

TESIS DOCTORAL



UCAM

UNIVERSIDAD CATÓLICA
DE MURCIA

ESCUELA INTERNACIONAL DE DOCTORADO

Programa de Doctorado en Ciencias de la Salud

Validez de una aplicación móvil para detectar fragilidad y sarcopenia en ancianos residentes en la comunidad

Autor:

D. Alessio Montemurro

Directores:

Dr. D. Juan Diego Ruiz Cárdenas

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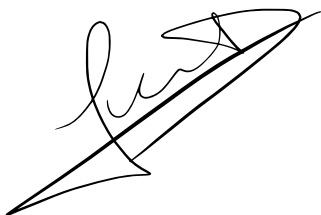
Murcia, junio de 2024

AUTORIZACIÓN DEL DIRECTOR DE LA TESIS PARA SU PRESENTACIÓN

El Dr. D. Juan Diego Ruiz Cárdenas y el Dr. D. Juan José Rodríguez Juan como Directores⁽¹⁾ de la Tesis Doctoral titulada “Validez de una aplicación móvil para detectar fragilidad y sarcopenia en ancianos residentes en la comunidad” realizada por D. Alessio Montemurro en el Programa de Doctorado en Ciencias de la Salud, **autoriza su presentación a trámite** dado que reúne las condiciones necesarias para su defensa.

Lo que firmo, para dar cumplimiento al Real Decreto 99/2011 de 28 de enero, en Murcia a 12 de junio de 2024.

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RESUMEN

Sarcopenia y fragilidad constituyen dos condiciones que surgen durante el proceso de envejecimiento. Ambas condiciones se asocian al desarrollo de eventos adversos relacionados con la salud, tales como caídas, hospitalización o incluso a un incremento del riesgo de mortalidad. Adicionalmente, cuando ambas condiciones están presentes en un mismo sujeto de forma simultánea, el riesgo de mortalidad es mayor que el riesgo observado al sufrir solamente una o ninguna de las dos condiciones. A pesar de esto, ambas condiciones pueden llegar a revertirse sin ser detectadas de manera precoz. Sin embargo, el personal clínico destaca la falta de herramientas de bajo coste y fácil acceso que permitan un diagnóstico rápido y fiable. Esta tesis doctoral se centró en desarrollar y validar una aplicación móvil (*Sit to Stand*) basada en el análisis de video del gesto de levantarse de una silla que fuese capaz de detectar ambas patologías, de forma aislada o de forma conjunta, en ancianos residentes en la Región de Murcia.

Para asegurar la máxima transparencia en la difusión de los resultados derivados de esta investigación, se llevó a cabo el registro del protocolo de investigación de forma prospectiva y se difundió en una revista académica en formato artículo científico (**Artículo I**). Adicionalmente, teniendo en cuenta que la mayoría de las aplicaciones para dispositivos móviles están disponibles exclusivamente para usuarios Apple, en esta tesis doctoral se llevó a cabo la validación de la aplicación *Sit to Stand* en la plataforma Android. Esta herramienta resultó igual de fiable que la versión para dispositivos Apple para determinar el tiempo, la velocidad y la potencia generados durante el gesto de levantarse de una silla, encontrando un error de medida < 5%. Además, la aplicación resultó fiable para discriminar las personas sanas de aquellas con sarcopenia, baja velocidad de marcha y bajo rendimiento físico (**Artículo II**).

En el tercer estudio de esta tesis se analizó la influencia de los diferentes puntos de corte propuestos por consenso europeo (EWGSOP2) para diagnosticar sarcopenia en una muestra de ancianos que viven en nuestra comunidad. La prevalencia de la enfermedad varió considerablemente (2% al 12%) en función del criterio diagnóstico utilizado, observando un bajo acuerdo (κ -rango: 0,13–0,66) entre los criterios diagnósticos. Además, cada criterio diagnóstico se asoció de

forma diferente con eventos adversos relacionados con la salud (**Artículo III**). Este análisis nos condujo a la necesidad de utilizar todos los puntos de corte propuestos por el EWGSOP2 como estándar de referencia para desarrollar nuestra aplicación móvil.

Finalmente, la aplicación móvil *Sit to Stand*, basada en los valores de potencia generados durante el gesto de levantarse de una silla y en los valores antropométricos de la circunferencia de pantorrilla, resultó ser una herramienta válida y precisa para detectar tanto sarcopenia de manera aislada (**Artículo IV**), como de forma simultánea a la presencia de fragilidad o prefragilidad (**Artículo V**), en personas mayores de 60 años residentes en la Región de Murcia. Adicionalmente, las personas con sarcopenia o con la coexistencia de ambas enfermedades diagnosticadas con la aplicación móvil tuvieron un riesgo mayor de sufrir eventos adversos relacionados con la salud comparado con las personas sanas o con aquellas que fueron diagnosticadas con una de las dos condiciones.

PALABRAS CLAVE

Sarcopenia; fragilidad; potencia; sit-to-stand; smartphone; ancianos; diagnóstico.

ABSTRACT

Sarcopenia and Frailty Syndrome represents two health conditions which appear during the physiological ageing process. Both conditions are associated with the occurrence of many adverse health-related outcomes like falls, hospitalization, or even mortality. Additionally, when both conditions are simultaneously present in the same subject, mortality risk is higher than the risk observed suffering either condition alone or none. Nevertheless, if early detected, both conditions could be reversed. However, healthcare professionals highlight the lack of a low cost and easily accessible tool to detect an early and feasible diagnosis. So, this thesis aimed to develop and to validate a mobile app to detect both conditions, either alone, or simultaneously present, in community-dwelling older adults living in the Region of Murcia.

To ensure as much transparency as possible during the sharing of the research results, the study protocol was previously recorded, and it was shared in article-format on a high-impact journal (**Article I**). Additionally, since most of the apps are available just for Apple users, this thesis aimed to validate the *Sit to Stand* app on the Android platform. The tool showed the same reliability as the previously validated version in Apple app to measure time, velocity and power generated during a single sit-to-stand task, with a measurement error < 5%. Furthermore, the app showed good reliability to discriminate cases with sarcopenia, low gait speed and poor physical function from their healthy counterparts (**Article II**).

In the third study of this thesis the influence of different cut-off points proposed by the European Working Group on Sarcopenia in Older People 2 (EWGSOP2) to detect sarcopenia in community-dwelling older people was analyzed. Prevalence of the disease varied considerably (2% to 12%) depending on the diagnostic criteria employed, showing low agreement (κ -range: 0.13–0.66) among the diagnostic criteria. Moreover, each diagnostic criteria were diversely associated with different health-related adverse events (**Article III**). This led us to the necessity of using each cut-off point proposed by the EWGSOP2 as standard reference for the development of our mobile app.

Finally, the app, which is based on both power generated during a single sit-to-stand task and anthropometric values of calf circumference, resulted in a reliable and accurate tool to detect both sarcopenia alone (**Article IV**), as well as its simultaneous presence (**Article V**) with frailty or prefrailty, in men and women older than 60 living in the Region of Murcia. Additionally, subjects with sarcopenia alone or with the coexistence of both conditions detected by the app were more likely to suffer adverse health-related outcomes compared to their healthy counterparts or with subjects only having one condition alone.

KEYWORDS

Sarcopenia; frailty; power; sit-to-stand; smartphone; older adults; diagnosis.

AGRADECIMIENTOS

Este trabajo es el culmen de un proceso de aprendizaje que no empezó hace cuatro años, sino que mucho antes. Si es verdad que, como cuentan, somos la suma de las personas que están a nuestro alrededor, este trabajo contiene una pequeña parte de todos ellos.

En este trabajo está presente mi familia, que me ha brindado apoyo constante en todas las etapas de mi vida, enseñándome el valor y el honor del trabajo duro.

Mis amigos, que hicieron que este camino fuese más llevadero y de los cuales aprendí que es posible cambiar el mundo hasta con una cerveza, una coca cola o un entrenamiento.

Mis compañeros y amigos del departamento de Fisioterapia, que me acogieron y protegieron como los padres hacen con los hijos. Con sus experiencias me dieron todas las herramientas necesarias para hacer que este trabajo no fuese tan duro y tedioso como se cuenta.

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Espero que estéis orgullosos de este trabajo, porque habéis sido los autores.

Gracias por aportar tanto a mi vida.

«If you find a path with no obstacles, it probably doesn't lead anywhere».
Frank A. Clark (1860-1936).

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SIGLAS Y ABREVIATURAS

AUC, Área Bajo la Curva

BIA, Análisis de Impedancia Bioeléctrica

CES-D, Centre for Epidemiological Studies – Depression

DXA, Absorciometría de rayos X de energía dual

EWGSOP2, European Working Group on Sarcopenia in Older People 2

HR, Hazard Ratio

OR, Odds Ratio

RR, Risk Ratio

SPPB, Short Physical Performance Battery test

TUG, Time Up and Go

VREM, Versión Reducida en Español del cuestionario de actividad física en el tiempo libre de Minnesota

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I – INTRODUCCIÓN



I - INTRODUCCIÓN

1.1. EL ENVEJECIMIENTO: CONSECUENCIAS DESDE EL PUNTO DE VISTA FISIOPATOLÓGICO

La población mundial está envejeciendo año tras año. Se estima que para el año 2030, el número de personas mayores de 60 años alcanzará los 1,4 mil millones, incrementando alrededor de 400 millones con respecto a las cifras alcanzadas en el año 2020. Adicionalmente, se prevé que para el año 2050 el número total de mayores de 60 alcanzará los 2,1 mil millones (*World Health Organization*, 2022). En España, país con una de las mayores esperanzas de vida a nivel europeo, los datos relativos al año 2021 establecieron que las personas de 65 años o mayores constituían el 21% de la población total, lo que suponía un aumento de un 5% con respecto al año 2001 (Instituto Nacional de Estadística, 2023).

El envejecimiento se define como el deterioro de las funciones fisiológicas necesarias para la supervivencia y la fertilidad asociado con el transcurso del tiempo (Gilbert, 2000). Existen numerosas teorías que tratan de proporcionar una explicación fisiopatológica de este proceso: alteraciones del ADN mitocondrial y de los núcleos celulares causados por la acumulación de daño genético, el desgaste de los telómeros que ocurre durante los ciclos de reproducción celular, desequilibrios de la homeostasis proteica, la excesiva proliferación de radicales libres, o la senescencia celular, que consiste en la detención irreversible del ciclo celular (López-Otín et al., 2013).

Independientemente de la causa exacta que lo determine, este proceso se traduce en unas consecuencias que afectan al organismo a nivel multisistémico (Valenzuela et al., 2019). A nivel hemático, el envejecimiento se caracteriza por una disminución de las citoquinas anti-inflamatorias, proteínas de bajo peso molecular encargadas de mediar y suprimir los procesos inflamatorios que ocurren en el organismo. Este proceso se ve acompañado por el respectivo aumento de las citoquinas pro-inflamatorias, responsables de la acción contraria (Dinarelli, 2000); desequilibrio que, cuando se mantiene en el tiempo, desemboca en un estado de inflamación de bajo grado constante, un proceso conocido como *inflammaging* (Valenzuela et al., 2019). Además, se observa una disminución de los niveles de hormonas de crecimiento, de los factores de crecimiento similares a la insulina y de

la testosterona libre en sangre; todas ellas desempeñan un rol fundamental para el mantenimiento de las funciones fisiológicas y de la masa muscular (Navaratnarajah & Jackson, 2017).

En relación con los cambios producidos sobre el sistema cardiorrespiratorio, a nivel cardíaco se produce un ensanchamiento de las paredes del ventrículo izquierdo, así como un aumento de la rigidez, tanto de las válvulas cardíacas como de los vasos sanguíneos circunstantes, que incluso puede terminar en su calcificación, ocasionando un aumento de la presión arterial. Finalmente, se observa la disminución del gasto cardíaco, producido principalmente por la disminución del volumen de eyección (Ferrari et al., 2003; Navaratnarajah & Jackson, 2017; Scott-Warren & Maguire, 2017). Asimismo, los pulmones ven su capacidad elástica disminuirse de manera significativa, acompañándose por una mayor rigidez de la caja torácica y por una disminución progresiva de los niveles de fuerza de la musculatura respiratoria. Dichos cambios estructurales del tejido pulmonar desembocan en la disminución de la capacidad vital, de la capacidad vital forzada, del volumen espiratorio forzado en el primer segundo y un aumento de la capacidad residual funcional (Navaratnarajah & Jackson, 2017; Scott-Warren & Maguire, 2017).

Por otro lado, en el sistema neuromuscular se observa una pérdida parcial y progresiva de las motoneuronas- α y de las unidades motoras, consecuencias fisiológicas de la denervación y de la atrofia de las fibras musculares de tipo I y tipo II, siendo estas últimas las más afectadas (Miljkovic et al., 2015; Valenzuela et al., 2019). Disminuye la velocidad de la transmisión del impulso nervioso que, junto con una disminución de la excitabilidad a nivel corticoespinal, tienen como consecuencia la disminución tanto de la capacidad del músculo para contraerse voluntariamente, como de la capacidad para reclutar las unidades motoras. Estos procesos dan lugar a una contracción muscular que se vuelve cada vez menos eficiente. Además, los cambios en la arquitectura del sistema muscular implican la disminución de la masa muscular y de la fuerza. Concretamente, a partir de los 50 años los individuos pierden alrededor de un 1,4% de su masa muscular y hasta el 2,2% de su fuerza máxima cada año, afectando en mayor medida a las extremidades inferiores (Frontera et al., 2000). Sin embargo, la potencia muscular, definida como el producto de la capacidad para generar fuerza por la velocidad de

desplazamiento, disminuye antes y más rápidamente que la fuerza y la masa muscular (Metter et al., 1997). La potencia representa un biomarcador de salud importante, debido a sus asociaciones con el desarrollo de numerosos eventos adversos, como caídas, dependencia e, incluso, mortalidad (Reid et al., 2014).

El envejecimiento trae consigo cambios que afectan los tejidos óseo y cartilagíneo. En primer lugar, a partir de los 40 años se aprecia una pérdida lineal y progresiva de la masa ósea, que afecta en mayor medida a las mujeres (Boss & Seegmiller, 1981). En un estudio de cohortes con un seguimiento de 10 años se observó como hombres mayores de 50 años perdieron anualmente entre el 0,75% y el 1% de la densidad mineral ósea, mientras que en mujeres varió entre el 0,71% y el 1,48% (Daly et al., 2013). Una posible explicación de la desmineralización ósea podría encontrarse en el desequilibrio entre formación y reabsorción de tejido. Frente a los mismos estresores o micro-impactos, el organismo durante el envejecimiento deja de reaccionar con la misma estimulación de actividad osteoblástica, responsable de la formación de nuevo tejido óseo, respondiendo con una mayor actividad osteoclástica, responsable de la reabsorción del tejido óseo (Kiebzak, 1991). Esto tiene como consecuencia cambios en la arquitectura y estructura del hueso cortical y trabecular que ocasionan una mayor sensibilidad frente a los impactos o traumatismos, y que desembocan en consecuencias negativas para la salud de las personas como microfracturas u osteoporosis (Kiebzak, 1991). Por otro lado, el cartílago articular disminuye de forma importante su contenido de agua, aumenta la producción de colágeno tipo I y II, y aumenta la actividad proteolítica y la fragmentación de moléculas de colágeno, implicando una menor resistencia frente a las fuerzas de tracción (S. Roberts et al., 2016).

Adicionalmente, cambios en el interior de la articulación, como una reducida producción de ácido hialurónico y de proteínas que disminuyen la fricción entre superficies articulares, así como la pérdida de elasticidad y flexibilidad de la capsula articular, junto con una mayor rigidez de tendones y ligamentos, dan lugar a unas articulaciones con menor capacidad para absorber impactos y más rígidas, ocasionando problemas de movilidad (Gul et al., 2024).

En términos generales, los cambios multisistémicos ocasionados por el proceso de envejecimiento repercuten en la alteración de la homeostasis de los individuos, predisponiéndolos a una mayor vulnerabilidad frente a los estresores diarios (Fried et al., 2001). Además, este proceso podría dar lugar a la manifestación de algunas enfermedades como sarcopenia y fragilidad (Valenzuela et al., 2019).

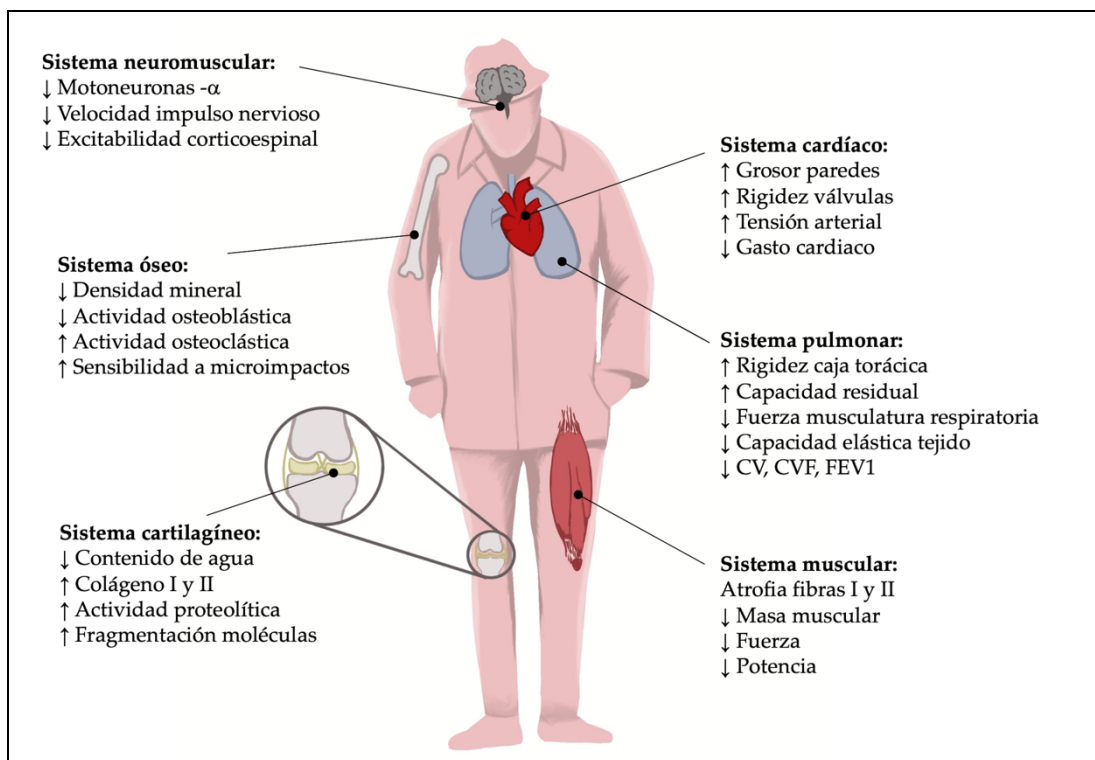


Figura 1. Cambios derivados del envejecimiento.

Abreviaturas: CV, Capacidad Vital; CVF, Capacidad vital forzada, FEV1, Volumen espiratorio forzado en el primer segundo. Se agradece a D. Iñigo Fernández de Luco Santamaría por la concesión de la ilustración.

1.2. SARCOPENIA

1.2.1. Definición de sarcopenia

A nivel etimológico, el término «sarcopenia» deriva de las palabras griegas «sarx», carne, y «penia», pobreza. Fue empleado por primera vez en un documento científico en el año 1989 por Irwin H. Rosenberg en el ámbito de la nutrición, indicando la pérdida de masa muscular relacionado con el proceso de

envejecimiento, que puede desembocar en consecuencias serias para la salud de las personas mayores, como una reducida ingesta calórica o de nutrientes, la alteración de la capacidad para deambular o la pérdida de su independencia (Rosenberg, 1989). En aquel manuscrito, el autor arrojó luz sobre este proceso, indicándolo como el deterioro más importante que ocurre durante el envejecimiento, que afecta simultáneamente la deambulación, la movilidad, la ingesta de energía y de nutrientes, la independencia y la respiración de las personas ancianas (Rosenberg, 1997). A pesar de las importantes consecuencias que trae consigo la pérdida de tejido muscular, el estudio de sus mecanismos pasó desapercibido, enfocándose más sobre el deterioro de otros tejidos, como la disminución de la masa mineral ósea. De hecho, en la literatura se identificaron unos determinados umbrales de pérdida de masa ósea a partir de los cuales existía un mayor riesgo de fracturas, mientras que los umbrales de pérdida de masa muscular seguían siendo desconocidos. En este sentido, Rick Baumgartner en el año 1998 propuso un modelo dicotómico para identificar los casos que sufrían esta condición de salud, definiendo una baja masa muscular como dos desviaciones típicas por debajo de la masa muscular de una población de referencia de personas jóvenes, los llamados T-Scores (Baumgartner et al., 1998).

Además de todas las consecuencias negativas que implica sobre la salud, la pérdida de masa muscular también repercute en la pérdida de fuerza y de función física. En efecto, en una línea temporal de eventos, lo primero que ocurre durante el envejecimiento es la pérdida de masa muscular, acompañada por la pérdida de fuerza y, en última instancia, por la pérdida de función física (Janssen, 2010). Sin embargo, se observó como tan solo una mínima parte (alrededor del 5%) de la pérdida de fuerza dependía de la pérdida de masa muscular (Hughes et al., 2001), indicando una neta separación entre eventos. Fue por ello, que en una definición posterior, la sarcopenia se definió como pérdida de fuerza y de masa muscular (Morley et al., 2001). Esta definición se mantuvo hasta el primer Consenso Europeo sobre Sarcopenia en Personas Mayores (EWGSOP) que se celebró en el año 2010, en el cual la sarcopenia se definió a nivel operativo como pérdida de masa y de función muscular, entendiéndose esta última como pérdida de fuerza o desempeño físico (Cruz-Jentoft et al., 2010). Con el paso del tiempo, la relación entre la pérdida de fuerza, masa muscular y función física, así como su posible relación causal se fue explorando. Se observó que existía una interdependencia entre variables: la baja

masa muscular se asocia a la debilidad, que a su vez se asocia con una escasa función física y a discapacidad. Sin embargo, la asociación entre baja masa muscular y función física o discapacidad es débil o nula (Studenski et al., 2014) Por todo ello, hoy en día la sarcopenia, reconocida como una enfermedad con código propio (ICD-10-CM, código M62.84), queda definida como la pérdida progresiva de masa muscular, de fuerza y de función física (Cruz-Jentoft et al., 2019).

Esta condición de salud suele manifestarse a lo largo del proceso de envejecimiento, denominándose sarcopenia primaria. Por otro lado, cuando esta se desarrolla a raíz de una enfermedad subyacente se denomina sarcopenia secundaria (Cruz-Jentoft et al., 2019). En la literatura científica se han indicado múltiples factores de riesgo relacionados con el desarrollo de la sarcopenia. Estos factores pueden dividirse esencialmente en dos categorías: factores modificables; es decir, que mediante intervenciones específicas podrían cambiarse, y factores no modificables. Entre los factores de riesgo no modificables se destacan el sexo femenino y la edad avanzada. Por otro lado, entre los factores de riesgo modificables más destacables se pueden observar la comorbilidad; es decir, la presencia simultánea de dos o más enfermedades crónicas, la depresión, unos bajos niveles de actividad física, un elevado porcentaje de grasa, un bajo nivel socioeconómico, malos hábitos alimenticios y el hábito tabáquico (Cruz-Jentoft & Sayer, 2019; Landi et al., 2012; Yuan & Larsson, 2023)

Abordar adecuadamente esta enfermedad resulta de importancia primordial, ya que está asociada con unas consecuencias que, si no tratadas, podrían ser potencialmente devastadoras, como la pérdida de habilidades físicas y cognitivas, depresión, caídas, menor calidad de vida, y un mayor riesgo de hospitalización y mortalidad (Beaudart et al., 2017).

Además, la sarcopenia no solamente tiene consecuencias en el nivel de salud de los individuos, sino que también representa un verdadero problema a nivel socioeconómico. La presencia de esta condición se asoció con un incremento en los costes hospitalarios de entre el 34% y el 58,5%, con respecto a los costes relativos a personas sin esta condición (Sousa et al., 2016). Concretamente, datos económicos relativos al año 2000 evidenciaron que los costes directamente atribuibles a la sarcopenia en Estados Unidos fueron de 18,5 millones de dólares, siendo mayores en hombres (Janssen et al., 2004).

1.2.2. Prevalencia de la enfermedad

Teniendo en cuenta el constante aumento de la esperanza de vida de la población mundial, el número de personas que sufren sarcopenia está destinado a incrementar durante las próximas décadas. Actualmente, se estima que la prevalencia a nivel mundial de la enfermedad varía del 10% hasta el 27%, dependiendo del criterio diagnóstico empleado para su detección (Petermann-Rocha et al., 2022). Estos porcentajes difieren mucho en función de la muestra analizada, siendo más prevalente en personas institucionalizadas que en los individuos residentes en la comunidad. En cuanto a su distribución geográfica, los continentes más afectados por la presencia de sarcopenia son Oceanía y Sudamérica, con un 40% y un 35% de prevalencia, respectivamente. En Europa, el porcentaje de personas que sufren dicha condición oscila entre el 1% y el 33% (Petermann-Rocha et al., 2022). Más concretamente, en España la sarcopenia afecta entre el 7,4% y el 21,5% de los ancianos residentes en la comunidad (Guillamón-Escudero et al., 2020; Masanes Toran et al., 2012), mientras que su prevalencia alcanza el 41,4% en personas institucionalizadas (Bravo-José et al., 2018).

1.2.3. Diagnóstico de la enfermedad

La definición de sarcopenia ha sido sujeta a numerosas revisiones a lo largo de su historia. De definirse como la mera pérdida de masa muscular en el año 1989, se llegó a convertir en una definición más actual en la que se concibe esta enfermedad como la pérdida de masa muscular, fuerza y función física (Cruz-Jentoft et al., 2019). Los numerosos cambios en la definición de sarcopenia desembocaron en la propuesta de diferentes definiciones operativas y criterios diagnósticos capaces de detectarla que quedan resumidas en la Tabla I.

Tabla 1. Consensos y criterios diagnósticos para sarcopenia confirmada.

Consenso	Puntos de corte						
	Masa muscular		Fuerza		Función física		
	Hombre	Mujer	Hombre	Mujer			
Baumgartner (Baumgartner et al., 1998)	SMI >2 SD debajo de población referencia		No valorado		No valorado		
SCWD (Morley et al., 2011)	SMI > 2 SD debajo de población referencia		No valorado	+	Marcha < 1m/s 6 min marcha < 400m		
IWGS (Fielding et al., 2011)	SMI < 7,23 kg/m²	SMI < 5,67 kg/m²	No valorado		+	Marcha < 1m/s	
FNIH (Studenski et al., 2014)	ASM _{BMI} < 0,789	ASM _{BMI} < 0,512	+	< 26 kg	< 16 kg	No valorado	
ESPEN (Cederholm et al., 2017)	SMI < 7,26 kg/m²	SMI < 5,5 kg/m²	+	< 30 kg	< 20 kg	o	Marcha < 1 m/s
EWGSOP2 (Cruz-Jentoft et al., 2019)	ASM < 20 kg	ASM < 15 kg	+	< 27 kg	< 16 kg	o	5-STST > 15 seg
	SMI < 7 kg/m²	SMI < 5,5 kg/m²					
AWGS (Chen et al., 2020)	SMI < 7 kg/m² (DXA)	SMI < 5,4 kg/m² (DXA)	+	< 28 kg	< 18 kg	o	Marcha < 1 m/s
	SMI < 7 kg/m² (BIA)	SMI < 5,7 kg/m² (BIA)					SPPB ≤ 9 puntos 5-STST ≥ 12 seg
SDOC (Bhasin et al., 2020)	No valorado		< 35,5 kg	< 20 kg	+		Marcha < 0,8 m/s
ANZSSFR (Zanker et al., 2023)	ASM < 20 kg	ASM < 15 kg	+	< 27 kg	< 16 kg	o	5-STST > 15 seg
	SMI < 7 kg/m²	SMI < 5,5 kg/m²					

Abreviaturas: SCWD, Society on Sarcopenia, Cachexia, and Wasting Disorders; IWGS, International Working Group on Sarcopenia; EWGSOP2, European Working Group on Sarcopenia in Older People; AWGS, Asian Working Group on Sarcopenia; FNIH, Foundation for the National Institutes of Health Biomarkers Consortium Sarcopenia Project; ESPEN, European Society of Clinical Nutrition and Metabolism; SDOC, Sarcopenia Definitions and Outcomes Consortium; ANZSSFR, The Australian and New Zealand Society for Sarcopenia and Frailty Research; ASM, masa muscular appendicular; ASM_{BMI}, masa muscular apendicular relativizada por índice de masa corporal; SMI, Skeletal muscle index; SPPB, Short Physical Performance Battery test; 5-STS, 5 times Sit to Stand.

A pesar de que existen múltiples definiciones operativas para detectar la sarcopenia, las recomendaciones propuestas en el segundo consenso europeo sobre sarcopenia en personas mayores (EWGSOP2) representan los criterios diagnósticos más utilizados (Petermann-Rocha et al., 2022).

El primer consenso europeo para el diagnóstico de sarcopenia fue publicado por primera vez en el año 2010. En estas primeras recomendaciones, la sarcopenia fue definida como la pérdida de masa muscular y de fuerza (Cruz-Jentoft et al., 2010). Nueve años más tarde se publicó la actualización de este consenso, donde se reconoció el rol de la función física en la enfermedad, incluyéndose finalmente en la actual definición de sarcopenia (Cruz-Jentoft et al., 2019).

Esta nueva actualización propuso un algoritmo diagnóstico para ayudar a los clínicos a detectar a las personas con esta enfermedad. El primer paso de este algoritmo consiste en un cribado de todas aquellas personas que podrían padecer esta condición, preguntando directamente por la manifestación de algún signo y síntoma típico de la enfermedad, como caídas previas, una baja velocidad de marcha, falta de fuerza o dificultad para levantarse de una silla. En caso de manifestar alguno de estos síntomas, el consenso europeo recomienda el empleo de un cuestionario de *screening*, como el cuestionario SARC-F. Dicho cuestionario valora la dificultad percibida por los sujetos para ejercer fuerza, caminar, levantarse de una silla, subir escaleras y el número de caídas en el último año. A cada ítem se atribuye de 0 a 2 puntos, representando este último el máximo grado de dificultad experimentado durante la ejecución de la tarea. La puntuación máxima alcanzable es de 10 puntos, siendo necesaria una puntuación de al menos 4 puntos para considerar el cuestionario positivo (Malmstrom et al., 2016).

Aquellas personas con un cuestionario positivo se categorizan como con «posible sarcopenia», y tienen que proceder a la ejecución de ulteriores pruebas para confirmar el diagnóstico. La primera prueba a la que los sujetos tienen que someterse es la medición de los niveles de fuerza. El consenso europeo propone dos pruebas para la medición de dichos niveles: el test de fuerza de agarre y el test de levantarse de la silla cinco veces. La ejecución del test de fuerza de agarre está basada en el protocolo de Southampton, que tiene como objetivo estandarizar el proceso de medición (H. C. Roberts et al., 2011). Por otro lado, en el test de levantarse de la silla cinco veces se mide el tiempo necesario para levantarse cinco

veces a la máxima velocidad. Unos niveles de fuerza inferiores a 27 kg en hombres y 16 kg en mujeres, así como un tiempo superior a 15 segundos en el test de levantarse de la silla cinco veces son los puntos de corte indicados por el consenso europeo por debajo de los cuales los sujetos se clasifican como con «probable sarcopenia» (Cruz-Jentoft et al., 2019).

Para confirmar el diagnóstico, los sujetos con probable sarcopenia tienen que cuantificar sus niveles de masa muscular. El consenso europeo, en este caso, propone el empleo de diferentes herramientas para realizar dicha medición, siendo la absorciometría de rayos X de energía dual (DXA) y la bioimpedancia (BIA) las más empleadas en contexto clínico y de investigación. Aquellos individuos con una masa muscular relativa a las cuatro extremidades, denominada masa muscular apendicular, inferior a 20 kg en hombres y a 15 kg en mujeres se consideran como con baja masa muscular, confirmando el diagnóstico de sarcopenia. Asimismo, la masa muscular también puede expresarse en términos relativos, ajustando la masa muscular apendicular por el cuadrado de la talla de los sujetos. En este caso los puntos de corte establecidos son una masa muscular relativa inferior a 7 kg/m² en hombres, e inferior a 5,5 kg/m² en mujeres (Cruz-Jentoft et al., 2019).

Finalmente, aquellos sujetos con un diagnóstico de sarcopenia confirmada tienen que determinar el grado de severidad de la enfermedad mediante cuatro posibles herramientas: el Short Physical Performance Battery test (SPPB; punto de corte: ≤ 8 puntos), que es la opción más empleada, el test de velocidad de marcha habitual (punto de corte: $\leq 0,8$ m/s), el Timed-Up and Go test (TUG; punto de corte: ≥ 20 segundos), o un test de marcha de 400m (punto de corte: ≥ 6 minutos) (Cruz-Jentoft et al., 2019).

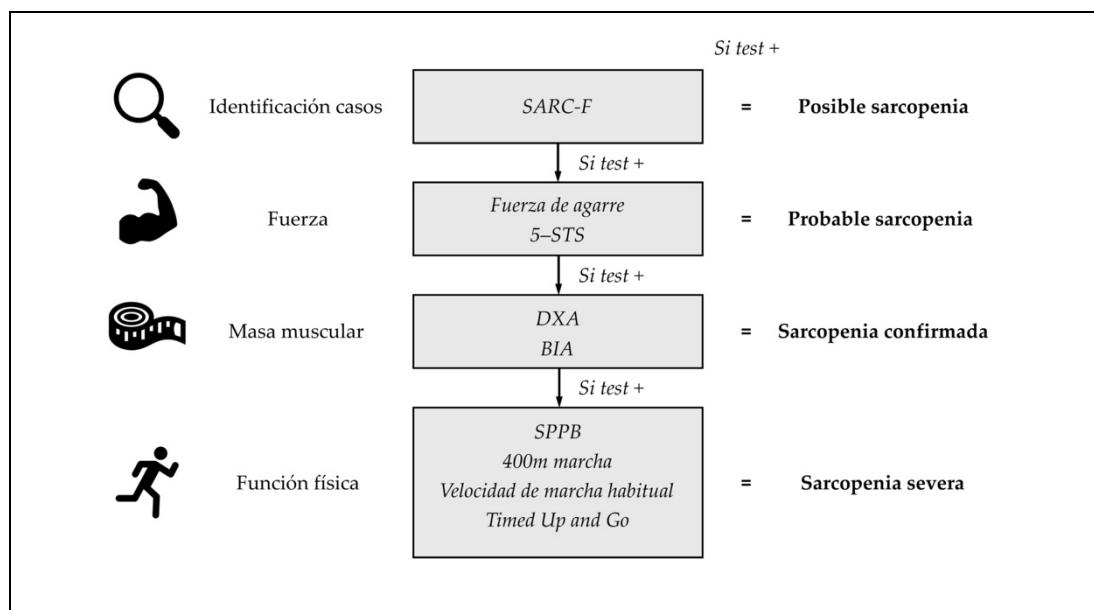


Figura 2. Algoritmo diagnóstico para sarcopenia según el consenso EWGSOP2.
Elaboración propia.

1.3. SÍNDROME DE FRAGILIDAD

1.3.1. Definición de fragilidad

La palabra fragilidad proviene de la palabra francés «*frêle*», haciendo referencia a un estado de baja resistencia (Diaz et al., 2015). El concepto de fragilidad empezó a aparecer en la literatura médica geriátrica entre los años 1950 y 1960, y se profundizó entre los años 1970 y 1980 (Sobhani et al., 2021). Al inicio de los años '70, el Consejo General sobre el Envejecimiento introdujo el término «anciano frágil» para hacer referencia a aquellas personas mayores de 75 años que, debido a la acumulación de distintos problemas precisan de uno/varios servicios de apoyo para afrontar sus actividades diarias (Hogan, 2018). A partir de este punto, muchos autores empezaron a proponer una interpretación propia del concepto de fragilidad (Gobbens et al., 2010; Sobhani et al., 2021). Sin embargo, su verdadero nacimiento se atribuye a Linda Fried, geriatra y epidemióloga estadounidense, que en el año 2001 definió esta condición como un estado de mayor vulnerabilidad ante los estresores diarios o agudos, que se origina a partir del declive de las funciones fisiológicas que ocurre durante el envejecimiento (Fried

et al., 2001). En este estudio, denominado «Estudio sobre la Salud Cardiovascular» en el que se analizaron los datos de 5317 personas mayores de 65 años, se postuló por primera vez la existencia de un fenotipo de fragilidad, aludiendo a un conjunto de signos y síntomas de carácter eminentemente físico que cuando están presentes definen la presencia de fragilidad y que ocasionan la manifestación de eventos adversos relacionados con la salud (Fried et al., 2001). Esto ocurre de manera cíclica, tomando el nombre de ciclo de fragilidad: la presencia de un signo o síntoma típico de esta condición desencadena la aparición de todos los demás (Fried et al., 2001).

Por otro lado, en el mismo año, Rockwood y colaboradores definieron la fragilidad como un conjunto de déficits a nivel multisistémico (signos, síntomas, desequilibrios funcionales y anomalías en pruebas de laboratorio), que se emplea para describir el estado individual de las personas mayores, reflejando la gravedad de la enfermedad o la cercanía a la muerte (Mitnitski et al., 2001). Cuatro años más tarde, los mismos autores desarrollaron el Índice de Fragilidad, que consiste en la valoración de múltiples ítems a nivel multidimensional, incluyendo la valoración de la esfera social, mental y cognitiva de las personas mayores (Rockwood et al., 2005). Mientras que con el fenotipo de Fried hace referencia a un síndrome específico y de carácter eminentemente físico, este segundo modelo clínico representa un estado de acumulación de déficits multisistémicos, a partir de los cuales es posible estimar la esperanza de vida de los individuos (Rockwood & Howlett, 2018). De hecho, este modelo nació como consecuencia de las críticas recibidas por el fenotipo de Fried por abordar únicamente la esfera física (Sobhani et al., 2021). A pesar de que los dos enfoques definan el síndrome de fragilidad desde dos puntos de vista distintos, no existe un consenso claro acerca de cuál de las dos sea la definición conceptual más apropiada para describir este estado: ambas constituyen definiciones válidas y ambas se emplean en la práctica clínica (Kojima et al., 2019; Rockwood & Howlett, 2018).

En una revisión sistemática del año 2010 los autores concluyeron que para que una definición conceptual del síndrome de fragilidad sea válida, es necesario que respete cinco criterios: que aborde esta condición desde un punto de vista multidimensional, que la entienda como un estado dinámico en la que los individuos pueden mejorar o empeorar su condición, que sea capaz de predecir

eventos adversos relacionados con la salud, que no se pueda confundir con otras definiciones, y que sea práctica (Gobbens et al., 2010).

La ausencia de un estándar que sirva como referencia para definir claramente el concepto de fragilidad ha generado confusión en torno a esta condición, de manera que se han empleado indistintamente algunos términos similares a ella – pero no iguales – como la discapacidad y la comorbilidad (Fried et al., 2001). Si bien existe cierto solapamiento entre estas tres condiciones, se trata de estados bien diferenciados, ya que no todos aquellos individuos frágiles sufren discapacidad o comorbilidad, y viceversa. Además, la literatura sugiere que las tres condiciones son factores pronósticos mutuos y que, por ejemplo, un individuo frágil sucesivamente podría desarrollar comorbilidad o discapacidad (Fried et al., 2004).

A nivel operativo, la presencia de esta condición puede detectarse utilizando distintos criterios (Sternberg et al., 2011). Sin embargo, uno de los criterios más empleados son aquellos propuestos en el fenotipo de Fried (Khezrian et al., 2017). Según este modelo, la fragilidad se define como la presencia de una baja fuerza de agarre, baja velocidad de marcha, bajos niveles de actividad física, sensación de agotamiento y pérdida de peso involuntaria (Fried et al., 2001). En función del grado de afectación, las personas se pueden dividir en tres categorías. En primer lugar, se denominan «robustos» aquellos individuos que no presentan ninguno de estos signos y síntomas. En segundo lugar, aquellos individuos que se encuentran en las fases incipientes, manifestando uno o dos signos o síntomas típico de la condición, se denominan «prefrágiles». Finalmente, cuando los individuos presentan al menos tres signos o síntomas típico de la condición, viendo su estado funcional comprometido, se categorizan como «frágiles» (Fried et al., 2001).

El deterioro funcional experimentado por aquellos individuos con fragilidad afecta al organismo a nivel multisistémico, predisponiéndolo a sufrir consecuencias importantes ante eventos adversos de intensidad relativa, incluso pudiendo desencadenar la hospitalización o la muerte prematura de los individuos (Clegg & Young, 2011).

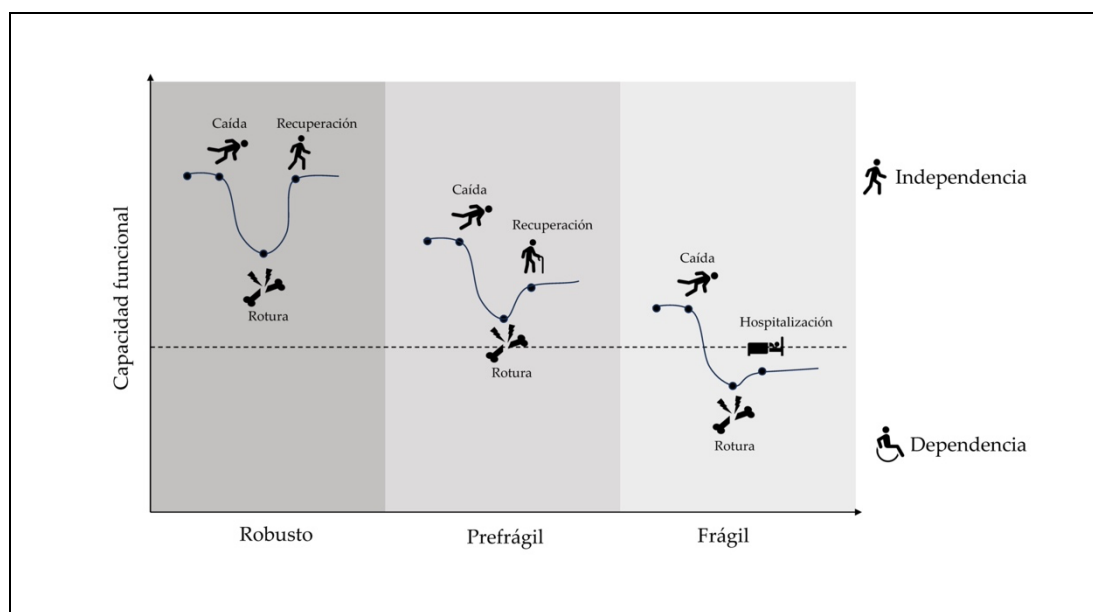


Figura 3. Desarrollo del síndrome de fragilidad.

