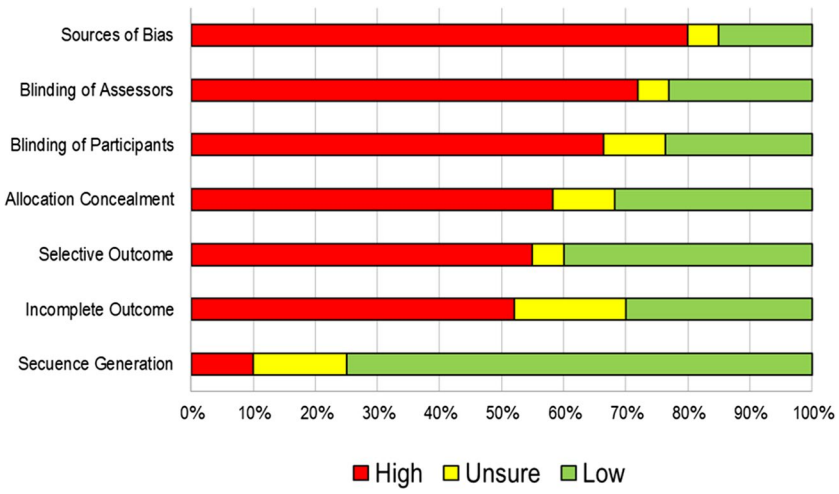

Fig. 3 Results of assessment for risk of bias

ketogenic diet with protein replacement for 5–7 weeks or a low-calorie diet for 11–21 weeks, showed the most positive effects. The study by Webber et al. [35] with an Intuitive Eating program (IE) or stress reduction program (EBT), and the study by Miller et al. [36] with an integrative group for weight management, incorporating cognitive, behavioral, acceptance, and commitment, systems, and mindfulness techniques also found the most benefit for FA symptoms. The studies included in the meta-analysis suggested beneficial effects on FA symptomatology in adults with overweight/obesity through surgical, pharmacological, and behavioral interventions, in that order. However, it is important to note that surgical interventions were accompanied by dietary and behavioral guidelines and other lifestyle changes. Previous works have highlighted the beneficial role of bariatric-metabolic surgery on some psychological traits. For instance, a significant decrease in depression and anxiety in the year after surgery has been previously described compared to controls treated with diet counseling and exercise [55]. Furthermore, a recent study has shown that patients themselves rate the beneficial effects of surgery on their mental health very positively [56]. Moreover, although many patients continue to suffer from psychologically stressful eating behaviors after surgery, even in these cases, it has been suggested that binge symptomatology may be alleviated, likely because patients are required to follow strict small-meal diets postoperatively [57]. The reduction of symptoms associated with food addiction after obesity surgery that we have been able to describe in the present work confirms and expands the beneficial effects of bariatric-metabolic surgery on the mental health issues of these patients. Considering that, in the past, eating disorders were in many countries considered a "no-go" for bariatric surgery, in our opinion, the identification of addictive-like behaviors should be considered a "pro-point" for undergoing bariatric surgery in these patients. Several aspects may rely on the higher effect of surgical interventions. As commented, the post-surgery dietary patterns are radically different from the pre-intervention patterns. Furthermore, weight losses are significantly greater in this type of intervention [58]. Finally, the quality and follow-up of studies based on bariatric-metabolic surgery were much higher than other interventions. Nevertheless, the small number of studies suggests the need for more evidence before stating that surgery is the solution to food-related addictive symptoms. Apart from the physical aspects of weight loss, obesity surgery is often accompanied by profound lifestyle changes that can have a significant impact on a person's mental health. In this line, a previous report showed that patients who underwent weight loss surgery exhibit an increase in substance use (drug use, alcohol use, and cigarette smoking) to compensate for the marked decrease in food intake [59]. Therefore, a psychiatric evaluation would be essential to identify and treat underlying psychological factors, like food and other substance or behavioral addictions, that may affect surgical outcomes and long-term success [60].

Several limitations of the present work should be mentioned, with the most important being the inclusion of low-quality trials with methodological limitations, such as study designs that lacked a control group, and pilot or small studies reporting preliminary results, which may have limited the robustness of the meta-analysis. Overall, we should not fool ourselves into believing that bariatric-metabolic surgery is the solution for a person with obesity and food addiction, and more studies with higher-quality methodological designs are still necessary. We also observed a lack of male participants, so caution should be exercised when generalizing these results to men. The average retention rate of the included studies at the final follow-up was 72.4% (range 21.7–100%) similar to the 78.2% (range 44–100%) retention rate in male participants' weight maintenance interventions [28]. It is known that individuals with addictions and obesity often exhibit deficiencies in executive function domains, such as decision-making and sustained attention [25]. This may explain the lack of participant commitment and the difficulty in conducting long-term studies. Future studies should also apply the intention-to-treat approach and differentiate the effects of weight loss versus addiction symptoms. Furthermore, exploring the potential effectiveness of substance addiction treatments in the case of food addiction would be valuable, as we only have found one study supporting this [41].

Conclusion

In conclusion, the present systematic review and meta-analysis described the positive impact of the different available interventions on FA symptomatology among adults with overweight or obesity. Our findings underline the effectiveness of different approaches, with bariatric-metabolic surgical interventions demonstrating the most significant effect, followed by pharmacological and behavioral interventions, respectively. It is important to highlight, however, that the low number of studies based on pharmacological and bariatric-metabolic surgical interventions, along with the poor general quality of behavioral studies, warrants cautious interpretation. In addition, there was significant heterogeneity due to the different study designs and durations of the interventions over time. Overall, our findings suggest a more favorable impact of bariatric-metabolic surgical interventions on food addiction symptomatology. However, it is imperative to exercise prudence in conclusively asserting the adequacy of obesity surgery for addressing food addiction at this time. Moreover, in the search for a more comprehensive and effective intervention, our research underscores the need to incorporate psychiatric evaluations into the care framework

for individuals undergoing obesity surgery. Recognizing the complex interplay between mental health and food addiction, such assessments, are essential to identify and address underlying psychological factors that may influence surgical outcomes. Nevertheless, a higher quality evidence base is needed to inform clinical practice in people with food addiction symptomatology.

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Data Availability The corresponding author confirms that all data generated or analysed during this study are included in this published article. Nevertheless, specific information about meta-analysis data extraction or any other information can be requested to Dr. Juan José Hernández Morante (jjhernandez@ucam.edu).

Declarations

Ethical Approval For this type of study formal consent is not required.

Informed Consent Informed consent does not apply.

Conflict of Interest The authors declare no competing interests.

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