Posibles consecuencias del síndrome de fragilidad en función del estado en el que se encuentran los individuos.

Escenario 1 (área gris oscura): el individuo robusto, tras una caída (evento estresor), sufre una fractura, recuperándose sin complicaciones transcurrido el tiempo fisiológico. **Escenario 2 (área intermedia):** el individuo prefrágil, cuya capacidad funcional ya está afectada, sufre la misma fractura, recuperándose con algunas limitaciones (necesidad de ayudas técnicas). **Escenario 3 (área gris claro):** el individuo frágil, tras sufrir una fractura, permanece encamado y dependiente. Elaboración propia adaptada de Dent et al. 2019

A nivel clínico, los individuos con fragilidad se caracterizan por tener unos elevados niveles de fatiga, indicado como el primer síntoma en manifestarse, además de una pérdida de peso no intencional e infecciones frecuentes (Clegg et al., 2013; Dent, Martin, et al., 2019; Xue, 2011). A menudo aparecen deterioros del aparato vestibular, con consecuente afectación del equilibrio y de su velocidad de marcha, viendo incrementado su riesgo de sufrir caídas (Clegg et al., 2013). El deterioro funcional también afecta a los niveles de alerta y el estado cognitivo, dando lugar a la aparición de un fenómeno conocido como «*delirium*», que consiste en un estado de confusión aguda debido a los cambios estructurales que se generan en el cerebro durante el proceso de envejecimiento (Clegg et al., 2013).

Al tratarse de un síndrome de carácter multisistémico, los factores de riesgo relacionados con el desarrollo de la fragilidad son de distintos tipos. Entre los más importantes es posible destacar la localización geográfica, el sexo femenino, la edad avanzada, enfermedades subyacentes (especialmente de tipo cardiovascular), el hábito tabáquico, la comorbilidad, el sobrepeso o la obesidad, bajos recursos

económicos, bajos niveles de salud autopercebida, síntomas depresivos y deterioro cognitivo (Mello et al., 2014).

La importancia de esta condición podría radicarse en dos aspectos fundamentales: en primer lugar, el síndrome de fragilidad se observó ser precursor del desarrollo de múltiples eventos adversos, entre los cuales destacan el mayor riesgo de hospitalización, una peor calidad de vida, un mayor riesgo de caídas y, incluso, la mortalidad prematura (Dent, Martin, et al., 2019; Lin et al., 2019). Por otro lado, las personas que la padecen pueden mejorar o empeorar su condición, incluso sin que exista la necesidad de un tratamiento: un individuo clasificado como frágil podría volver a un estado de robustez, así como un individuo clasificado como robusto podría pasar a clasificarse como frágil, únicamente con el paso del tiempo (Hwang et al., 2021). Esta condición se conoce como «*continuum* de fragilidad», y hace referencia al carácter dinámico de la patología (Dent, Martin, et al., 2019; Lang et al., 2009). Por lo tanto, se trata de un estado potencialmente reversible: un individuo frágil, mediante un diagnóstico precoz y un tratamiento adecuado, puede volver a un estado de robustez (Travers et al., 2019)

Además de las importantes consecuencias que conlleva sobre la salud de los individuos, el síndrome de fragilidad también conlleva unas grandes repercusiones en los costes sociosanitarios. En un metanálisis reciente se observó la existencia de una relación dosis–respuesta entre el estado de fragilidad y los costes sociosanitarios; es decir, a mayor severidad mayores costes (Kojima, 2019). Dichos hallazgos se confirmaron dos años más tarde, en un metanálisis compuesto por siete estudios de cohorte, en el cual se observó que, comparado con las personas robustas, los costes de una persona con prefragilidad incrementaron entre 80–13.500\$, mientras que en las personas frágiles incrementaron entre \$600–32.600 (Chi et al., 2021). En España, un individuo con fragilidad supone el doble del gasto sanitario que un individuo sin fragilidad (~2500€/año en sujetos frágiles vs ~1250€/año en sujetos no frágiles) (García-Nogueras et al., 2017).

1.3.2. Prevalencia del síndrome

Al igual que la sarcopenia, el número de personas que sufre el síndrome de fragilidad está destinado a incrementar. A nivel global, los datos de incidencia disponibles estiman que aparecen 43 nuevos casos de fragilidad por cada 1000

personas mayores de 60 años residentes en la comunidad. En el caso de la prefragilidad, la incidencia es de 150 casos nuevos cada año por cada 1000 personas ancianas (Ofori-Asenso et al., 2019).

La prevalencia global de esta condición en personas mayores de 50 años oscila entre 12% y el 24%, dependiendo de los criterios diagnósticos que se empleen para determinarla, mientras que la prefragilidad varía del 46% al 49% (O’Caoimh et al., 2021). Además, la prevalencia de dicha condición aumenta conforme aumenta la edad de las personas. En personas de 50 a 59 años la prevalencia se sitúa en torno al 11%, mientras que entre 80 y 89 años se registra una prevalencia del 31%, y alcanza hasta el 51% en aquellas personas mayores de 90 años (O’Caoimh et al., 2021). En el territorio español, la fragilidad está presente en el 19% de las personas mayores de 65 años. Sin embargo, este porcentaje se ve influenciado por el entorno, ya que es mayor en personas institucionalizadas (45%) que en los individuos que residen en la comunidad (12%) (O’Caoimh et al., 2018).

1.3.3. Diagnóstico del síndrome

Para llegar a revertir el estado de fragilidad es indispensable un diagnóstico adecuado y temprano de esta condición. A pesar de ello, a día de hoy no existe un consenso claro sobre cuáles son las herramientas más adecuadas para detectar su presencia. Pese a su potencial utilidad, no existe suficiente evidencia que permita recomendar el empleo de cuestionarios de cribado de manera sistemática para identificar posibles casos de fragilidad (Ambagtsheer et al., 2019). Sin embargo, varias investigaciones sugirieron que estas herramientas deberían emplearse en toda persona de 65 años o mayor (Dent, Morley, et al., 2019). Adicionalmente, se recomienda que aquellos individuos con un resultado positivo en los cuestionarios de cribado se sometan a un proceso de valoración completo para confirmar la presencia de este síndrome (Dent, Morley, et al., 2019). Hoy en día, existen muchas herramientas que permiten detectar el síndrome de fragilidad de forma válida y fiable. Una de ellas es el Índice de Fragilidad (FI) (Rockwood et al., 2005), herramienta propuesta por el Dr. Kenneth Rockwood, que identifica a las personas frágiles por medio de un sistema de déficit acumulativo que abarca 70 diferentes aspectos básicos como la presencia de enfermedades subyacentes, el estado cognitivo, nivel de dependencia, movilidad o caídas. Cada ítem se puntúa con 1

punto, pudiendo llegar a un máximo de 70 puntos; el total alcanzado se divide por el total de ítems evaluados. El punto de corte más empleado para categorizar a los ancianos residentes en la comunidad como frágiles es de 0,25 (Gordon et al., 2021). A pesar de representar una herramienta válida para la detección de fragilidad en esta población, no existe un consenso general que recomiende de forma clara su empleo.

Por otro lado, el fenotipo de Fried (Fried et al., 2001) constituye la herramienta más conocida y, probablemente, la más empleada para la identificación de dicha condición, recomendada en guías de práctica clínica internacionales (Dent, Morley, et al., 2019). Según el fenotipo de Fried, la fragilidad se define como la presencia de al menos 3 de los siguientes criterios: velocidad de marcha reducida, disminución de la fuerza de agarre, bajos niveles de actividad física, elevados niveles de fatiga y pérdida de peso no intencional. Concretamente, la velocidad de marcha se mide mediante un test de velocidad habitual en un recorrido de 15 pies (~ 4,5 metros), definiendo una baja velocidad de marcha como cualquier valor inferior al percentil 20, estratificado por el sexo y la talla de los individuos. Sin embargo, con el fin de medir la velocidad de marcha mediante test uniformes y válidos que empleen el Sistema de Unidades Internacionales, el Ministerio de Sanidad español recomienda que la velocidad de marcha habitual se mida en un recorrido de 4 metros (Ministerio de Sanidad, 2022). Cada individuo tiene a disposición dos intentos, teniendo en cuenta el mejor resultado obtenido; el punto de corte que define una baja velocidad de marcha es una velocidad inferior a 0,8 m/s.

La fuerza de agarre o de prensión manual de los individuo se valora a través de un dinamómetro manual, basando la ejecución del test sobre el mismo protocolo empleado para la detección de sarcopenia (H. C. Roberts et al., 2011). Se definen como bajos niveles de fuerza todos aquellos valores inferiores al percentil 20, estratificados por el sexo y el índice de masa corporal de los sujetos.

Los niveles de actividad física se valoran a través de la escala *Minnesota Leisure Time Activity*, definiendo como baja actividad física los valores por debajo del primer quintil, estratificados por sexo. En el territorio español, está disponible la versión traducida y validada de dicha escala, conocida como escala VREM (Ruiz Comellas et al., 2012).

Los niveles de agotamiento y la pérdida de peso involuntario se miden mediante dos preguntas autorreportadas. Concretamente, la primera está dirigida a medir la frecuencia con la que se experimentan dos estados extraídos del cuestionario *Centre for Epidemiological Studies – Depression* (CES-D): «no tengo ganas de hacer nada», «siento que todo lo que hago constituye un esfuerzo». A cada frase corresponde una posible puntuación de 0, si la frecuencia con la que se experimentan dichos estados es nula, 1 punto si se experimenta a veces, y 2 puntos si dicho estado se experimenta con frecuencia. Una puntuación total de 2 o 3 puntos será necesaria para categorizar como elevados los niveles de agotamiento. La pérdida de peso no intencional se valora preguntando directamente a los individuos si han experimentado una pérdida de peso no intencional de 4,5 kg o del 5% con respecto al año anterior.

Como mencionado anteriormente, la presencia de 3 de estos 5 criterios permitirá clasificar a los sujetos evaluados como frágiles; la presencia de al menos un criterio corresponde con un estado de prefragilidad, mientras que la ausencia de todas las componentes evaluadas permitirá clasificar a los individuos como robustos (Fried et al., 2001).

1.4. COEXISTENCIA DE FRAGILIDAD Y SARCOPENIA

1.4.1. ¿Fragilidad y sarcopenia se refieren a un mismo estado?

El síndrome de fragilidad y la sarcopenia comparten una relación muy estrecha. Ambas son enfermedades que pertenecen al ámbito eminentemente geriátrico, que suelen manifestarse a raíz del proceso de envejecimiento fisiológico, y que pueden desembocar en la pérdida de la función física y de la independencia (Mori & Tokuda, 2019). Desde un punto de vista operativo, según el fenotipo de Fried, la fragilidad se define como la presencia de al menos 3 de estos 5 criterios: baja velocidad de marcha, pérdida de fuerza, niveles elevados de fatiga, pérdida de peso involuntaria y bajos niveles de actividad física (Fried et al., 2001). Por otro lado, según el consenso europeo EWGSOP2, a una persona se le diagnosticaría sarcopenia cuando tenga bajos niveles de fuerza, masa muscular y funcionalidad (Cruz-Jentoft et al., 2019). De esta forma, es posible observar cómo ambas

patologías compartan algunos criterios diagnósticos, como la pérdida de fuerza y de la función física (Cesari et al., 2014; Dodds & Sayer, 2015).

Asimismo, ambas patologías se asocian con el desarrollo de numerosos eventos adversos como osteoporosis, riesgo de caídas o de fracturas, y el abordaje terapéutico propuesto para el tratamiento de ambas está basado en manejo nutricional o en el ejercicio físico (Martin & Ranhoff, 2021).

Si bien originariamente se empezaron a estudiar como entidades diferentes, la sarcopenia con un foco dirigido a la investigación y la fragilidad desde una perspectiva clínica, las similitudes entre ambas condiciones dieron pie a que se empezara a estudiarlas y entenderlas como una única condición clínica (Cesari et al., 2014).

1.4.2. Perspectivas según la evidencia más reciente

A pesar de que exista una clara asociación entre ambas condiciones y de que existan muchos elementos comunes entre ambas, la evidencia científica actual parece indicar que estos términos no deben emplearse de forma indistinta.

Si fragilidad y sarcopenia constituyeran una misma única condición, todos aquellos individuos que se categoricen como frágiles también deberían categorizarse como con sarcopenia, y viceversa. De esta forma, en términos estadísticos se obtendría una asociación perfecta entre ellas. Sin embargo, se observó que existe un bajo grado de acuerdo entre fragilidad y sarcopenia y que, al mismo tiempo, el riesgo de desarrollar fragilidad partiendo de la sarcopenia es mayor que el riesgo de desarrollar sarcopenia partiendo de la presencia de fragilidad (Em et al., 2016). Adicionalmente, en diferentes estudios se observó que el grado de solapamiento entre la prevalencia de ambas condiciones en ningún caso fue del 100%, indicando que sarcopenia y fragilidad constituyen dos entidades distintas (Álvarez-Bustos et al., 2022; Davies et al., 2018; Mori & Tokuda, 2019).

Por otro lado, de acuerdo con las definiciones operativas propuestas por el fenotipo de Fried y el consenso EWGSOP2, una persona con sarcopenia también debería clasificarse como prefrágil, debido a unos bajos niveles de fuerza. Sin embargo, como mencionado anteriormente, la literatura descartó que una persona prefrágil o frágil siempre tendría sarcopenia (Álvarez-Bustos et al., 2022; Davies

et al., 2018; Thompson et al., 2021; Wilson et al., 2017). Lejos de representar un sinónimo de fragilidad, la sarcopenia podría considerarse como una precursora del síndrome de fragilidad y como uno de los mayores determinantes responsable de las transiciones entre diferentes estados de fragilidad (Álvarez-Bustos et al., 2022). De hecho, trabajos anteriores observaron cómo los individuos frágiles con sarcopenia confirmada tienen el doble del riesgo de empeorar su estado de fragilidad con respecto a aquellos individuos sin sarcopenia (Álvarez-Bustos et al., 2022).

1.4.3. Prevalencia de la coexistencia de ambas patologías

En la literatura disponible, los estudios que analizaron la presencia simultánea de ambas patologías son escasos. A nivel general, la prevalencia de ambas patologías, a pesar de la heterogeneidad en los procedimientos empleados para su detección, es inferior al 10%. Concretamente, en un estudio sobre ancianos residentes en una comunidad de Japón se observó que 12 sujetos de los 331 individuos analizados (3,6%) tenían simultáneamente fragilidad y sarcopenia (Mori & Tokuda, 2019). Por otro lado, en otro estudio llevado a cabo en Japón sobre una muestra compuesta por un total de 963 ancianos se observó una prevalencia del 0,1% de sujetos que tenían ambas patologías de forma simultánea (Yoshimura et al., 2019).

Thompson y colaboradores (2021) en su estudio observaron que 20 de los 716 (2,8%) sujetos ancianos residentes en la comunidad de Australia analizados padecía simultáneamente fragilidad y sarcopenia, mientras que el 15,5% solamente tenía fragilidad y el 3,5% solamente tenía sarcopenia.

Finalmente, tan solo dos estudios analizaron la prevalencia de fragilidad y sarcopenia de manera simultánea en ancianos residentes en comunidades españolas (Álvarez-Bustos et al., 2022; Davies et al., 2018). En el estudio de Davies y colaboradores (2018) se observó que entre el 1,8% y el 3,2% de los 1611 participantes que formaron parte del estudio tenía ambas condiciones, mientras que en el estudio de Álvarez-Bustos et al. (2022) la prevalencia observada en una muestra de un total de 1538 participantes osciló entre el 1,6% y el 8,2%, dependiendo de los criterios diagnósticos empleados.

1.4.4. Relevancia clínica

Distinguir entre los diferentes estados de fragilidad y sarcopenia, así como determinar su presencia simultánea en las personas mayores es de vital importancia para asegurar una buena evolución clínica (Davies et al., 2018). La evidencia disponible parece indicar que la sarcopenia constituye un modulador de la fragilidad, ya que aquellas personas frágiles que también sufren sarcopenia tienen dos veces más riesgo de empeorar su estado de fragilidad comparado con aquellas que solamente son frágiles (Álvarez-Bustos et al., 2022).

El padecimiento de ambas condiciones al mismo tiempo predispone a los individuos a sufrir un incremento del riesgo de eventos adversos. Mori y Tokuda (2019) observaron que la presencia de ambas patologías de forma simultánea se asociaba a un mayor riesgo de sufrir caídas recurrentes (RR: 11,8; IC 95%: 2,68–52,0), así como a menores niveles de fuerza (RR: 8,05; IC 95%: 1,85–35,0) y a una menor funcionalidad de miembros inferiores (RR: 20,3; IC 95%: 4,54–91,2), comparado con personas sanas. Además, algunos autores observaron grandes repercusiones en términos de la mortalidad (Thompson et al., 2021). El riesgo de muerte prematura observado en aquellos individuos que sufrían ambas patologías al mismo tiempo fue de 3 veces mayor que el riesgo sufrido por aquellos individuos que no tenían ninguna de estas dos condiciones (HR: 3,52; IC 95 %: 1,81–6,85). Adicionalmente, el riesgo fue dos veces mayor con respecto a aquello observado en los individuos que solamente tenían fragilidad (HR: 2,03; IC 95 %: 1,34–3,08) (Thompson et al., 2021). Sin embargo, en otro estudio se estudió la influencia de la presencia de sarcopenia en el pronóstico de personas mayores de 65 años con fragilidad o prefragilidad en términos de mortalidad o discapacidad física (Davies et al., 2022). En esta muestra, compuesta por 1531 ancianos españoles, se observó que fragilidad y prefragilidad se asociaron con la mortalidad incluso cuando el análisis se ajustó según la presencia de sarcopenia (HR: 1,58; IC 95%: 1,12–2,24; $p = 0,01$), y que la presencia de sarcopenia en personas con fragilidad o prefragilidad es predictora del empeoramiento del estado de discapacidad (Davies et al., 2022).

A pesar de la relevancia que tienen estas condiciones en la salud de las personas ancianas, a día de hoy no existe ninguna herramienta capaz de detectar de forma simultánea ambas patologías.

1.5. ¿SE DIAGNOSTICAN AMBAS PATOLOGÍAS?

1.5.1. Resultados de estudios de encuestas sobre fragilidad y sarcopenia

Dada la gran relevancia clínica que tiene la presencia simultánea de fragilidad y sarcopenia sobre la salud de las personas ancianas, y teniendo en cuenta la capacidad de revertir estos procesos, la detección precoz de ambas condiciones resulta fundamental en la prevención y tratamiento de enfermedades ligadas al envejecimiento (Tan et al., 2017; Yao et al., 2022).

Pese a esto, un estudio reciente observó que tan solo el 63% del personal sanitario tenía un conocimiento exhaustivo acerca del síndrome de fragilidad (Moloney et al., 2023). Dichos resultados están en línea con lo reportado por Mesquita y Ricci (2022), que informaron de que el 87,5% de los profesionales sanitarios describieron de manera incorrecta el concepto de fragilidad. Adicionalmente, la mitad de las personas entrevistadas tenía un conocimiento escaso o nulo sobre esta patología (Mesquita & Ricci, 2022).

Con respecto a la sarcopenia, se pudo apreciar la misma problemática. Guralnik y colaboradores (2023) reportaron que menos de una quinta parte de los internistas y de los médicos de familia entrevistados estaban al corriente de la definición de esta patología. Porcentajes mayores pudieron observarse en médicos geriatras (70%) y en traumatólogos o rehabilitadores (41%). En conjunto, estos datos parecen indicar que existe un importante desconocimiento de ambas condiciones, pudiendo desembocar en su identificación tardía o, incluso, en la falta de su detección (Guralnik et al., 2023; Moloney et al., 2023; Yao et al., 2022).

Adicionalmente, se observó que solamente la mitad de los encuestados empleaba alguna herramienta para determinar la presencia de sarcopenia en pacientes hospitalizados, con un porcentaje parecido observado en pacientes de ambulatorio (Offord et al., 2019). Si bien el porcentaje en cuanto al diagnóstico de fragilidad fuese bastante mayor (90%), existe una gran heterogeneidad en términos de herramientas diagnósticas empleadas, lo cual constituye una de las barreras relacionadas con la detección de estas condiciones de salud (Offord et al., 2019).

En el estudio de Bruyère (2017) se observó que 9 de cada 10 profesionales llevaba a cabo el diagnóstico de la fragilidad. Sin embargo, solamente la mitad de

la muestra total entrevistada llevaba a cabo el diagnóstico de manera frecuente, mientras que el 38,1% lo llevaba a cabo de forma poco constante. Es de especial interés que alrededor del 64% de aquellos que llevaban a cabo el diagnóstico de fragilidad reportó haber recurrido al empleo de más de una herramienta diagnóstica, siendo el test de velocidad de marcha habitual y el SPPB las pruebas que, de manera combinada junto con otras herramientas, más se utilizaron en el diagnóstico de este síndrome (89,3% y 73,3%, respectivamente).

1.5.2. Barreras relacionadas con el diagnóstico de las patologías

Las causas por las que el diagnóstico de sarcopenia y fragilidad no suele llevarse a cabo de manera habitual y constante en la práctica clínica son diferentes. Si bien se observó una gran heterogeneidad en cuanto a las herramientas utilizadas, las principales barreras indicadas por el personal clínico que impiden un adecuado proceso diagnóstico podrían resumirse en tres categorías.

Por un lado, en la literatura es posible destacar un gran desconocimiento entorno a los conceptos de fragilidad y sarcopenia. Por ejemplo, en el estudio de Yeung et al. (2020) se observó que menos de una quinta parte del personal clínico entrevistado supo denominar correctamente la sarcopenia, identificándola como una enfermedad. Asimismo, se observó que tan solo el 2% de los entrevistados conocía los puntos de corte necesarios para determinar la presencia de dicha condición. De la misma forma, Reijnierse et al. (2017) observaron que, si bien alrededor del 70% del personal sanitario entrevistado sabía definir adecuadamente el concepto de sarcopenia, tan solo uno de cada cinco de ellos conocía alguna herramienta diagnóstica con la que detectar su presencia en la práctica clínica.

En relación con la fragilidad, el escenario observado fue bastante parecido. Moloney y colaboradores (2023) observaron que tan solo el 63% de los entrevistados supo definir correctamente el concepto de fragilidad. Además, de acuerdo con lo observado en el estudio de Bruyère (2017) casi un encuestado de cada diez afirmó que no llevaba a cabo el diagnóstico de fragilidad debido a que no sentían disponer de las competencias necesarias.

En segundo lugar, la falta de tiempo constituye otra barrera que impide que el diagnóstico de ambas condiciones se lleve a cabo de forma rutinaria en la práctica

clínica. Reijnierse et al. (2017) reportaron que un tercio del personal clínico entrevistado reportó haber experimentado problemas relacionados con la falta de tiempo que les impidieron llevar a cabo el diagnóstico de sarcopenia. Paralelamente, Bruyère y colaboradores (2017) observaron que en el 12,5% de los entrevistados indicó la falta de tiempo como el impedimento más frecuentemente durante el diagnóstico de fragilidad.

Finalmente, la detección de estas condiciones en la práctica clínica se ve limitada por la falta de disponibilidad de herramientas diagnósticas. Si bien existen diferentes criterios capaces de determinar la presencia de sarcopenia, la fuerza de agarre representa el criterio más empleado (Reijnierse et al., 2017). Sin embargo, una décima parte de los que experimentaron dificultades para diagnosticar estas condiciones indicó como principal causa la imposibilidad para acceder a un dinamómetro manual para valorar la fuerza. Adicionalmente, el porcentaje de aquellos que no pudieron acceder a dispositivos diseñados para el análisis de la masa muscular fue aún mayor, alcanzando el 30,6% (Reijnierse et al., 2017), siendo este criterio fundamental para confirmar la presencia de sarcopenia (Cruz-Jentoft et al., 2019).

1.6. SOLUCIONES PARA INCREMENTAR EL DIAGNOSTICO DE LAS PATOLOGÍAS

1.6.1. Aplicación móvil para medir la potencia muscular

El diseño de nuevas herramientas dirigidas al diagnóstico de sarcopenia y fragilidad debería tener en cuenta las barreras experimentadas por parte del personal sanitario. De esta forma, su detección podría ser más eficaz y los cuidados ofrecidos a las personas con dichas condiciones podrían mejorar de manera considerable (Moloney et al., 2023; Reijnierse et al., 2017). Desafortunadamente, hoy en día en el entorno clínico no se cuenta con ninguna herramienta que reúna todas las características necesarias para abarcar los obstáculos reportados por el personal clínico durante el diagnóstico de estas condiciones.

La capacidad para levantarse de una silla, que constituye una tarea básica de la vida cotidiana, es considerada un biomarcador de salud para las personas mayores, ya que está asociado con variables muy importantes como la

independencia funcional, la movilidad, caídas y mortalidad. (Bandinelli et al., 2009; Bohannon, 2015; Campbell et al., 1989; Cooper et al., 2010; Eriksrud & Bohannon, 2003). La medición de las diferentes modalidades de este gesto, como el tiempo necesario para levantarse de la silla cinco veces o el número de levantamientos durante un minuto, proporciona datos sobre la fuerza de las extremidades inferiores, la funcionalidad y el equilibrio (Anabitarte-García et al., 2021).

Gracias al desarrollo tecnológico, hoy en día es posible llevar a cabo un análisis cinemático de este gesto, pudiendo además discriminar entre ancianos a priori sanos y aquellos con fragilidad o sarcopenia (Kera et al., 2022; Millor et al., 2017; Zech et al., 2011). Sin embargo, este tipo de análisis tiene la desventaja de requerir de herramientas de alto coste tales plataformas de fuerza, sensores inerciales de movimiento, además de un personal cualificado para que la interpretación de sus resultados sea fiable (Orange et al., 2020).

Recientemente, nuestro grupo de investigación ha desarrollado una aplicación móvil llamada *Sit to Stand*, con el objetivo de proporcionar a los usuarios la posibilidad de medir la potencia muscular generada durante el gesto de levantarse de una silla (J. D. Ruiz-Cárdenas et al., 2018). Esta herramienta contempla el empleo de las cámaras de grabación a alta velocidad (240 imágenes por segundo) integradas en los dispositivos móviles para grabar el gesto de levantarse de una silla. Mediante el análisis a cámara lenta del gesto y un sistema de cuadrículas integrado en la aplicación, esta herramienta permite detectar con precisión el principio y el final del movimiento, proporcionando de manera automatizada los valores promedio de tiempo, velocidad y potencia generados. Este procedimiento se validó contra plataformas de fuerza (J. D. Ruiz-Cárdenas et al., 2018), cámaras de movimiento 3D y sensores inerciales de movimiento (Orange et al., 2020), demostrando ser una herramienta fiable, sencilla, fácilmente disponible y económica, pudiendo representar un recurso de absoluto interés tanto a nivel de investigación como a nivel clínico.

Dicha aplicación se validó solamente en dispositivos móviles con sistema operativo iOS (Apple Inc.), debido a que eran los únicos dispositivos que permitían llevar a cabo una grabación a 240 imágenes por segundo. Sin embargo, el desarrollo tecnológico ha hecho que hoy en día muchos dispositivos con un sistema operativo diferente lleven este sistema de captación de imágenes integrado.

1.6.2. ¿Por qué la potencia?

Como mencionado anteriormente, la aplicación móvil *Sit to Stand* analiza el gesto de levantarse de una silla para proporcionar valores promedio de potencia muscular, entre otros. La potencia muscular se define como el producto de la fuerza generada por la velocidad (Laird & Rozier, 1979). Este parámetro constituye un biomarcador de salud, especialmente durante el proceso de envejecimiento debido a las asociaciones observadas con importantes pronósticos de salud como independencia funcional, riesgo de hospitalización, de caídas y mortalidad (Cheng et al., 2014; Losa-Reyna et al., 2022; Reid & Fielding, 2012; Wagner et al., 2016).

La capacidad de un sujeto para producir potencia depende tanto de factores estructurales, dentro de los cuales se encuentran la cantidad de masa muscular disponible y las propiedades contráctiles de las fibras musculares, así como de factores neurales, entre las cuales se encuentran la tasa de disparo de la unidad motora y la velocidad de conducción del impulso nervioso (Reid & Fielding, 2012). Durante el proceso de envejecimiento existe una disminución progresiva tanto de los factores que regulan la producción de fuerza, como de los factores que regulan la velocidad de contracción de los músculos, dando lugar a una pérdida progresiva de potencia (Boros & Freemont, 2017; Mobasheri & Mendes, 2013).

Si bien la capacidad para producir fuerza está considerada como un biomarcador de salud fundamental durante el proceso de envejecimiento, la potencia muscular decae antes y en mayor medida (Skelton et al., 1994). Se estima que cada año los individuos pierden entre el 1% y el 2% de fuerza, mientras que la potencia decae a una velocidad del 3% al año (Skelton et al., 1994). Por lo tanto, con un objetivo de prevención, monitorizar la potencia muscular de los individuos podría ser fundamental para su posterior mantenimiento.

En un contexto de envejecimiento, algunos estudios observaron que la potencia es capaz de predecir el desempeño funcional mejor que la fuerza en personas ancianas (Byrne et al., 2016). Además, este parámetro es capaz de predecir el desarrollo de fragilidad. Burbank et al. (2023) observaron que aquellas personas con bajos niveles de potencia tuvieron un incremento del riesgo de desarrollar prefragilidad y fragilidad del 24% y 70%, respectivamente. Además, en un estudio se observó como la potencia medida a través de sensores de movimiento inerciales es capaz de discriminar entre diferentes estados de fragilidad (Millor et al., 2017).

De la misma forma, la potencia calculada a partir de datos de fuerza de reacción contra el suelo producidas durante un test de levantarse de la silla mostró una capacidad discriminatoria excelente para identificar aquellos sujetos con sarcopenia (Kera et al., 2022). Estos hallazgos hacen pensar que la potencia muscular derivada la aplicación *Sit to Stand* podría desempeñar un papel fundamental para el diagnóstico de estas condiciones clínicas.

1.6.3. El rol de las variables antropométricas

La medición de la cantidad de masa muscular es un requerimiento necesario para determinar la presencia de la sarcopenia (Cruz-Jentoft et al., 2019). Además, se observó como aquellos individuos categorizados como frágiles tenían una menor densidad y cantidad de masa muscular con respecto a los individuos sanos (Cesari et al., 2006).

Si bien la masa muscular constituye un elemento clave en el desarrollo tanto de la sarcopenia como de la fragilidad, su medición en la práctica clínica, como visto anteriormente, no está implementada de forma rutinaria debido al difícil acceso a las herramientas necesarias para determinarla (Reijnierse et al., 2017). Las mediciones del perímetro de la pantorrilla y del brazo se indicaron como alternativas válidas a herramientas de alto coste como el DXA o la BIA en un entorno clínico (Gort-van Dijk et al., 2021; Santos et al., 2019).

Diferentes estudios encontraron asociaciones entre una baja circunferencia de pantorrilla y variables relacionadas con la salud o incluso con la mortalidad. Concretamente, en el estudio de Bian y colaboradores (2023), el quintil de circunferencia de gemelo más bajo se asoció con el doble de riesgo de presentar hipertensión arterial y dislipemia, así como un incremento del 40% del riesgo de tener problemas relacionados con el metabolismo de la glucosa. Adicionalmente, Fernandes et al. (2022) observaron que la circunferencia de gemelo es un predictor independiente de mortalidad, y que circunferencias de gemelo inferiores a 34,5 cm y a 31 cm se asociaron con un incremento del riesgo de mortalidad (HR: 1,72 y 2,11, respectivamente). De manera similar, en otro estudio, se observó que el quintil de circunferencia de gemelo mayor se asoció con la mitad del riesgo de mortalidad por cualquier causa, y con un 57% menos de riesgo de mortalidad por problemas cardiovasculares con respecto al quintil con la circunferencia menor (Huang et al.,

2021). Además, cada centímetro de incremento de la misma supuso una reducción del 8% de riesgo de mortalidad por cualquier causa y del 10% por problemas cardiovasculares (Huang et al., 2021). Paralelamente, en un estudio de Landi y colaboradores (2010) se observó que el tercíl mayor de circunferencia del tercio superior del brazo se asoció con una reducción del riesgo de mortalidad del 55%. Adicionalmente, los mismos sujetos se desempeñaron mejor en pruebas funcionales con respecto a los individuos con una circunferencia menor, observándose diferencias de casi 0,2 m/s en el test de velocidad de marcha y de 10 kg en el test de fuerza de agarre (Landi et al., 2010). Asimismo, unas reducciones de ambos perímetros han sido asociadas con la presencia tanto de fragilidad (Closs et al., 2017; Valdivieso et al., 2021), como de sarcopenia (Esteves et al., 2020; Hu et al., 2021; G.-M. Kim et al., 2022).

Adicionalmente, se observó que añadir un valor de medida antropométrica como la circunferencia de la pantorrilla a un test de cribado para la sarcopenia mejoró su precisión a la hora de identificar posibles casos de sarcopenia (Barbosa-Silva et al., 2016; Ito et al., 2021; Kandinata et al., 2023; Yang et al., 2018). Entonces, añadir parámetros de masa muscular fácilmente medibles como las circunferencias de pantorrilla y del tercio proximal del brazo podría incrementar la capacidad de la herramienta desarrollada por nuestro equipo de investigación para la detección de fragilidad y sarcopenia en ancianos residentes en la comunidad.

II – JUSTIFICACIÓN

II - JUSTIFICACIÓN

Entre los diferentes objetivos que esta tesis doctoral pretendía alcanzar, la publicación de un protocolo de estudio sobre la validez de una aplicación móvil para detectar prefragilidad y sarcopenia se consideró como prioritario. Hoy en día la publicación de un protocolo de estudio de precisión diagnóstica es una práctica que cada vez más investigadores están llevando a cabo, muchas veces antes de empezar el reclutamiento (Cohen et al., 2016). Además, esta práctica implica diferentes beneficios para aquellos que quieran llevar a cabo un análisis profundo de la validez del estudio, para aquellos que quieran replicarlo y para el personal clínico que quiera emplear los procedimientos diagnósticos que dicho estudio pretende validar. Esto se debe a que el protocolo de estudio suele contener informaciones minuciosas sobre la metodología que se empleará en la investigación, información que podría no aparecer en la versión final del artículo debido a aspectos relativos a la política de las revistas (Cohen et al., 2016). Asimismo, los protocolos de estudio permiten averiguar a los lectores si los resultados de investigación que se publican posteriormente reflejan los propósitos iniciales planteados por los investigadores. Adicionalmente, proporcionan informaciones a la comunidad científica sobre qué investigaciones se están llevando a cabo, permitiendo evitar la publicación de estudios duplicados o innecesarios (Ohtake & Childs, 2014). Finalmente, los protocolos de estudios aseguran la total transparencia por parte de los investigadores, forzándolos a cumplir con lo anteriormente publicado, evitando de este modo el sesgo de notificación selectiva de datos, que consiste en el reporte favorable de resultados con el objetivo de facilitar el proceso de publicación de dicha investigación (Uppstad & McTigue, 2020).

La potencia se postuló como biomarcador fundamental en el proceso de envejecimiento debido a las asociaciones que se observaron con eventos adversos relacionados con la salud de las personas, como la independencia funcional o incluso la mortalidad (Losa-Reyna et al., 2022). Hoy en día, gracias al avance tecnológico, es posible determinar los niveles de potencia generados en un test de levantarse de una silla por medio de una aplicación para teléfonos móviles con sistema operativo iOS (J. D. Ruiz-Cárdenas et al., 2018). Esta aplicación constituye

una solución frente a las barreras indicadas por el personal clínico, tales como la falta de herramientas económicas, la necesidad de un personal entrenado para la interpretación de datos o la portabilidad de los instrumentos (Orange et al., 2020). A pesar de haberse demostrado una herramienta válida, solamente se validó para usuarios de la plataforma iOS. Si bien la plataforma iOS cuenta con un mayor número de usuarios y con un mayor número de aplicaciones relacionadas con la salud, el sistema Android está destinado a crecer, incluso a mayor velocidad la plataforma iOS (Mosa et al., 2012; Ventola, 2014). Por todo ello, proporcionar al personal clínico, usuario de la plataforma Android, una herramienta para medir la potencia generada durante un test de levantarse de una silla fue el segundo objetivo de esta tesis doctoral.

Fragilidad y sarcopenia son procesos que traen consigo unas consecuencias importantes para la salud de los ancianos, asociándose incluso con un incremento del riesgo de mortalidad prematura. Además, cuando se muestran presentes de manera simultánea, el riesgo de mortalidad incrementa exponencialmente (Thompson et al., 2021). Numerosos estudios de investigación previos han observado que su detección temprana, así como un plan de tratamiento adecuado permiten incluso revertir estos estados (Evans, 1996; Travers et al., 2019). A pesar de esto, el control rutinario de ambas patologías no está sedimentado en la práctica clínica debido al alto coste de los materiales empleados, o por su escasa disponibilidad, dificultando por lo tanto este proceso (Bruyère et al., 2017; Offord et al., 2019).

Si bien muchos trabajos de investigación previos subrayaron la importancia y las repercusiones que la fragilidad y la sarcopenia tienen sobre la salud de los ancianos, todavía sigue existiendo heterogeneidad a la hora de determinar adecuadamente su presencia. El fenotipo de Fried y las recomendaciones propuestas en el consenso europeo EWGSOP2 constituyen las herramientas más empleadas para diagnóstico del síndrome de fragilidad y de sarcopenia, respectivamente. El consenso europeo define la sarcopenia confirmada como la presencia de bajos niveles de fuerza y de masa muscular (Cruz-Jentoft et al., 2019). La fuerza, de acuerdo con el consenso, puede medirse de dos formas distintas, a través de la evaluación de la fuerza de agarre o mediante el test de levantarse de una silla cinco veces. Por otro lado, la cantidad de masa muscular puede expresarse

como masa muscular apendicular en términos absolutos, o en términos relativos, dividiendo la masa muscular absoluta por el peso de los individuos. Combinando los diferentes criterios se obtienen un total de cuatro formas distintas para determinar la presencia de sarcopenia en ancianos, sin que exista una indicación clara por parte del consenso europeo EWGSOP2 sobre cuál es la más adecuada. Determinar si el uso de un criterio diagnóstico sobre otro repercute en la detección de casos con sarcopenia y en cómo cada criterio diagnóstico puede asociarse con eventos adversos para la salud, podría proporcionar al personal clínico una visión completa sobre la herramienta más indicada a emplear de cara al diagnóstico de la sarcopenia, así como disminuir de manera sensible los casos de infradiagnósticos. Por ejemplo, una persona podría considerarse como sana o con sarcopenia dependiendo del criterio diagnóstico empleado. Conociendo qué criterio diagnóstico dentro de los recomendados por el consenso europeo EWGSOP2 podría ser el más adecuado, nos ayudaría a seleccionar nuestro estándar de referencia para diagnosticar sarcopenia en nuestro estudio de validación diagnóstica de la aplicación móvil.

Finalmente, la sarcopenia se indicó ser un moderador del estado de fragilidad, y que su presencia aumenta el riesgo de desarrollar o empeorar el estado de fragilidad (Álvarez-Bustos et al., 2022). Adicionalmente, cuando presente de manera simultánea a la fragilidad, el riesgo de sufrir el deterioro de la función física o de mortalidad es mayor que cuando dichas patologías están presentes de manera aislada (Davies et al., 2022; Thompson et al., 2021). A pesar de las consecuencias potencialmente devastadoras que la presencia simultánea de ambas enfermedades tiene sobre la salud de las personas mayores, ambas son reversibles mediante un diagnóstico precoz y un tratamiento adecuado (Evans, 1996; Travers et al., 2019). Por lo tanto, el desarrollo de una herramienta capaz de determinar de forma válida la presencia de ambas condiciones y que tenga en cuenta todas las barreras que impiden su diagnóstico, podría facilitar que el diagnóstico se lleve a cabo en estadios más tempranos de las mismas, aumentando las probabilidades de revertirlas.

III – OBJETIVOS

III - OBJETIVOS

Los objetivos propuestos para el desarrollo de esta tesis doctoral fueron:

- I. Publicar un protocolo de estudio sobre la validez de una aplicación móvil para detectar la presencia de prefragilidad y sarcopenia en ancianos residentes en la comunidad. (**Artículo I**)
- II. Desarrollar y validar una aplicación móvil para dispositivos Android para medir el tiempo, la velocidad, y la potencia generada durante el gesto de levantarse de la silla, así como determinar su capacidad discriminativa en ancianos residentes en la comunidad. (**Artículo II**)
- III. Analizar la prevalencia de sarcopenia en función de los criterios diagnósticos recomendados por el consenso europeo EWGSOP2, su grado de acuerdo, y su asociación con factores de riesgo relacionados con la salud en ancianos residentes en la comunidad. (**Artículo III**)
- IV. Determinar la validez de una aplicación móvil capaz de detectar la sarcopenia, así como analizar su validez de constructo con variables relacionadas con la salud en ancianos residentes en la comunidad. (**Artículo IV**)
- V. Desarrollar y validar una aplicación móvil para detectar la presencia simultánea de prefragilidad y sarcopenia, así como analizar su validez de constructo con variables relacionadas con la salud en ancianos residentes en la comunidad. (**Artículo V**)

IV – ARTÍCULO I

IV -ARTÍCULO I

Título del artículo:

Validity of an iPhone App to Detect Prefrailty and Sarcopenia Syndromes in Community-Dwelling Older Adults: The Protocol for a Diagnostic Accuracy Study

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Article

Validity of an iPhone App to Detect Prefrailty and Sarcopenia Syndromes in Community-Dwelling Older Adults: The Protocol for a Diagnostic Accuracy Study

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Abstract: Prefrailty and sarcopenia in combination are more predictive of mortality than either condition alone. Early detection of these syndromes determines the prognosis of health-related adverse events since both conditions can be reversed through appropriate interventions. Nowadays, there is a lack of cheap, portable, rapid, and easy-to-use tools for detecting prefrailty and sarcopenia in combination. The aim of this study is to validate an iPhone App to detect prefrailty and sarcopenia syndromes in community-dwelling older adults. A diagnostic test accuracy study will include at least 400 participants aged 60 or over without cognitive impairment and physical disability recruited from elderly social centers of Murcia (Spain). Sit-to-stand muscle power measured through a slow-motion video analysis mobile application will be considered as the index test in combination with muscle mass (calf circumference or upper mid-arm circumference). Frailty syndrome (Fried's Phenotype) and sarcopenia (EWGSOP2) will both be considered as reference standards. Sensibility, specificity, positive and negative predictive values and likelihood ratios will be calculated as well as the area under the curve of the receiver operating characteristic. This mobile application will add the benefit for screening large populations in short time periods within a field-based setting, where space and technology are often constrained (NCT05148351).

Keywords: aging; sit-to-stand; frail; sarcopenia; functional capacity; muscle power; chair rise; smartphone



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1. Introduction

Frailty and sarcopenia are syndromes related to the biological ageing process which can lead to adverse health-related consequences. Although not formally recognized as a disease, frailty is defined as a biological state characterized by reduced muscle strength, endurance, and physiological function that increases vulnerability to stressor events including loss of autonomy, disability, falls, hospitalizations, and deaths [1]. Although this syndrome seems to overlap with sarcopenia, in fact they are not synonyms. Indeed, sarcopenia is defined as a generalized and progressive loss of strength, skeletal muscle mass, and physical function [2] and it has been considered a precursor syndrome for developing frailty [3]. However, frailty is a multidimensional geriatric syndrome which not only includes physical but also cognitive and social dimensions. While sarcopenia is now formally recognized as a muscle disease with an ICD-10-MC Diagnosis Code, there is still a need for an ICD code for frailty to promote clinicians, public health agencies, and governments to report diagnosis, treatment strategies, and disease prevalence with enough accuracy [4].

Prevalence studies in European community-dwelling older adults have shown, with regional and criteria-related variations for diagnosis, that approximately 22% of them can

be classified as sarcopenic [5], while 17% of them can be classified as frail, with Spain being among the countries with the highest prevalence rates [6]. However, few studies have analyzed the prevalence of both syndromes in combination and have reported prevalence rates of 2.8% and 3.6% in Australian [7] and Japanese [8] community-dwelling older adults, respectively, whereas the prevalence is even higher in the Spanish population, showing rates ranging from 8.2% to 15.7% depending on the diagnostic criteria used [9]. While both syndromes share many common features linked to the ageing process, recent studies have demonstrated that their coexistence increases the incidence of recurrent falls, poor health-related quality of life, and mortality compared to those neither frail nor sarcopenic [7,8]. Although sarcopenia and frailty are not the same condition, their association might respond to the existence of different clinical forms of frailty, i.e., those with or without sarcopenia, with different pathophysiological processes and increased risk of adverse outcomes [7,9,10]. Therefore, assessing sarcopenic status once a patient is diagnosed of frailty would have potential prognostic and diagnostic consequences [9].

Given the growing importance of the early identification of frailty (prefrailty status) and sarcopenia to prevent subsequent functional decline, disability, and the increased mortality risk, a clinical affordable easy-to-use diagnostic tool for detecting prefrailty and sarcopenia syndromes in combination might have implications for prognosis, optimizing care, and planning interventions for community-dwelling older adults. In this regard, time needed to stand from a chair is considered a biomarker of mortality and frailty in older people [1,11], as well as a reliable diagnostic criteria for probable sarcopenia [2]. Although time to complete the sit-to-stand test is the primary measure of function and can be easily measured with a stopwatch, muscle power derived from inertial measurement unit sensors has been associated with frailty and has a greater discriminatory capacity to detect frailty compared to the time to complete the test [12]. Similarly, kinematics data related to muscle power obtained from ground reaction forces have been associated with sarcopenia syndrome and showed an excellent discriminatory ability for detecting sarcopenia in a sample of 627 community-dwelling older adults [13]. However, although this technology seems to be sensitive to detect both syndromes, it is not readily available or affordable in clinical or field-based testing environments and some of the current methods remain complex, difficult and time consuming to analyze.

Recent advances in hand-held technology offer an opportunity to assess muscle power during sit-to-stand test through a smartphone mobile application as valid as a force plate and 3D motion capture cameras [14,15] with the advantage of acquiring muscle power with a short assessment duration and automatic data processing response. Indeed, the purpose of this study is to develop and validate an update of the *Sit-to-Stand* App for detecting prefrailty and sarcopenia syndromes in combination in community-dwelling older adults. Since several studies have shown that low muscle mass measured by calf circumference or mid upper-arm circumference has been associated with frailty and sarcopenia syndromes [16,17], one could expect that the incorporation of these two measures, muscle power and muscle mass, into a single diagnostic tool integrated in a mobile application will result in a portable and unique easy-to-use tool capable of early detecting both syndromes in combination with enough accuracy. This mobile application will add the benefit for screening large populations in short time periods within a field-based setting, where space and technology are often constrained.

2. Materials and Methods

2.1. Study Design and Protocol Registration

This is a protocol for a retrospective diagnostic accuracy study. Standards for Reporting of Diagnostic Accuracy Studies (STARD) [18] have been used to ensure the completeness and the transparency of this protocol (see Supplementary Materials Table S1). This study has been registered on [ClinicalTrials.gov](https://www.clinicaltrials.gov) (21/12/08): NCT0514835. This study was approved by the Ethical Committee of Catholic University of Murcia (CE022108) and is in accordance with the principles of the Declaration of Helsinki.

2.2. Eligibility Criteria

Participants aged 60 or over will be enrolled at elderly social centers of the city of Murcia (Region of Murcia, Spain). Participants self-reporting severe cardiovascular problems such as heart valve disease, uncontrolled heart rhythm problems, automatic defibrillator, and pacemakers will be excluded. Additionally, participants with a Barthel score less than 90, less than 3 points in the Mini-Cog test, or those who are unable to stand up from a chair without assistance will be excluded from this study. All participants will provide written informed consent to participate in this study.

2.3. Participants Recruitment

Centers will be contacted and informed for participation in the development of this study. After obtaining consent from the social centers, each potentially eligible subject will be contacted via telephone or face to face in order to individually provide a detailed explanation of the assessment procedure, as well as to obtain his/her written consent after receiving oral and written information about this study. Participants will be informed that they can withdraw at any time from this study. Participants' recruitment will be carried out with a convenience model.

2.4. General Data Collection

All data collection will be performed at the same day. Data relative to age and sex of the subjects will be collected in form of self-reported questionnaire. Moreover, the following information will be collected through a list of observations: presence of depressive symptoms, socioeconomic status, education level, presence of comorbidity, polypharmacy, number of falls in the last year, number of hospitalizations in the last year and smoking habits. All data will be registered by a single researcher in a spreadsheet and then cross-checked point by point from the original data register by another researcher. Detailed information about general data collection can be found in Table A1.

The procedure for data collection will be performed in the following order: (i) clinical interview; (ii) index test; (iii) frailty assessment; (iv) sarcopenia assessment.

2.5. Index Test: Smartphone Mobile Application (App)

Participants' sit-to-stand capacity will be assessed using an iPhone App called *Sit-to-Stand* (version 1.1.1.) installed on an iPhone 13 device running iOS 15.3; Apple Inc., Cupertino, CA, USA. This App was created to determine muscle power derived from one time rise from a chair using a slow-motion video captured camera (240 frames per second). Participants will sit on a rigid and adjustable height chair with their arms crossed over their chest with their hip, knee and ankle joints visually positioned at 90 degrees. Then, subjects will be instructed to stand from the chair "as fast as possible", while the execution of the test will be filmed simultaneously with the smartphone. The smartphone will be placed horizontally on a 0.7 m-high tripod placed 3 m from the right or left side of the participant. This App estimates muscle power relative to body weight (in watts per kilogram; W/kg) from the subsequent analysis of the video recording using the following equation:

$$\text{Muscle Power} = 2.773 - 6.228 \times t + 18.224 \times d$$

where t is the time to rising, i.e., the time from seat off until the hip and knee joints reach full extension in an upright stance, and d is the femur length of the subject, i.e., the vertical displacement during the sit-to-stand test. Femur length will be measured as the distance between the superior aspect of the greater trochanter and femoral lateral condyle on the participants' right or left side. A reflective marker will be placed on the greater trochanter in order to identify the start and end of the sit-to-stand movement. The start of the movement is determined when the pelvis began to move forward after anterior trunk tilt which is time-matched when the reflective marker crossed the first horizontal grid line on the screen of the App (Figure 1). The end of the movement is defined when full extension of hip

and knee is achieved in an upright stance which is time-matched when the reflective marker achieves the highest vertical point during the upright movement cycle. The results provided from this App has been twice validated against 3D motion capture camera and force plates in community-dwelling older adults [14,15].

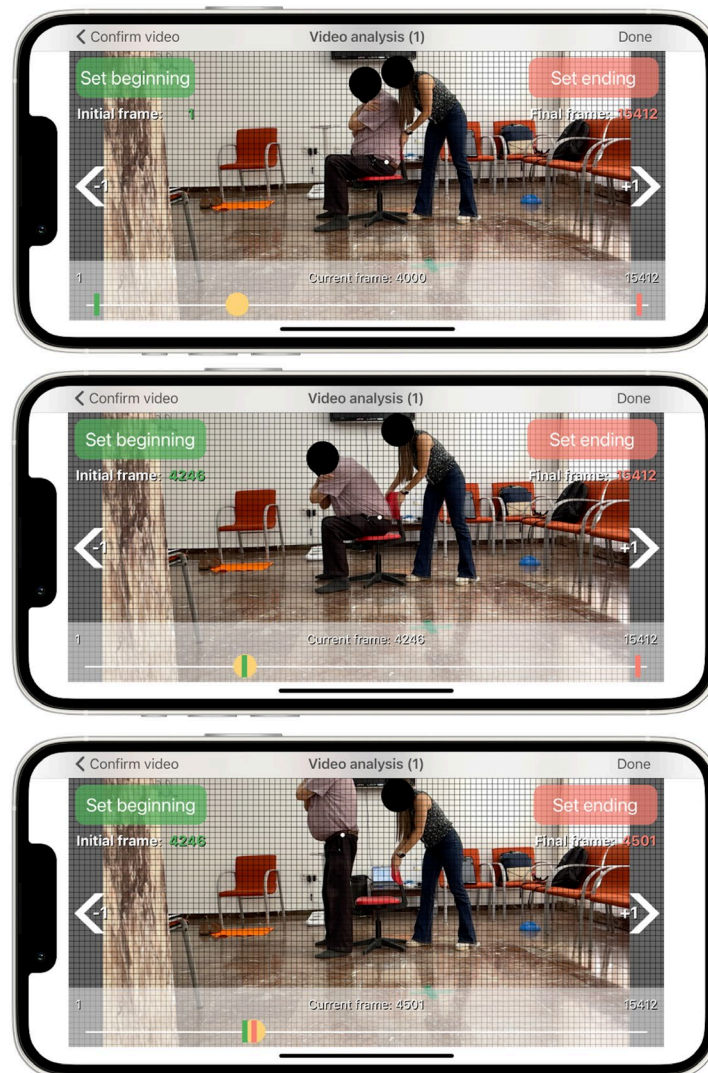


Figure 1. User interface of the App. White dot represents the reflective marker placed on the greater trochanter while the subject is in a sitting position (**top panel**), at the beginning of the vertical movement when the reflective marker crosses the first horizontal grip line on the screen (**middle panel**), and at the end of the vertical movement, when the reflective marker achieves the highest point (**lower panel**).

In addition, participants' calf circumference and mid-upper arm circumference will be measured and added together with sit-to-stand power values to improve diagnostic test accuracy. Calf circumference will be measured at the point of greatest circumference on the non-dominant leg (right leg for left-handed persons) in a sitting position with the knee and ankle at 90 degrees. Calf circumference has been shown to predict performance and survival in older people [17]. Mid-upper arm circumference will be measured at the midpoint of the participants' upper arm between the tip of the acromion and olecranon process of the dominant arm in a sitting position [19]. Both anthropometric measurements will be measured in a relaxed state using an inelastic but flexible measuring tape without compressing the skin.

2.6. Reference Standard for Frailty Syndrome

Frailty syndrome will be assessed through frailty phenotype proposed by Linda Fried [20]. Although there is no gold standard for the detection of frailty, this tool is probably the most used in the scientific literature [3]. This multidimensional tool determines frailty through five domains: gait speed, exhaustion, unintentional weight loss, strength and physical activity levels. Gait speed will be assessed using the 4 m gait test at usual and comfortable pace. Unintentional weight loss will be assessed by asking the subject if he/she experienced unintentional weight loss over 4.5 kg through the previous year. Exhaustion assessment will be collected asking to participants to rate from 0 (never) to 3 (most of the time) the frequency with which they experience the following statements: “I felt that everything I did was an effort” and “I could not get going”. Strength level will be assessed using handgrip strength with a Takei 5401 hand grip digital dynamometer (Takei Scientific Instruments Co., Ltd., Tokyo, Japan) and data relative to the physical activity levels of the participants will be collected through the Spanish validated short version of the Minnesota leisure time physical activity questionnaire [21]. The presence of at least 3 of 5 criteria will be necessary to define a frail state, whereas the presence of at least 1 criterion will be sufficient to identify prefrailty state [20].

2.7. Reference Standard for Sarcopenia

The presence and the stage of sarcopenia will be determined following the recommendations provided by the European Working Group on Sarcopenia in Older People 2 (EWGSOP2) [2]. Accordingly, muscle strength will be determined through repeating sit-to-stand test five times, with a cut-off point higher than 15 s representing probable sarcopenia. Then, sarcopenia will be confirmed by appendicular skeletal muscle mass with a cut-off point lower than 20 and 15 kg for men and women, respectively. Appendicular skeletal muscle mass will be determined using bioelectrical impedance analysis (TANITA MC-580, Tanita Corp., Tokyo, Japan). Resistance index and reactance values will be used in the validated equation developed by Sergi et al. [22] as recommended by the EWGSOP2 [2]. Low physical performance will be assessed using the Short Physical Performance Battery test (SPPB) [23]. A score lower than 9 points will be indicative of low function and, therefore, severe sarcopenia. The EWGSOP2 recommends this tool for assessing the degree of severity of sarcopenia [2].

2.8. Sample Size Estimation

Since the prevalence of both syndromes (prefrailty and sarcopenia) in combination has been reported in a range from 13% to 40% in Spanish community-dwelling older adults [9,10], sample size was estimated according to the lowest prevalence rate to be more confident. Therefore, a minimum sample size of 200 participants per sex was estimated in accordance with Bujang and Adnan [24] to detect an effect size equal or higher than 0.80 area under the curve (AUC), with an alpha error of 0.05 and statistic power of 80%. Since the study aim is to develop a specific tool to be used as a diagnostic tool, a high degree of both sensitivity and specificity is usually necessary (for a detailed information, see Tables/Figures 1–3 in [24]).

2.9. Statistical Analysis

The database will be created in Microsoft Excel®, Microsoft Corp., Redmond, WA, USA and the software IBM SPSS Statistics 26.0, SPSS Inc., Chicago, Ill, USA will be used for further analysis. A descriptive analysis of data will be carried out to report the participants' characteristics. We will provide values represented as mean, standard deviation, and 95% confidence interval (CI) for continuous variables and frequencies and percentages for categorical variables. Kolmogorov–Smirnov's test will be used to assess the normal data distribution. A data scrub will be performed with range and logic tests and we will search for unknown or unlikely values.

A complete case analysis will be performed. The AUC of the receiver operating characteristic (ROC) will be calculated to identify the best cut-off point of muscle power to discriminate subjects with both syndromes separately and in combination. Then, a multiple logistic regression equation with muscle power and calf circumference or mid upper-limb circumference will be generated and an additional ROC analysis will be performed using predictive probability from the results of the multiple logistic regression analysis to identify the best cut-off point for detecting both syndromes for each sex. Cross-tabulations of the index test with the reference standards (prefrailty and sarcopenia syndromes) will be performed and sensibility, specificity, positive and negative predictive values, and positive and negative likelihood ratios will be calculated. Finally, after classifying the status of the subjects into robust, prefrail, sarcopenia or the combination of both syndromes, the chi-square tests will be used to assess differences in proportion regarding their clinical profile (Table A1) and the Odds Ratio with 95% CI will be calculated.

3. Discussion

For years, in order to prevent adverse health-related consequences in older adults, several studies have paid special attention to sarcopenia and frailty syndrome separately. Both syndromes have been used to categorize people according to their risk for developing disability, falls, hospitalizations, and mortality as well as to individualize appropriate interventions in order to revert these pathological conditions. Moreover, the phenotypic and criteria–diagnosis similarities between both syndromes have led to an undistinguished use of both concepts as if they were connected to one another. However, despite of the correlation between frailty and sarcopenia syndromes, recent studies have evidenced that they are distinct disorders [7–10]. In fact, whereas frailty individuals have shown two-fold increased mortality risk, frailty-sarcopenic individuals have shown more than three-fold mortality risk compared to neither frail nor sarcopenic individuals, highlighting that both syndromes act independently having an additive effect on mortality [7]. Furthermore, mortality risk has been recently reported to be superior in prefrail sarcopenic than prefrail non-sarcopenic individuals and prefrail individuals only experienced disability more frequently than robust one when they were also sarcopenic [10].

Given the growing interest for analyzing both syndromes in combination and the importance of the early identification of frailty (prefrailty status) and sarcopenia to prevent subsequent functional decline, disability, and the increased mortality risk, a clinical affordable easy-to-use diagnostic tool for detecting both syndromes in combination might have implications for prognosis, optimizing care, and planning interventions for community-dwelling older adults. Thus, the aim of this study is to develop and validate an update of the *Sit-to-Stand* App for detecting prefrailty and sarcopenia syndromes in combination in community-dwelling older adults.

Previous studies have analyzed the role of kinematic parameters during sit-to-stand test derived from sophisticated assessment tools such as force plates or inertial measurement units for detecting frailty and sarcopenia syndrome separately [12,13]. These studies have shown high specificity and sensitivity for detecting frailty or sarcopenia [12,13]; however, this technology, although sensitive to these syndromes, is not readily available or affordable for clinical or field-based testing environments and some current methods remain complex, difficult and time consuming to analyze. These characteristics represent barriers for clinicians that requires valid easy-to-use tools with automatic data processing and real-time results without complicated interpretation or instrumentation.

Recent advances in hand-held technology offer an opportunity to assess muscle power during sit-to-stand test through a smartphone mobile application (*Sit-to-Stand* App) based on high-speed video recording at 240 frames per second which can accurately detect the subject's sit-to-stand motion [14,15]. This affordable technology only requires the use of a smartphone and an adjustable height chair to set starting knee joint position at 90 degrees for standardization purposes, since it is well known that chair height influences test performance [25–27]. This application has the potential to identify the rising phase

of the sit-to-stand test, i.e., when the body loses contact with the seat and the center of mass is lifted until knee and hip extension is reached which is critical for muscle power calculation [28–30], otherwise muscle power could be underestimated. The application converts the time of this phase into muscle power relative to body weight through a regression equation which has been twice prospectively validated against 3D motion capture camera and force plates in community-dwelling older adults [14,15].

Since muscle mass has been related to frailty and sarcopenia syndrome and can be easily measured through calf circumference or upper mid-arm circumference [16,17], the integration of both outcomes (muscle mass and muscle power) into the mobile application will have the potential for detecting prefrailty and sarcopenia with enough accuracy. Thus, the update of this application will provide to the clinicians the ability to determine both syndromes either in combination or separately in a short time period with an easy-to-use interface and automatic data processing overcoming the aforementioned barriers.

Despite a rigorous approach towards data collection and synthesis, this research is not without limitations. First, the retrospective validation design of this study will limit the external validity of the mobile application for diagnosing purposes. However, prior to performing a prospective validation, a retrospective design is necessary. Second, since this study will be focused on people attending elderly social centers, these people are likely to be fitter or healthier than community-dwelling older adults who do not attend these centers. Therefore, the cut-off points estimated for diagnosing these syndromes in this research could be superior than those established in less fit people, so sensitivity and specificity might be influenced.

4. Conclusions

Considering the high socioeconomical impact of these syndromes, the creation of a highly reliable tool for detecting sarcopenia and prefrailty status will provide to the scientific community and clinical personnel the possibility to diagnose both syndromes with an easy-to-use interface and automatic data processing in short time periods within the environmental context of daily living. This innovative portable tool will have potential implications for prognosis, optimizing care, and planning interventions. In fact, it is well known that early detection of these syndromes might potentially increase the chances of reversibility.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/s22166010/s1>, Table S1. STARD 2015 Checklist.

Author Contributions: Conceptualization, A.M., J.D.R.-C., J.J.R.-J. and M.d.M.M.-G.; methodology, J.D.R.-C. and J.J.R.-J.; investigation and resources, A.M., J.D.R.-C., J.J.R.-J. and M.d.M.M.-G.; data curation, A.M. and J.D.R.-C.; writing—original draft preparation, A.M.; writing—review and editing, A.M., J.D.R.-C., J.J.R.-J. and M.d.M.M.-G.; supervision, J.D.R.-C. and J.J.R.-J.; project administration, J.D.R.-C. and J.J.R.-J.; funding acquisition, J.D.R.-C., J.J.R.-J. and M.d.M.M.-G. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of Universidad Católica de Murcia (protocol code CE022108 21/02/26).

Informed Consent Statement: Informed consent will be obtained from all subjects involved in this study.

Data Availability Statement: Data will be made available upon request from the authors.

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Conflicts of Interest: The last author of this article is the creator of the app and may benefit financially from purchases of the App. Nevertheless, to guarantee the objectivity of the results, the first author will be blinded to the prefrailty and sarcopenia status of the subjects and will perform data analysis from the app. The remaining authors have no conflicts of interest to declare.

Appendix A

Table A1. General data collection.

Domain	Question	List of Possible Answers
Health Status	Do you smoke?	Yes/No
	Have you been diagnosed with one or more of these diseases?	Hypertension Diabetes Type I or II Cardiovascular Disease Chronic Obstructive Pulmonary Disease Acute Myocardial Infarction Cancer Asthma Bronchitis Urinary Incontinence Anemia Thyroid Disease Others
	Do you take five or more pills a day?	Yes/No
	How is your health in general?	Very good Good Fair Bad Very bad
	Please, choose the option relative to your study level	None Primary Lower Secondary Upper Secondary Bachelor's or equivalent Master's or equivalent Doctorate's or equivalent
	Please, choose the option that better fits with your annual salary	0–10,000 € 10,000–20,000 € 20,000–30,000 € 30,000–40,000 € >40,000 €
	Are you basically satisfied with your life?	Yes/No
Depression	Do you often get bored?	Yes/No
	Do you often feel helpless?	Yes/No
	Do you prefer staying at home instead of going out and doing new things?	Yes/No
	Is it hard for you to get started on new projects?	Yes/No
Adverse Events	Have you experienced two or more falls during the last year?	Yes/No
	Have you been hospitalized during the last year?	Yes/No

References

1. Ma, L. Current Situation of Frailty Screening Tools for Older Adults. *J. Nutr. Health Aging* **2019**, *23*, 111–118. [[CrossRef](#)] [[PubMed](#)]
2. Cruz-Jentoft, A.J.; Bahat, G.; Bauer, J.; Boirie, Y.; Bruyère, O.; Cederholm, T.; Cooper, C.; Landi, F.; Rolland, Y.; Sayer, A.A.; et al. Sarcopenia: Revised European Consensus on Definition and Diagnosis. *Age Ageing* **2019**, *48*, 16–31. [[CrossRef](#)] [[PubMed](#)]
3. Valenzuela, P.L.; Castillo-García, A.; Morales, J.S.; Izquierdo, M.; Serra-Rexach, J.A.; Santos-Lozano, A.; Lucia, A. Physical Exercise in the Oldest Old. *Compr. Physiol.* **2019**, *9*, 1281–1304. [[CrossRef](#)]

4. Muscedere, J. Editorial: The Need to Implement Frailty in the International Classification of Disease (ICD). *J. Frailty Aging* **2020**, *9*, 2–3. [\[CrossRef\]](#) [\[PubMed\]](#)
5. Petermann-Rocha, F.; Balntzi, V.; Gray, S.R.; Lara, J.; Ho, F.K.; Pell, J.P.; Celis-Morales, C. Global Prevalence of Sarcopenia and Severe Sarcopenia: A Systematic Review and Meta-Analysis. *J. Cachexia Sarcopenia Muscle* **2022**, *13*, 86–99. [\[CrossRef\]](#) [\[PubMed\]](#)
6. Santos-Eggimann, B.; Cuénoud, P.; Spagnoli, J.; Junod, J. Prevalence of Frailty in Middle-Aged and Older Community-Dwelling Europeans Living in 10 Countries. *J. Gerontol. A Biol. Sci. Med. Sci.* **2009**, *64*, 675–681. [\[CrossRef\]](#)
7. Thompson, M.Q.; Yu, S.; Tucker, G.R.; Adams, R.J.; Cesari, M.; Theou, O.; Visvanathan, R. Frailty and Sarcopenia in Combination Are More Predictive of Mortality than Either Condition Alone. *Maturitas* **2021**, *144*, 102–107. [\[CrossRef\]](#)
8. Mori, H.; Tokuda, Y. Differences and Overlap between Sarcopenia and Physical Frailty in Older Community-Dwelling Japanese. *Asia Pac. J. Clin. Nutr.* **2019**, *28*, 157–165. [\[CrossRef\]](#)
9. Davies, B.; García, F.; Ara, I.; Artalejo, F.R.; Rodríguez-Mañas, L.; Walter, S. Relationship Between Sarcopenia and Frailty in the Toledo Study of Healthy Aging: A Population Based Cross-Sectional Study. *J. Am. Med. Dir. Assoc.* **2018**, *19*, 282–286. [\[CrossRef\]](#)
10. Davies, B.; Walter, S.; Rodríguez-Laso, A.; Carnicero Carreño, J.A.; García-García, F.J.; Álvarez-Bustos, A.; Rodríguez-Mañas, L. Differential Association of Frailty and Sarcopenia With Mortality and Disability: Insight Supporting Clinical Subtypes of Frailty. *J. Am. Med. Dir. Assoc.* **2022**, in press. [\[CrossRef\]](#)
11. Knudtson, M.D.; Klein, B.E.K.; Klein, R. Biomarkers of Aging and Falling: The Beaver Dam Eye Study. *Arch. Gerontol. Geriatr.* **2009**, *49*, 22–26. [\[CrossRef\]](#) [\[PubMed\]](#)
12. Millor, N.; Lecumberri, P.; Gomez, M.; Martinez, A.; Martinikorena, J.; Rodriguez-Manas, L.; Garcia-Garcia, F.J.; Izquierdo, M. Gait Velocity and Chair Sit-Stand-Sit Performance Improves Current Frailty-Status Identification. *IEEE Trans. Neural Syst. Rehabil. Eng. Publ. IEEE Eng. Med. Biol. Soc.* **2017**, *25*, 2018–2025. [\[CrossRef\]](#) [\[PubMed\]](#)
13. Kera, T.; Kawai, H.; Takahashi, J.; Hirano, H.; Watanabe, Y.; Fujiwara, Y.; Ihara, K.; Kim, H.; Obuchi, S. Development of a Screening Formula for Sarcopenia Using Ground Reaction Force during Sit-to-Stand Motion. *Gait Posture* **2022**, *93*, 177–182. [\[CrossRef\]](#) [\[PubMed\]](#)
14. Ruiz-Cárdenas, J.D.; Rodríguez-Juan, J.J.; Smart, R.R.; Jakobi, J.M.; Jones, G.R. Validity and Reliability of an iPhone App to Assess Time, Velocity and Leg Power during a Sit-to-Stand Functional Performance Test. *Gait Posture* **2018**, *59*, 261–266. [\[CrossRef\]](#) [\[PubMed\]](#)
15. Orange, S.T.; Metcalfe, J.W.; Liefieith, A.; Jordan, A.R. Validity of Various Portable Devices to Measure Sit-to-Stand Velocity and Power in Older Adults. *Gait Posture* **2020**, *76*, 409–414. [\[CrossRef\]](#) [\[PubMed\]](#)
16. Ishii, S.; Tanaka, T.; Shibasaki, K.; Ouchi, Y.; Kikutani, T.; Higashiguchi, T.; Obuchi, S.P.; Ishikawa-Takata, K.; Hirano, H.; Kawai, H.; et al. Development of a Simple Screening Test for Sarcopenia in Older Adults. *Geriatr. Gerontol. Int.* **2014**, *14* (Suppl. S1), 93–101. [\[CrossRef\]](#)
17. Landi, F.; Onder, G.; Russo, A.; Liperoti, R.; Tosato, M.; Martone, A.M.; Capoluongo, E.; Bernabei, R. Calf Circumference, Frailty and Physical Performance among Older Adults Living in the Community. *Clin. Nutr. Edinb. Scotl.* **2014**, *33*, 539–544. [\[CrossRef\]](#)
18. Bossuyt, P.M.; Reitsma, J.B.; Bruns, D.E.; Gatsonis, C.A.; Glasziou, P.P.; Irwig, L.; Lijmer, J.G.; Moher, D.; Rennie, D.; de Vet, H.C.W.; et al. STARD 2015: An Updated List of Essential Items for Reporting Diagnostic Accuracy Studies. *BMJ* **2015**, *351*, h5527. [\[CrossRef\]](#)
19. Hu, F.-J.; Liu, H.; Liu, X.-L.; Jia, S.-L.; Hou, L.-S.; Xia, X.; Dong, B.-R. Mid-Upper Arm Circumference as an Alternative Screening Instrument to Appendicular Skeletal Muscle Mass Index for Diagnosing Sarcopenia. *Clin. Interv. Aging* **2021**, *16*, 1095–1104. [\[CrossRef\]](#)
20. Fried, L.P.; Tangen, C.M.; Walston, J.; Newman, A.B.; Hirsch, C.; Gottdiener, J.; Seeman, T.; Tracy, R.; Kop, W.J.; Burke, G.; et al. Frailty in Older Adults: Evidence for a Phenotype. *J. Gerontol. A Biol. Sci. Med. Sci.* **2001**, *56*, M146–M156. [\[CrossRef\]](#)
21. Ruiz-Comellas, A.; Pera, G.; Baena Díez, J.M.; Mundet Tudurí, X.; Alzamora Sas, T.; Elosua, R.; Torán Monserrat, P.; Heras, A.; Forés Raurell, R.; Fusté Gamisans, M.; et al. Validation of a Spanish Short Version of the Minnesota Leisure Time Physical Activity Questionnaire (VREM). *Rev. Esp. Salud Publica* **2012**, *86*, 495–508. [\[CrossRef\]](#)
22. Sergi, G.; De Rui, M.; Veronese, N.; Bolzetta, F.; Berton, L.; Carraro, S.; Bano, G.; Coin, A.; Manzato, E.; Perissinotto, E. Assessing Appendicular Skeletal Muscle Mass with Bioelectrical Impedance Analysis in Free-Living Caucasian Older Adults. *Clin. Nutr. Edinb. Scotl.* **2015**, *34*, 667–673. [\[CrossRef\]](#) [\[PubMed\]](#)
23. Guralnik, J.M.; Simonsick, E.M.; Ferrucci, L.; Glynn, R.J.; Berkman, L.F.; Blazer, D.G.; Scherr, P.A.; Wallace, R.B. A Short Physical Performance Battery Assessing Lower Extremity Function: Association with Self-Reported Disability and Prediction of Mortality and Nursing Home Admission. *J. Gerontol.* **1994**, *49*, M85–M94. [\[CrossRef\]](#)
24. Bujang, M.A.; Adnan, T.H. Requirements for Minimum Sample Size for Sensitivity and Specificity Analysis. *J. Clin. Diagn. Res. JCDR* **2016**, *10*, YE01–YE06. [\[CrossRef\]](#) [\[PubMed\]](#)
25. Schenkman, M.; Riley, P.O.; Pieper, C. Sit to Stand from Progressively Lower Seat Heights – Alterations in Angular Velocity. *Clin. Biomech. Bristol Avon* **1996**, *11*, 153–158. [\[CrossRef\]](#)
26. Kuo, Y.-L. The Influence of Chair Seat Height on the Performance of Community-Dwelling Older Adults' 30-Second Chair Stand Test. *Aging Clin. Exp. Res.* **2013**, *25*, 305–309. [\[CrossRef\]](#)
27. Weiner, D.K.; Long, R.; Hughes, M.A.; Chandler, J.; Studenski, S. When Older Adults Face the Chair-Rise Challenge. A Study of Chair Height Availability and Height-Modified Chair-Rise Performance in the Elderly. *J. Am. Geriatr. Soc.* **1993**, *41*, 6–10. [\[CrossRef\]](#)

-
28. Lindemann, U.; Claus, H.; Stuber, M.; Augat, P.; Muche, R.; Nikolaus, T.; Becker, C. Measuring Power during the Sit-to-Stand Transfer. *Eur. J. Appl. Physiol.* **2003**, *89*, 466–470. [[CrossRef](#)] [[PubMed](#)]
 29. Kralj, A.; Jaeger, R.J.; Muni, M. Analysis of Standing up and Sitting down in Humans: Definitions and Normative Data Presentation. *J. Biomech.* **1990**, *23*, 1123–1138. [[CrossRef](#)]
 30. Stevermer, C.A.; Gillette, J.C. Kinematic and Kinetic Indicators of Sit-to-Stand. *J. Appl. Biomech.* **2016**, *32*, 7–15. [[CrossRef](#)]

V – ARTÍCULO II

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Concurrent and discriminant validity and reliability of an Android App to assess time, velocity and power during sit-to-stand test in community-dwelling older adults

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Abstract

Introduction Nowadays, smartphones are equipped with the most sophisticated hardware which provides the opportunity to develop specific smartphone apps to analyze kinetic and kinematic parameters during sit-to-stand test in a clinical setting. The aims were to ascertain whether a new Android video-analysis based-App is comparable to the previously validated Apple-App for measuring time, velocity and power during sit-to-stand test, to determine its reliability and discriminant validity. **AQ1**

Methods One-hundred sixty-one older adults (61–86 years) were recruited from an elderly social center. Sit-to-stand variables were simultaneously recorded through the Android and Apple-App. Their validity and inter-rater, intra-rater, and test–retest reliability was tested using an intraclass correlation coefficient (ICC_{2-1}). Low gait speed (< 1.0 m/s), low physical performance (Short Physical Performance Battery < 10 points), and sarcopenia (EWGSOP2 guideline) were used to determine discriminant validity which was reported as the area under the curves (AUC) and their effect sizes (Hedges' g) for independent sample t -test. **AQ2**

Results Excellent reproducibility ($ICC_{2-1} > 0.85$) and strong agreement ($ICC_{2-1} > 0.90$) between operating systems for sit-to-stand variables derived from the App was found. Older adults classified as sarcopenic (11.2%), low physical performance (15.5%), or reduced gait speed (14.3%) showed worse sit-to-stand time, velocity and power with large effect sizes (Hedges' g : > 0.8) compared to their respective counterpart. These variables showed the acceptable-to-excellent ability to identify low gait speed, low physical performance, and sarcopenic older adults (AUC-range: 0.73–0.82).

Conclusion The new *Sit-to-Stand* App running on the Android operating system is comparable to the previously validated Apple App. Excellent reproducibility and acceptable-to-excellent discriminant validity were found.

Keywords Validity · Reliability · Agreement · Sit-to-stand · Smartphone · Older adults

Introduction

Ageing is associated with a progressive decline across multiple physiological systems which limit the ability to develop activities of daily living such as rising from a chair. Inability to rise from a chair without using the arms of the chair is considered a biomarker of aging [1, 2] and has been independently associated up to four times increase risk of mortality in community-dwelling older adults [2]. Kinetic and kinematic analyses during rising from a chair have been widely investigated for years with the aim of detecting age-related functional impairments [3–5] and for developing strategies that minimize functional deficits in older adults [6–8]. Variables derived from kinetic and kinematic analyses during sit-to-stand test have been related to the ageing process [9] and health-related outcomes such as falls [4], poor physical

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function [10, 11], sarcopenia [12] or even frailty [13, 14]. Early detection and treatment of these deficits could prevent subsequent age-related functional decline. However, these analyses have been usually restricted to research setting mainly due to the limitations imposed by specific tools which are very expensive, require technical expertise, are not portable and are time-consuming to analyze. These issues represent barriers for clinicians that require low-cost easy-to-use tools with automatic data processing and without the need for complex instrumentation or specialized personnel.

Nowadays, in a world powered by technology, smartphones are equipped with the most sophisticated hardware similar to those found in a laboratory setting, such as inertial measurement units or high-speed video cameras which provide the opportunity to develop specific smartphone apps to analyze kinetic and kinematic parameters in the clinical setting [9, 15, 16]. In an attempt to overcome the aforementioned barriers, our research group developed and validated a consumer Apple App to analyze the rising phase of the sit-to-stand movement via high-speed video recording through an easy-to-use interface and an automatic data processing after video analysis which allows clinicians to obtain kinetic and kinematic parameters such as the time to rising, vertical velocity and vertical power during the sit-to-stand functional performance test in short-time periods [9]. Our App showed negligible bias and small errors compared to force plate [9] and 3D motion capture camera [15] in adults with a broad age range (21–91 years). Moreover, these variables have been related to several measures of physical function [9, 10, 13–15] and enhance the information obtained from functional tests currently used in clinical practice [13, 17, 18].

However, the main weakness of this App is the compatibility restriction to Apple devices which affects the accessibility to clinicians with Android operating system (OS) smartphones. Therefore, to make this tool available to the two most widely used mobile OS, we developed a new *Sit to Stand* App compatible with Android OS. Yet, prior to recommend its use it is mandatory to develop a validation process to ascertain whether the new Android App is equivalent to the previously validated Apple one [9, 15] since changing the mobile OS could lead to different measurement errors affecting their data accuracy and validity [19]. In fact, a recent study aimed to validate four famous step count based-Apps reported considerable differences in terms of accuracy between the same Apps running simultaneously on different OS [19]. Therefore, a previously validated App designed for Apple iOS might not be valid for Android OS (or vice versa) and a validation process is required prior to recommend its use.

The aims of this study were (1) to ascertain whether the new Android App is comparable to the previously validated Apple App, (2) to determine the intra-rater, inter-rater, and test–retest reliability, and (3) to analyze the discriminant

validity of this App to differentiate community-dwelling older adults with sarcopenia, low gait speed and low physical performance with their respective counterpart.

Materials and methods

Study design

This was a cross-sectional study design aimed to assess the validity and reliability of the new *Sit to Stand* App installed on a Samsung A52 G device (Samsung Electronics Co., Ltd., Suwon, South Korea) running Android OS 14.0. The study was designed according to the Guidelines for Reporting Reliability and Agreement Studies (GRRAS) [20] (see Supplementary Information). The study was developed in an elderly social center in the city of Murcia (Spain) from February to October 2022. All data collection was collected on the same day. Primary outcomes were rising time, vertical velocity, and vertical power derived from the *Sit to Stand* App which were used for agreement and reliability analysis. Secondary outcomes were sarcopenia, gait speed, and physical performance assessed with the Short Physical Performance Battery which were used for discriminant validity. This study was developed in parallel with the previously published protocol [21] NCT05148351 at ClinicalTrials.gov.

Eligibility criteria

A non-probability sample of community-dwelling adults aged 60 or more was enrolled from an elderly social center in the city of Murcia. Participants were contacted either face-to-face or via telephone to participate in the study. Exclusion criteria were participants at risk of dementia (Mini-Cog < 3 points), self-reporting cardiovascular problems (automatic defibrillator, pacemakers, heart valve disease, and uncontrolled heart rhythm problems), unable to stand up from a chair without assistance, or any health condition that affects the performance of the functional tests such as stroke sequelae, low back pain or osteoarthritis. Physical activity level was measured with the Spanish Short Version of the Minnesota Leisure Time Physical Activity Questionnaire. Participants were informed of the study procedures before providing written informed consent and the study was approved by the Ethical Committee of the Catholic University of Murcia (CE022108). All procedures conformed to the Declaration of Helsinki.

Procedures

The *Sit to Stand* App (version 1.0) was developed using Android Studio Chipmunk 2021.2.1 Patch 1, the Kotlin 1.5.21 programming language and the Compose 1.0.1 UI

framework for MacOS. For capturing, importing and manipulating high-speed videos the CameraX 1.1.0 framework was used. The App was designed to analyze the rising phase of the sit-to-stand movement via high-speed video recording at 240 frames-per-second. The variables provided by the App are rising time, vertical velocity, and vertical power. Vertical velocity is calculated from vertical displacement (d) which is introduced into the App by the user and automatically divided by the rising time (t), as obtained between two user-selected frames after analyzing the video. Vertical displacement is equal to the femur length, the distance between the superior aspect of the greater trochanter and femoral lateral condyle when the participant sat at 90 degrees of the knee joint. Subsequently, vertical power is estimated from the following regression equation (R^2 adjusted = 0.917; $p = 0.035$; standard error of estimate = 0.45) [9, 15]:

$$\text{Power (W/Kg)} = 2.773 - 6.228 \times t + 18.224 \times d$$

After obtaining written informed consent, participants performed the single sit-to-stand test, sarcopenia assessment, gait speed test, and the Short Physical Performance Battery at the same day.

Single sit-to-stand test

Prior to the execution of the test, the distance between the superior aspect of the greater trochanter and the femoral lateral condyle of the participants was measured using an inelastic but flexible measuring tape. A visual marker (colored sticker) was placed on the greater trochanter to identify the beginning and the end of the rising phase. The sit-to-stand movement was simultaneously recorded with two smartphone models running the *Sit to Stand* App, the Samsung A52 G device running Android OS 14.0 and the iPhone 13 device running iOS 15.3. The smartphones were placed horizontally on a 0.7 m-high tripod placed 3 m from the left of the participant using a dual mount adapter (Fig. 1). Participants were instructed to stand up “as fast as possible” from an adjustable height chair without footwear with their arms crossed over their chest and the hip, knee, and ankle joints at 90 degrees. Three repetitions were performed and the fast repetition was used for further analyses. After 30 min of rest, participants were instructed to repeat the sit-to-stand test for test–retest reliability purposes.

Rater characteristics and data analysis

Video analysis from both Apple and Android Apps was undertaken by two independent raters for inter-rater analysis. For intra-rater analysis, one rater analyzed twice the videos from the Android App one-week apart. The raters were blinded to each other's findings in the case of inter-rater

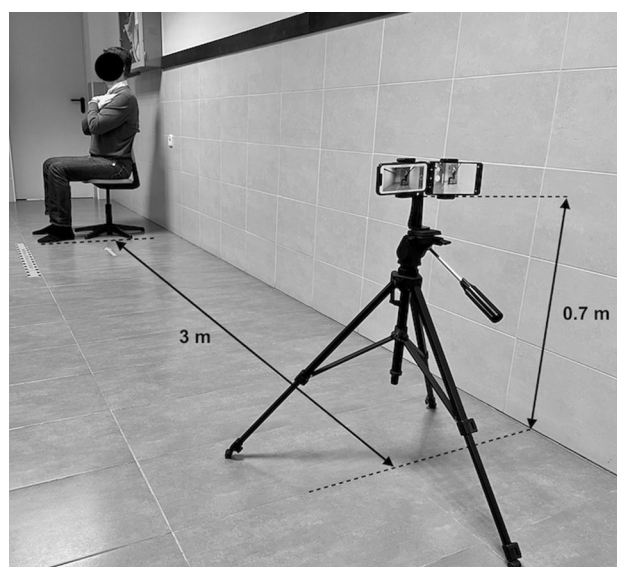


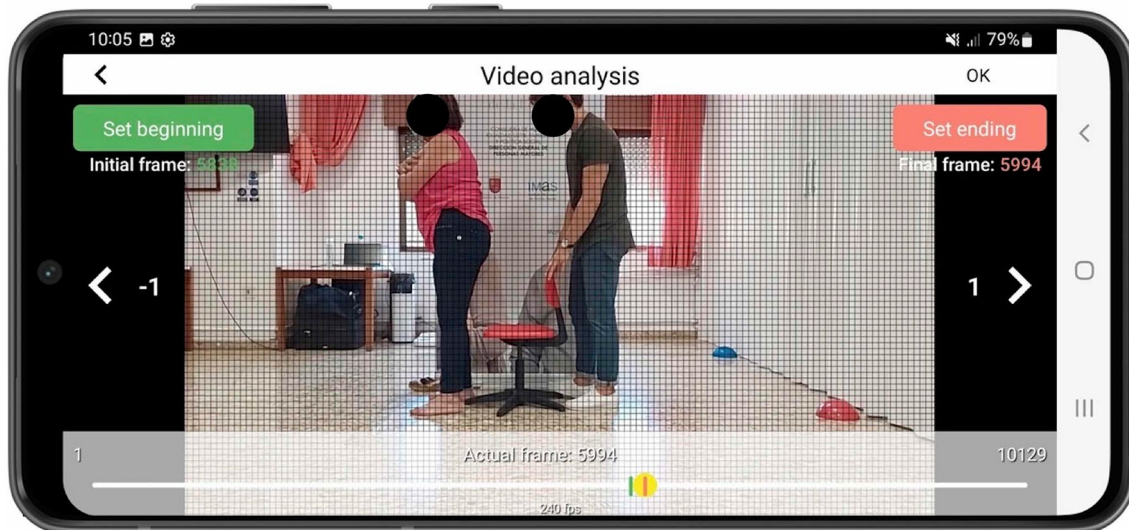
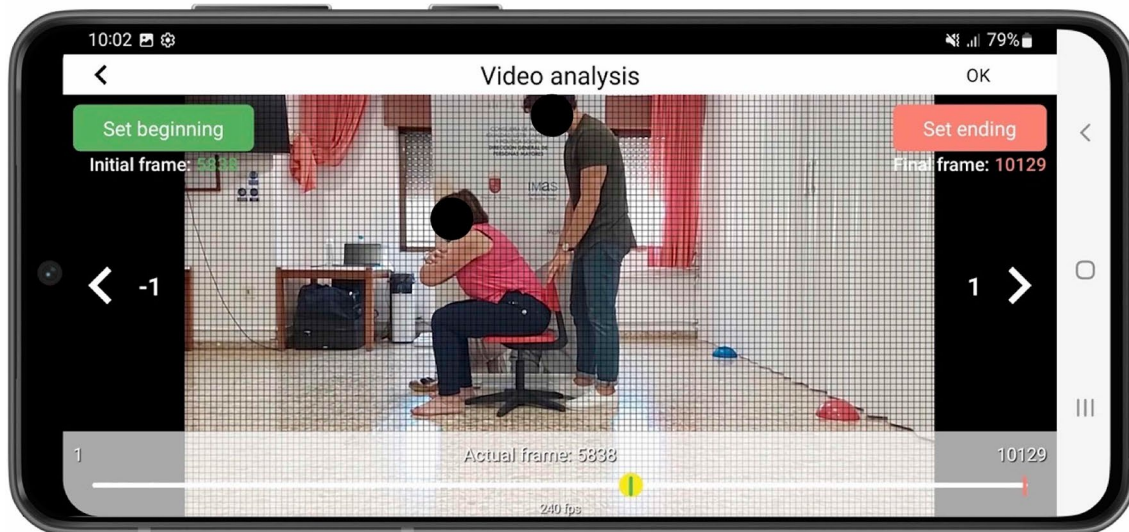
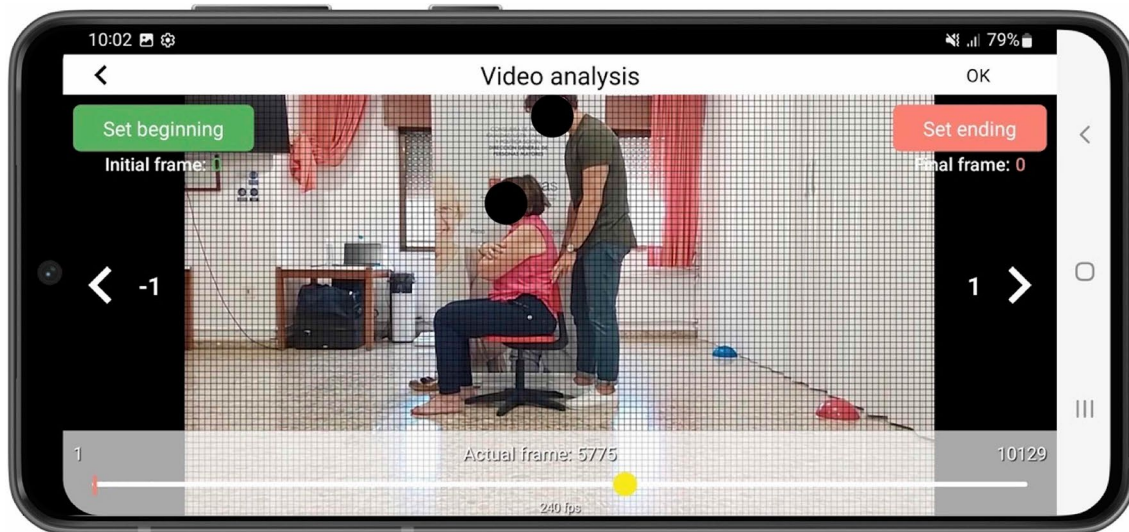
Fig. 1 Measurement environment. *Sit to Stand* App running on Apple and Android OS positioned on a 0.7 m-high tripod using a dual mount adapter placed 3 m from the left side of the participant

analysis, to their own analysis one week apart in the case of intra-rater analysis, and to participant characteristics, *i.e.*, sarcopenia, gait speed and physical performance measures, in the case of discriminant analysis.

To objectively determine the onset and the end of the rising phase, a visual grid for reference was built into the App as an overlay (Fig. 2). According to the instruction of the App, the onset of the rising phase was determined when the pelvis began to move forward after anterior trunk tilt which is time-matched when the colored sticker crossed the first horizontal grid line on the screen of the App. The end of this phase was defined when full extension of hip and knee is achieved in an upright stance which is time-matched when the colored sticker achieves the highest vertical point.

Sarcopenia assessment

The presence of sarcopenia was determined following the recommendations provided by the European Working Group on Sarcopenia in Older People 2 (EWGSOP2) [22]. Subjects were instructed to complete, as rapidly as possible, five chairs stand repetitions on a 0.45 m chair with their arms crossed over the chest. A stop-watch was started with the word “Go” and stopped when the participant sat on the chair for the fifth time [23]. Probable sarcopenia was defined with a cut-off point of > 15 s during the chair stand test. Then, sarcopenia was confirmed when the participant shows reduced appendicular skeletal muscle mass (cut-off point lower than 20 and 15 kg for men and women, respectively). Muscle mass was estimated using bioelectrical impedance analysis (TANITA MC-580, Tanita Corp., Tokyo, Japan). Resistance



◀**Fig. 2** User interface of the *Sit to Stand* App running on Android OS. White dot represents the colored sticker placed on the greater trochanter while the subject was at rest (top panel), at the beginning of the vertical movement (end of the preparation phase) when white dot crossed the first horizontal grip line on the screen (middle panel), and at the end of the rising phase when white dot achieved the highest point (lower panel). Example of a subject with 0.37 m of femur length. Rising time: 0.65 s; Velocity: 0.569 m/s; Power: 5.47 W/Kg

index and reactance raw values were used in the validated equation developed by Sergi et al. [24] as recommended by the EWGSOP2 [22].

Low gait speed

Low gait speed was defined with a cut-off < 1.0 m/s since it has been associated with an increased risk of hospitalization and mortality in well-functioning older adults [25]. Gait speed was measured via stop-watch using 4-m walking test. Two meters were provided prior to and following the timed portion (4-m) to allow for acceleration and deceleration phases. Participants were instructed to walk at their normal comfortable pace. The test was completed two times to improve the accuracy of the procedure and the fastest was selected for further analysis.

Low physical performance: short physical performance battery

Low physical performance was assessed through the Short Physical Performance Battery and defined with a cut-off < 10 points since it has been shown to be predictive of all-cause of mortality [26]. This battery includes the measure of gait speed, balance, and five repetitions chair stand test. Gait speed was measured as previously described. Balance was evaluated by examining the ability to stand with the feet together in the side-by-side, semi-tandem, and tandem position for 10 s. The five-times chair rising test was performed in a fixed-height chair (0.45 m) as previously described. A stop-watch was started on the word “Go” and unlike to sarcopenia assessment the stop-watch was stopped when the participant achieved the standing position at the end of the fifth stand [27].

Statistical analysis

Objective 1 and 2—reliability and concurrent validity

To determine the reliability and concurrent validity of sit-to-stand variables (time, velocity, and power) between the *Sit to Stand* App running Android OS compared to those obtained from the Apple iOS, Pearson’s correlation coefficient (r) with 95% confidence intervals (CI), intra-class correlation coefficient two-way mixed effects absolute agreement

(ICC₂₋₁) with 95% CI and Cronbach’s alpha were used. Mean absolute percentage error (MAPE) and coefficient of variation were also calculated. To identify potential systematic bias Bland–Altman plots were conducted. Furthermore, to test the inter- and intra-rater reliability of the sit-to-stand variables from the Android App as well as to identify potential systematic differences, the ICC₂₋₁ absolute agreement with 95% CI was used. Finally, to determine test–retest reliability two measures from the same subjects 30 min apart were selected and the ICC₂₋₁ absolute agreement with 95% CI was used. Reliability was interpreted as poor (< 0.5), moderate (0.5 to < 0.75), good (0.75 to 0.9), and excellent (> 0.90). The minimal detectable change (MDC₉₅) which is the minimal amount of change in the score of an instrument that must occur in an individual to be sure that the change in score is not simply attributable to a measurement error was calculated for test–retest reliability and expressed as absolute and percentage of change.

Objective 3—discriminant validity

Independent sample t test was used to compare means of sit-to-stand variables between subjects classified as low usual gait speed, low physical performance, and sarcopenic and their respective counterpart. The effect sizes were calculated as Hedges’ g , which was interpreted as small (< 0.2), medium (0.2 to 0.8), or large (> 0.8) effect and the Common Language Effect Size (CLES) was calculated to estimate the probability of a random observation from one population being larger than a random observation from the other population. Additionally, the Area Under the Curve (AUC) of the receiver operating characteristic was calculated to evaluate the discriminatory capacity of the sit-to-stand variables to differentiate subjects classified as low usual gait speed, low physical performance, and sarcopenic. AUC scores were interpreted as poor (0.5 to < 0.7), acceptable (0.7 to < 0.8), excellent (0.8 to < 0.9), and (≥ 0.9) outstanding discrimination. Given a sample size of 161 participants, the study was sufficiently powered (> 80%) to detect an effect size that was 0.8 (Hedges’ g) or larger for two-tailed test.

Results

Participant and rater characteristics

A total of 174 community-dwelling older adults from an elderly social center were initially recruited. Six older adults were classified at risk of dementia (Mini-Cog < 3 points), four individuals were unable to stand up from a chair without assistance, and three data were lost due to unintentional video deletion. Therefore, a total of 161 community-dwelling older adults were finally recruited (Table 1) from which 322

Table 1 Sample characteristics
(*n* = 161)

	Mean	SD	Minimum	Maximum
Age (years)	72.05	5.3	61	86
Weight (Kg)	69.91	12.4	45	104.8
Height (m)	1.59	0.08	1.38	1.79
Femur Length (m)	0.37	0.03	0.27	0.435
ASMM (Kg)	17.06	6.99	9.59	84.95
Physical Activity Level ^a (MET-min-week ⁻¹)	2355.7	—	1669.1	3402.3
Usual Gait Speed (m/s)	1.23	0.26	0.49	2.42
SPPB (pts)	11.41	0.98	5.00	12.00
Five Chair Rising Test (s)	12.04	2.60	7.42	25.88
Low Physical Performance (<i>n</i> , %)	25 (15.5%)	—	—	—
Low Usual Gait Speed (<i>n</i> , %)	23 (14.3%)	—	—	—
Sarcopenia (<i>n</i> , %)	18 (11.2%)	—	—	—
Sit to Stand App Variables ^b				
Time (s)	0.683	0.14	0.45	1.26
Velocity (m/s)	0.559	0.12	0.30	0.89
Power (W/Kg)	5.216	1.01	1.83	7.43

Appendicular Skeletal Muscle Mass (ASMM); Short Physical Performance Battery (SPPB). ^aData are reported as median and interquartile range. ^bValues obtained from *Sit to Stand* App running on Android OS

observations were analyzed by one rater for intra-rater analysis and 322 observations were analyzed by the other rater for inter-rater and test–retest analysis. Both raters were physiotherapists with 8 and 13 years of clinical experience. However, they did not use the App in their routine clinical practice.

Objective 1—concurrent validity: Android App versus Apple App

Pearson's correlation coefficients revealed a very strong relationship between the Android App assessed variables for sit-to-stand time ($r=0.92$; 95% CI: 0.89–0.94; $P<0.001$), sit-to-stand velocity ($r=0.95$; 95% CI: 0.93–0.96; $P<0.001$), and sit-to-stand power ($r=0.93$; 95% CI: 0.91–0.95; $P<0.001$) and those derived from the Apple App (Fig. 3). Additionally, there was strong agreement between sit-to-stand time (ICC₂₋₁: 0.91; 95% CI: 0.88–0.94; $\alpha=0.96$), sit-to-stand velocity (ICC₂₋₁: 0.94; 95% CI: 0.91–0.96; $\alpha=0.97$), and sit-to-stand power (ICC₂₋₁: 0.93; 95% CI: 0.9–0.95; $\alpha=0.97$) assessed with the Android and the Apple App. The coefficients of variation were as follows: 6.3%, 5.1%, 5% for sit-to-stand time, velocity, and power, respectively. Only 6 from a total of 161 observations were out of the limits of agreement. The measurements error (MAPE) for sit-to-stand time, velocity and power were 5.3, 4.8, and 5%, respectively.

Objective 2—intra-rater, inter-rater, and test–retest reliability

There was strong agreement between the measurements taken by the same rater within one week apart for sit-to-stand

time (ICC₂₋₁: 0.97; 95% CI: 0.96–0.98; $\alpha=0.99$), sit-to-stand velocity (ICC₂₋₁: 0.98; 95% CI: 0.97–0.98; $\alpha=0.99$), and sit-to-stand power (ICC₂₋₁: 0.98; 95% CI: 0.97–0.99; $\alpha=0.99$). Similarly, there was strong agreement between the two raters for sit-to-stand time (ICC₂₋₁: 0.97; 95% CI: 0.96–0.98; $\alpha=0.99$), sit-to-stand velocity (ICC₂₋₁: 0.98; 95% CI: 0.97–0.98; $\alpha=0.99$), and sit-to-stand power (ICC₂₋₁: 0.98; 95% CI: 0.97–0.99; $\alpha=0.99$). Furthermore, excellent test-retest reliability was found between the two repetitions performed 30 min apart for sit-to-stand time (ICC₂₋₁: 0.86; 95% CI: 0.81–0.90; $\alpha=0.93$), sit-to-stand velocity (ICC₂₋₁: 0.91; 95% CI: 0.87–0.93; $\alpha=0.95$), and sit-to-stand power (ICC₂₋₁: 0.90; 95% CI: 0.87–0.92; $\alpha=0.95$). The MDC₉₅ for sit-to-stand time, velocity and power was 0.152 seg (22%), 0.101 m/s (18.3%), and 0.895 W/Kg (17.3%).

Objective 3—discriminant validity: physical performance measures and sarcopenia

A total of 18 (11.2%) from 161 older adults were classified as sarcopenic, whereas 25 (15.5%) were classified as low physical performance and 23 (14.3%) showed a reduced gait speed (Table 1). Older adults classified either as sarcopenic, low physical performance, or low usual gait speed showed higher sit-to-stand times and lower velocity and power values than their respective counterpart with large effect sizes (Hedges' $g>0.8$). The probability of a random observation from the healthy groups being better than a randomly selected observation from the non-healthy groups was in range of 73% to 80%. Additionally, the variables derived from the Android App showed an acceptable to excellent

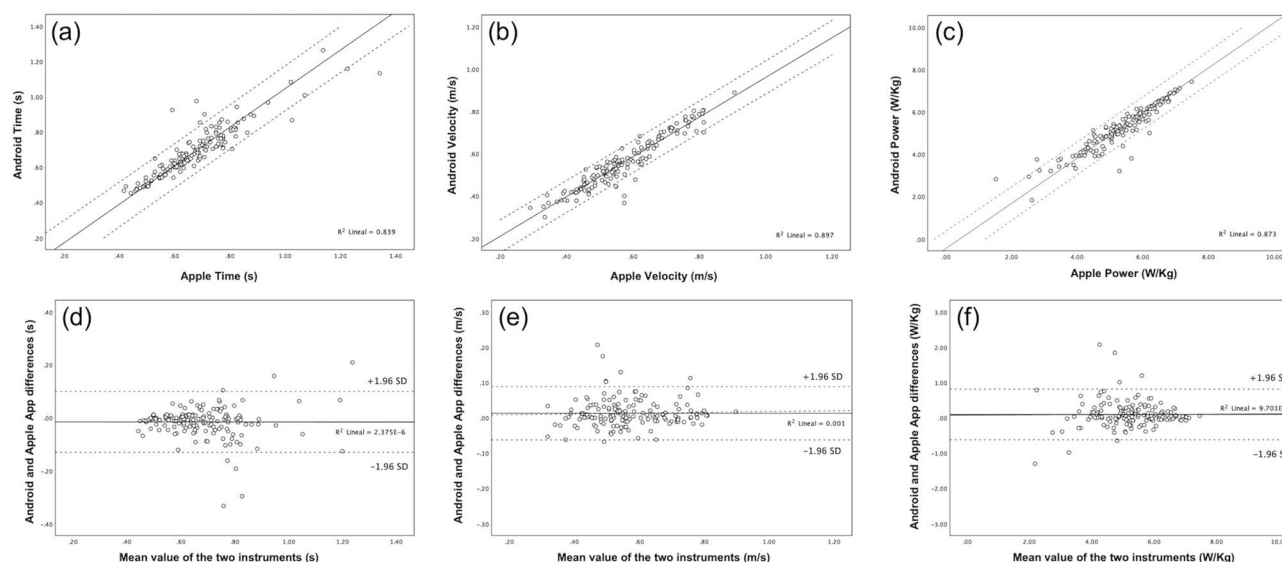


Fig. 3 Coefficient of determination for the *Sit to Stand* App running on Apple and Android OS for rising time (a), vertical velocity (b) and vertical power (c). Bland–Altman plots reflect the differences for rising time (d), vertical velocity (e) and vertical power (f) for the *Sit to*

Stand App running on Apple and Android OS. The horizontal thin line represents the systematic bias while the dashed line represents the ± 1.96 standard deviations (SD)

ability to identify low usual gait speed, low physical performance, and sarcopenic older adults (AUCs ranged from 0.73 to 0.82) (Table 2).

Discussion

The aims of this study were to ascertain whether a new Android video analysis based-App is comparable to the previously validated Apple App, to determine its reliability, and to analyze the discriminant validity of the new App to differentiate people with sarcopenia, low gait speed and

low physical performance with their respective counterpart. The results from this study showed excellent reliability and strong agreement for kinetic and kinematic variables derived from the App running on different OS. Moreover, these variables demonstrated acceptable to excellent validity to identify community-dwelling older adults classified as sarcopenic, low usual gait speed and low physical performance.

The consensus to determine the validity of consumer wearable and smartphone Apps evokes the need to systematically and transparently develop validation processes to ensure the use of this technology in a reliable and safe way [28]. However, there is still limited evidence about how the

Table 2 Discriminant validity: Areas under the curve (AUC) of the receiving operating characteristic and between-group comparison of the *Sit to Stand* App variables running on Android OS ($n=161$)

	Low Usual Gait Speed (< 1 m/s)			Low physical performance (SPPB < 10 points)			Sarcopenia		
	Mean diff. (95% CI)	Hedges' <i>g</i> (CLES)	AUC (95% CI)	Mean diff. (95% CI)	Hedges' <i>g</i> (CLES)	AUC (95% CI)	Mean diff. (95% CI)	Hedges' <i>g</i> (CLES)	AUC (95% CI)
STS Time (s)	0.141 (0.08 to 0.2)	1.04 (0.73)	0.75 (0.66 to 0.86)	0.137 (0.09 to 0.21)	1.02 (0.74)	0.76 (0.65 to 0.86)	0.149 (0.08 to 0.22)	1.07 (0.74)	0.75 (0.63 to 0.86)
STS Velocity (m/s)	-0.118 (-0.16 to -0.08)	1.05 (0.8)	0.81 (0.72 to 0.89)	-0.107 (-0.15 to -0.06)	0.96 (0.75)	0.79 (0.70 to 0.88)	-0.1 (-0.16 to -0.04)	0.85 (0.75)	0.74 (0.64 to 0.85)
STS Power (W/Kg)	-1.114 (-1.5 to -0.7)	1.19 (0.8)	0.82 (0.73 to 0.90)	-1.021 (-1.47 to -0.57)	1.08 (0.78)	0.79 (0.71 to 0.87)	-0.878 (-1.36 to -0.39)	0.88 (0.73)	0.73 (0.63 to 0.83)

Between-group mean difference (mean diff.); Sit-to-Stand (STS); Short Physical Performance Battery (SPPB); 95% Confidence Interval (95% CI); Common Language Effect Size (CLES)

validity of these Apps can be affected when different OS are used. From our knowledge, only one study [19] aimed to assess the validity of four commercially available step count and distance travelled based-Apps running simultaneously on Apple and Android OS. Their results showed considerable differences in measurement errors (MAPEs) for the four Apps running on different OS. In fact, the widely downloaded Argus App showed MAPE for distance travelled of 18% and 35% when the App was used on Apple and Android OS, respectively. Therefore, a previously validated App designed for a specific OS might not be valid running on a different OS and a validation process should be required prior to recommend its use.

The *Sit to Stand* App running simultaneously on Apple and Android OS showed extremely low levels of measurement error ($\text{MAPE} \leq 5\%$) [28] and excellent levels of reproducibility, either intra- and inter-rater reliability ($\text{ICC}_{2-1} \geq 0.97$), similar to those reported when the App was running on Apple iOS [9]. These results suggest that App's usability is equivalent between OS and the outcomes derived from the *Sit to Stand* App are not affected by differences between Apple and Android OS. This is noteworthy as previous studies [29, 30] aimed to validate smartphone video analysis based-Apps (similar to *Sit to Stand* App) on two identical smartphone devices running Apple iOS have shown coefficient of variations up to 10.4% between devices despite an excellent intra-rater reliability. These results were named as inherent technical error (*i.e.*, the agreement between two devices from the same model and brand). Considering these results, one would expect a higher coefficient of variation derived from the *Sit to Stand* App since it was working on different smartphone devices running Apple and Android OS. However, our results showed a coefficient of variations $< 10\%$ for kinetic and kinematic variables derived from the App highlighting its compatibility between OS.

Kinetic and kinematic variables derived from the sit-to-stand test such as time, velocity and power have been widely associated with several measures of physical function in older adults [9–11, 15]. These variables have also demonstrated their potential to discriminate between apparently healthy older adults to those with a history of falls, sarcopenia or even frailty [4, 10, 12–14]. However, these analyses have been usually performed through specialized equipment in a laboratory setting which requires technical expertise and are time-consuming to analyze limiting their potential to be used in clinical settings. Our results derived from the Android App showed an acceptable to excellent validity to discriminate between community-dwelling older adults classified as sarcopenic, low gait speed and low physical function compared to their respective counterpart. These results are similar to those reported by previous studies using force plates, linear encoders and inertial measurement units (Hedges' g : > 0.8) [4, 10, 12, 13] but with the advantage of

an easy-to-use interface and automatic data processing from the App after video analysis which allows the clinicians to obtain kinetic and kinematic parameters in short-time periods emphasizing its clinical validity.

Although in a clinical setting the sit-to-stand transition is usually measured using a stop-watch, measurement errors from manual recordings are greater compared to more sophisticated wearable technology [18]. Moreover, kinetic variables such as vertical velocity or power were more sensitive to detect age-related functional decline [9] and to discriminate between older adults classified as sarcopenic, frail or poor physical performance compared to the time to complete the test, even when it was recorded through sophisticated technologies [12, 13, 18]. Additionally, vertical velocity and power have shown a higher responsiveness to detect exercise training effects than the time to complete the test or other clinical measures such as isometric quadriceps strength, timed-up and go and Berg balance scale [17]. However, vertical velocity or power can only be calculated from the rising phase of the test, *i.e.*, when the body loses contact with the seat and the center of mass is lifted until the full extension of the hip and knee joint [3, 31, 32], which is unviable to be collected using a stop-watch. Otherwise, calculating vertical velocity and power from the time to complete the test instead of from the rising phase would lead to underestimation up to $\sim 62\%$ of these variables [3, 33] since it would take into account the preparatory phase when trunk is accelerated forward prior to seat-off, and the stabilization phase just after the rising phase when the hip extension velocity reached zero and the stance of the body is achieved in a quasi-static balance way [3, 31, 32]. Thus, vertical velocity and power as well as the rising time can be easily and reliably detected in short time periods (< 5 min) without the need for specialized personnel and instrument using the *Sit to Stand* App running on Apple and Android OS.

Despite these promising results, this study is not without limitations. First, the study was performed in community-dwelling older adults from an elderly social center where physical activities were encouraged as can be observed in their levels of physical activity (median: 2356 MET-min-week⁻¹). Therefore, these results could not be inferred from mobility-limited older adults. In fact, the App was created for early detection of age-related functional impairments in clinical practice, so the ability to differentiate community-dwelling older adults classified as reduced gait speed, low physical performance and sarcopenic from their respective counterpart is a strength of this study. Second, due to the low prevalence of participant classified as a low gait speed, low physical performance and sarcopenic a discriminatory analysis categorized by sex could not be performed. Finally, muscle quantity was assessed by bioelectrical impedance analysis due to its portability, however, it

is not recognized as the gold standard for the assessment of this variable. To overcome this limitation, a cross-validated equation in a sample with similar characteristics was used as previously recommended [22, 24, 34].

Conclusion

The present study showed that the new *Sit to Stand App* running on Android OS is comparable to the previously validated Apple App and demonstrated excellent reliability. Moreover, the variables derived from the App exhibited acceptable to excellent ability to identify community-dwelling older adults classified as sarcopenic, low usual gait speed and low physical performance. Further studies should analyze the App's responsiveness to an exercise intervention such as resistance training in older adults to identify its potential for rehabilitation monitoring.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s40520-023-02451-6>.

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Data availability All data generated or analyzed during this study are included in this article. Datasets may be made available to editors, reviewers, and readers upon request to the corresponding author.

Declarations

Conflict of interest The authors have no conflicts of interest to declare.

Ethics approval This study protocol was reviewed and approved by the Ethical Committee of the Catholic University of Murcia, approval number CE022108.

References

- Knudtson MD, Klein BEK, Klein R (2009) Biomarkers of aging and falling: the Beaver Dam eye study. *Arch Gerontol Geriatr* 49:22–26. <https://doi.org/10.1016/j.archger.2008.04.006>
- Cooper R, Kuh D, Hardy R et al (2010) Objectively measured physical capability levels and mortality: systematic review and meta-analysis. *BMJ* 341:c4467. <https://doi.org/10.1136/bmj.c4467>
- Kralj A, Jaeger RJ, Munih M (1990) Analysis of standing up and sitting down in humans: definitions and normative data presentation. *J Biomech* 23:1123–1138
- Fleming BE, Wilson DR, Pendergast DR (1991) A portable, easily performed muscle power test and its association with falls by elderly persons. *Arch Phys Med Rehabil* 72:886–889. [https://doi.org/10.1016/0003-9993\(91\)90006-5](https://doi.org/10.1016/0003-9993(91)90006-5)
- Alexander NB, Schultz AB, Warwick DN (1991) Rising from a chair: effects of age and functional ability on performance biomechanics. *J Gerontol* 46:M91–98. <https://doi.org/10.1093/geronj/46.3.m91>
- Lippi L, de Sire A, Mezian K et al (2022) Impact of exercise training on muscle mitochondria modifications in older adults: a systematic review of randomized controlled trials. *Aging Clin Exp Res* 34:1495–1510. <https://doi.org/10.1007/s40520-021-02073-w>
- Lopez P, Izquierdo M, Radaelli R et al (2018) Effectiveness of multimodal training on functional capacity in frail older people: a meta-analysis of randomized controlled trials. *J Aging Phys Act* 26:407–418. <https://doi.org/10.1123/japa.2017-0188>
- Hurst C, Weston KL, McLaren SJ et al (2019) The effects of same-session combined exercise training on cardiorespiratory and functional fitness in older adults: a systematic review and meta-analysis. *Aging Clin Exp Res* 31:1701–1717. <https://doi.org/10.1007/s40520-019-01124-7>
- Ruiz-Cárdenas JD, Rodríguez-Juan JJ, Smart RR et al (2018) Validity and reliability of an iPhone App to assess time, velocity and leg power during a sit-to-stand functional performance test. *Gait Posture* 59:261–266. <https://doi.org/10.1016/j.gaitpost.2017.10.029>
- Glenn JM, Gray M, Binns A (2017) Relationship of sit-to-stand lower-body power with functional fitness measures among older adults with and without sarcopenia. *J Geriatr Phys Ther* 40:42–50. <https://doi.org/10.1519/JPT.0000000000000072>
- Balachandran AT, Vigotsky AD, Quiles N et al (2021) Validity, reliability, and measurement error of a sit-to-stand power test in older adults: a pre-registered study. *Exp Gerontol* 145:111202. <https://doi.org/10.1016/j.exger.2020.111202>
- Kera T, Kawai H, Takahashi J et al (2022) Development of a screening formula for sarcopenia using ground reaction force during sit-to-stand motion. *Gait Posture* 93:177–182. <https://doi.org/10.1016/j.gaitpost.2022.02.001>
- Millor N, Lecumberri P, Gomez M et al (2017) Gait velocity and chair sit-stand-sit performance improves current frailty-status identification. *IEEE Trans Neural Syst Rehabil Eng Publ IEEE Eng Med Biol Soc* 25:2018–2025. <https://doi.org/10.1109/TNSRE.2017.2699124>
- Zech A, Steib S, Sportwiss D et al (2011) Functional muscle power testing in young, middle-aged, and community-dwelling nonfrail and prefrail older adults. *Arch Phys Med Rehabil* 92:967–971. <https://doi.org/10.1016/j.apmr.2010.12.031>
- Orange ST, Metcalfe JW, Liefheith A et al (2020) Validity of various portable devices to measure sit-to-stand velocity and power in older adults. *Gait Posture* 76:409–414. <https://doi.org/10.1016/j.gaitpost.2019.12.003>
- Marques DL, Neiva HP, Pires IM et al (2021) An experimental study on the validity and reliability of a smartphone application to acquire temporal variables during the single sit-to-stand test with older adults. *Sensors* 21:2050. <https://doi.org/10.3390/s21062050>
- Regterschot GRH, Folkersma M, Zhang W et al (2014) Sensitivity of sensor-based sit-to-stand peak power to the effects of training leg strength, leg power and balance in older adults. *Gait Posture* 39:303–307. <https://doi.org/10.1016/j.gaitpost.2013.07.122>

18. van Lummel RC, Walgaard S, Maier AB et al (2016) The instrumented sit-to-stand Test (iSTS) has greater clinical relevance than the manually recorded sit-to-stand test in older adults. *PLoS ONE* 11:e0157968. <https://doi.org/10.1371/journal.pone.0157968>
19. Adamakis M (2021) Criterion validity of iOS and android applications to measure steps and distance in adults. *Technologies* 9:55. <https://doi.org/10.3390/technologies9030055>
20. Kottner J, Audigé L, Brorson S et al (2011) Guidelines for Reporting Reliability and Agreement Studies (GRRAS) were proposed. *J Clin Epidemiol* 64:96–106. <https://doi.org/10.1016/j.jclinepi.2010.03.002>
21. Montemurro A, Ruiz-Cárdenas JD, Martínez-García MDM et al (2022) Validity of an iPhone App to Detect Prefrailty and Sarcopenia Syndromes in Community-Dwelling Older Adults: the Protocol for a Diagnostic Accuracy Study. *Sensors* 22:6010. <https://doi.org/10.3390/s22166010>
22. Cruz-Jentoft AJ, Bahat G, Bauer J et al (2019) Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing* 48:16–31. <https://doi.org/10.1093/ageing/afy169>
23. Montemurro A, Ruiz-Cárdenas JD, Martínez-García MDM et al (2023) Consequences of applying the different criteria of the EWGSOP2 guideline for sarcopenia case-finding in Spanish community-dwelling older adults. *Arch Gerontol Geriatr* 109:104964. <https://doi.org/10.1016/j.archger.2023.104964>
24. Sergi G, De Rui M, Veronese N et al (2015) Assessing appendicular skeletal muscle mass with bioelectrical impedance analysis in free-living Caucasian older adults. *Clin Nutr Edinb Scotl* 34:667–673. <https://doi.org/10.1016/j.clnu.2014.07.010>
25. Abellna Van Kan G, Rolland Y, Andrieu S et al (2009) Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people an International Academy on Nutrition and Aging (IANA) Task Force. *J Nutr Health Aging* 13:881–889. <https://doi.org/10.1007/s12603-009-0246-z>
26. Pavasini R, Guralnik J, Brown JC et al (2016) Short Physical Performance Battery and all-cause mortality: systematic review and meta-analysis. *BMC Med* 14:215. <https://doi.org/10.1186/s12916-016-0763-7>
27. Guralnik JM, Simonsick EM, Ferrucci L et al (1994) A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol* 49:M85–94
28. Johnston W, Judice PB, Molina García P et al (2021) Recommendations for determining the validity of consumer wearable and smartphone step count: expert statement and checklist of the INTERLIVE network. *Br J Sports Med* 55:780–793. <https://doi.org/10.1136/bjsports-2020-103147>
29. Courel-Ibáñez J, Martínez-Cava A, Morán-Navarro R et al (2019) Reproducibility and repeatability of five different technologies for bar velocity measurement in resistance training. *Ann Biomed Eng* 47:1523–1538. <https://doi.org/10.1007/s10439-019-02265-6>
30. Martínez-Cava A, Hernández-Belmonte A, Courel-Ibáñez J et al (2020) Reliability of technologies to measure the barbell velocity: implications for monitoring resistance training. *PLoS ONE* 15:e0232465. <https://doi.org/10.1371/journal.pone.0232465>
31. Schenkman M, Berger RA, Riley PO et al (1990) Whole-body movements during rising to standing from sitting. *Phys Ther* 70:638–648. <https://doi.org/10.1093/ptj/70.10.638>
32. Hirschfeld H, Thorsteinsdottir M, Olsson E (1999) Coordinated ground forces exerted by buttocks and feet are adequately programmed for weight transfer during sit-to-stand. *J Neurophysiol* 82:3021–3029. <https://doi.org/10.1152/jn.1999.82.6.3021>
33. Lindemann U, Claus H, Stuber M et al (2003) Measuring power during the sit-to-stand transfer. *Eur J Appl Physiol* 89:466–470. <https://doi.org/10.1007/s00421-003-0837-z>
34. Beaudart C, Bruyère O, Geerinck A et al (2020) Equation models developed with bioelectric impedance analysis tools to assess muscle mass: a systematic review. *Clin Nutr ESPEN* 35:47–62. <https://doi.org/10.1016/j.clnesp.2019.09.012>

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VI – ARTÍCULO III

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Consequences of applying the different criteria of the EWGSOP2 guideline for sarcopenia case-finding in Spanish community-dwelling older adults

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Abstract

Introduction: Sarcopenia prevalence varies according to differences in diagnostic criteria used. In order to overcome this issue, the European Working Group on Sarcopenia in Older People-2 (EWGSOP2) published a consensus to increase harmonization for sarcopenia diagnosis. This study aimed to determine the prevalence and risk factors across the different sarcopenia diagnosis criteria recommended by EWGSOP2 and to analyze its agreement.

Methods: A total of 699 community-dwelling older adults (median-age: 72, 60% female) were recruited in this cross-sectional study. Sarcopenia prevalence was obtained by different combinations of muscle strength (handgrip strength or 5-times sit-to-stand) and muscle quantity (appendicular skeletal mass or skeletal muscle index) as recommended by the EWGSOP2. Cohen's Kappa coefficient was calculated to analyze agreement among the four sarcopenia diagnostic criteria and logistic regressions were performed to identify risks associated to health-related outcomes for each diagnostic criterion.

Results: Sarcopenia prevalence varied from 2.1% to 11.6%, depending on the diagnostic criteria used. Weak-to-moderate agreements (κ -range: 0.13–0.66) were observed among the four sarcopenia diagnosis criteria. There was scarce overlap in sarcopenic people when different diagnostic criteria were used leading to up to 10.4% of underdiagnosis. Sarcopenia defined by 5-times sit-to-stand was more associated with health-related outcomes compared to handgrip strength.

Conclusions: Sarcopenia prevalence rates vary considerably depending on the diagnostic criteria used. These criteria should not be used in an interchangeable way due to their weak agreement. Sarcopenia diagnosis criteria defined by 5-times sit-to-stand could be more suitable in Spanish community-dwelling older adults due their associations with health-related outcomes.

Keywords: sarcopenia, older adults, agreement, prevalence, EWGSOP2.

1. Introduction

Sarcopenia is formally recognized as a disease of the musculoskeletal system and connective tissue (ICD code: M62.84) characterized by a progressive and generalized loss of muscle mass, strength, and physical function associated with ageing process (Cruz-Jentoft et al., 2019). This disease is related with a wide spectrum of health-related adverse outcomes like falls, fractures, physical disability, and mortality (Cruz-Jentoft et al., 2019). Despite the importance of this disease, a single diagnostic criterion has not yet been established. Actually, sarcopenia prevalence in Europe varies between 1% and 33% according to differences in diagnostic criteria and cut-off points used (Petermann-Rocha et al., 2022). In order to provide a systematic and consistent identification of people with sarcopenia or its risk, the European Working Group on Sarcopenia in Older People 2 (EWGSOP2) published a consensus to facilitate early detection and better treatment of sarcopenia in clinical practice. Concretely, probable sarcopenia is defined as low levels of muscle strength and is confirmed when both low strength and low muscle quantity are present. Finally, physical performance is measured as an indicator of severity (Cruz-Jentoft et al., 2019).

The European consensus (EWGSOP2) provides a list of validated tools, including cut-off values, for the measurement of muscle strength and muscle quantity to increase harmonization for sarcopenia diagnosis in clinical practice and research studies. Muscle strength can be assessed through handgrip strength or 5-times sit-to-stand test (5STS) and muscle quantity can be measured as appendicular skeletal mass either absolute (ASM) or adjusted for height also named skeletal muscle index (SMI). However, although different options for muscle strength assessment could facilitate sarcopenia diagnosis in clinical practice in those cases where a handgrip dynamometer is not available, the use of a specific parameter instead of another could greatly affect the prevalence of the disease and some people could be underdiagnosed (Johansson et al., 2020). A recent study showed that when muscle strength was assessed by 5STS test, sarcopenia was twice as prevalent than when muscle strength was determined by handgrip strength in community-dwelling older adults (Johansson et al., 2020). Moreover, only 10% of participants manifested sarcopenia when both diagnostic criteria overlapped, showing a very weak agreement ($\kappa = 0.18$) between muscle strength assessment parameters. Therefore, there is a need to analyze the impact of sarcopenia prevalence and health-related risk factors according to the recommendations provided by the EWGSOP2 guidelines, as well as the agreement between sarcopenia diagnosis criteria in Spanish community-dwelling older adults.

The aim of this study was to determine the prevalence of sarcopenia with the different parameters

recommended by the EWGSOP2 for both muscle strength and muscle quantity, to analyze the agreement among sarcopenia diagnosis criteria, as well as to analyze the association for each diagnostic criterion with socioeconomic status, education level, smoking habit, polypharmacy, self-perceived health and health-related adverse outcomes, such as comorbidities, depression, falls and hospitalization in Spanish community-dwelling older adults.

2. Methods

2.1. Design and Protocol Registration

This cross-sectional study was designed according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement (von Elm et al., 2008) and registered on ClinicalTrial.gov (NCT05148351). The study was approved by the Ethical Committee of the Catholic University of Murcia (CE022108) and was in accordance with the principles of the Declaration of Helsinki.

2.2. Participants recruitment and setting

This study is a secondary analysis from a previous published protocol carried out from February to October 2022 (Montemurro et al., 2022). Community-dwelling adults aged 60 or more were recruited from elderly social centers of the Region of Murcia. Participants were contacted either via telephone or face-to-face and were instructed about the study development. After being provided with the detailed information about the assessment procedure and its related risk, their written informed consent was obtained. Participants were informed that they could withdraw at any time from the study.

Participants who reported severe cardiovascular problems (such as heart valve disease, uncontrolled heart rhythm problems, automatic defibrillator, and pacemakers), moderate dependency (less than 90 in Barthel score), likelihood of dementia or cognitive impairment (less than 3 points in the Mini-Cog test), inability of standing without assistance or any health condition that affects the performance of the functional tests such as stroke sequelae, neuropathy, low back pain or osteoarthritis were excluded.

2.3. Data Collection

Participants were systematically asked about sex, age, presence of depressive symptoms (Geriatric Depression Scale 5-items; cut-off point: ≥ 2), socioeconomic status (low income cut-off point: net salary $< 10,000$ €/year), education level (low education level cut-off point: primary or less), presence of comorbidity (two or more chronic conditions), polypharmacy (five or more drugs/day), self-perceived health (low self-perceived health cut-off point: very bad, bad or fair), presence of two or more falls in the last year, hospitalizations in the last year, current smoking habit, and physical activity levels with the Spanish Short Version Minnesota leisure time Physical

Activity Questionnaire (Ruiz-Comellas et al., 2012). Further information of the registered socioeconomic and health-related outcomes can be found in the study protocol (Montemurro et al., 2022).

2.4. Sarcopenia Assessment

Prevalence of sarcopenia was determined according to the recommendations proposed by the EWGSOP2 (Cruz-Jentoft et al., 2019). Muscle strength was measured by using either handgrip strength or 5STS test. Handgrip strength test was carried out using a handgrip digital dynamometer (Takei 5401, Takei Scientific Instruments Co., Ltd., Tokyo, Japan). Participants were instructed to maximally squeeze the device two times with each hand alternatively for a total of four trials while sitting on a chair with their elbow flexed at 90 degrees, wrist on a neutral position and thumb facing upwards. Maximal score was registered to determine low levels of muscle strength (cut-off points in men <27 kg and women <16 kg). For the 5STS test, participants were instructed to fully rise from a chair five times as fast as possible with arms crossed on their chest. Time taken to sit down on the chair at the fifth repetition was recorded with a stopwatch. A time longer than 15 seconds was used as cut-off point for low levels of muscle strength.

For sarcopenia diagnosis confirmation, muscle quantity was assessed as absolute ASM (kg) or adjusted for squared height, also named SMI (kg/m²), through bioelectrical impedance analysis (BIA) (TANITA MC-580, Tanita Corp., Tokyo, Japan). Following the EWGSOP2 recommendations, resistance index and reactance values from BIA were introduced in the Sergi's validated equation (Sergi et al., 2015) to calculate ASM and SMI. Cut-off points for low ASM were <20 kg for men and <15 kg for women, while cut-off points for low SMI were <7 kg/m² for men and <5.5 kg/m² for women. Therefore, following these recommendations a total of four diagnostic criteria can be obtained (Table 1).

Table 1. Sarcopenia definitions according to the EWGSOP2.

Sarcopenia diagnostic criteria	Low muscle strength	Low muscle quantity
Sarcopenia _{HG+ASM}	Handgrip Strength	Appendicular Skeletal Mass
Sarcopenia _{HG+SMI}	Handgrip Strength	Skeletal Muscle Index
Sarcopenia _{5STS+ASM}	5-times Sit-to-Stand	Appendicular Skeletal Mass
Sarcopenia _{5STS+SMI}	5-times Sit-to-Stand	Skeletal Muscle Index

Cut-off points: Handgrip (men <27kg; women <16kg); Appendicular Skeletal Mass (men <20kg; women <15kg); Skeletal Muscle Index (men <7 kg/m²; women <5.5 kg/m²); 5-times Sit-to-Stand (>15 seconds for men and women).

2.5. Statistical Analysis

A database was created in Microsoft Excel© (Microsoft Corp., Redmond, WA, USA) and the software IBM SPSS Statistics 26.0 (SPSS Inc., Chicago, Ill, USA) was used for data analysis. Continuous variables were reported as median and interquartile range due to non-normal distribution, while frequencies and percentages were used for categorical data.

Prevalence of sarcopenia was calculated using four different combinations of sarcopenia determinants according to the EWGSOP2 guidelines (see Table 1). Cohen's Kappa coefficient (κ) was used for agreement analysis among sarcopenia definitions and 95% confidence intervals (CI) were reported. Values lower than 0.4 were considered as weak, 0.4 and 0.79 as moderate, and higher than 0.8 as strong. Unadjusted and adjusted logistic regression analyses for age, sex, and body mass index were carried to identify associations between each sarcopenia diagnostic criterion with the risk of develop health-related adverse outcomes. Therefore, each sarcopenia diagnostic criterion was used as the dependent variable and socioeconomic status, education level, comorbidities, smoking habit, self-perceived health, depression, polypharmacy, falls, and hospitalization were used as independent variables. Odds ratios (ORs) with 95% CI were calculated and statistical significance was fixed at $p < 0.05$. An observed OR value less than 1 indicates that the odds of exposure among sarcopenic participants are lower than the odds of exposure among apparently healthy participants, whereas an observed OR value greater than 1 indicates that the odds of exposure among sarcopenic participants are greater compared the odds of exposure among apparently healthy participants which could be interpreted with caution as a risk factor of the disease. The Haldane-Anscombe correction was used to avoid infinity values in the calculation of the ORs.

3. Results

3.1. Participant characteristics

A total of 775 older adults from elderly social centers of the Region of Murcia were screened for eligibility. Seventy-six participants reported at least one of the exclusion criteria ($n= 59$ Mini-Cog test positive; $n= 17$ implanted electronic devices), therefore a total of 699 community-dwelling older adults (418 women and 281 men) with age ranges between 60–92 years were finally included in the analysis. Detailed information is available in Table 2.

3.2. Sarcopenia prevalence according to EWGSOP2 definitions

Prevalence of sarcopenia ranged from 2.1% to 11.6% depending on the diagnostic criteria used. Concretely, sarcopenia prevalence was highest when both 5STS and ASM values were combined ($\text{Sarcopenia}_{5\text{STS}+\text{ASM}}$). In contrast, the lowest prevalence of sarcopenia was found when both handgrip and SMI were considered ($\text{Sarcopenia}_{\text{HG}+\text{SMI}}$). In fact, a prevalence gradient in sarcopenia diagnosis was found showing greater prevalence when low muscle strength was defined as 5STS rather than handgrip strength test as well as when low muscle quantity was defined as ASM rather than SMI (Table 2).

Low muscle strength determined by 5STS was present 119 participants (17.1%) whereas low handgrip strength was present in 43 participants (6.2%). Low muscle quantity determined by ASM was present 387 participants (55.4%) whereas low SMI was detected in 206 participants (29.5%).

Table 2. Characteristics of participants (n= 699).

Outcome	Women	Men
Number of participants (%)	418 (60)	281 (40)
Age (years)	72 (68–76)	72 (68–76)
Height (m)	1.55 (1.51–1.59)	1.69 (1.64–1.72)
Weight (kg)	66.4 (59.8–73.3)	79.3 (71.6–88.6)
BMI (kg/m ²)	27.4 (24.5–30.2)	28.1 (25.8–31.3)
ASM (kg)	14.4 (13.2–15.7)	20.2 (18.7–22.3)
SMI (kg/m ²)	5.9 (5.5–6.4)	7.2 (6.7–7.7)
Handgrip Strength (kg)	22.5 (19.7–25.4)	37.9 (32.5–41.5)
5STS (s)	12.1 (10.6–14.1)	12.2 (10.7–14.2)
Physical activity levels (%)		
<i>Sedentary</i>	26 (6.2)	42 (14.9)
<i>Physically active</i>	392 (93.8)	239 (85.1)
Smokers	32 (7.6)	42 (14.9)
Comorbidities	244 (58.3)	137 (48.7)
Polypharmacy	80 (19.1)	71 (25.2)
Self-perceived Health (%)		
<i>Very Bad</i>	0 (0)	0 (0)
<i>Bad</i>	6 (1.4)	1 (0.3)
<i>Fair</i>	85 (20.3)	45 (16.0)
<i>Good</i>	268 (64.1)	198 (70.4)
<i>Very Good</i>	59 (14.1)	37 (13.1)
Education level (%)		
<i>None</i>	78 (18.6)	55 (19.5)
<i>Primary</i>	116 (27.7)	77 (2.5)
<i>Lower secondary</i>	14 (3.3)	18 (6.4)
<i>Upper secondary</i>	46 (11)	45 (16.0)
<i>Qualified profession</i>	68 (16.2)	34 (12.1)
<i>Degree</i>	63 (15.0)	25 (8.9)
<i>Licensed</i>	22 (5.2)	22 (7.8)
<i>PhD</i>	1 (0.2)	4 (1.4)
Socioeconomical status (%)		
<i>0–10k €</i>	63 (15)	37 (13.1)
<i>10–20k €</i>	139 (33.2)	83 (29.5)
<i>20–30k €</i>	111 (26.5)	85 (30.2)
<i>30–40k €</i>	44 (10.5)	48 (17.1)
<i>>40k €</i>	29 (6.9)	16 (5.7)
Falls (2 or more) (%)	66 (15.6)	24 (8.3)
Hospitalization (%)	46 (10.9)	48 (16.6)
Depression (GDS $\geq$ 2) (%)	40 (9.5)	13 (4.5)
Sarcopenia prevalence (%)		
<i>Sarcopenia_{HG+ASM}</i>	21 (5)	11 (3.9)
<i>Sarcopenia_{HG+SMI}</i>	8 (1.9)	7 (2.5)
<i>Sarcopenia_{5STS+ASM}</i>	51 (12.2)	30 (10.7)
<i>Sarcopenia_{5STS+SMI}</i>	20 (4.8)	24 (8.5)

BMI: Body Mass Index; ASM: Appendicular Skeletal Mass; SMI: Skeletal Muscle Index; 5STS: 5-times sit-to-stand; GDS: Geriatric Depression Scale. Continuous variables are shown as median and interquartile range due to non-normal distribution, while categorical variables are shown as absolute frequencies and percentages.

3.3. Agreement among sarcopenia definitions

The overall results showed weak to moderate agreements among EWGSOP2 sarcopenia definitions. As expected, the highest agreements were found when low muscle strength diagnostic criteria concurred and low muscle quantity was exchanged, Sarcopenia_{5STS+ASM} vs. Sarcopenia_{5STS+SMI} ($\kappa = 0.66$; 95% CI: 0.56 to 0.76) and Sarcopenia_{HG+ASM} vs. Sarcopenia_{HG+SMI} ($\kappa = 0.63$; 95% CI: 0.46 to 0.80). However, when low muscle quantity concurred as diagnostic criteria and low muscle strength was exchanged the results shown weak agreements between sarcopenia definitions, Sarcopenia_{5STS+ASM} vs. Sarcopenia_{HG+ASM} ($\kappa = 0.21$; 95% CI: 0.11 to 0.32) and Sarcopenia_{5STS+SMI} vs. Sarcopenia_{HG+SMI} ($\kappa = 0.25$; 95% CI: 0.10 to 0.40). Finally, the lowest agreements were found when neither low muscle strength and low muscle quantity concurred as diagnostic criteria, Sarcopenia_{5STS+SMI} vs. Sarcopenia_{HG+ASM} ($\kappa = 0.17$; 95% CI: 0.04 to 0.29) and Sarcopenia_{5STS+ASM} vs. Sarcopenia_{HG+SMI} ($\kappa = 0.13$; 95% CI: 0.04 to 0.23).

Additionally, overlapped participants between diagnostic criteria were analyzed looking for those who could be potentially underdiagnosed, *i.e.*, when a sarcopenic participant was categorized as apparently healthy using another criterion proposed by the EWGSOP2 guideline. In the worst scenario, a total of 73 participants (10.4%) were underdiagnosed using our lowest prevalence criterion (Sarcopenia_{HG+SMI}) compared to the highest prevalence criterion (Sarcopenia_{5STS+ASM}) as could be expected due to weak agreement. However, despite of moderate level of agreement between Sarcopenia_{5STS+ASM} and Sarcopenia_{5STS+SMI}, a total of 38 participants (5.4%) were underdiagnosed when SMI was used as muscle quantity instead of ASM, likewise 66 participants (9.4%) were underdiagnosed when ASM concurred as criteria and 5STS was exchanged by handgrip strength. Only when Sarcopenia_{HG+ASM} was used as diagnosis criteria sarcopenic participants categorized by Sarcopenia_{HG+SMI} were overlapped. Detailed information about underdiagnosed participants is provided in Figure 1.

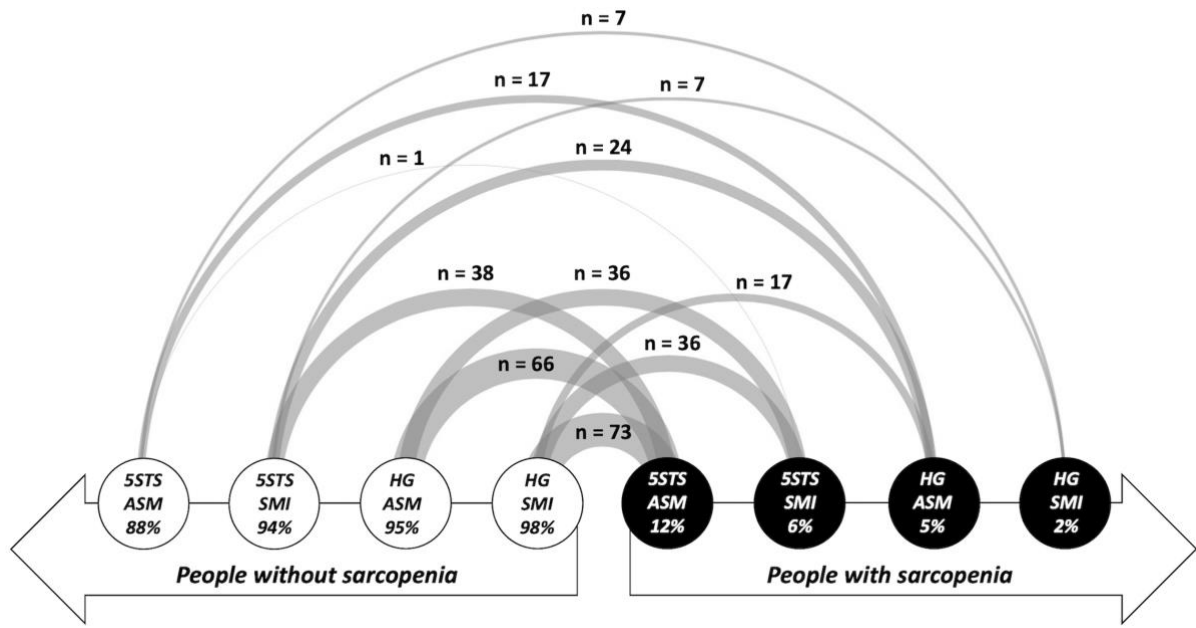


Figure 1. Agreement between sarcopenia diagnostic criteria (n = 699).

White circles represent the proportion of non-sarcopenic people whereas black circles represent sarcopenia prevalence according to the four diagnostic criteria proposed in the EWGSOP2. Arc lines represent the flow of people moving across disease to non-disease (or vice versa) according to the four diagnostic criteria. For example, a total of 66 participants were classified as apparently healthy using Sarcopenia_{HG+ASM} criterion whereas they were classified as sarcopenic using Sarcopenia_{5STS+ASM} criterion. 5STS: 5-times sit-to-stand test; HG: Handgrip; ASM: Appendicular Skeletal Mass; SMI: Skeletal Muscle Index.

(Note: 2-column fitting image.)

3.4. Risk factors for sarcopenia diagnosis criteria

In our adjusted analyses, Sarcopenia_{5STS+ASM} and Sarcopenia_{5STS+SMI} were the diagnostic criteria most associated with health-related adverse outcomes. Sarcopenia_{5STS+ASM} was associated with education level (OR: 2.26; 95% CI: 1.39 to 3.68), comorbidities (OR: 2.12; 95% CI: 1.28 to 3.50), polypharmacy (OR: 3.69; 95% CI: 2.18 to 6.21), depression (OR: 2.33; 95% CI: 1.37 to 3.96), and hospitalization (OR: 2.10; 95% CI: 1.16 to 3.79). Similar associations were reported for Sarcopenia_{5STS+SMI}, but with the exception of comorbidities (OR: 1.79; 95% CI: 0.93 to 3.46) and the addition of previous falls (OR: 2.50; 95% CI: 1.07 to 5.81). Sarcopenia_{HG+ASM} and Sarcopenia_{HG+SMI} only showed associations with polypharmacy (OR: 2.43; 95% CI: 1.11 to 5.31; OR: 4.14; 95% CI: 1.30 to 13.15; respectively). All sarcopenia diagnostic criteria showed unexpected associations to self-perceived health. Those participants with better self-perceived health showed more odds to be diagnosed with sarcopenia. Detailed information of risk factors for sarcopenia diagnostic criteria are reported in Table 3.

Table 3. Associations between sarcopenia diagnostic criteria with health-related risk factors (n= 699).

Risk factors		n	Sarcopenia _{5STS+ASM}		Sarcopenia _{5STS+SMI}		Sarcopenia _{HG+ASM}		Sarcopenia _{HG+SMI}	
			OR (95% CI)	Adjusted	OR (95% CI)	Adjusted	OR (95% CI)	Adjusted	OR (95% CI)	Adjusted
Education level	<i>High level</i>	373								
	<i>Low level</i>	326	1.88 (1.17–3.02)	2.26 (1.39–3.68)	1.71 (0.92–3.18)	2.46 (1.26–4.80)	1.71 (0.83–3.52)	1.96 (0.94–4.07)	1.31 (0.47–3.67)	1.75 (0.61–5.01)
Socioeconomic level	<i>High level</i>	100								
	<i>Low level</i>	599	0.64 (0.35–1.16)	0.56 (0.30–1.03)	1.06 (0.44–2.58)	0.84 (0.32–2.21)	0.71 (0.28–1.77)	0.65 (0.26–1.65)	5.33 (0.32–89.80) ^a	N/A
Comorbidities	<i><2 pathologies</i>	318								
	<i>≥2 pathologies</i>	381	1.78 (1.09–2.9)	2.12 (1.28–3.50)	1.22 (0.65–2.27)	1.79 (0.93–3.46)	1.41 (0.68–2.93)	1.58 (0.75–3.32)	1.69 (0.57–4.99)	2.27 (0.75–6.85)
Smoking habit	<i>Not Smoking</i>	624								
	<i>Smoking</i>	74	1.08 (0.51–2.26)	0.98 (0.46–2.08)	1.66 (0.71–3.86)	1.09 (0.44–2.70)	0.12 (0.01–2.02) ^a	N/A	0.26 (0.02–4.46) ^a	N/A
Polypharmacy	<i><5 drugs</i>	545								
	<i>≥5 drugs</i>	151	2.72 (1.67–4.44)	3.69 (2.18–6.21)	2.43 (1.29–4.60)	4.30 (2.05–9.03)	1.96 (0.92–4.16)	2.43 (1.11–5.31)	2.46 (0.86–7.03)	4.14 (1.30–13.15)
Self-perceived Health	<i>High level</i>	137								
	<i>Low level</i>	565	0.43 (0.26–0.72)	0.35 (0.21–0.60)	0.63 (0.31–1.25)	0.39 (0.18–0.83)	0.38 (0.18–0.80)	0.33 (0.16–0.71)	0.48 (0.16–1.42)	0.32 (0.10–0.99)
Depression	<i>Not Depressed</i>	565								
	<i>Depressed</i>	134	2.08 (1.25–3.49)	2.33 (1.37–3.96)	1.64 (0.82–3.27)	2.30 (1.08–4.87)	1.99 (0.92–4.31)	2.21 (0.97–4.64)	1.55 (0.49–4.94)	2.03 (0.61–6.69)
Falls last year	<i><2 falls</i>	608								
	<i>≥2 falls</i>	89	1.66 (0.90–3.07)	1.74 (0.93–3.26)	1.84 (0.85–3.97)	2.50 (1.07–5.81)	1.62 (0.65–4.05)	1.63 (0.64–4.13)	1.05 (0.23–4.74)	1.22 (0.26–5.68)
Hospitalization	<i>Not Hospitalized</i>	605								
	<i>Hospitalized</i>	92	2.13 (1.19–3.80)	2.10 (1.16–3.79)	3.44 (1.75–6.77)	2.90 (1.38–6.06)	1.55 (0.62–3.88)	1.55 (0.61–3.90)	1.01 (0.22–4.56)	0.76 (0.16–3.56)

HG: Handgrip strength; 5STS: 5-times sit-to-stand tests; ASM: Appendicular Skeletal Mass; SMI: Skeletal Muscle Index; CI: Confidence Interval. Adjusted odds ratio (OR) for age, sex and body mass index. Statistical significance at an alpha level 0.05 is represented by bold numbers. ^(a) Haldane-Anscombe correction. N/A: Not assessed due to zero cases.

4. Discussion

This study was originally designed to provide readers with a reflection on different ways to estimate sarcopenia prevalence using the EWGSOP2 guidelines, as well as to determine its agreement and the risk associated with sarcopenia diagnostic criteria in community-dwelling older adults.

Overall prevalence of sarcopenia in our study ranged from 2.1% to 11.6%, depending on the EWGSOP2 criteria used. These results are in line with the global prevalence estimated at 10% (95% CI: 2.0 to 17) in a recent meta-analysis in 5,720 older adults using the EWGSOP2 criteria defined as low handgrip strength and low SMI (Petermann-Rocha et al., 2022). However, few studies have analyzed differences in sarcopenia prevalence among the recommended criteria developed in the EWGSOP2 (Chew et al., 2020; Johansson et al., 2020; Kim & Won, 2019). To the best of our knowledge, only three studies (Chew et al., 2020; Johansson et al., 2020; Kim & Won, 2019) aimed to analyze differences in sarcopenia prevalence using upper limb (handgrip) or lower limb (5STS) muscle strength criteria when low muscle quantity was defined as SMI in community-dwelling older adults. Whereas two studies (Chew et al., 2020; Kim & Won, 2019) showed 1.3 and 3.5 times more prevalence using handgrip strength instead of 5STS in Asian community-dwelling older adults, the study of Johansson et al., (Johansson et al., 2020) reported a prevalence more than twofold using 5STS instead of handgrip strength in European community-dwelling older adults. One possible reason for the inconsistent findings could be the differences in sociodemographic characteristics between studies as the optimal 5STS cut-off point to predict disability in Japanese community-dwelling older adults is ≥ 9 seconds (Makizako et al., 2017), whereas the cut-off point proposed in the EWGSOP2 is >15 seconds (Cruz-Jentoft et al., 2019). These results highlight the need of using population-specific cut-off points for determining low muscle strength, especially in those parameters that depend upon body size (height, weight or body mass index). In our study, sarcopenia prevalence was more than threefold using 5STS instead of handgrip criterion when low muscle quantity was defined as SMI, and more than twofold when low muscle quantity was defined as ASM. This issue may be due to the fact that during ageing process loss of muscle strength is greater in lower limb than upper limb leading to greater prevalence rates (Ditroilo et al., 2010; Hughes et al., 2001).

Therefore, considering this circumstance and given the higher sarcopenia prevalence obtained when assessing lower limb muscle strength, one could think that using 5STS as diagnostic criterion would lead to an earlier detection of the disease compared to when low handgrip strength is used. This hypothesis would be confirmed if positive case-findings using handgrip strength are overlapped using 5STS as diagnostic criterion.

However, the results from our study did not shown overlap between lower limb and upper limb diagnostic criteria. In fact, a total of 17 participants would be underdiagnosed using Sarcopenia_{5STS+ASM} compared to Sarcopenia_{HG+ASM}. The scenario worsens when Sarcopenia_{HG+SMI} is used instead of our criterion with the highest prevalence rate (Sarcopenia_{5STS+ASM}), a total of 73 participants (10.4%) were underdiagnosed. This is remarkable, since it seems that Sarcopenia_{HG+SMI} is the most used criterion among studies (Petermann-Rocha et al., 2022) which could lead to an underdiagnosis and undertreatment of this disease, especially in populations in which underweight or malnutrition is uncommon. Several studies have found negligible prevalence ($< 0.3\%$) in overweight and obese community-dwelling older adults using Sarcopenia_{HG+SMI} as diagnostic criteria. However, when muscle quantity was adjusted for body mass index using a reference population, a prevalence from 4 to $\sim 15\%$ was found (Bahat et al., 2021; Maïmoun et al., 2022). These results emphasize the need of using specific cut-off point in overweight and obese population in order to not underestimate sarcopenia prevalence and potential undertreatment. However, from our knowledge, there is no specific cut-off point to adjust muscle quantity for body mass index in Spanish community-dwelling older adults. These issues could explain the low prevalence rate in our study when muscle quantity was adjusted by squared height (SMI).

Our results showed moderate agreements between sarcopenia definitions only when the criteria for low muscle strength concurred and low muscle quantity was exchanged, otherwise agreements between sarcopenia definitions were weak ($\kappa < 0.26$). Similar to our results, Johansson et al. (Johansson et al., 2020) observed low level of agreement when low muscle quantity concurred and low muscle strength was defined by 5STS or handgrip strength ($\kappa = 0.18$). These results could be due to the low construct validity between 5STS and handgrip testing (Harris-Love et al., 2018; Yee et al., 2021). This is of notable importance since some studies have used 5STS for diagnosing sarcopenia when missing data on handgrip testing occurred (Swan et al., 2022; Trevisan et al., 2022). This could be not surprising since the EWGSOP2 guidelines states that probable sarcopenia (*i.e.*, low muscle strength) can be determined by handgrip strength test or 5STS test, suggesting interchangeability of these measures. However, our results did not support the use of any of the combinations proposed in the EWGSOP2 in an interchangeable way. Lack of agreement between sarcopenia diagnostic criteria using the EWGSOP2 for detecting probable sarcopenia has been also recently reported in geriatric rehabilitation inpatients ($\kappa = 0.08$) (Verstraeten et al., 2022). Therefore, the aforementioned evidence suggests that both handgrip strength and 5STS should be used for detecting probable sarcopenia in clinical practice in order to avoid missing sarcopenia case-findings and possible undertreated older adults.

Furthermore, confirmed sarcopenia determined by 5STS showed more relationships with health-related adverse events when compared to handgrip strength as diagnostic criterion. Similar results were observed by Chew et al. (Chew et al., 2020) who aimed to compare the predictive validity of probable sarcopenia defined as 5STS or handgrip strength for two years health-related outcomes. Their results showed that muscle strength determined by 5STS was more associated with poor physical performance compared to handgrip strength in community-dwelling older adults. However, contrary findings were reported by Verstraeten et al. (Verstraeten et al., 2022) who concluded that probable sarcopenia defined by 5STS was not useful to predict adverse outcomes in geriatric rehabilitation inpatients. In fact, probable sarcopenia defined by handgrip strength was associated to institutionalization at three months and mortality at three months and one year whereas no association were observed for probable sarcopenia defined by 5STS. Inconsistent findings could be due to differences in sample characteristics across studies, since only few geriatric rehabilitation inpatients scored above the cut-off points proposed by the EWGSOP2 guideline leading to an important floor effect (Verstraeten et al., 2022). Taken together, these results suggest that probable and confirmed sarcopenia defined by 5STS could be potentially more useful in well-functioning older adults while handgrip strength could be more suitable for older adults with poor physical function to predict health-related adverse events using the cut-off proposed by the EWGSOP2 guideline. Therefore, particular attention is needed when decision about diagnostic criteria has to be taken.

The recommendations proposed by the EWGSOP2 are aimed at facilitating early detection and better treatment of sarcopenia in clinical practice. Thus, to assess for evidence of sarcopenia, EWGSOP2 recommends use of grip strength or 5STS test with specific cut-off-points for each test. However, in order to avoid underdiagnosis cases it would be recommended to evaluate handgrip strength together with 5STS test whenever possible, since there is a large difference in prevalence rate and weak agreement among the different tools proposed to diagnose sarcopenia. As EWGSOP2 recommends, there is a high priority for research studies for developing validated cut-off points based on normative data and their predictive value for hard end-points for each population (Cruz-Jentoft et al., 2019). Thus, longitudinal studies are needed to elucidate whether differences in diagnosis criteria have an impact on health-related adverse outcomes.

This study is not without limitations. First, participants of this study were recruited in elderly social centers where movement-based activities are encouraged. In fact, only 9.7% of participants were sedentary while most of the participants were moderately active. Physical activity has a protective role against sarcopenia reducing till 55% the odds of its development later in life (Steffl et al., 2017). This could explain the low prevalence of

sarcopenia observed in our sample, as well as the associations observed between sarcopenia diagnostic criteria and socioeconomic and health-related adverse outcomes. Additionally, these outcomes were self-reported in a cross-sectional time point, therefore the information provided depended on subject's comprehension and perception and cross-sectional data do not allow causal relationship between measures. Moreover, muscle quantity was assessed by BIA which is not recognized as the gold standard for the assessment of this variable. In order to overcome this limitation, a cross-validated equation in a sample with similar characteristics was used as previously recommended (Beaudart et al., 2020; Cruz-Jentoft et al., 2019; Sergi et al., 2015). Additionally, muscle quantity was only adjusted for height squared and not for body mass index. However, from our knowledge, there is no reference values of muscle quantity adjusted for body mass index in young Spanish population. Further studies are needed to elaborate specific cut-off point for assessing sarcopenia in overweight and obese Spanish community-dwelling older adults.

5. Conclusion

The present study showed that sarcopenia prevalence rates vary considerably using the different combinations for sarcopenia diagnosis proposed in the EWGSOP2. These combinations have weak to moderate level of agreement and should not be used in an interchangeable way. Sarcopenia diagnosis criteria defined by 5STS could be more suitable in Spanish community-dwelling older adults due to their associations with health-related outcomes. Further studies should analyze the consequences of using different diagnosis criterion during follow-up period for better understand the risk associated to this disease in community-dwelling older adults.

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Ethics approval

The study was approved by the Ethical Committee of the Catholic University of Murcia (CE022108).

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6. References

- Bahat, G., Kilic, C., Ozkok, S., Ozturk, S., & Karan, M. A. (2021). Associations of sarcopenic obesity versus sarcopenia alone with functionality. *Clinical Nutrition (Edinburgh, Scotland)*, 40(5), 2851–2859. <https://doi.org/10.1016/j.clnu.2021.04.002>
- Beaudart, C., Bruyère, O., Geerinck, A., Hajaoui, M., Scafoglieri, A., Perkisas, S., Bautmans, I., Gielen, E., Reginster, J.-Y., & Buckinx, F. (2020). Equation models developed with bioelectric impedance analysis tools to assess muscle mass: A systematic review. *Clinical Nutrition ESPEN*, 35, 47–62. <https://doi.org/10.1016/j.clnesp.2019.09.012>
- Chew, J., Yeo, A., Yew, S., Lim, J. P., Tay, L., Ding, Y. Y., & Lim, W. S. (2020). Muscle Strength Definitions Matter: Prevalence of Sarcopenia and Predictive Validity for Adverse Outcomes Using the European Working Group on Sarcopenia in Older People 2 (EWGSOP2) Criteria. *The Journal of Nutrition, Health & Aging*, 24(6), 614–618. <https://doi.org/10.1007/s12603-020-1371-y>
- Cruz-Jentoft, A. J., Bahat, G., Bauer, J., Boirie, Y., Bruyère, O., Cederholm, T., Cooper, C., Landi, F., Rolland, Y., Sayer, A. A., Schneider, S. M., Sieber, C. C., Topinkova, E., Vandewoude, M., Visser, M., & Zamboni, M. (2019). Sarcopenia: Revised European consensus on definition and diagnosis. *Age and Ageing*, 48(1), 16–31. <https://doi.org/10.1093/ageing/afy169>
- Ditroilo, M., Forte, R., Benelli, P., Gambarara, D., & De vito, G. (2010). Effects of age and limb dominance on upper and lower limb muscle function in healthy males and females aged 40–80 years. *Journal of Sports Sciences*, 28(6), 667–677. <https://doi.org/10.1080/02640411003642098>
- Harris-Love, M. O., Benson, K., Leasure, E., Adams, B., & McIntosh, V. (2018). The Influence of Upper and Lower Extremity Strength on Performance-Based Sarcopenia Assessment Tests. *Journal of Functional Morphology and Kinesiology*, 3(4), 53. <https://doi.org/10.3390/jfmk3040053>
- Hughes, V. A., Frontera, W. R., Wood, M., Evans, W. J., Dallal, G. E., Roubenoff, R., & Singh, M. A. F. (2001). Longitudinal Muscle Strength Changes in Older Adults: Influence of Muscle Mass, Physical Activity, and Health. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 56(5), B209–B217. <https://doi.org/10.1093/gerona/56.5.B209>
- Johansson, J., Strand, B. H., Morseth, B., Hopstock, L. A., & Grimsgaard, S. (2020). Differences in sarcopenia prevalence between upper-body and lower-body based EWGSOP2 muscle strength criteria: The Tromsø study 2015–2016. *BMC Geriatrics*, 20(1), 461. <https://doi.org/10.1186/s12877-020-01860-w>
- Kim, M., & Won, C. W. (2019). Prevalence of sarcopenia in community-dwelling older adults using the definition of the European Working Group on Sarcopenia in Older People 2: Findings from the Korean Frailty and Aging Cohort Study. *Age and Ageing*, 48(6), 910–916. <https://doi.org/10.1093/ageing/afz091>
- Maïmoun, L., Serrand, C., Mura, T., Renard, E., Nocca, D., Lefebvre, P., Boudousq, V., Avignon, A., Mariano-Goulart, D., & Sultan, A. (2022). Definition of an adapted cut-off for determining low lean tissue mass in older women with obesity: A comparison to current cut-offs. *Scientific Reports*, 12(1), 16905. <https://doi.org/10.1038/s41598-022-21258-5>
- Makizako, H., Shimada, H., Doi, T., Tsutsumimoto, K., Nakakubo, S., Hotta, R., & Suzuki, T. (2017). Predictive Cutoff Values of the Five-Times Sit-to-Stand Test and the Timed “Up & Go” Test for Disability Incidence in Older People Dwelling in the Community. *Physical Therapy*, 97(4), 417–424. <https://doi.org/10.2522/ptj.20150665>
- Montemurro, A., Ruiz-Cárdenas, J. D., Martínez-García, M. del M., & Rodríguez-Juan, J. J. (2022). Validity of an iPhone App to Detect Prefrailty and Sarcopenia Syndromes in Community-Dwelling Older Adults: The Protocol for a Diagnostic Accuracy Study. *Sensors*, 22(16), Article 16. <https://doi.org/10.3390/s22166010>
- Petermann-Rocha, F., Balntzi, V., Gray, S. R., Lara, J., Ho, F. K., Pell, J. P., & Celis-Morales, C. (2022). Global prevalence of sarcopenia and severe sarcopenia: A systematic review and meta-analysis. *Journal of Cachexia, Sarcopenia and Muscle*, 13(1), 86–99. <https://doi.org/10.1002/jcsm.12783>

- Ruiz-Comellas, A., Pera, G., Baena Díez, J. M., Mundet Tudurí, X., Alzamora Sas, T., Elosua, R., Torán Monserrat, P., Heras, A., Forés Raurell, R., Fusté Gamisans, M., & Fàbrega Camprubí, M. (2012). [Validation of a Spanish Short Version of the Minnesota Leisure Time Physical Activity Questionnaire (VREM)]. *Revista Espanola De Salud Publica*, 86(5), 495–508. <https://doi.org/10.4321/S1135-57272012000500004>
- Sergi, G., De Rui, M., Veronese, N., Bolzetta, F., Berton, L., Carraro, S., Bano, G., Coin, A., Manzato, E., & Perissinotto, E. (2015). Assessing appendicular skeletal muscle mass with bioelectrical impedance analysis in free-living Caucasian older adults. *Clinical Nutrition (Edinburgh, Scotland)*, 34(4), 667–673. <https://doi.org/10.1016/j.clnu.2014.07.010>
- Steffl, M., Bohannon, R. W., Sontakova, L., Tufano, J. J., Shiells, K., & Holmerova, I. (2017). Relationship between sarcopenia and physical activity in older people: A systematic review and meta-analysis. *Clinical Interventions in Aging, Volume 12*, 835–845. <https://doi.org/10.2147/CIA.S132940>
- Swan, L., Warters, A., & O’Sullivan, M. (2022). Socioeconomic Disadvantage is Associated with Probable Sarcopenia in Community-Dwelling Older Adults: Findings from the English Longitudinal Study of Ageing. *The Journal of Frailty & Aging*, 11(4), 398–406. <https://doi.org/10.14283/jfa.2022.32>
- Trevisan, C., Vetrano, D. L., Calvani, R., Picca, A., & Welmer, A.-K. (2022). Twelve-year sarcopenia trajectories in older adults: Results from a population-based study. *Journal of Cachexia, Sarcopenia and Muscle*, 13(1), 254–263. <https://doi.org/10.1002/jcsm.12875>
- Verstraeten, L. M. G., de Haan, N. J., Verbeet, E., van Wijngaarden, J. P., Meskers, C. G. M., & Maier, A. B. (2022). Handgrip strength rather than chair stand test should be used to diagnose sarcopenia in geriatric rehabilitation inpatients: RESStORing health of acutely unwell adulTs (RESORT). *Age and Ageing*, 51(11), afac242. <https://doi.org/10.1093/ageing/afac242>
- von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., & Vandenbroucke, J. P. (2008). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: Guidelines for reporting observational studies. *Journal of Clinical Epidemiology*, 61(4), 344–349. <https://doi.org/10.1016/j.jclinepi.2007.11.008>
- Yee, X. S., Ng, Y. S., Allen, J. C., Latib, A., Tay, E. L., Abu Bakar, H. M., Ho, C. Y. J., Koh, W. C. C., Kwek, H. H. T., & Tay, L. (2021). Performance on sit-to-stand tests in relation to measures of functional fitness and sarcopenia diagnosis in community-dwelling older adults. *European Review of Aging and Physical Activity*, 18(1), 1. <https://doi.org/10.1186/s11556-020-00255-5>

VII – ARTÍCULO IV

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Sit-to-Stand Video Analysis–Based App for Diagnosing Sarcopenia and Its Relationship With Health-Related Risk Factors and Frailty in Community-Dwelling Older Adults: Diagnostic Accuracy Study

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Abstract

Background: Probable sarcopenia is determined by a reduction in muscle strength assessed with the handgrip strength test or 5 times sit-to-stand test, and it is confirmed with a reduction in muscle quantity determined by dual-energy X-ray absorptiometry or bioelectrical impedance analysis. However, these parameters are not implemented in clinical practice mainly due to a lack of equipment and time constraints. Nowadays, the technical innovations incorporated in most smartphone devices, such as high-speed video cameras, provide the opportunity to develop specific smartphone apps for measuring kinematic parameters related with sarcopenia during a simple sit-to-stand transition.

Objective: We aimed to create and validate a sit-to-stand video analysis–based app for diagnosing sarcopenia in community-dwelling older adults and to analyze its construct validity with health-related risk factors and frailty.

Methods: A total of 686 community-dwelling older adults (median age: 72 years; 59.2% [406/686] female) were recruited from elderly social centers. The index test was a sit-to-stand video analysis–based app using muscle power and calf circumference as proxies of muscle strength and muscle quantity, respectively. The reference standard was obtained by different combinations of muscle strength (handgrip strength or 5 times sit-to-stand test result) and muscle quantity (appendicular skeletal mass or skeletal muscle index) as recommended by the European Working Group on Sarcopenia in Older People-2 (EWGSOP2). Sensitivity, specificity, positive and negative predictive values, and area under the curve (AUC) of the receiver operating characteristic curve were calculated to determine the diagnostic accuracy of the app. Construct validity was evaluated using logistic regression to identify the risks associated with health-related outcomes and frailty (Fried phenotype) among those individuals who were classified as having sarcopenia by the index test.

Results: Sarcopenia prevalence varied from 2% to 11% according to the different combinations proposed by the EWGSOP2 guideline. Sensitivity, specificity, and AUC were 70%-83.3%, 77%-94.9%, and 80.5%-87.1%, respectively, depending on the diagnostic criteria used. Likewise, positive and negative predictive values were 10.6%-43.6% and 92.2%-99.4%, respectively. These results proved that the app was reliable to rule out the disease. Moreover, those individuals who were diagnosed with sarcopenia according to the index test showed more odds of having health-related adverse outcomes and frailty compared to their respective counterparts, regardless of the definition proposed by the EWGSOP2.

Conclusions: The app showed good diagnostic performance for detecting sarcopenia in well-functioning Spanish community-dwelling older adults. Individuals with sarcopenia diagnosed by the app showed more odds of having health-related

risk factors and frailty compared to their respective counterparts. These results highlight the potential use of this app in clinical settings.

Trial Registration: ClinicalTrials.gov NCT05148351; <https://clinicaltrials.gov/study/NCT05148351>

International Registered Report Identifier (IRRID): RR2-10.3390/s22166010

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KEYWORDS

sarcopenia; power; calf circumference; diagnosis; screening; affordable; community dwelling; older adults; smartphone

Introduction

Sarcopenia is an age-related muscle disease defined as the progressive loss of both muscle strength and muscle mass, which can lead to adverse health-related consequences [1]. Sarcopenia has been shown to be associated with clinical, lifestyle, and social risk factors such as depression, comorbidities, polypharmacy, smoking habit, low physical activity, low education level, and low socioeconomic status [2-6]. People with sarcopenia have an increased risk of developing frailty, falls, hospitalization, and mortality [7-10].

The prevalence of sarcopenia varies widely depending on the definition used, ranging from approximately 10% to 40% in community-dwelling older adults [11]. In order to allow the systematic and consistent identification of people with sarcopenia, the European Working Group on Sarcopenia in Older People-2 (EWGSOP2) published a consensus with specific cutoff points to facilitate sarcopenia diagnosis in research and clinical practice [1]. Accordingly, sarcopenia is determined by a reduction in both muscle strength and muscle quantity assessed with the handgrip strength test or 5 times sit-to-stand (5STS) test and by dual-energy X-ray absorptiometry or bioelectrical impedance analysis, respectively. However, in most settings, dynamometers are not widely available to measure muscle strength and access to muscle mass measurement techniques is limited or restricted [12]. In fact, several surveys have highlighted that most health care professionals do not diagnose sarcopenia mainly due to a lack of equipment and time constraints [13-15].

Given the growing importance of the early detection of sarcopenia to prevent subsequent adverse health-related consequences, a clinical, affordable, easy-to-use tool for sarcopenia screening and diagnosis might have implications for prognosis in community-dwelling older adults. In this context, several studies have reported that variables derived from kinematic analysis during a simple sit-to-stand transition could have the potential to discriminate between apparently healthy older adults and those with a history of falls, sarcopenia, or even frailty [16-19]. However, kinematic analysis during this functional task is characterized to be time-consuming and to require technical expertise and specialized equipment, such as 3D motion capture cameras, force plates, and inertial measurement units [17,18,20], which are usually restricted to laboratory settings. These issues represent barriers for health care professionals who require low-cost easy-to-use tools with automatic data processing and without the need for complex instrumentation.

Nowadays, the technical innovations incorporated in most smartphone devices, such as high-speed video cameras, provide the opportunity to develop specific smartphone apps [20,21] or web-based applications [22] for measuring kinematic parameters related with sarcopenia during sit-to-stand transition. This study was planned to develop and validate a video analysis-based app for detecting sarcopenia in community-dwelling older adults, using a muscle power kinematic parameter obtained during a simple sit-to-stand transition as a proxy of muscle strength and a calf circumference anthropometric parameter obtained with a simple measuring tape as a proxy of muscle quantity, according to the definition proposed by the EWGSOP2 guideline. Muscle power was selected as a proxy of muscle strength owing to its rapid decline during aging [23,24] and because it has been shown to be associated with several measures of physical function and sarcopenia determinants such as handgrip strength and the 5STS test in community-dwelling older adults with and without sarcopenia [21,25]. Additionally, calf circumference was selected as a proxy of muscle quantity owing to its association with appendicular skeletal mass (ASM) [26] and because it has been shown to improve the diagnostic accuracy of sarcopenia [27].

Since more than 5.4 billion people worldwide use mobile phones [28], the creation of a valid, affordable, and easy-to-use app that incorporates these 2 simple measures to detect sarcopenia could provide an excellent opportunity for health care professionals to assess sarcopenia status in community-dwelling older adults, where muscle strength dynamometers or muscle mass measurement techniques are usually limited or restricted [12].

Considering that sarcopenia diagnostic criteria should be based on their predictive value for hard outcomes [1], the aims of this study were to (1) create and validate a sit-to-stand video analysis-based app for diagnosing sarcopenia in community-dwelling older adults and (2) analyze its construct validity with clinical, lifestyle, and social risk factors such as depression, comorbidities, polypharmacy, smoking habit, low education level, low socioeconomic status, self-perceived health, falls, hospitalization, and frailty.

Methods

Study Design

A diagnostic accuracy study was carried out between February and October 2022 in 11 elderly social centers of the Region of Murcia (Spain). This study has been registered at ClinicalTrials.gov (NCT05148351).

Ethical Considerations

The study complied with the Declaration of Helsinki and was approved by the Ethical Committee of the Catholic University of Murcia (CE022108).

Eligibility Criteria

Community-dwelling adults aged 60 years or older were contacted via telephone or face-to-face to provide information to participate in the study. We excluded participants at risk of dementia (Mini-Cog score <3 points); those self-reporting cardiovascular problems (automatic defibrillator, pacemaker implantation, heart valve disease, and uncontrolled heart rhythm problems); those who were unable to stand up from a chair without assistance; and those with any health conditions that may affect the performance of functional tests, such as stroke sequelae, neuropathy, low back pain, and osteoarthritis.

Procedures

After obtaining written informed consent, participants performed the following tests on the same day: (1) a single sit-to-stand test plus calf circumference measurement, (2) sarcopenia assessment, (3) frailty phenotype assessment, and (4) clinical interview.

The single sit-to-stand test plus calf circumference measurement was used as an index test to diagnose sarcopenia through a video analysis-based app. Sarcopenia assessment according to the EWGSOP2 guideline was used as the reference standard. Additionally, the Fried frailty phenotype and a clinical profile consisting of health-related risk factors assessed through a face-to-face interview were used for construct validity of the index test.

Index Test: Sit to Stand App

A video analysis-based app (*Sit to Stand* app) installed on an iPhone 13 device running iOS 15.3 (Apple Inc) was created to analyze the sit-to-stand movement via a high-speed video recorded at 240 frames per second. The app was developed using Xcode and the Swift programming language (Apple Inc) for MacOS. The AVFoundation and AVKit frameworks (Apple Inc) were used for capturing, importing, and manipulating the high-speed videos. Then, the app was replicated and validated for running on Android in order to provide this tool for the 2 most widely used mobile operating systems [29]. The Android app was developed using Android Studio Chipmunk 2021.2.1 Patch 1, the Kotlin 1.5.21 programming language, and the Compose 1.0.1 UI framework for MacOS. For capturing, importing, and manipulating the high-speed videos, the CameraX 1.1.0 framework was used.

Prior to the execution of the single sit-to-stand test, the femur length (cm) and calf circumference (cm) of the participant were measured using an inelastic but flexible measuring tape. Femur length was measured as the distance between the superior aspect of the greater trochanter and femoral lateral condyle, while calf circumference was measured at the point of the greatest circumference on the nondominant leg in the sitting position

with the knee and ankle joints at 90 degrees. A visual marker (colored sticker) was placed on the greater trochanter in order to identify the beginning and the end of the rising phase. To execute the test, participants sat on an adjustable height chair without footwear, with the hip, knee, and ankle joints at 90 degrees. Participants were instructed to stand from the chair “as fast as possible” with their arms crossed over their chest while the test was filmed simultaneously with the smartphone. The smartphone was placed horizontally on a 0.7-m-high tripod placed 3 m from the right or left side of the participant.

The variables provided from the app were rising time, vertical velocity, and vertical power. Rising time (s) was calculated from 2 selected frames by the user after analyzing the video. Vertical velocity (m/s) was automatically calculated from rising time and vertical distance. Vertical distance was introduced by the user into the app as femur length (cm), that is, the distance traveled from the sitting position at 90 degrees of the knee joint to full extension of the hip and knee joints. Finally, vertical power relative to body weight (W/kg) was estimated from the following regression equation (R^2 adjusted=0.917; $P=.04$; standard error of estimate=0.45):

$$\text{Power (W/kg)} = 2.773 - 6.228 \times t + 18.224 \times d$$

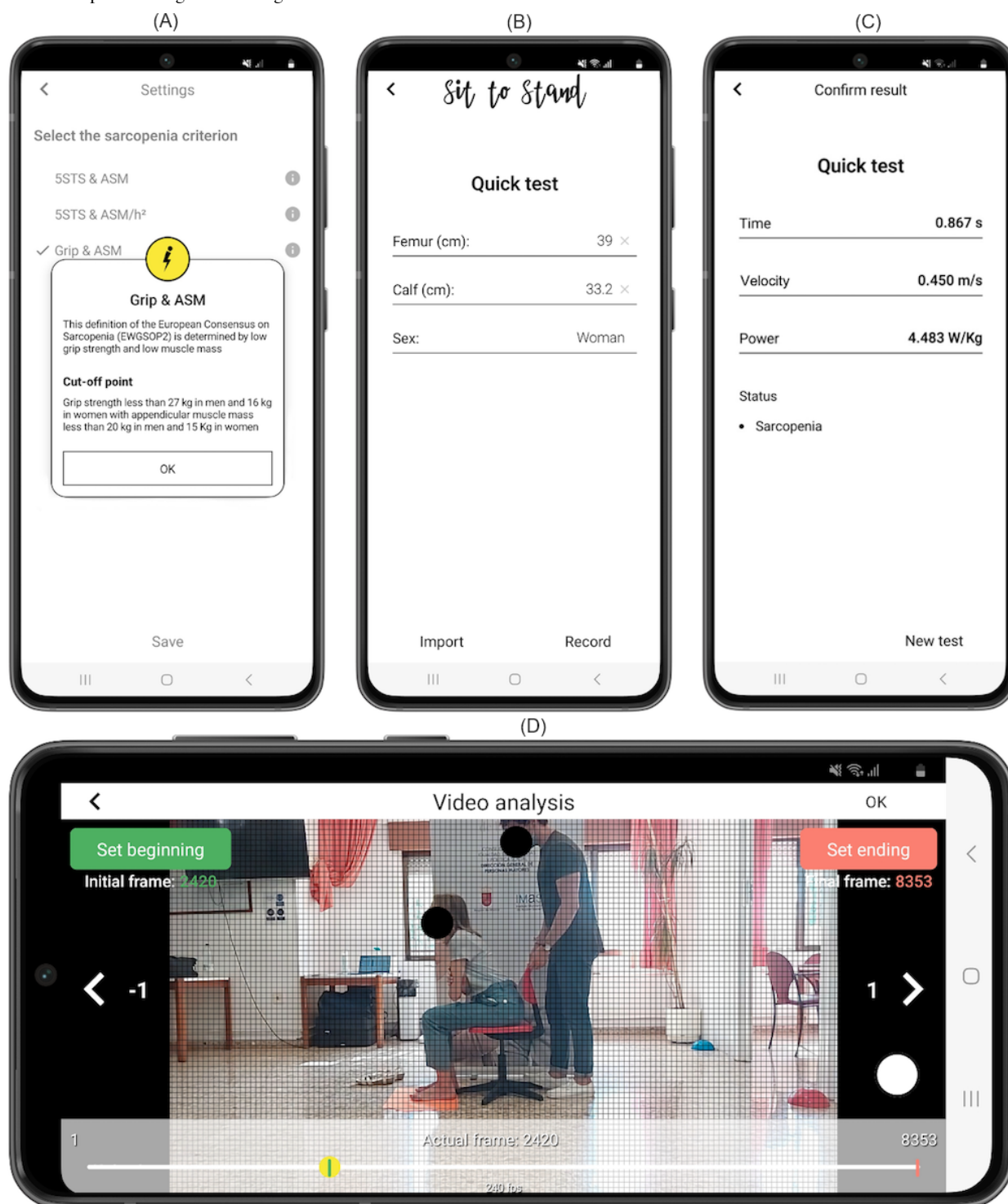
where t is the rising time and d is the femur length. The *Sit to Stand* app has been previously validated against a 3D motion capture camera and force plates in community-dwelling older adults [20,21].

Data Analysis From the Sit to Stand App

The sit-to-stand movement can be divided into 3 phases: preparation phase, rising phase, and stabilization phase. The preparation phase starts when the trunk of the participant begins to accelerate forward and ends when the participant achieves seat-off. Then, the rising phase begins and ends when full extension of the knee and hip joints is achieved. In this phase, vertical velocity and power can be calculated. Finally, there is a stabilization phase where the hip extension velocity reaches zero and the stance of the body is achieved with quasi-static balance [30-32].

To accurately determine the onset and the end of the rising phase, a visual grid for reference was built into the app as an overlay (Figure 1). Video analysis involved a manual process consisting of selecting 2 frames after video recording. The user selected the first frame and the final frame by pressing start and stop buttons, respectively. The onset of the rising phase was determined when the pelvis began to move forward after anterior trunk tilt, which was time-matched when the sticker was diagonally moved to the following square on the screen of the app. The end of this phase was defined when full extension of the hip and knee was achieved, which was time-matched when the sticker achieved the highest vertical point. A detailed explanation about video analysis can be found elsewhere [33]. Video analysis from the app was undertaken by a researcher blinded to sarcopenia assessment.

Figure 1. User interface of the Sit to Stand app running on the Android operating system. (A) Settings for selecting the different criteria proposed by the European Working Group on Sarcopenia in Older People-2 (EWGSOP2) guideline. (B) Participant characteristics. (C) Results from the app after video analysis. (D) Video analysis at 240 frames per second selecting the first frame corresponding to the beginning of the rising phase. Example of a woman with sarcopenia having a femur length of 0.39 m and calf circumference of 0.332 m.



Reference Standard: Sarcopenia by the EWGSOP2 Guideline

Sarcopenia was defined according to the recommendations proposed by the EWGSOP2 guideline [1]. Thus, a sarcopenia diagnosis was confirmed by the presence of both low muscle strength and muscle quantity. Low muscle strength was determined by using either handgrip strength or the 5STS test result as recommended by the EWGSOP2. Handgrip strength

was evaluated using a handgrip digital dynamometer (Takei 5401, Takei Scientific Instruments Co, Ltd). Two repetitions from each hand were performed in the sitting position with the elbow flexed at 90 degrees, wrist in a neutral position, and thumb facing upwards. The maximal score was recorded, and a cutoff point for low muscle strength of <27 kg in men and <16 kg in women was used. For the 5STS test, participants were instructed to fully rise from a chair 5 times as fast as possible with their arms crossed over their chest. The time taken to sit

down on the chair at the fifth repetition was recorded with a stopwatch. The cutoff point for low muscle strength was >15 s. Muscle quantity was assessed with regard to ASM (kg) or skeletal muscle index (kg/m^2) through bioelectrical impedance analysis (TANITA MC-580, Tanita Corp). For muscle quantity calculation, the resistance index and reactance raw values were

introduced in the validated equation by Sergi et al [34]. The cutoff points for low muscle quantity were <20 kg or <7 kg/m^2 for men and <15 kg or <5.5 kg/m^2 for women. Following the EWGSOP2 recommendations, 4 sarcopenia diagnostic criteria can be obtained (Table 1).

Table 1. Sarcopenia diagnostic criteria according to the European Working Group on Sarcopenia in Older People-2 (EWGSOP2) guideline.

Diagnostic criteria ^a	Low muscle strength	Low muscle quantity
SARC _{HG+ASM}	Handgrip strength	Appendicular skeletal mass
SARC _{HG+SMI}	Handgrip strength	Skeletal muscle index
SARC _{5STS+ASM}	Five times sit-to-stand test	Appendicular skeletal mass
SARC _{5STS+SMI}	Five times sit-to-stand test	Skeletal muscle index

^aCutoff points: handgrip strength (men <27 kg; women <16 kg); appendicular skeletal mass (men <20 kg; women <15 kg); skeletal muscle index (men <7 kg/m^2 ; women <5.5 kg/m^2); 5 times sit-to-stand test (>15 seconds for men and women).

Construct Validity

Health-Related Risk Factors

Participants were systematically asked about the presence of depressive symptoms using the Spanish validated version of the Geriatric Depression Scale 5-items (cutoff point: ≥ 2), socioeconomic status (cutoff point: net salary $<10,000$ €/year [$<11,000$ US\$/year]), education level (cutoff point: primary or less), presence of comorbidity (two or more chronic conditions), polypharmacy (five or more drugs/day), self-perceived health (cutoff point: very bad, bad, or fair), current smoking habit, presence of two or more falls in the last year, and hospitalizations in the last year. Additional information about the registered health-related outcomes can be found in the study protocol [35].

Frailty

Frailty syndrome was defined according to the Fried frailty phenotype assessment [36], which includes slowness (by usual pace 4-meter walking speed), exhaustion (by the Center for Epidemiologic Studies depression scale), unintentional weight loss (≥ 4.5 kg or $\geq 5\%$ in the last year), weakness (by handgrip strength), and low activity (by the Spanish Short Version Minnesota leisure time Physical Activity Questionnaire). Detailed information can be found in previous publications [35,36]. The presence of at least three of five criteria was defined as frailty.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics 26.0 (SPSS Inc) and JASP software 0.17.1 (JASP Team). Continuous variables have been presented as means and standard deviations if normally distributed or as medians and IQRs if not normally distributed. Frequencies and percentages were used for categorical data. The minimum estimated sample size was 200 participants per sex to detect an effect size equal to or higher than 0.80 area under the curve (AUC), with an α error of .05 and statistic power of 80% according to Bujang and Adnan [37].

Objective 1: Diagnostic Accuracy

The principle of parsimony was carried out to create multiple logistic regression equations with the smallest possible number of parameters, which allows adequate representation of the data. Therefore, multiple logistic regression equations stratified by sex with sarcopenia as the dependent variable and vertical power and calf circumference parameters as the independent variables were performed to create predictive equations to diagnose sarcopenia. The Hosmer-Lemeshow goodness-of-fit test was used to assess the calibration of the models. These analyses were presented for the 4 sarcopenia diagnostic criteria according to the EWGSOP2 guideline (Table 1). The models were internally validated using the bootstrap method by generating 1000 resampled data sets from the original cohort. Differences in performance (*c* statistic) between the initial and bootstrap models were checked using a paired sample design in order to correct for overoptimism if needed.

Then, receiver operating characteristic analyses were carried out using predictive probability from the results of the multiple logistic regression analyses to identify the best cutoff point for diagnosing sarcopenia. An AUC of 0.5 was interpreted as no discrimination, 0.7 to <0.8 as acceptable, 0.8 to 0.9 as excellent, and more than 0.9 as outstanding. These predictive equations were introduced into the *Sit to Stand* app with their respective cutoff points to automate diagnosis after video analysis.

Finally, participants were categorized as sarcopenic or healthy according to the index test (*Sit to Stand* app), and cross-tabulations with the reference standards were performed. Sensitivity, specificity, accuracy, positive and negative likelihood ratios, positive and negative predictive values, the number needed to get a false-positive result, and the number needed to get a false-negative result were calculated and expressed with their 95% CI. All statistical tests were 2-tailed.

Objective 2: Construct Validity

Associations between health-related outcomes (socioeconomic status, education level, smoking habit, polypharmacy, self-perceived health, comorbidities, depression, falls, and hospitalization) and the presence of frailty in those participants

categorized as sarcopenic according to the index test (*Sit to Stand* app) were assessed using unadjusted and adjusted logistic regression analyses for age, sex, and BMI. The odds ratios (ORs) and their 95% CIs were calculated following a unidirectional rationale approach (1-tailed test).

Results

Participant Characteristics

A total of 775 older adults from 11 elderly social centers of the Region of Murcia (Spain) were screened for eligibility.

Seventy-six participants reported at least one of the exclusion criteria (Mini-Cog test positive, $n=59$; implanted electronic devices, $n=17$). The data of 13 participants were lost due to unintentional video deletion ($n=3$), a lack of femur length measurement ($n=5$), and a lack of calf circumference measurement ($n=5$). Therefore, a total of 686 community-dwelling older adults aged between 60 and 88 years were finally included in the analysis ([Table 2](#)).

Sarcopenia prevalence ranged from 1.7% to 11.3% in women and 2.5% to 10.7% in men, depending on the diagnostic criteria proposed by the EWGSOP2 guideline.

Table 2. Characteristics of the participants (N=686).

Outcome	Women	Men
Participants, n (%)	406 (59.2)	280 (40.8)
Age (years), median (IQR)	71 (68-75)	72 (68-76)
Height (m), mean (SD)	1.55 (0.06)	1.68 (0.06)
Weight (kg), median (IQR)	66.0 (59.6-73.2)	79.3 (71.6-88.5)
BMI (kg/m ²), median (IQR)	27.4 (24.4-30.1)	28.1 (25.8-31.2)
ASM ^a (kg), median (IQR)	14.4 (13.1-15.7)	20.2 (18.7-22.3)
SMI ^b (kg/m ²), median (IQR)	5.9 (5.5-6.4)	7.2 (6.7-7.7)
Calf circumference (m)^c, median (IQR)	0.36 (0.34-0.38)	0.37 (0.35-0.39)
P25	0.34	0.35
P50	0.36	0.37
P75	0.38	0.39
Femur length (m), median (IQR)	0.36 (0.34-0.38)	0.39 (0.36-0.4)
Handgrip strength (kg), mean (SD)	22.6 (4.3)	37.5 (6.8)
5STS ^d (s), median (IQR)	12.1 (10.6-14.1)	12.2 (10.7-14.2)
Vertical power (W/kg)^e, mean (SD)	5.0 (1.1)	5.89 (1.0)
P25	4.5	5.4
P50	5.1	6.0
P75	5.7	6.6
Physical activity levels, n (%)		
Sedentary	22 (5.4)	42 (15.0)
Physically active	392 (93.8)	239 (85.1)
Sarcopenia prevalence, n (%)		
SARC _{HG} ^e +ASM	20 (4.9)	11 (3.9)
SARC _{HG} +SMI	7 (1.7)	7 (2.5)
SARC _{5STS} +ASM	46 (11.3)	30 (10.7)
SARC _{5STS} +SMI	18 (4.4)	24 (8.6)
Frailty phenotype, n (%)	11 (2.7)	10 (3.6)

^aASM: appendicular skeletal mass.^bSMI: skeletal muscle index.^cPercentiles are shown as P25, P50, and P75.^d5STS: 5 times sit-to-stand.^eHG: handgrip strength.

Objective 1: Diagnostic Accuracy

A total of 4 predicted equations per sex were created and introduced into the app with their respective cutoff points for sarcopenia diagnosis ([Multimedia Appendix 1](#)). The predicted models were well calibrated, and bootstrapping revealed stability of the models with differences in performance between the original and corrected *c* statistic lower than 0.004, resulting in the absence of overoptimism ([Multimedia Appendix 2](#)).

These predicted equations showed excellent ability (AUC range: 80.5%-87.1%) to discriminate between individuals with sarcopenia and apparently healthy individuals among both women and men. Sensitivity ranged from 0.70 to 0.83, whereas specificity ranged from 0.77 to 0.95, depending on the diagnostic criterion proposed by the EWGSOP2 guideline ([Table 3](#)). Sensitivity was higher when sarcopenia was defined according to the 5STS test instead of the handgrip strength test, whereas specificity was very similar between the diagnostic criteria used. Cross-tabulations of the index test and the reference standards of sarcopenia can be found in [Multimedia Appendix 3](#).

Table 3. Diagnostic accuracy for detecting sarcopenia through the Sit to Stand app in women and men (N=686).

Gender and variable	Diagnostic criteria for sarcopenia			
	SARC _{HG} ^a +ASM ^b	SARC _{HG} +SMI ^c	SARC _{5STS} ^d +ASM	SARC _{5STS} +SMI
Women (n=406)				
Cutoff point ^e	0.0503135	0.0378703	0.1223178	0.0638602
AUC ^f (%), value (95% CI)	80.8 (71.3-90.3)	84.3 (69.7-98.9)	80.5 (73.2-87.9)	85.7 (76.4-95.0)
Sensitivity (%), value (95% CI)	70.0 (48.1-85.5)	71.4 (35.9-91.8)	71.7 (57.5-82.7)	77.8 (54.8-91.0)
Specificity (%), value (95% CI)	77.2 (72.8-81.1)	89.5 (86.1-92.1)	78.1 (73.5-82.0)	86.1 (82.3-89.2)
Accuracy (%), value (95% CI)	76.8 (72.4-80.9)	89.2 (85.7-92.0)	77.3 (73.0-81.3)	85.7 (81.9-89.0)
PLR ^g , value (95% CI)	3.1 (2.2-4.3)	6.8 (3.9-11.7)	3.3 (2.5-4.3)	5.6 (3.9-7.9)
NLR ^h , value (95% CI)	0.4 (0.2-0.8)	0.3 (0.1-1.0)	0.4 (0.2-0.6)	0.3 (0.1-0.6)
PPV ⁱ (%), value (95% CI)	13.7 (10.2-18.3)	10.6 (6.4-17.1)	29.5 (24.2-35.3)	20.6 (15.4-26.9)
NPV ^j (%), value (95% CI)	98.0 (96.2-99.0)	99.4 (98.2-99.8)	95.6 (93.1-97.1)	98.8 (97.2-99.5)
NNM _{FP} ^k (1:100), value (95% CI)	21.7 (17.7-25.7)	10.3 (7.4-13.3)	19.5 (15.6-23.3)	13.3 (10.0-16.6)
NNM _{FN} ^l (1:100), value (95% CI)	1.5 (0.3-2.7)	0.5 (0.0-1.2)	3.2 (1.5-4.9)	1.0 (0.0-1.9)
Men (n=280)				
Cutoff point ^e	0.0915922	0.0736029	0.1735792	0.1437517
AUC (%), value (95% CI)	84.8 (72.4-97.2)	85.1 (71.6-98.6)	87.1 (81.0-93.3)	86.8 (79.6-93.9)
Sensitivity (%), value (95% CI)	72.7 (43.4-90.3)	71.4 (35.9-91.8)	80.0 (62.7-90.5)	83.3 (64.2-93.3)
Specificity (%), value (95% CI)	94.4 (91.4-96.9)	94.9 (91.6-96.9)	87.6 (82.9-91.1)	86.7 (82.0-90.3)
Accuracy (%), value (95% CI)	93.6 (90.0-96.1)	94.3 (90.9-96.7)	86.8 (82.3-90.5)	86.4 (81.8-90.2)
PLR, value (95% CI)	13.0 (7.1-24.0)	13.9 (7.0-27.8)	6.4 (4.4-9.4)	6.3 (4.4-9.0)
NLR, value (95% CI)	0.3 (0.1-0.8)	0.3 (0.1-0.9)	0.2 (0.1-0.5)	0.2 (0.1-0.5)
PPV (%), value (95% CI)	34.8 (22.5-49.5)	26.3 (15.2-41.7)	43.6 (34.7-52.9)	37.0 (29.1-45.8)
NPV (%), value (95% CI)	98.8 (97.0-99.5)	99.2 (97.6-99.8)	97.4 (94.7-98.7)	98.2 (95.7-99.3)
NNM _{FP} (1:100), value (95% CI)	5.4 (2.7-8.0)	5.0 (2.4-7.6)	11.1 (7.4-14.7)	12.1 (8.3-16.0)
NNM _{FN} (1:100), value (95% CI)	1.1 (0.0-2.3)	0.7 (0.0-1.7)	2.1 (0.4-3.8)	1.4 (0.0-2.8)

^aHG: handgrip strength.^bASM: appendicular skeletal mass.^cSMI: skeletal muscle index.^d5STS: 5 times sit-to-stand.^eCutoff points are based on predictive probability as follows: $\hat{p}_{ez} = \exp[\hat{\alpha} + \hat{\beta}_1 \times e + \hat{\beta}_2 \times z] / (1 + \exp[\hat{\alpha} + \hat{\beta}_1 \times e + \hat{\beta}_2 \times z])$, where $\hat{\alpha}$, $\hat{\beta}_1$, and $\hat{\beta}_2$ are the estimated regression coefficients (Multimedia Appendix 1), and e and z are the independent variables (ie, vertical power and calf circumference).^fAUC: area under the curve.^gPLR: positive likelihood ratio.^hNLR: negative likelihood ratio.ⁱPPV: positive predictive value.^jNPV: negative predictive value.^kNNM_{FP}: number needed to get a false-positive result.^lNNM_{FN}: number needed to get a false-negative result.

The accuracy of the index test was higher than 76% for women and higher than 86% for men. Among each 100 individuals tested, 10 to 22 women and 5 to 12 men could get a

false-positive result, depending on the diagnostic criterion used by the EWGSOP2. The mean vertical power among those participants who got a false-positive result was lower than the

20th percentile of vertical power for women (<4.23 W/Kg) and the 15th percentile of vertical power for men (<4.92 W/Kg), whereas the mean calf circumference was lower than the 26th percentile for women (<34.2 cm) and the 15th percentile for men (<34.1 cm) in the sample analyzed.

Additionally, among each 100 individuals tested, 0 to 3 women and 1 to 2 men could get a false-negative result. The mean vertical power in those participants who got a false-negative result regardless of the diagnostic criterion used was 4.9 W/kg for women and 6.1 W/kg for men, whereas the mean calf circumference was >36.2 cm for women and >36.3 cm for men.

Objective 2: Construct Validity

Overall, those individuals diagnosed with sarcopenia according to the index test (*Sit to Stand* app) showed more odds of having health-related adverse outcomes compared to their respective counterparts, regardless of the diagnostic criterion proposed by the EWGSOP2 guideline.

In our adjusted analysis, $SARC_{5STS+SMI}$ was the diagnostic criterion most associated with health-related adverse outcomes. Individuals with sarcopenia according to the $SARC_{5STS+SMI}$

criterion showed more odds of having a low education level (OR 1.69, 95% CI 1.15-2.48), a low socioeconomic level (OR 2.13, 95% CI 1.27-3.58), comorbidities (OR 3.74, 95% CI 2.15-6.50), a smoking habit (OR 1.83, 95% CI 1.03-3.27), polypharmacy (OR 2.80, 95% CI 1.80-4.34), and low self-perceived health (OR 2.32, 95% CI 1.48-3.62). Similar relationships were presented for $SARC_{5STS+ASM}$ with the exception of current smoking habit. The $SARC_{HG+ASM}$ criterion showed associations with a low education level (OR 1.48, 95% CI 1.03-2.14), comorbidities (OR 2.56, 95% CI 1.49-4.39), polypharmacy (OR 2.32, 95% CI 1.53-3.51), and low self-perceived health (OR 1.92, 95% CI 1.27-2.91). Likewise, similar relationships were presented for $SARC_{HG+SMI}$ with the inclusion of two or more falls in the last year (OR 1.79, 95% CI 1.00-3.23).

All individuals diagnosed with sarcopenia according to the index test showed more odds of having frailty, regardless of the diagnostic criterion proposed by the EWGSOP2. In our adjusted analysis, $SARC_{HG+SMI}$ was the diagnostic criterion most strongly associated with frailty (OR 6.64, 95% CI 2.61-16.87). Further details are provided in [Table 4](#).

Table 4. Associations of sarcopenia determined by the index test (Sit to Stand app) with health-related risk factors and the frailty phenotype (N=686).

Risk factor	Diagnostic criteria for sarcopenia							
	SARC _{HG} ^a +ASM ^b		SARC _{HG} +SMI ^c		SARC _{5STS} ^d +ASM		SARC _{5STS} +SMI	
	OR ^e (95% CI)	Adjusted OR (95% CI)	OR (95% CI)	Adjusted OR (95% CI)	OR (95% CI)	Adjusted OR (95% CI)	OR (95% CI)	Adjusted OR (95% CI)
Education level								
High level (n=356; reference)								
Low level (n=319)	1.71 (1.23-2.39) ^f	1.48 (1.03-2.14) ^f	2.19 (1.40-3.43) ^f	1.93 (1.18-3.14) ^f	1.76 (1.31-2.38) ^f	1.68 (1.21-2.35) ^f	1.62 (1.15-2.27) ^f	1.69 (1.15-2.48) ^f
Socioeconomic level								
High level (n=545; reference)								
Low level (n=97)	1.55 (1.01-2.40) ^f	1.21 (0.75-1.96)	1.75 (0.10-2.99) ^f	1.40 (0.77-2.56)	1.95 (1.32-2.88) ^f	1.89 (1.22-2.94) ^f	1.85 (1.21-2.84) ^f	2.13 (1.27-3.58) ^f
Comorbidities								
<2 pathologies (n=159; reference)								
≥2 pathologies (n=527)	3.03 (1.82-5.03) ^f	2.56 (1.49-4.39) ^f	5.17 (2.18-12.24) ^f	5.03 (2.05-12.30) ^f	2.87 (1.87-4.43) ^f	2.94 (1.85-4.67) ^f	2.93 (1.76-4.87) ^f	3.74 (2.15-6.50) ^f
Smoking habit								
Not smoking (n=611; reference)								
Smoking (n=74)	0.67 (0.38-1.21)	1.28 (0.67-2.41)	0.65 (0.29-1.44)	1.10 (0.46-2.63)	0.99 (0.62-1.60)	1.60 (0.94-2.70)	1.31 (0.80-2.16)	1.83 (1.03-3.27) ^f
Polypharmacy								
<5 drugs (n=538; reference)								
≥5 drugs (n=145)	2.03 (1.41-2.92) ^f	2.32 (1.53-3.51) ^f	2.52 (1.61-3.96) ^f	2.92 (1.74-4.91) ^f	2.23 (1.60-3.11) ^f	2.62 (1.79-3.84) ^f	2.12 (1.47-3.05) ^f	2.80 (1.80-4.34) ^f
Self-perceived health								
High level (n=553; reference)								
Low level (n=133)	2.14 (1.48-3.10) ^f	1.92 (1.27-2.91) ^f	2.29 (1.44-3.64) ^f	2.29 (1.37-3.85) ^f	1.89 (1.34-2.66) ^f	1.96 (1.33-2.88) ^f	1.81 (1.24-2.65) ^f	2.32 (1.48-3.62) ^f
Depression								
Not depressed (n=557; reference)								
Depressed (n=129)	1.74 (1.19-2.54) ^f	1.42 (0.93-2.15)	1.57 (0.96-2.58)	1.36 (0.79-2.33)	1.52 (1.07-2.17) ^f	1.39 (0.94-2.04)	1.29 (0.86-1.92)	1.29 (0.81-2.03)
Falls in the last year								
<2 falls (n=599; reference)								
≥2 falls (n=85)	1.68 (1.08-2.62) ^f	1.31 (0.73-2.33)	2.07 (1.21-3.55) ^f	1.79 (1.00-3.23) ^f	1.63 (1.08-2.45) ^f	1.46 (0.93-2.30)	1.39 (0.87-2.20)	1.37 (0.80-2.32)
Hospitalization								
Not hospitalized (n=594; reference)								

Risk factor	Diagnostic criteria for sarcopenia							
	SARC _{HG} ^a +ASM ^b		SARC _{HG} +SMI ^c		SARC _{5STS} ^d +ASM		SARC _{5STS} +SMI	
	OR ^e (95% CI)	Adjusted OR (95% CI)	OR (95% CI)	Adjusted OR (95% CI)	OR (95% CI)	Adjusted OR (95% CI)	OR (95% CI)	Adjusted OR (95% CI)
Hospitalized (n=90)	1.23 (0.78-1.95)	1.27 (0.80-2.12)	1.36 (0.76-2.43)	1.15 (0.61-2.17)	1.57 (1.05-2.35) ^f	1.50 (0.95-2.35)	1.84 (1.19-2.83) ^f	1.49 (0.90-2.48)
Frailty phenotype								
Not frail (n=665; reference)								
Frail (n=21)	4.35 (2.08-9.10) ^f	3.95 (1.69-9.27) ^f	6.44 (2.97-13.95) ^f	6.64 (2.61-16.87) ^f	3.59 (1.72-7.48) ^f	3.32 (1.44-7.67) ^f	2.97 (1.39-6.35) ^f	3.42 (1.38-8.59) ^f

^aHG: handgrip strength.

^bASM: appendicular skeletal mass.

^cSMI: skeletal muscle index.

^d5STS: 5 times sit-to-stand.

^eOR: odds ratio.

^fStatistical significance at an α level of .05 ($P<.05$; 1-tailed test).

Discussion

Principal Findings

This diagnostic accuracy study involving 686 community-dwelling older adults from elderly social centers revealed that sit-to-stand kinematic analysis through a video analysis-based app together with a simple measure of calf circumference had excellent ability (AUC range: 80.5%-87.1%) to discriminate between individuals with sarcopenia and apparently healthy individuals, regardless of the diagnostic criterion proposed by the EWGSOP2 guideline. Additionally, people categorized as sarcopenic through the *Sit to Stand* app showed more odds of having health-related adverse outcomes and frailty compared to their respective counterparts.

Kinematic variables derived from the sit-to-stand test, such as vertical velocity and vertical power, have been widely associated with several measures of physical function in older adults [20,21,25,38]. These variables have also demonstrated their potential to discriminate between apparently healthy older adults and those with a history of falls, sarcopenia, or even frailty [16-19]. However, these analyses have been usually performed through specialized equipment in laboratory settings, which are not affordable, require technical expertise, and are time-consuming to analyze, limiting their potential to be used in clinical settings. Our results derived from the *Sit to Stand* app showed a similar ability to discriminate between individuals with sarcopenia and apparently healthy older adults compared with the ability reported in previous studies using force plates (AUC range: 85.8%-90.6%) [17], but with the advantage of an easy-to-use interface and automatic data processing from the app, which allows health care professionals to screen for sarcopenia in short time periods (<5 min), emphasizing its clinical utility.

Previous validated questionnaires for identifying sarcopenia cases in short time periods, such as the SARC-F or its modified version adding calf circumference, have been recommended for

identifying sarcopenia cases by the international sarcopenia guideline [39] and 2 expert consensus guidelines (the EWGSOP2 and the Asian Working Group for Sarcopenia-2019) [1,40], owing to their affordability, rapid and simple assessment, and association with adverse clinical outcomes, which represent advantages to be used in clinical settings. However, a recent systematic review and meta-analysis provided strong evidence that their use in clinical practice could be nonoptimal mainly due to their low to moderate sensitivity (29%-57%) despite moderate to high specificity (69%-91%), independent of the sarcopenia definition [27]. This issue would lead to an underdiagnosis of individuals with sarcopenia, predisposing them to progress toward adverse health-related consequences [27]. The sensitivity of the *Sit to Stand* app ranged from 70% to 83.3%, with a low false-negative rate and high negative predictive values ranging from 95.6% to 99.4%, depending on the diagnostic criteria used. In other words, among each 100 individuals tested, 0 to 3 women and 1 to 2 men could get a false-negative result according to the different diagnostic criteria by the EWGSOP2 guideline. These results proved the exclusion of sarcopenia in cases of a negative test result, showing that the app was quite reliable to rule out the disease.

Recent studies have reported differences in prevalence between the diagnostic criteria proposed by the EWGSOP2 guideline, showing a more than 2-fold prevalence when the 5STS test result was used as a low muscle strength criterion instead of handgrip strength in European community-dwelling older adults [6,41]. In our study, sarcopenia prevalence ranged from 2% to 11%, with a higher value when the 5STS test result was used as a diagnostic criterion compared to handgrip strength. The low prevalence rate found in our study could be due to the characteristics of the sample analyzed, with participants being recruited from elderly social centers where movement-based activities are encouraged. In fact, only 10% of the participants were sedentary, while most of them were moderately active. It is well known that physical activity has a protective effect against sarcopenia, reducing the odds of its development by up

to 55% [42]. The development of a valid diagnostic test with enough sensitivity in low prevalence settings is a challenge. If the setting includes individuals with sarcopenia having a more advanced disease, there may be fewer false-negative results than in settings where individuals are unsuspected of having the disease, and sensitivity may be overestimated [43]. Despite the low prevalence rate, the *Sit to Stand* app showed moderate to high sensitivity, with a better value when the 5STS test result was used as a diagnostic criterion instead of handgrip strength possibly due to the higher prevalence found.

The app was validated against the different criteria proposed by the EWGSOP2 guideline since it has been recently reported that there is scarce overlap in people with sarcopenia when different diagnostic criteria are used [6,41,44], that is, some people diagnosed as having sarcopenia using the handgrip strength criterion were categorized as healthy using the 5STS criterion or vice versa, leading to underdiagnosis of up to 10% [6]. Additionally, recent studies have reported that the relationships between sarcopenia and adverse clinical outcomes could be dependent on the diagnostic criteria used [6,45,46]. Chew et al [46] showed that the 5STS test result had the best predictive validity for adverse outcomes at 2 years compared to handgrip strength in community-dwelling older adults with sarcopenia. Our results indicated that those individuals diagnosed with sarcopenia according to the index test (*Sit to Stand* app) showed more odds of having health-related adverse outcomes. These relationships were very consistent between the diagnostic criteria proposed by the EWGSOP2 guideline. Moreover, all individuals diagnosed with sarcopenia according to the index test showed more odds of having frailty, regardless of the diagnostic criterion used. It was not surprising since transitions from robustness to frailty status according to the Fried frailty phenotype are more frequent in community-dwelling older adults with sarcopenia than in those without sarcopenia [10]. These results highlight the validity of our index test for predicting adverse outcomes. This app could serve as a simple clinical tool for sarcopenia screening to potentially prevent the risk of further adverse events and the progression to severe sarcopenia, as well as the transition to other conditions such as frailty. This is of great importance since the combination of sarcopenia and frailty could lead to a higher risk of developing disability [47] and mortality [48] than either condition alone.

In our index test, false-positive results were mainly associated with a reduced muscle power below the 20th percentile or a reduced calf circumference below the 26th percentile (<34.2 cm) in the sample analyzed. A reduction in muscle power below the 33rd percentile has been previously shown to be associated with disability in activities of daily living and reduced physical performance to a greater extent than probable or confirmed sarcopenia [49]. Moreover, muscle power below the 33rd percentile has been shown to be independently associated with mortality and hospitalization in older adults [50]. Likewise, reduced calf circumference has been previously shown to be related to a higher frailty index and lower functional performance and strength [51]. Furthermore, calf circumference below 34.5 cm has been reported to be independently associated with an increased risk of mortality during 9 years of follow-up

in community-dwelling older adults [52]. Therefore, our false-positive individuals probably had a higher risk of developing health-related adverse outcomes than their respective counterparts. Thus, despite the moderate rate of false-positive results from the *Sit to Stand* app, these individuals should not go unnoticed with the aim of treatment through appropriate interventions, such as resistance training and optimal dietary intake, to improve muscle strength, muscle power, and muscle quantity as recommended [53]. The fact that the criteria for sarcopenia diagnosis in our index test were based on reduced muscle power and calf circumference, which have been widely associated with health adverse consequences, emphasizes the use of this app in clinical settings where muscle strength dynamometers or muscle mass measurement techniques are usually limited or restricted [12]. Furthermore, since muscle power declines with aging at an earlier and faster rate compared with muscle mass and strength [23,24], which are the base factors of the definition of sarcopenia, this app could potentially detect the early stages of sarcopenia where declines in muscle strength or mass are still not recognized. Thus, detecting reduced muscle power below a specific threshold might be a sign to start an appropriate intervention in these individuals. Further studies are needed to independently evaluate the validity of this app in community-dwelling older adults and to define a specific threshold of reduced vertical power using this app and its associated risk with health-related adverse outcomes.

Limitations

One of the main limitations of our study is the low prevalence rate of individuals with sarcopenia at elderly social centers. This situation led to imprecise estimates of the sensitivity parameter as can be observed in its wide CIs. This issue is usually reported in diagnostic studies with a low prevalence rate [43]. However, there is a need to develop diagnostic tools in those settings where sarcopenia could be overlooked or is uncommon as anticipatory strategies for detecting the disease and preventing health adverse consequences in community-dwelling older adults. Our predicted models were well calibrated, and bootstrapping revealed stability of the models, but further studies are needed to confirm the validity of our results. The app also showed a relationship with health-related risk factors, but these outcomes were self-reported in a cross-sectional time point. Therefore, the information collected depended on the subject's perception, and cross-sectional data do not allow causal relationships between measures. Finally, muscle quantity was assessed by bioelectrical impedance analysis, which is not considered as the gold standard for the assessment of this variable. In order to overcome this limitation, a cross-validated equation in a sample with similar characteristics was used as previously recommended [1,34].

Conclusions

The *Sit to Stand* app appears to have good diagnostic performance for detecting sarcopenia in well-functioning Spanish community-dwelling older adults. Individuals with sarcopenia diagnosed by the video analysis-based app showed more odds of having health-related risk factors and frailty compared to their respective counterparts, regardless of the diagnostic criteria proposed by the EWGSOP2 guideline. Further

studies are needed to independently evaluate the validity of this app in community-dwelling older adults.

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Conflicts of Interest

None declared.

Multimedia Appendix 1

Multiple logistic regression equations stratified by sex.

[\[DOCX File , 17 KB-Multimedia Appendix 1\]](#)

Multimedia Appendix 2

Differences in performance (c statistic) between the bootstrap models and the initial models stratified by sex.

[\[DOCX File , 15 KB-Multimedia Appendix 2\]](#)

Multimedia Appendix 3

Cross-tabulation of the index test (Sit to Stand app) and the reference standards of sarcopenia according to the European Working Group on Sarcopenia in Older People-2 (EWGSOP2) guideline in women and men (N=686).

[\[DOCX File , 16 KB-Multimedia Appendix 3\]](#)

References

1. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T, et al. Writing Group for the European Working Group on Sarcopenia in Older People 2 (EWGSOP2), the Extended Group for EWGSOP2. Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing*. 2019 Jan 01;48(1):16-31 [[FREE Full text](#)] [doi: [10.1093/ageing/afy169](https://doi.org/10.1093/ageing/afy169)] [Medline: [30312372](#)]
2. Steffl M, Bohannon RW, Petr M, Kohlikova E, Holmerova I. Relation between cigarette smoking and sarcopenia: meta-analysis. *Physiol Res*. 2015;64(3):419-426 [[FREE Full text](#)] [doi: [10.33549/physiolres.932802](https://doi.org/10.33549/physiolres.932802)] [Medline: [25536323](#)]
3. Volpato S, Bianchi L, Cherubini A, Landi F, Maggio M, Savino E, et al. Prevalence and clinical correlates of sarcopenia in community-dwelling older people: application of the EWGSOP definition and diagnostic algorithm. *J Gerontol A Biol Sci Med Sci*. 2014 Apr;69(4):438-446 [[FREE Full text](#)] [doi: [10.1093/gerona/glt149](https://doi.org/10.1093/gerona/glt149)] [Medline: [24085400](#)]
4. Chang K, Hsu T, Wu W, Huang K, Han D. Is sarcopenia associated with depression? A systematic review and meta-analysis of observational studies. *Age Ageing*. 2017 Sep 01;46(5):738-746 [doi: [10.1093/ageing/afx094](https://doi.org/10.1093/ageing/afx094)] [Medline: [28633395](#)]
5. Pacifico J, Geerlings MAJ, Reijnierse EM, Phassouliotis C, Lim WK, Maier AB. Prevalence of sarcopenia as a comorbid disease: A systematic review and meta-analysis. *Exp Gerontol*. 2020 Mar;131:110801 [[FREE Full text](#)] [doi: [10.1016/j.exger.2019.110801](https://doi.org/10.1016/j.exger.2019.110801)] [Medline: [31887347](#)]
6. Montemurro A, Ruiz-Cárdenas JD, Martínez-García MDM, Rodríguez-Juan JJ. Consequences of applying the different criteria of the EWGSOP2 guideline for sarcopenia case-finding in Spanish community-dwelling older adults. *Arch Gerontol Geriatr*. 2023 Jun;109:104964 [doi: [10.1016/j.archger.2023.104964](https://doi.org/10.1016/j.archger.2023.104964)] [Medline: [36821872](#)]
7. Liu P, Hao Q, Hai S, Wang H, Cao L, Dong B. Sarcopenia as a predictor of all-cause mortality among community-dwelling older people: A systematic review and meta-analysis. *Maturitas*. 2017 Sep;103:16-22 [doi: [10.1016/j.maturitas.2017.04.007](https://doi.org/10.1016/j.maturitas.2017.04.007)] [Medline: [28778327](#)]
8. Zhao Y, Zhang Y, Hao Q, Ge M, Dong B. Sarcopenia and hospital-related outcomes in the old people: a systematic review and meta-analysis. *Aging Clin Exp Res*. 2019 Jan;31(1):5-14 [doi: [10.1007/s40520-018-0931-z](https://doi.org/10.1007/s40520-018-0931-z)] [Medline: [29549649](#)]
9. Veronese N, Demurtas J, Soysal P, Smith L, Torbahn G, Schoene D, et al. Special Interest Groups in Systematic Reviews Meta-analyses for healthy ageing Sarcopenia Frailty resilience in older persons of the European Geriatric Medicine Society (EuGMS). Sarcopenia and health-related outcomes: an umbrella review of observational studies. *Eur Geriatr Med*. 2019 Dec;10(6):853-862 [doi: [10.1007/s41999-019-00233-w](https://doi.org/10.1007/s41999-019-00233-w)] [Medline: [34652767](#)]
10. Álvarez-Bustos A, Carnicero-Carreño J, Davies B, García-García FJ, Rodríguez-Artalejo F, Rodríguez-Mañas L, et al. Role of sarcopenia in the frailty transitions in older adults: a population-based cohort study. *J Cachexia Sarcopenia Muscle*. 2022 Oct;13(5):2352-2360 [[FREE Full text](#)] [doi: [10.1002/jcsm.13055](https://doi.org/10.1002/jcsm.13055)] [Medline: [35903871](#)]

11. Mayhew A, Amog K, Phillips S, Parise G, McNicholas P, de Souza R, et al. The prevalence of sarcopenia in community-dwelling older adults, an exploration of differences between studies and within definitions: a systematic review and meta-analyses. *Age Ageing*. 2019 Jan 01;48(1):48-56 [doi: [10.1093/ageing/afy106](https://doi.org/10.1093/ageing/afy106)] [Medline: [30052707](https://pubmed.ncbi.nlm.nih.gov/30052707/)]
12. Sayer AA, Cruz-Jentoft A. Sarcopenia definition, diagnosis and treatment: consensus is growing. *Age Ageing*. 2022 Oct 06;51(10):afac220 [FREE Full text] [doi: [10.1093/ageing/afac220](https://doi.org/10.1093/ageing/afac220)] [Medline: [36273495](https://pubmed.ncbi.nlm.nih.gov/36273495/)]
13. Reijnierse EM, de van der Schueren MAE, Trappenburg MC, Doves M, Meskers CGM, Maier AB. Lack of knowledge and availability of diagnostic equipment could hinder the diagnosis of sarcopenia and its management. *PLoS One*. 2017;12(10):e0185837 [FREE Full text] [doi: [10.1371/journal.pone.0185837](https://doi.org/10.1371/journal.pone.0185837)] [Medline: [28968456](https://pubmed.ncbi.nlm.nih.gov/28968456/)]
14. Yeung SSY, Reijnierse EM, Trappenburg MC, Meskers CGM, Maier AB. Current knowledge and practice of Australian and New Zealand health-care professionals in sarcopenia diagnosis and treatment: Time to move forward!. *Australas J Ageing*. 2020 Jun;39(2):e185-e193 [FREE Full text] [doi: [10.1111/ajag.12730](https://doi.org/10.1111/ajag.12730)] [Medline: [31617296](https://pubmed.ncbi.nlm.nih.gov/31617296/)]
15. Offord NJ, Clegg A, Turner G, Dodds RM, Sayer AA, Witham MD. Current practice in the diagnosis and management of sarcopenia and frailty - results from a UK-wide survey. *J Frailty Sarcopenia Falls*. 2019 Sep;4(3):71-77 [FREE Full text] [doi: [10.22540/JFSF-04-071](https://doi.org/10.22540/JFSF-04-071)] [Medline: [32300721](https://pubmed.ncbi.nlm.nih.gov/32300721/)]
16. Fleming BE, Wilson DR, Pendergast DR. A portable, easily performed muscle power test and its association with falls by elderly persons. *Arch Phys Med Rehabil*. 1991 Oct;72(11):886-889 [doi: [10.1016/0003-9993\(91\)90006-5](https://doi.org/10.1016/0003-9993(91)90006-5)] [Medline: [1929806](https://pubmed.ncbi.nlm.nih.gov/1929806/)]
17. Kera T, Kawai H, Takahashi J, Hirano H, Watanabe Y, Fujiwara Y, et al. Development of a screening formula for sarcopenia using ground reaction force during sit-to-stand motion. *Gait Posture*. 2022 Mar;93:177-182 [FREE Full text] [doi: [10.1016/j.gaitpost.2022.02.001](https://doi.org/10.1016/j.gaitpost.2022.02.001)] [Medline: [35180686](https://pubmed.ncbi.nlm.nih.gov/35180686/)]
18. Millor N, Lecumberri P, Gomez M, Martinez A, Martinikorena J, Rodriguez-Manas L, et al. Gait Velocity and Chair Sit-Stand-Sit Performance Improves Current Frailty-Status Identification. *IEEE Trans Neural Syst Rehabil Eng*. 2017 Nov;25(11):2018-2025 [doi: [10.1109/TNSRE.2017.2699124](https://doi.org/10.1109/TNSRE.2017.2699124)] [Medline: [28463202](https://pubmed.ncbi.nlm.nih.gov/28463202/)]
19. Zech A, Steib S, Sportwiss D, Freiburger E, Pfeifer K. Functional muscle power testing in young, middle-aged, and community-dwelling nonfrail and prefrail older adults. *Arch Phys Med Rehabil*. 2011 Jun;92(6):967-971 [doi: [10.1016/j.apmr.2010.12.031](https://doi.org/10.1016/j.apmr.2010.12.031)] [Medline: [21514567](https://pubmed.ncbi.nlm.nih.gov/21514567/)]
20. Orange ST, Metcalfe JW, Liefheith A, Jordan AR. Validity of various portable devices to measure sit-to-stand velocity and power in older adults. *Gait Posture*. 2020 Feb;76:409-414 [doi: [10.1016/j.gaitpost.2019.12.003](https://doi.org/10.1016/j.gaitpost.2019.12.003)] [Medline: [31945676](https://pubmed.ncbi.nlm.nih.gov/31945676/)]
21. Ruiz-Cárdenas JD, Rodríguez-Juan JJ, Smart RR, Jakobi JM, Jones GR. Validity and reliability of an iPhone App to assess time, velocity and leg power during a sit-to-stand functional performance test. *Gait Posture*. 2018 Jan;59:261-266 [FREE Full text] [doi: [10.1016/j.gaitpost.2017.10.029](https://doi.org/10.1016/j.gaitpost.2017.10.029)] [Medline: [29102856](https://pubmed.ncbi.nlm.nih.gov/29102856/)]
22. Boswell MA, Kidziński Ł, Hicks JL, Uhlrich SD, Falisse A, Delp SL. Smartphone videos of the sit-to-stand test predict osteoarthritis and health outcomes in a nationwide study. *NPJ Digit Med*. 2023 Mar 04;6(1):32 [FREE Full text] [doi: [10.1038/s41746-023-00775-1](https://doi.org/10.1038/s41746-023-00775-1)] [Medline: [36871119](https://pubmed.ncbi.nlm.nih.gov/36871119/)]
23. Skelton DA, Greig CA, Davies JM, Young A. Strength, power and related functional ability of healthy people aged 65-89 years. *Age Ageing*. 1994 Sep;23(5):371-377 [doi: [10.1093/ageing/23.5.371](https://doi.org/10.1093/ageing/23.5.371)] [Medline: [7825481](https://pubmed.ncbi.nlm.nih.gov/7825481/)]
24. Reid KF, Pasha E, Doros G, Clark DJ, Patten C, Phillips EM, et al. Longitudinal decline of lower extremity muscle power in healthy and mobility-limited older adults: influence of muscle mass, strength, composition, neuromuscular activation and single fiber contractile properties. *Eur J Appl Physiol*. 2014 Jan;114(1):29-39 [FREE Full text] [doi: [10.1007/s00421-013-2728-2](https://doi.org/10.1007/s00421-013-2728-2)] [Medline: [24122149](https://pubmed.ncbi.nlm.nih.gov/24122149/)]
25. Glenn JM, Gray M, Binns A. Relationship of Sit-to-Stand Lower-Body Power With Functional Fitness Measures Among Older Adults With and Without Sarcopenia. *J Geriatr Phys Ther*. 2017;40(1):42-50 [doi: [10.1519/JPT.0000000000000072](https://doi.org/10.1519/JPT.0000000000000072)] [Medline: [26428899](https://pubmed.ncbi.nlm.nih.gov/26428899/)]
26. Santos LP, Gonzalez MC, Orlandi SP, Bielemann RM, Barbosa-Silva TG, Heymsfield SB, et al. COCONUT Study Group. New Prediction Equations to Estimate Appendicular Skeletal Muscle Mass Using Calf Circumference: Results From NHANES 1999-2006. *JPEN J Parenter Enteral Nutr*. 2019 Nov;43(8):998-1007 [doi: [10.1002/jpen.1605](https://doi.org/10.1002/jpen.1605)] [Medline: [31081126](https://pubmed.ncbi.nlm.nih.gov/31081126/)]
27. Voelker SN, Michalopoulos N, Maier AB, Reijnierse EM. Reliability and Concurrent Validity of the SARC-F and Its Modified Versions: A Systematic Review and Meta-Analysis. *J Am Med Dir Assoc*. 2021 Sep;22(9):1864-1876.e16 [FREE Full text] [doi: [10.1016/j.jamda.2021.05.011](https://doi.org/10.1016/j.jamda.2021.05.011)] [Medline: [34144049](https://pubmed.ncbi.nlm.nih.gov/34144049/)]
28. The Mobile Economy 2023. GSMA. URL: <https://www.gsma.com/mobileeconomy/wp-content/uploads/2023/02/270223-The-Mobile-Economy-2023.pdf> [accessed 2023-11-27]
29. Ruiz-Cárdenas JD, Montemurro A, Del Mar Martínez-García M, Rodríguez-Juan JJ. Concurrent and discriminant validity and reliability of an Android App to assess time, velocity and power during sit-to-stand test in community-dwelling older adults. *Aging Clin Exp Res*. 2023 Aug;35(8):1631-1640 [doi: [10.1007/s40520-023-02451-6](https://doi.org/10.1007/s40520-023-02451-6)] [Medline: [37306926](https://pubmed.ncbi.nlm.nih.gov/37306926/)]
30. Kralj A, Jaeger RJ, Muni M. Analysis of standing up and sitting down in humans: definitions and normative data presentation. *J Biomech*. 1990;23(11):1123-1138 [doi: [10.1016/0021-9290\(90\)90005-n](https://doi.org/10.1016/0021-9290(90)90005-n)] [Medline: [2277047](https://pubmed.ncbi.nlm.nih.gov/2277047/)]
31. Schenkman M, Berger RA, Riley PO, Mann RW, Hodge WA. Whole-body movements during rising to standing from sitting. *Phys Ther*. 1990 Oct;70(10):638-648; discussion 648 [doi: [10.1093/ptj/70.10.638](https://doi.org/10.1093/ptj/70.10.638)] [Medline: [2217543](https://pubmed.ncbi.nlm.nih.gov/2217543/)]

32. Hirschfeld H, Thorsteinsdottir M, Olsson E. Coordinated ground forces exerted by buttocks and feet are adequately programmed for weight transfer during sit-to-stand. *J Neurophysiol*. 1999 Dec;82(6):3021-3029 [FREE Full text] [doi: [10.1152/jn.1999.82.6.3021](https://doi.org/10.1152/jn.1999.82.6.3021)] [Medline: [10601437](https://pubmed.ncbi.nlm.nih.gov/10601437/)]
33. Ruiz-Cárdenas JD, Montemurro A, Martínez-García MDM, Rodríguez-Juan JJ. Sit-to-Stand video analysis based-app for diagnosing sarcopenia. OSF. URL: <https://osf.io/kh643/> [accessed 2023-11-27]
34. Sergi G, De Rui M, Veronese N, Bolzetta F, Berton L, Carraro S, et al. Assessing appendicular skeletal muscle mass with bioelectrical impedance analysis in free-living Caucasian older adults. *Clin Nutr*. 2015 Aug;34(4):667-673 [doi: [10.1016/j.clnu.2014.07.010](https://doi.org/10.1016/j.clnu.2014.07.010)] [Medline: [25103151](https://pubmed.ncbi.nlm.nih.gov/25103151/)]
35. Montemurro A, Ruiz-Cárdenas JD, Martínez-García MDM, Rodríguez-Juan JJ. Validity of an iPhone App to Detect Pre frailty and Sarcopenia Syndromes in Community-Dwelling Older Adults: The Protocol for a Diagnostic Accuracy Study. *Sensors (Basel)*. 2022 Aug 11;22(16):6010 [FREE Full text] [doi: [10.3390/s22166010](https://doi.org/10.3390/s22166010)] [Medline: [36015771](https://pubmed.ncbi.nlm.nih.gov/36015771/)]
36. Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gottdiener J, et al. Cardiovascular Health Study Collaborative Research Group. Frailty in older adults: evidence for a phenotype. *J Gerontol A Biol Sci Med Sci*. 2001 Mar;56(3):M146-M156 [doi: [10.1093/gerona/56.3.m146](https://doi.org/10.1093/gerona/56.3.m146)] [Medline: [11253156](https://pubmed.ncbi.nlm.nih.gov/11253156/)]
37. Bujang MA, Adnan TH. Requirements for Minimum Sample Size for Sensitivity and Specificity Analysis. *J Clin Diagn Res*. 2016 Oct;10(10):YE01-YE06 [FREE Full text] [doi: [10.7860/JCDR/2016/18129.8744](https://doi.org/10.7860/JCDR/2016/18129.8744)] [Medline: [27891446](https://pubmed.ncbi.nlm.nih.gov/27891446/)]
38. Balachandran AT, Vigotsky AD, Quiles N, Mookink LB, Belio MA, Glenn JM. Validity, reliability, and measurement error of a sit-to-stand power test in older adults: A pre-registered study. *Exp Gerontol*. 2021 Mar;145:111202 [doi: [10.1016/j.exger.2020.111202](https://doi.org/10.1016/j.exger.2020.111202)] [Medline: [33347922](https://pubmed.ncbi.nlm.nih.gov/33347922/)]
39. Dent E, Morley JE, Cruz-Jentoft AJ, Arai H, Kritchevsky SB, Guralnik J, et al. International Clinical Practice Guidelines for Sarcopenia (ICFSR): Screening, Diagnosis and Management. *J Nutr Health Aging*. 2018;22(10):1148-1161 [doi: [10.1007/s12603-018-1139-9](https://doi.org/10.1007/s12603-018-1139-9)] [Medline: [30498820](https://pubmed.ncbi.nlm.nih.gov/30498820/)]
40. Chen L, Woo J, Assantachai P, Auyeung T, Chou M, Iijima K, et al. Asian Working Group for Sarcopenia: 2019 Consensus Update on Sarcopenia Diagnosis and Treatment. *J Am Med Dir Assoc*. 2020 Mar;21(3):300-307.e2 [doi: [10.1016/j.jamda.2019.12.012](https://doi.org/10.1016/j.jamda.2019.12.012)] [Medline: [32033882](https://pubmed.ncbi.nlm.nih.gov/32033882/)]
41. Johansson J, Strand BH, Morseth B, Hopstock LA, Grimsgaard S. Differences in sarcopenia prevalence between upper-body and lower-body based EWGSOP2 muscle strength criteria: the Tromsø study 2015-2016. *BMC Geriatr*. 2020 Nov 10;20(1):461 [FREE Full text] [doi: [10.1186/s12877-020-01860-w](https://doi.org/10.1186/s12877-020-01860-w)] [Medline: [33172391](https://pubmed.ncbi.nlm.nih.gov/33172391/)]
42. Steffl M, Bohannon RW, Sontakova L, Tufano JJ, Shiells K, Holmerova I. Relationship between sarcopenia and physical activity in older people: a systematic review and meta-analysis. *Clin Interv Aging*. 2017;12:835-845 [FREE Full text] [doi: [10.2147/CIA.S132940](https://doi.org/10.2147/CIA.S132940)] [Medline: [28553092](https://pubmed.ncbi.nlm.nih.gov/28553092/)]
43. Holtman GA, Berger MY, Burger H, Deeks JJ, Donner-Banzhoff N, Fanshawe TR, et al. Development of practical recommendations for diagnostic accuracy studies in low-prevalence situations. *J Clin Epidemiol*. 2019 Oct;114:38-48 [doi: [10.1016/j.jclinepi.2019.05.018](https://doi.org/10.1016/j.jclinepi.2019.05.018)] [Medline: [31150837](https://pubmed.ncbi.nlm.nih.gov/31150837/)]
44. Trevisan C, Vetrano DL, Calvani R, Picca A, Welmer A. Twelve-year sarcopenia trajectories in older adults: results from a population-based study. *J Cachexia Sarcopenia Muscle*. 2022 Feb;13(1):254-263 [FREE Full text] [doi: [10.1002/jcsm.12875](https://doi.org/10.1002/jcsm.12875)] [Medline: [34846095](https://pubmed.ncbi.nlm.nih.gov/34846095/)]
45. Verstraeten LMG, de Haan NJ, Verbeet E, van Wijngaarden JP, Meskers CGM, Maier AB. Handgrip strength rather than chair stand test should be used to diagnose sarcopenia in geriatric rehabilitation inpatients: REStORing health of acutely unwell adults (RESORT). *Age Ageing*. 2022 Nov 02;51(11):afac242 [FREE Full text] [doi: [10.1093/ageing/afac242](https://doi.org/10.1093/ageing/afac242)] [Medline: [36413590](https://pubmed.ncbi.nlm.nih.gov/36413590/)]
46. Chew J, Yeo A, Yew S, Lim JP, Tay L, Ding YY, et al. Muscle Strength Definitions Matter: Prevalence of Sarcopenia and Predictive Validity for Adverse Outcomes Using the European Working Group on Sarcopenia in Older People 2 (EWGSOP2) Criteria. *J Nutr Health Aging*. 2020;24(6):614-618 [doi: [10.1007/s12603-020-1371-y](https://doi.org/10.1007/s12603-020-1371-y)] [Medline: [32510114](https://pubmed.ncbi.nlm.nih.gov/32510114/)]
47. Davies B, Walter S, Rodríguez-Laso A, Carnicero Carreño J, García-García F, Álvarez-Bustos A, et al. Differential Association of Frailty and Sarcopenia With Mortality and Disability: Insight Supporting Clinical Subtypes of Frailty. *J Am Med Dir Assoc*. 2022 Oct;23(10):1712-1716.e3 [doi: [10.1016/j.jamda.2022.03.013](https://doi.org/10.1016/j.jamda.2022.03.013)] [Medline: [35472314](https://pubmed.ncbi.nlm.nih.gov/35472314/)]
48. Thompson MQ, Yu S, Tucker GR, Adams RJ, Cesari M, Theou O, et al. Frailty and sarcopenia in combination are more predictive of mortality than either condition alone. *Maturitas*. 2021 Feb;144:102-107 [doi: [10.1016/j.maturitas.2020.11.009](https://doi.org/10.1016/j.maturitas.2020.11.009)] [Medline: [33358201](https://pubmed.ncbi.nlm.nih.gov/33358201/)]
49. Bahat G, Kilic C, Eris S, Karan MA. Power Versus Sarcopenia: Associations with Functionality and Physical Performance Measures. *J Nutr Health Aging*. 2021;25(1):13-17 [doi: [10.1007/s12603-020-1544-8](https://doi.org/10.1007/s12603-020-1544-8)] [Medline: [33367457](https://pubmed.ncbi.nlm.nih.gov/33367457/)]
50. Losa-Reyna J, Alcazar J, Carnicero J, Alfaro-Acha A, Castillo-Gallego C, Rosado-Artalejo C, et al. Impact of Relative Muscle Power on Hospitalization and All-Cause Mortality in Older Adults. *J Gerontol A Biol Sci Med Sci*. 2022 Apr 01;77(4):781-789 [doi: [10.1093/gerona/glab230](https://doi.org/10.1093/gerona/glab230)] [Medline: [34407184](https://pubmed.ncbi.nlm.nih.gov/34407184/)]
51. Landi F, Onder G, Russo A, Liperoti R, Tosato M, Martone AM, et al. Calf circumference, frailty and physical performance among older adults living in the community. *Clin Nutr*. 2014 Jun;33(3):539-544 [doi: [10.1016/j.clnu.2013.07.013](https://doi.org/10.1016/j.clnu.2013.07.013)] [Medline: [23948128](https://pubmed.ncbi.nlm.nih.gov/23948128/)]

52. Fernandes DPDS, Juvanhol LL, Lozano M, Ribeiro AQ. Calf circumference is an independent predictor of mortality in older adults: An approach with generalized additive models. *Nutr Clin Pract*. 2022 Oct;37(5):1190-1198 [doi: [10.1002/ncp.10780](https://doi.org/10.1002/ncp.10780)] [Medline: [34648208](https://pubmed.ncbi.nlm.nih.gov/34648208/)]
53. Cruz-Jentoft AJ, Landi F, Schneider SM, Zúñiga C, Arai H, Boirie Y, et al. Prevalence of and interventions for sarcopenia in ageing adults: a systematic review. Report of the International Sarcopenia Initiative (EWGSOP and IWGS). *Age Ageing*. 2014 Nov;43(6):748-759 [FREE Full text] [doi: [10.1093/ageing/afu115](https://doi.org/10.1093/ageing/afu115)] [Medline: [25241753](https://pubmed.ncbi.nlm.nih.gov/25241753/)]

Abbreviations

5STS: 5 times sit-to-stand

ASM: appendicular skeletal mass

AUC: area under the curve

EWGSOP2: European Working Group on Sarcopenia in Older People-2

OR: odds ratio

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VIII – ARTÍCULO V

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Abstract

Objectives: Sarcopenia and frailty have been associated with an increased risk of suffering health-related adverse events but the combination of both conditions results in worse health-related outcomes than either condition alone. Since both syndromes are reversible states, their early detection is fundamental. This study aims to validate a video analysis-based App to detect the presence of frailty or prefrailty plus sarcopenia syndromes and to analyze its construct validity with health-related risk factors.

Methods: A total of 686 community-dwelling older adults (median-age: 72, 59% female) were enrolled. Muscle power generated during a sit-to-stand test using the App and calf circumference were considered the index test. The reference standards were the EWGSOP2 criteria (five-chair stand test plus appendicular skeletal mass or skeletal muscle index) and Fried's frailty phenotype. Area under the curve (AUC), sensitivity, specificity, positive and negative predictive values (PPV and NPV) were calculated.

Results: The prevalence of both syndromes varied from 2.9% to 7.2% depending on the diagnostic criteria used for sarcopenia assessment. Excellent-to-outstanding AUC values were observed (range 0.80–0.92). Sensitivity and specificity ranged from 75% to 100% and 81.7% to 87.2%, respectively. PPV and NPV ranged from 12.1% to 37.5% and 97.9% to 100%, respectively. Individuals diagnosed by the App showed an increased risk of polypharmacy, depression, comorbidities, falls, hospitalization, low socioeconomical and educational levels, and smoking and poor self-perceived health compared to their healthy counterparts.

Conclusions: This App seems to be reliable to detect the simultaneous presence of both syndromes in community-dwelling older adults. Individuals diagnosed by the App showed more odds to have health-related risk factors.

Keywords

Aged, frailty, sarcopenia, sit-to-stand, diagnosis, physical examination, motion capture, smartphone, muscle power, calf circumference

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Introduction

Sarcopenia and frailty represent two of the main concerns related to the biological ageing process, given their intimate relationship with adverse health-related outcomes. Concretely, sarcopenia is a formally recognized disease (ICD-10-CM Diagnosis Code) defined as the generalized and progressive loss of strength, skeletal muscle mass, and/or physical function.¹ Sarcopenia increases the risk of suffering physical

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disabilities, depression, polypharmacy, falls, hospitalization, and mortality.¹ On the other hand, frailty is defined as a biological state characterized by reduced muscle strength, endurance, and physiological function that increases vulnerability to stressor events.² Similarly, the presence of frailty has been related to an increased risk of falls, fractures, disability, hospitalization, and premature death.³

Nowadays, there is no gold standard for the detection of frailty and sarcopenia syndromes leading to differences in prevalence estimate ranging from 4% to 59% and 1% to 23% in European community-dwelling older adults, respectively.^{4,5} However, one of the most used criteria for diagnosing these conditions are the Fried's frailty phenotype and The European Working Group on Sarcopenia in Older People 2 (EWGSOP2).^{4,5} The Fried's frailty phenotype assessment includes gait speed, unintentional weight loss, physical activity levels, exhaustion levels, and muscle weakness determined by handgrip strength test,⁶ whereas the EWGSOP2 guideline defines sarcopenia as a reduction in muscle mass and strength, this latter also usually measured using handgrip strength test.⁵ Regardless of the similarities between their definitions and diagnosis, these two terms do not refer to the same state and cannot be used interchangeably.^{7,8} In fact, sarcopenia could be considered a precursor of frailty.⁷ In spite of the debate on which syndrome manifests first, scientific literature has observed that its simultaneous presence is predictive of worsening disability⁹ and has been associated to up to threefold of risk of mortality compared to those without neither sarcopenia nor frailty.¹⁰ Moreover, transitions between robustness to frailty states (prefrail or frail) are more frequent in sarcopenic individuals whereas improvement from frailty states are more frequent in non-sarcopenic individuals.⁷ Since both sarcopenia and frailty are reversible states, their early detection covers a fundamental role in the management of their progression. Unfortunately, sarcopenia and frailty assessment is not implemented routinely in clinical practice due to the lack of equipment and time constraints.^{11,12}

Muscle power declines with aging at an earlier and faster rate compared with muscle mass and strength,^{13,14} being both the base of the definition of sarcopenia, and it has been considered a predictor of frailty.^{15,16} Although muscle power has been usually recorded through specialized instrument such as 3D-motion capture cameras, inertial measurement units and force plates,^{15,17,18} recent advances in smartphone technology provide the opportunity to access muscle power during a simple functional test using a video analysis-based App in a clinical setting.^{17–19} Muscle power derived from this App during the sit-to-stand test has been associated to several measures of physical function and frailty determinants such as handgrip strength or reduced gait speed in community-dwelling older adults.^{17–19} Moreover, a recent study showed that muscle power using this App had the ability to discriminate between sarcopenic and non-sarcopenic individuals without the need of using expensive muscle mass measurement techniques such as

dual-energy X-ray absorptiometry or bioelectrical impedance analysis which are not always accessible in a clinical setting.¹⁹ Thus, one could think that adding to this App a proxy of muscle mass could improve its potential for diagnosis both sarcopenia and frailty syndromes. For instance, simple measurements of calf and mid-upper arm circumferences have been observed to represent acceptable surrogates of muscle mass in clinical practice.²⁰ Reduced calf and mid-upper arm circumferences have been associated to the presence of frailty syndrome²¹ and sarcopenia^{22,23} in community-dwelling older adults. Thus, integrating both muscle power as a proxy of muscle weakness and calf or mid-upper arm circumference as a proxy of muscle mass in a unique tool would be capable of early detecting the simultaneous presence of sarcopenia and frailty syndromes with the advantage of responding to the demands of the clinical setting. Although research in sarcopenia and frailty has increased in recent years, much remains to be done regarding the implementation of these syndromes in clinical practice. Several surveys have highlighted that most healthcare professionals do not use validated instruments for diagnosing frailty and/or sarcopenia and many of them having no clear knowledge of how to diagnose it.^{24–26} For many healthcare professionals lack of time and lack of appropriate tools are considered the main barriers for screening and diagnosis in clinical practice.^{11,12,24,25,27} Therefore, the development of a valid and reliable tool to diagnosis both syndromes that is feasible in the clinical setting is much needed. This App might overcome these barriers providing an affordable and valid easy-to-use instrument to rapidly diagnose both syndromes.

The aims of this study were (a) to validate a video analysis App based on muscle power generated during a simple sit-to-stand test and calf or mid-upper arm circumference as a proxy of muscle mass to detect the simultaneous presence of both syndromes in community-dwelling older adults, and (b) to determine its construct validity with health-related adverse events such as falls, hospitalization, comorbidities, depressive symptoms, poor self-perceived health, low socioeconomic and educational levels, and smoking habits and polypharmacy.

Methods

Design and protocol registration

This study aims to report the results of a previous published protocol.²⁸ Briefly, this was a retrospective diagnostic accuracy study based on Standards for Reporting of Diagnostic Accuracy Studies (STARD) recommendations. The study protocol was registered on ClinicalTrials.gov database (NCT05148351; registration date: 21/12/08) and approved by the Ethical Committee of Catholic University of Murcia (CE022108). The study completely fulfilled the principles stated in the Declaration of Helsinki.

Study participants and eligibility criteria

Individuals aged 60 or more from elderly social centers of the Region of Murcia (Spain) were enrolled over an 8-month period (starting date: February 2022; finishing date: October 2022). Potentially eligible participants were recruited using a convenience model. First, elderly social centers were contacted, providing them information about the development of the study. Once centers gave their consent to carry out the study, potentially eligible participants were contacted either via telephone or face to face, furnishing them a complete explanation (written and oral) of the study procedure. Finally, written consent from each participant was obtained. Participants reporting any severe cardiovascular condition (e.g. heart valve disease, uncontrolled arrhythmias, cardiac implants or pacemakers), a Barthel Index score lower than 90 points, a Mini-Cog test score lower than 3 points, as well as inability to stand up from a chair without assistance were excluded from the study.

Data collection procedure

Data collection was performed on a single day and information was gathered by a single researcher on a spreadsheet and another researcher crosschecked each data point by point. The following information was collected: (a) a single sit-to-stand test and calf and mid-upper arm circumference measurement, (b) frailty assessment, (c) sarcopenia assessment, and (d) clinical interview.

Muscle power recorded during the sit-to-stand test and anthropometric circumferences were used as index test to diagnose the simultaneous presence of both syndromes through a video analysis-based App, while the EWGSOP2 recommendations and Fried's frailty phenotype were considered as the reference standards. Furthermore, a clinical interview about health-related risk factors was used as construct validity of the index test.

Index test: muscle power, calf and mid-upper arm circumference

A single sit-to-stand test was carried out and recorded using the *Sit to Stand* App (version 2.0.1.) installed on an iPhone 13 device running iOS 15.3 (Apple Inc., Cupertino, CA, USA). This app aimed to determine muscle power derived from the rising phase of the sit-to-stand test using a slow-motion video-captured camera (240 frames-per-second). Briefly, participants sat on a rigid and adjustable chair, having their arms crossed over their chest with their hip, and both knee and ankle joints positioned at 90 degrees. Participants had to stand up completely from the chair to the best of their speed. The smartphone was placed horizontally on a 0.7-m-high tripod placed 3 m from the right or left side of the participant. Relativized

values of muscle power (W/Kg) generated during the test were determined by the App using the following regression equation:

$$\text{Muscle Power} = 2.773 - 6.228 \times t + 18.224 \times d$$

In which t is the rising time, i.e. the time transition from seat off to complete upright position with the full extension of knee and hip joints, and d represents the vertical distance covered during the test, represented by femur length. Femur length was defined as the distance between the superior aspect of the greater trochanter and the femoral lateral condyle. Following the instructions of the App, to accurately determine the beginning and the end of the movement, a reflective marker was placed on the superior aspect of participants' greater trochanter. The rising phase started when the pelvis began to move forward after anterior trunk tilt which is time-matched when the reflective marker crossed the first horizontal grid line on the screen of the App. The end of the rising phase was determined when full extension of hip and knee joints was reached which is time-matched when the reflective marker achieved the highest vertical point. This entire procedure has been previously validated and reported negligible bias and small errors compared to force plates and 3D-motion cameras in adults with a broad age range (21–91 years).^{17,18}

Additionally, calf and upper-mid arm circumference were measured as a proxy of muscle mass and entered together with muscle power values in a set of multiple logistic regression equations to determine its ability to predict the presence of both syndromes. Calf circumference was measured through a flexible and inelastic tape placed on the point of greatest circumference of the non-dominant leg, while participants were in a sitting position with the knee and ankle at 90 degrees.^{21,23} Dominant mid-upper arm circumference was measured placing the tape at the midpoint of the tip of the acromion and olecranon of the arm with participants sitting on a chair.²² Skin compression was avoided for both measurements. Researchers performed the index test were blinded to the reference standards.

Reference standards

The Fried's frailty phenotype and the EWGSOP2 guideline were used as reference standards to determine the presence of both syndromes in combination. The presence of both syndromes was considered when the participant was classified as prefrail or frail plus confirmed sarcopenia. Since both reference standards share the criteria of muscle weakness using handgrip strength test, we used the alternative criteria recommended by the EWGSOP2 for assessing muscle weakness which involves the five times sit-to-stand test (5STS) instead of handgrip strength test. This was selected in order to avoid overlap between diagnostic criteria. Researchers performed the reference standards were blinded to the index test.

Frailty Assessment. The Fried's frailty phenotype determines frailty state assessing five domains: muscle weakness, unintentional weight loss, physical activity levels, exhaustion levels, and gait speed.⁶ Briefly, handgrip strength was used to measure muscle weakness using a digital dynamometer (Takei Scientific Instruments Co., Ltd, Tokyo, Japan) and employing the cut-off points stratified by sex and body mass index (BMI). Self-reported unintentional weight loss was defined as a loss of 4.5 Kg or more during the prior year. Physical activity levels were measured through the Spanish-validated short version of the Minnesota leisure time physical activity questionnaire. To determine the exhaustion levels, participants were asked to rate from 0 (rarely or none of the time) to 3 (most of the time) the frequency with which they experienced the following statements during the prior week: "I felt that everything I did was an effort" and "I could not get going." Gait speed was assessed with the 4 m usual gait speed test, in which participants were asked to walk at their usual pace a 4 m haul. Cut-off points were stratified by gender and height of the participants.⁶ Participants were classified as robust (met none of the frailty criteria), prefrail (met one or two criteria), or frail (met three or more criteria) according to Fried and colleagues.⁶

Sarcopenia Assessment. The EWGSOP2 guideline defines probable sarcopenia as a reduction in muscle strength determined as more than 15 s to complete the 5STS test. Then, sarcopenia is confirmed whether a reduction in appendicular skeletal muscle mass (ASM) is present either in absolute values or relative to squared-height, also named skeletal muscle index (SMI).¹ The analysis of muscle mass was performed using a TANITA MC-580 (Tanita Corp., Tokyo, Japan) and reactance and resistance index raw values were introduced in Sergi's validated equation.²⁹ The cut-off point for ASM was lower than 20 Kg for men and 15 Kg for women whereas the cut-off point for SMI was lower than 7 kg/m² in men and 5.5 kg/m² in women. Therefore, two definitions of sarcopenia were obtained, sarcopenia_{5STS + ASM} and sarcopenia_{5STS + SMI}.

Construct validity: risk factors for adverse health-related outcomes

A face-to-face interview was used to obtain information regarding the presence of depressive symptoms (Geriatric Depression Scale; cut-off point: ≥ 2), self-perceived health (low self-perceived health cut-off point: very bad, bad or fair), socioeconomic status (annual net salary <10,000€), educational level (low educational level cut-off point: primary or less), presence of comorbidity (two or more chronic conditions), polypharmacy (daily intake ≥ 5 drugs), presence of two or more falls in the last year, hospitalizations in the last year, and current smoking habit was registered and dichotomized in order to assess the construct

validity of our index test to determine the presence of risk factor for adverse health-related outcomes in those classified with both syndromes. Detailed information about general data collection can be found in the published version of the study protocol.²⁸

Sample size estimation

In a Spanish-based community-dwelling older population, the simultaneous prevalence of both syndromes is reported in a range from 10.5% to 13.7%.^{8,9} To ensure the most realistic sample size calculation, the lowest prevalence rate was taken as reference. Consequently, according to Bujang and Adnan's,³⁰ a minimum of 400 participants (200 men and 200 women) were necessary to achieve a statistical power of 80%, with an alpha error fixed at 0.05 and an area under the curve (AUC) of minimum 0.8.

Statistical analysis

A database was created on Microsoft Excel© (Microsoft Corp., Redmond, WA, USA) to record all participants data and IBM SPSS Statistics (26.0, SPSS Inc., Chicago, Ill, USA) was used to carry out data analysis. Continuous variables were reported as means and standard deviations in the presence of normal distribution otherwise data was expressed as median and interquartile range. Categorical data were expressed as frequencies and percentages. Statistical significance was fixed at $p < .05$.

Objective 1: Diagnostic accuracy. The presence of sarcopenia and frailty syndromes was defined when the participant was categorized as frail or prefrail plus sarcopenic_{5STS + ASM} or sarcopenic_{5STS + SMI}. Subsequently, a set of multiple logistic regression equations stratified by sex with both syndromes as the dependent variable and muscle power, calf circumference, and mid-upper-limb circumference as independent variables were performed to create predictive equations to diagnose both syndromes. Since calf circumference was more related with both syndromes than mid-upper-limb circumference, it was deleted from the final model (Supplementary Material, Table S1). Receiver operating characteristic analyses with their AUC were performed using predictive probability from the results of the multiple logistic regression analyses to identify the best cut-off point to discriminate the presence of both syndromes compared to either condition alone (prefrail, frail, or sarcopenic) and healthy (robust or non-sarcopenic) participants. Then, a sensitivity analysis was performed in order to assess the potential to discriminate between participants categorized with both syndromes and those categorized as either condition alone, as well as between participants categorized with both syndromes and those categorized as healthy participants. The AUC were reported and interpreted as no discrimination (0.5), acceptable (0.7 to <0.8), excellent (0.8 to 0.9), and outstanding (> 0.9). Values of sensitivity,

specificity, positive and negative predictive values (PPV and NPV), likelihood ratios, diagnostic accuracy and diagnostic odds ratios (OR) were calculated. Moreover, the number needed to get a false positive (NN_{FP}) and a false negative (NN_{FN}) test were determined and reported, as well as their 95% confidence interval (95% CI). To avoid infinite values in the diagnostic accuracy tests, Haldane-Anscombe correction was carried out. Missing data were excluded from the analysis and a two-tailed test was performed for all statistical analysis.

Objective 2: Construct validity. Relationships between health-related outcomes (socioeconomic status, education level, smoking habit, polypharmacy, self-perceived health, comorbidities, depression, falls and hospitalization) in those participants categorized with both syndromes according to the index test compared to their healthy counterpart were assessed using unadjusted and adjusted logistic regression analyses for age, sex, and BMI. The OR and their 95% CI were calculated. A unidirectional approach (one-tail) was performed for all statistical analysis.

Results

Participants characteristics

A total of 775 individuals took part in this study. Among them, a total of 59 individuals were excluded due to a potential risk of dementia (Mini-Cog < 3 points) and 17 individuals were excluded due to an implanted electronic device. Furthermore, a total of 10 individuals were excluded from data analysis due to the lack of essential data (i.e. femur length and circumference measurements), and three individuals were lost due to unintentional video deleted. Thus, a total of 406 women and 280 men were finally included.

According to the Fried's frailty phenotype, participants were classified as frail 3.1% ($n = 21$), prefrail 35.3% ($n = 242$), and robust 61.6% ($n = 423$). The EWGSOP2 criteria diagnosed sarcopenia_{5STS + ASM} in a total of 11.1% ($n = 76$) and sarcopenia_{5STS + SMI} in a total of 6.1% ($n = 42$) participants. Finally, the prevalence of both syndromes, i.e. people categorized as frail or prefrail plus sarcopenia was in a range from 2.9% to 7.2% depending on the diagnosis criteria used for sarcopenia assessment. Detailed information about sample characteristics is reported in Table 1. No serious adverse events were reported performing neither the index test nor the reference standards, but some participants hit their head against the wall when sitting down during the 5STS test because the chair was placed next to the wall.

Objective 1: diagnostic accuracy

After a set of multiple regression equations, muscle power and calf circumference represented the best-explained model to detect both syndromes compared to either condition alone

and healthy participants (Supplementary Material, Table S1). Therefore, these predictive equations were integrated into the App to assess their diagnostic accuracy (Figure 1).

Our sensitivity analysis showed that the App discriminated the simultaneous presence of both syndromes with AUC values from 0.74 (95% CI: 0.63–0.86) to 0.88 (95% CI: 0.78–0.93) compared to either condition alone, i.e. frail, prefrail or sarcopenic individuals. As expected, the ability to detect the presence of both syndromes compared to healthy individuals (robust or non-sarcopenic) improved with AUC values from 0.84 (95% CI: 0.73–0.94) to 0.96 (95% CI: 0.84–0.99) (Table 2). However, when the App was used to discriminate between both syndromes to those classified with either condition alone and healthy individuals, the AUC values ranged from 0.80 (95% CI: 0.70–0.91) to 0.92 (95% CI: 0.88–0.96). These results showed sensitivity values in a range of 75% to 100% and specificity values in a range of 81.7% to 87.2% depending on the diagnostic criteria used to determine sarcopenia (Table 3). From each 100 individuals tested, a range from 13 to 17 individuals could get a false positive test whereas a range from 0 to 2 individuals could get a false negative test. Additional information about diagnostic performance of the App is shown in Table 3. Cross-tabulations of the index test and the reference standards of sarcopenia can be found in Supplementary Material, Table S2.

Objective 2: construct validity

The presence of both syndromes in combination as detected by the App showed relationships with several health-related outcomes regardless of the diagnostic criteria used to determine sarcopenia. Concretely, in our adjusted analysis participants diagnosed with both frailty or prefrailty plus sarcopenia_{5STS + ASM} syndromes showed an increased odds to present low educational levels (OR: 2.29; 95% CI: 1.27–4.14), low socioeconomic level (OR: 2.35; 95% CI: 1.13–4.89), comorbidity (OR: 4.30; 95% CI: 1.69–10.96), smoking habit (OR: 2.73; 95% CI: 1.18–6.33), polypharmacy (OR: 5.00; 95% CI: 2.73–9.15), depression (OR: 4.56; 95% CI: 2.45–8.49), poor self-perceived health (OR: 6.39; 95% CI: 3.50–11.69), falls (OR: 2.35; 95% CI: 1.16–4.76), and hospitalization (OR: 2.84; 95% CI: 1.38–5.84), compared to their healthy counterpart. Similar relationships were observed for those participants categorized by the App with the presence of both frailty or prefrailty plus sarcopenia_{5STS + SMI} syndromes, but with the exception of the socioeconomic level and smoking habit. Detailed results are shown in Table 4.

Discussion

This study aimed to validate a video analysis App based on sit-to-stand kinetic and anthropometric data to detect community-dwelling older adults diagnosed with both frailty

Table 1. Sample characteristics (n = 686).

Outcome	Women	Men
n of participants (%)	406 (59.2)	288 (40.8)
Age (years)	71 (68–75)	72 (68–76)
Weight (kg)	66.4 (59.6–73.2)	79.3 (71.6–88.5)
Height (m)	1.55 (1.51–1.59)	1.68 (1.64–1.72)
BMI (kg/m ²)	27.4 (24.4–30.1)	28.1 (25.8–31.2)
ASM (kg)	14.4 (13.2–15.7)	20.1 (18.7–22.3)
SMI (kg/m ²)	5.9 (5.5–6.4)	7.2 (6.7–7.7)
MUA circumference (m)	0.29 (0.27–0.31)	0.29 (0.28–0.31)
Calf circumference (m)	0.36 (0.34–0.38)	0.37 (0.35–0.39)
Femur length (m)	0.36 (0.34–0.38)	0.39 (0.36–0.40)
Handgrip strength (kg)	22.6 (19.9–25.5)	37.8 (32.5–41.5)
4 m Usual Gait Speed (m/s)	3.3 (2.9–3.9)	3.3 (2.9–3.9)
5STS (s)	12.1 (10.6–14.1)	12.2 (10.7–14.2)
<i>Sit To Stand App variables</i>		
Mean time (sec)	0.7 (0.1)	0.6 (0.1)
Mean power (W/kg)	5.0 (1.1)	5.8 (1.0)
Robust (%)	256 (63.0)	167 (59.6)
Prefrail (%)	139 (34.2)	103 (36.8)
Frail (%)	11 (2.7)	10 (3.6)
Sarcopenia _{5STS + ASM} (%)	46 (11.3)	30 (10.7)
Sarcopenia _{5STS + SMI} (%)	18 (4.4)	24 (8.6)
Frail or prefrail plus sarcopenia _{5STS + ASM} (%)	28 (6.9)	22 (7.8)
Frail or prefrail plus sarcopenia _{5STS + SMI} (%)	8 (1.9)	12 (4.3)
<i>Physical activity levels (%)</i>		
<i>Physically active</i>	384 (94.6)	238 (85.0)
<i>Sedentary</i>	22 (5.4)	42 (15.0)

Continuous variables are shown as means and standard deviations or median and interquartile range due to non-normal distribution, while categorical variables are shown as absolute frequencies and percentages. BMI: Body mass index; MUA: Mid-upper arm; ASM: Appendicular skeletal muscle mass; SMI: Skeletal muscle index; 5STS: 5 times sit-to-stand test.

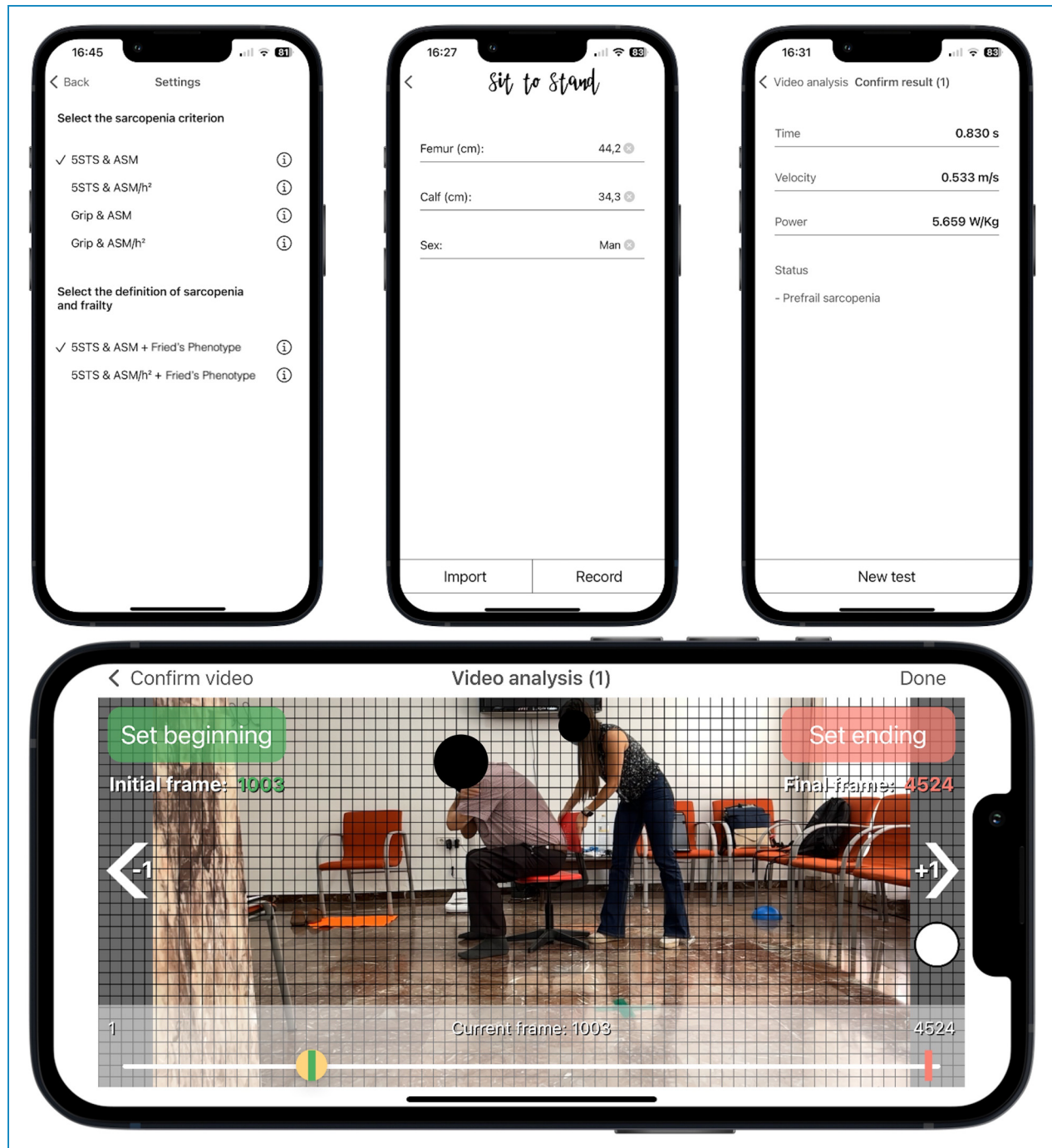


Figure 1. User interface of the *Sit to Stand* App running on an iPhone 13. Top left panel: Settings for selecting the different criteria proposed by the EWSGOP2 guideline. Top middle panel: Participant characteristic required by the App. Top right panel: Results from the App after video analysis. Horizontal panel: Video analysis at 240 frames-per-second selecting the first frame corresponding to the beginning of the rising phase, when the white dot crosses the first horizontal grip line on the screen. Example for a men diagnosed with both syndromes by the App with femur length 0.442 m and calf circumference of 0.343 m.

or prefrailty plus sarcopenia syndromes. In general, the App demonstrated excellent to outstanding ability (AUC range: 0.80–0.92) to discriminate both syndromes from their respective counterparts, regardless the diagnostic criteria used for sarcopenia assessment. Additionally, the simultaneous presence of

both syndromes detected by our index test was associated with an increased odds of adverse health-related outcomes such as polypharmacy, comorbidities, smoking habit depression, poor self-perceived health, falls, hospitalization, as well as low educational attainment and socioeconomic status.

Table 2. Sensitivity analysis of the Sit to Stand App to detect both syndromes compared to either condition alone and compared to healthy individuals.

Both syndromes	Either condition alone (n = 239)	Healthy individuals (n = 397)
Prefrail or frail plus sarcopenia _{5STS + ASM} (n = 50)		
Women	0.74 (0.63–0.86)	0.84 (0.73–0.94)
Men	0.88 (0.81–0.95)	0.95 (0.90–0.99)
	Either condition alone (n = 260)	Healthy individuals (n = 406)
Prefrail or frail plus sarcopenia _{5STS + SMI} (n = 20)		
Women	0.82 (0.70–0.94)	0.92 (0.81–1.00)
Men	0.86 (0.78–0.93)	0.96 (0.84–0.99)

Either condition alone is referred to frail, prefrail or sarcopenic people, whereas healthy individuals are referred to non-sarcopenic or robust people. Data are reported as area under the curve with their 95% confidence interval. 5STS: 5 times sit-to-stand test; ASM: Appendicular skeletal muscle mass; SMI: Skeletal muscle index.

Table 3. Sit to Stand App diagnostic accuracy to detect both syndromes compared to either condition alone plus healthy (n = 686).

Diagnostic accuracy	Women (n = 406)		Men (n = 280)	
	Prefrail or frail individuals plus		Prefrail or frail individuals plus	
	Sarcopenia _{ASM + 5STS}	Sarcopenia _{SMI + 5STS}	Sarcopenia _{ASM + 5STS}	Sarcopenia _{SMI + 5STS}
Cut-off point	0.090779	0.0258324	0.1052374	0.0469779
AUC	0.80 (0.70–0.91)	0.89 (0.79–1.00)	0.92 (0.87–0.97)	0.92 (0.88–0.96)
Sensitivity	75.0 (55.1–89.3)	87.5 (47.4–99.7)	95.5 (77.2–99.9)	100 (73.5–100)
Specificity	86.0 (82.1–89.3)	87.2 (83.5–90.3)	86.4 (81.6–90.4)	81.7 (76.6–86.2)
Accuracy	85.2 (81.4–88.5)	87.2 (83.6–90.3)	87.1 (82.7–90.8)	82.5 (77.5–86.8)
PLR	5.3 (3.8–7.4)	6.8 (4.7–9.8)	7.0 (5.1–9.7)	5.5 (4.2–7.1)
NLR	0.29 (0.15–0.55)	0.1 (0.1–0.9)	0.1 (0.1–0.3)	0.0 (0.0–0.2) ^a
PPV	28.4 (22.2–35.5)	12.1 (8.7–16.5)	37.5 (30.3–45.3)	19.7 (16.0–24.0)
NPV	97.9 (96.1–98.9)	99.7 (98.2–100)	99.6 (97.0–99.9)	100 (97.8–100)
DOR	18.4 (7.4–45.4)	47.6 (5.7–395.1)	133.8 (17.4–1026.4)	110.8 (6.4–1904.1) ^a
NN _{FP} (1:100)	13.1 (9.8–16.3)	12.6 (9.3–15.8)	12.5 (8.6–16.4)	17.5 (13.0–21.9)
NN _{FN} (1:100)	1.7 (0.5–3.0)	0.2 (0–0.7)	0.4 (0–1.1)	0.2 (0–0.7) ^a

Diagnostic accuracy parameters are presented as percentages; 95% confidence interval can be observed between parentheses. ASM: Appendicular skeletal muscle mass; SMI: Skeletal muscle index; 5STS: 5 times sit-to-stand test; AUC: Area under the curve; PLR: Positive likelihood ratio; NLR: Negative likelihood ratio; PPV: Positive predictive value; NPV: Negative predictive value; DOR: Diagnostic odds ratio; NN_{FP}: Number needed to get a false positive; NN_{FN}: Number needed to get a false negative. ^aHaldane-Anscombe correction. Cut-off points are based on predictive probability.

Table 4. Construct validity. Risk factors for both syndromes detected by the Sit to Stand App compared to their healthy counterpart.

			Prefrail or frail individuals plus		Prefrail or frail individuals plus	
			Sarcopenia _{5STS} + ASM		Sarcopenia _{5STS} + SMI	
Risk factors		(n)	OR (95% CI)	Adjusted	OR (95% CI)	Adjusted
Education level	High level	356				
	Low level	319	3.52 (2.04–6.07)*	2.29 (1.27–4.14)*	4.14 (1.74–9.84)*	2.98 (1.13–7.80)*
Socioeconomic level	High level	545				
	Low level	97	2.77 (1.47–5.22)*	2.35 (1.13–4.89)*	1.13 (0.32–4.01)	0.78 (0.18–3.40)
Comorbidities	< 2 pathologies	314				
	≥ 2 pathologies	372	4.52 (1.88–10.86)*	4.30 (1.69–10.96)*	3.47 (1.00–11.98)*	3.91 (1.02–14.96)*
Smoking habit	Not smoking	611				
	Smoking	74	1.31 (0.86–2.68)	2.73 (1.18–6.33)*	1.45 (0.50–4.19)	1.80 (0.53–6.14)
Polypharmacy	< 5 drugs	538				
	≥ 5 drugs	145	6.09 (5.60–10.30)*	5.00 (2.73–9.15)*	6.48 (2.99–14.05)*	6.65 (2.47–17.88)*
Self-perceived health	High level	553				
	Low level	133	6.41 (3.78–10.86)*	6.39 (3.50–11.69)*	7.12 (3.28–15.48)*	9.60 (3.62–25.40)*
Depression	Not depressed	557				
	Depressed	129	4.92 (2.85–8.49)*	4.56 (2.45–8.49)*	4.21 (1.87–9.50)*	4.16 (1.60–10.82)*
Falls last year	< 2 falls	599				
	≥ 2 falls	85	2.50 (1.34–4.68)*	2.35 (1.16–4.76)*	3.03 (1.24–7.40)*	3.16 (1.04–9.60)*
Hospitalization	Not hospitalized	594				
	Hospitalized	90	1.34 (1.80–6.21)*	2.84 (1.38–5.84)*	5.69 (2.50–12.98)*	3.20 (1.16–8.84)*

ASM: Appendicular skeletal muscle mass; SMI: Skeletal muscle index; 5STS: 5 times sit-to-stand test; OR: Odds ratio; CI: Confidence interval. Adjusted OR for age, sex, and body mass index. Statistical significance at an alpha level of 0.05 is represented by asterisks (* $P < .05$).

Nowadays, different options to screening for sarcopenia or frailty are available in ordinary clinical practice. Concretely, the EWGSOP2 recommends the use of SARC-F screening tool for the detection of possible cases of sarcopenia, representing an inexpensive and accessible method.¹ However, despite the good reliability, a recent systematic review and meta-analysis from 29 studies ($n = 21,855$ participants) recommends to apply the diagnostic criteria without screening because the SARC-F showed low to moderate sensitivity (29%–55%) which could lead to a high rate of false negative results.³¹ Similarly, the SARC-F has been suggested as a possible option to detect frailty in older adults. However,

in spite of the excellent specificity values observed (92.6%), this screening tool may not be suitable due to its low sensitivity (46.2%).³² Other more sophisticated instruments have been used in a research context for analyzing kinetic and kinematic variables derived from functional test. Vertical velocity, power and impulse obtained during the sit-to-stand test using inertial measurement units demonstrated excellent discriminatory capacity to distinguish among robust, prefrail, and frail individuals ($AUC > 93\%$).¹⁵ Similarly, vertical ground reaction force during the sit-to-stand test using a force plate was able to discriminate between sarcopenic and non-sarcopenic individuals with

AUC values of 87.9% and 84.4% for men and women, respectively.³³ However, these studies employed expensive and/or time-consuming technologies, which requires of technical competence for data analysis, representing a potential barrier for its implementation in clinical practice. Our results were similar to those reported in previous studies (AUC range: 80–92%) but providing an affordable and easy-to-use App for detecting the combined presence of both syndromes with the advantage of overcoming the aforementioned issues. This tool consisted in an updated version of a previous validated App based on muscle power values but adding calf circumference anthropometric measured.^{17,18} Mid-upper arm circumference has been observed to be a reliable alternative to muscle mass for sarcopenia diagnosis, as well as an important predictor of frailty.^{22,34} However, previous studies claimed that calf circumference could be a better marker of muscle mass than mid-upper arm circumference, since fat deposits in this body area are less likely than other regions.²⁰ These findings could explain the reason why calf circumference plus muscle power represented the best-explained model for detecting both syndromes in our study. Muscle power was shown to be a strong predictor of mortality, independently of muscle strength, muscle mass, and physical activity levels.³⁵ Similarly, calf circumference has been independently associated to an elevated risk of mortality at 9 years of follow-up.³⁶ These findings highlight the use of these variables integrated into a simple smartphone App for routine evaluation in a clinical setting.

The term sarcopenia has usually been used as a synonym of physical frailty probably because they share diagnostic criteria. Since there is no an established gold standard to detect both conditions simultaneously, the diagnostic ability of our App was tested against the most employed diagnostic tools, the EWGSOP2 recommendations and the Fried's frailty phenotype. Both tools use handgrip strength to determine muscle weakness as diagnostic criterion in their definition. Since the cut-off points established in sarcopenia assessment are lower than the ones established in frailty, a subject diagnosed with probable sarcopenia would automatically be categorized as prefrail, leading to an overlap between these two syndromes. Thus, in order to avoid a misleading overlap between conditions, the 5STS test was used in our study for muscle strength assessment in sarcopenia diagnosis. Additionally, two definitions of sarcopenia were used in our study because it has been recently reported that there is scarce overlap when sarcopenia is confirmed by a reduction in ASM or SMI, i.e. nearly 50% people diagnosed as sarcopenic_{5STS + ASM} were categorized as non-sarcopenic using the sarcopenia_{5STS + SMI} criterion.³⁷ In spite of this, the App reported good to excellent accuracy values (82.5%–87.2%) to identify the simultaneous presence of both syndromes regardless the definition used for sarcopenia diagnosis. The low PPV observed (12.1%–37.5%) could be influenced by the low prevalence rate (2.9%–7.2%) found in our study. This could be probably due to the fact that subjects

were enrolled from elderly social centers in which physical activity is highly promoted. In fact, 85% of men and almost 95% of women were categorized as physically active. A recent systematic review observed that physical activity could take an essential role in the prevention of both frailty and sarcopenia syndromes.³⁸ Even though these results seem not to differ from the ones of other screening tools employed for the identification of either sarcopenia or frailty alone in community-dwelling older adults.^{31,39} The NPV observed was excellent (97.5%–100%), indicating that this tool is very suitable to rule out the presence of both syndromes in community-dwelling older adults. This is supported by the low number needed to detect a false negative which ranged from 0% to 1.7%, i.e. in the worst-case scenario, for each 100 individuals analyzed with this App only 2 of them could get a false negative test. Additionally, our sensitivity analysis supported the notion that this App was capable to ascertain the presence of both syndromes compared to those participants categorized with either condition alone (frails, prefrails, or sarcopenic) (AUC range: 0.74–0.88) or compared to those participants categorized as healthy (robust or non-sarcopenic) (AUC range: 0.84–0.96). Therefore, these findings confirm that our analyses are not influenced by the presence of healthy individuals with extreme values of predictive probability.

Furthermore, participants identified with both syndromes by the App showed an increased odds for adverse health-related outcomes like falls, hospitalization, depression, polypharmacy, comorbidities, smoking habit, poor self-perceived health, as well as low educational and socioeconomic level compared to their healthy counterpart. These results are not surprising since previous studies have reported an increased risk of adverse outcomes such as falls, increased disability, or even threefold of mortality risk in those classified with both syndromes compared to their healthy counterparts.^{9,10,40} These results stress out the important consequences of the combination of sarcopenia and frailty for older adults' health. This App may provide clinicians the opportunity to early detect frailty or prefrailty plus sarcopenia syndromes, and especially to exclude their simultaneous presence, with the advantage of being an easy, affordable, and efficient tool.

This study is not without limitations. First, this was a retrospective diagnostic study, so its external validity is limited. However, this study represents the basis for future prospective validations. Additionally, participants' muscle mass was assessed through bioelectrical impedance analysis, which is a reliable tool but not the gold standard for muscle mass measurement. However, as recommended by the EWGSOP2 guideline, Sergi's cross-validated equation was used in order to overcome this issue.^{1,29} Last, the index test was associated with adverse health-related outcomes, but these outcomes were recorded in the form of self-reported questionnaire, and the cross-sectional nature of the study design do not allow causal relationship among variables.

Conclusions

The updated version of the *Sit to Stand App* combining muscle power and calf circumference seems to be a reliable tool to detect and rule out the simultaneous presence of frailty or prefrailty plus sarcopenia syndromes in Spanish community-dwelling older adults. Moreover, individuals identified by the App were more likely to present health-related risk factors compared to their healthy counterpart. Further studies are needed to independently evaluate the external validity of this App in community-dwelling older adults.

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References

1. Cruz-Jentoft AJ, Bahat G, Bauer J, et al. Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing* 2019; 48: 16–31.
2. Ma L. Current situation of frailty screening tools for older adults. *J Nutr Health Aging* 2019; 23: 111–118.
3. Kojima G, Liljas AEM and Iliffe S. Frailty syndrome: implications and challenges for health care policy. *Risk Manag Healthc Policy* 2019; 12: 23–30.
4. Collard RM, Boter H, Schoevers RA, et al. Prevalence of frailty in community-dwelling older persons: a systematic review. *J Am Geriatr Soc* 2012; 60: 1487–1492.
5. Petermann-Rocha F, Balntzi V, Gray SR, et al. Global prevalence of sarcopenia and severe sarcopenia: a systematic review and meta-analysis. *J Cachexia Sarcopenia Muscle* 2022; 13: 86–99.
6. Fried LP, Tangen CM, Walston J, et al. Frailty in older adults: evidence for a phenotype. *J Gerontol A Biol Sci Med Sci* 2001; 56: M146–M156.
7. Álvarez-Bustos A, Carnicero-Carreño JA, Davies B, et al. Role of sarcopenia in the frailty transitions in older adults: a population-based cohort study. *J Cachexia Sarcopenia Muscle* 2022; 13: 2352–2360.
8. Davies B, García F, Ara I, et al. Relationship between sarcopenia and frailty in the Toledo study of healthy aging: a population based cross-sectional study. *J Am Med Dir Assoc* 2018; 19: 282–286.
9. Davies B, Walter S, Rodríguez-Laso A, et al. Differential association of frailty and sarcopenia with mortality and disability: insight supporting clinical subtypes of frailty. *J Am Med Dir Assoc* 2022; 23: 1712–1716.e3.
10. Thompson MQ, Yu S, Tucker GR, et al. Frailty and sarcopenia in combination are more predictive of mortality than either condition alone. *Maturitas* 2021; 144: 102–107.
11. Offord NJ, Clegg A, Turner G, et al. Current practice in the diagnosis and management of sarcopenia and frailty – results from a UK-wide survey. *J Frailty Sarcopenia Falls* 2019; 4: 71–77.
12. Bruyère O, Buckinx F, Beaudart C, et al. How clinical practitioners assess frailty in their daily practice: an international survey. *Aging Clin Exp Res* 2017; 29: 905–912.
13. Reid KF, Pasha E, Doros G, et al. Longitudinal decline of lower extremity muscle power in healthy and mobility-limited older adults: influence of muscle mass, strength, composition, neuromuscular activation and single fiber contractile properties. *Eur J Appl Physiol* 2014; 114: 29–39.
14. Skelton DA, Greig CA, Davies JM, et al. Strength, power and related functional ability of healthy people aged 65–89 years. *Age Ageing* 1994; 23: 371–377.
15. Millor N, Lecumberri P, Gomez M, et al. Gait velocity and chair sit-stand-sit performance improves current frailty-status identification. *IEEE Trans Neural Syst Rehabil Eng Publ IEEE Eng Med Biol Soc* 2017; 25: 2018–2025.
16. Zech A, Steib S, Sportwiss D, et al. Functional muscle power testing in young, middle-aged, and community-dwelling nonfrail and prefrail older adults. *Arch Phys Med Rehabil* 2011; 92: 967–971.
17. Orange ST, Metcalfe JW, Liefteith A, et al. Validity of various portable devices to measure sit-to-stand velocity and power in older adults. *Gait Posture* 2020; 76: 409–414.
18. Ruiz-Cárdenas JD, Rodríguez-Juan JJ, Smart RR, et al. Validity and reliability of an iPhone App to assess time, velocity and leg power during a sit-to-stand functional performance test. *Gait Posture* 2018; 59: 261–266.
19. Ruiz-Cárdenas JD, Montemurro A, Del Mar Martínez-García M, et al. Concurrent and discriminant validity and reliability

- of an Android App to assess time, velocity and power during sit-to-stand test in community-dwelling older adults. *Aging Clin Exp Res* 2023; 35: 1631–1640.
20. Santos LP, Gonzalez MC, Orlandi SP, et al. New prediction equations to estimate appendicular skeletal muscle mass using calf circumference: results from NHANES 1999–2006. *JPEN J Parenter Enteral Nutr* 2019; 43: 998–1007.
 21. Landi F, Onder G, Russo A, et al. Calf circumference, frailty and physical performance among older adults living in the community. *Clin Nutr Edinb Scotl* 2014; 33: 539–544.
 22. Hu FJ, Liu H, Liu XL, et al. Mid-upper arm circumference as an alternative screening instrument to appendicular skeletal muscle mass Index for diagnosing sarcopenia. *Clin Interv Aging* 2021; 16: 1095–1104.
 23. Rose Berlin Piodena-Aportadera M, Lau S, Chew J, et al. Calf circumference measurement protocols for sarcopenia screening: differences in agreement, convergent validity and diagnostic performance. *Ann Geriatr Med Res* 2022; 26: 215–224.
 24. Reijnierse EM, de van der Schueren MAE, Trappenburg MC, et al. Lack of knowledge and availability of diagnostic equipment could hinder the diagnosis of sarcopenia and its management. *PLoS One* 2017; 12: e0185837.
 25. Yeung SSY, Reijnierse EM, Trappenburg MC, et al. Current knowledge and practice of Australian and New Zealand health-care professionals in sarcopenia diagnosis and treatment: time to move forward!. *Australas J Ageing* 2020; 39: e185–e193.
 26. Guralnik JM, Cawthon PM, Bhasin S, et al. Limited physician knowledge of sarcopenia: a survey. *J Am Geriatr Soc* 2023; 71: 1595–1602.
 27. Taylor JK, Fox J, Shah P, et al. Barriers to the identification of frailty in hospital: a survey of UK clinicians. *Future Healthc J* 2017; 4: 207–212.
 28. Montemurro A, Ruiz-Cárdenas JD, Martínez-García MDM, et al. Validity of an iPhone app to detect prefrailty and sarcopenia syndromes in community-dwelling older adults: the protocol for a diagnostic accuracy study. *Sensors* 2022; 22: 6010.
 29. Sergi G, De Rui M, Veronese N, et al. Assessing appendicular skeletal muscle mass with bioelectrical impedance analysis in free-living Caucasian older adults. *Clin Nutr Edinb Scotl* 2015; 34: 667–673.
 30. Bujang MA and Adnan TH. Requirements for minimum sample size for sensitivity and specificity analysis. *J Clin Diagn Res JCDR* 2016; 10: YE01–YE06.
 31. Voelker SN, Michalopoulos N, Maier AB, et al. Reliability and concurrent validity of the SARC-F and its modified versions: a systematic review and meta-analysis. *J Am Med Dir Assoc* 2021; 22: 1864–1876.e16.
 32. Bahat G, Ozkok S, Kilic C, et al. SARC-F questionnaire detects frailty in older adults. *J Nutr Health Aging* 2021; 25: 448–453.
 33. Kera T, Kawai H, Takahashi J, et al. Development of a screening formula for sarcopenia using ground reaction force during sit-to-stand motion. *Gait Posture* 2022; 93: 177–182.
 34. Valdivieso R, Azevedo LF, Moreira E, et al. Frailty phenotype and associated nutritional factors in a sample of Portuguese outpatients with heart failure. *Nutr Metab Cardiovasc Dis NMCD* 2021; 31: 2391–2397.
 35. Metter EJ, Talbot LA, Schrager M, et al. Arm-cranking muscle power and arm isometric muscle strength are independent predictors of all-cause mortality in men. *J Appl Physiol Bethesda Md* 1985 2004; 96: 814–821.
 36. Fernandes DdS, Juvanhol LL, Lozano M, et al. Calf circumference is an independent predictor of mortality in older adults: An approach with generalized additive models. *Nutr Clin Pract* 2022; 37: 1190–1198.
 37. Montemurro A, Ruiz-Cárdenas JD, Martínez-García MDM, et al. Consequences of applying the different criteria of the EWGSOP2 guideline for sarcopenia case-finding in Spanish community-dwelling older adults. *Arch Gerontol Geriatr* 2023; 109: 104964.
 38. Oliveira JS, Pinheiro MB, Fairhall N, et al. Evidence on physical activity and the prevention of frailty and sarcopenia among older people: a systematic review to inform the world health organization physical activity guidelines. *J Phys Act Health* 2020; 17: 1247–1258.
 39. Clegg A, Rogers L and Young J. Diagnostic test accuracy of simple instruments for identifying frailty in community-dwelling older people: a systematic review. *Age Ageing* 2015; 44: 148–152.
 40. Mori H and Tokuda Y. Differences and overlap between sarcopenia and physical frailty in older community-dwelling Japanese. *Asia Pac J Clin Nutr* 2019; 28: 157–165.

IX – RESULTADOS GLOBALES Y DISCUSIÓN

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Los objetivos de esta tesis doctoral fueron (i) publicar un protocolo de estudio sobre la validez de una aplicación móvil para detectar la presencia de prefragilidad y sarcopenia en ancianos residentes en la comunidad; (ii) desarrollar y validar una aplicación móvil para dispositivos Android para medir la velocidad, el tiempo y la potencia generadas en el gesto de levantarse de la silla, así como determinar su fiabilidad y capacidad discriminativa; (iii) analizar la prevalencia de sarcopenia según los criterios diagnósticos empleados, al igual que los factores de riesgo relacionados y su grado de acuerdo, y también su asociación con factores de riesgo relacionados con la salud en ancianos residentes en la comunidad; (iv) determinar la validez de una aplicación móvil capaz de detectar la sarcopenia, además de analizar su validez de constructo con variables relacionadas con la salud en ancianos residentes en la comunidad; (v) desarrollar y validar una aplicación móvil para detectar la presencia simultánea de prefragilidad y sarcopenia, así como analizar su validez de constructo con variables relacionadas con la salud en ancianos residentes en la comunidad.

Objetivo 1: Publicación de un protocolo de estudio.

La red EQUATOR (*Enhancing the QUALity and Transparency Of health Research*) es una iniciativa internacional dirigida a mejorar la fiabilidad y el valor de los artículos publicados en el ámbito sanitario, mediante la promoción de guías transparentes y precisas sobre el reporte adecuado de la información en los estudios científicos (Simera et al., 2009). En el año 2003 esta organización propuso una guía de reporte adecuado de la información para estudios de validez diagnóstica llamada STARD (*Standards for Reporting of Diagnostic Accuracy Studies*) con el objetivo de mejorar la exhaustividad y la transparencia del reporte de la información en los estudios de validez diagnóstica (Bossuyt et al., 2003). En su versión actualizada del año 2015, en el ítem 28 (*Número y nombre del registro*) se recomienda llevar a cabo un registro previo del protocolo de estudio en bases de datos internacionales como ClinicalTrials.gov, o en las que pertenecen a la Organización Mundial para la Salud, con el objetivo de permitir la identificación de los estudios que se están llevando a cabo en una área de investigación

determinada (Cohen et al., 2016). El registro y publicación de un protocolo de investigación representa además un signo de calidad y de transparencia de un estudio (Cohen et al., 2016; Ohtake & Childs, 2014). Los protocolos de estudio proporcionan una información minuciosa sobre la metodología empleada, que no suele incluirse en el estudio final debido a aspectos inherentes a la política de las revistas como el número limitado de palabras (Cohen et al., 2016). Además, los protocolos de estudios permiten establecer de forma temprana cuáles serán los objetivos del estudio, así como su rigor científico, impidiendo de esta forma la publicación de trabajos de investigación duplicados (S. Y. Kim, 2022; Ohtake & Childs, 2014; Uppstad & McTigue, 2020). Finalmente, la publicación de un protocolo de estudio permite evitar los sesgos de publicación y de reporte selectivo de datos (S. Y. Kim, 2022). Dichos sesgos representan un problema dentro de la literatura biomédica y su presencia ha sido detectada con frecuencia en estudios de tipo observacional, incluso con más frecuencia que en estudios de tipo experimental (Rifai et al., 2008).

En el estudio de Chan y colaboradores (2004), que analizó la presencia y la naturaleza del sesgo de la notificación selectiva de datos, se observó que en el 62% de los estudios incluidos se detectaron inconsistencias en el reporte de al menos una variable de estudio con respecto al protocolo original registrado previamente. Sorprendentemente, el 86% de los participantes entrevistados negó haber omitido informaciones a pesar de la clara evidencia de lo contrario. De forma parecida, el estudio de Wong y colaboradores (2019) determinó la frecuencia con la que se mencionaron los eventos adversos derivados de la aplicación de las intervenciones propuestas en los ensayos clínicos, comparándolas con sus respectivos protocolos. Se observó que el 19,4% de los estudios incluidos tuvieron inconsistencias relacionadas con el reporte de eventos adversos serios con respecto a los protocolos de investigación, destacando de esta manera la necesidad de un registro previo de los protocolos de estudio.

El reporte selectivo de los resultados de una investigación tiene como consecuencia la posible estimación errónea del efecto real de una intervención o de la verdadera precisión de una prueba diagnóstica (Rifai et al., 2008; Rutjes et al., 2006). Esto podría desembocar en decisiones inapropiadas por parte del personal

sanitario, implicando un posible daño para los pacientes y un gasto de recursos sanitarios innecesario (McGauran et al., 2010).

En el estudio de Levis (2017) se llevó a cabo un metanálisis para determinar el impacto del reporte selectivo de los puntos de corte de la escala de depresión *Patient Health Questionnaire-9* sobre las puntuaciones de sensibilidad y especificidad en distintos estudios. Concretamente, se observó que cuando los puntos de corte reportados fueron los que tuvieron el mejor rendimiento en cada estudio individual, los valores de sensibilidad fueron de entre el 5% y el 15% mayores que los valores obtenidos empleando un punto de corte estándar indicado por la literatura científica. Del mismo modo, en el estudio de Peters y colaboradores (2008), se determinó el efecto del reporte selectivo de estimaciones de riesgo ajustadas sobre el riesgo de sufrir eventos adversos en estudios observacionales. El reporte selectivo de las estimaciones de riesgo ajustadas es un tipo de sesgo que ocurre cuando los autores reportan estimaciones de riesgo ajustadas por las variables de confusión solamente cuando estas alcanzan la significación estadística o una gran efecto (Peters & Mengersen, 2008). Para determinar su presencia, los autores compararon las estimaciones de riesgo obtenidas ajustando por factores de confusión con las estimaciones de riesgo de análisis no ajustado, en el que no se tuvieron en cuenta estos factores. Se observó que cuando las estimaciones de riesgo reportadas se ajustaron selectivamente el riesgo fue del 61% mayor con respecto a los valores de riesgo no ajustado, desembocando en una sobreestimación del mismo (OR: 1,3; IC 95%: 0,7–2,4 vs OR: 2,1; IC 95%: 1,7–2,5).

Con el objetivo de asegurar la máxima transparencia posible, se llevó a cabo el registro del protocolo del primer estudio de esta tesis doctoral en la base de datos *ClinicalTrial.gov* (NCT05148351) y su difusión en formato artículo científico en una revista académica indexada en *Journal Citation Report*. Tras la publicación del protocolo de investigación, así como tras la obtención del permiso por parte del comité ético para llevar a cabo el estudio (véase Anexo 1 y Anexo 2), se pudo proceder al reclutamiento de los sujetos de estudio en los centros sociales de mayores de la Región de Murcia. Se recopilaron datos de un total de 775 personas (451 mujeres y 324 hombres) relativos a las características antropométricas, así como de su estado cognitivo y funcional (Anexo 3).

Objetivo 2: Desarrollo y validación de una aplicación móvil replicada para Android.

El segundo objetivo de esta tesis doctoral consistió en determinar la validez de una aplicación para usuarios con dispositivos móviles con sistema operativo Android llamada *Sit to Stand* para medir los valores de tiempo, velocidad y potencia generados durante un test de levantarse de una silla, utilizando como prueba de referencia la versión de la misma aplicación validada para dispositivos Apple (Orange et al., 2020; Ruiz-Cárdenas et al., 2018). Si bien la plataforma Android cuenta con más aplicaciones que la plataforma iOS (3,5 millones vs 1,6 millones) (*Biggest App Stores in the World 2022*, Statista), casi el 90% de las aplicaciones relacionadas con el ámbito de la salud pertenecen a la plataforma iOS (Dehling et al., 2015). Esto hace que la mayoría de las aplicaciones registradas en la plataforma de Apple podrían no estar disponibles para usuarios con un dispositivo con sistema operativo Android. Además, los sistemas operativos Android y iOS emplean sistemas para el desarrollo de aplicaciones muy diferentes entre sí, lo cual podría dar lugar a diferencias substanciales en términos de resultados observados entre ambas herramientas frente a un mismo procedimiento (Kubben, 2019). Por lo tanto, determinar la validez de una aplicación es fundamental para proporcionar al personal clínico con un móvil con sistema operativo Android una herramienta fiable.

En general, se observaron una asociación fuerte ($r > 0,9$), un grado de acuerdo excelente ($ICC_{2-1} > 0,9$) y un error de medida (MAPE) muy bajo ($\leq 5\%$) entre los valores de velocidad, tiempo y potencia calculados con ambos sistemas operativos. Esto indica que la aplicación para dispositivos Android es igual de fiable que la aplicación para dispositivos iOS para medir los valores de tiempo, velocidad y potencia generados en el test de levantarse de la silla. Adicionalmente, el MAPE observado en las medidas fue inferior al que se reportó en el estudio de Adamakis (2021), cuyo objetivo fue el de determinar la validez de criterio de cuatro aplicaciones diseñadas con el objetivo de medir los niveles de actividad física en dispositivos Android y iOS. En este caso, a pesar de un error extremadamente bajo observado en el cómputo de pasos total ($< 5\%$), el error observado en la distancia recorrida entre las cuatro aplicaciones fue bastante considerable ($> 10\%$). Los valores de error más elevados fueron observados en la aplicación Argus, en la que el MAPE fue del 18% para dispositivos móviles con sistema iOS, llegando hasta el

35% en dispositivos Android. Estos resultados nos indican que una misma aplicación validada en dispositivos iOS podría ser no válida en dispositivos Android, o viceversa, y por lo tanto se requiere de un proceso de validación antes de ser recomendada para su uso.

La aplicación *Sit to Stand* mostró excelentes niveles de concordancia inter e intra-observador ($ICC_{2-1} > 0,97$), así como una buena fiabilidad test-retest ($ICC_{2-1} > 0,86$) para los valores de tiempo, velocidad y potencia proporcionados por la aplicación Android. Los niveles de concordancia inter-observador detectados fueron parecidos a los niveles observados en el estudio de validación de la misma aplicación para dispositivos con sistema iOS ($ICC_{2-1} > 0,98$) para cada una de las variables analizadas (J. D. Ruiz-Cárdenas et al., 2018). Estos resultados sugieren que la facilidad de uso de la aplicación es equivalente entre los sistemas operativos y los resultados derivados de la aplicación *Sit to Stand* no se ven afectados por las diferencias entre los sistemas operativos Apple y Android.

Finalmente, los valores de tiempo, velocidad y potencia calculados mediante la aplicación *Sit to Stand* para dispositivos con sistema operativo Android tuvieron una capacidad de aceptable a excelente con valores de área bajo la curva (AUC) en un rango de 0,75 a 0,82, para discriminar entre ancianos residentes en la comunidad sanos y ancianos con sarcopenia, baja velocidad de marcha y baja función física. Estudios anteriores observaron como las variables derivadas del análisis biomecánico del gesto de levantarse de una silla se relacionaron con eventos adversos como caídas (Kera et al., 2020), o con patologías como la fragilidad y la sarcopenia en personas ancianas (Kera et al., 2022; Murao et al., 2023; Park et al., 2021). Sin embargo, en estos estudios se emplearon herramientas tecnológicas de alto coste como las plataformas de fuerza o sensores de movimiento, llevando a cabo minuciosos análisis que requieren de mucho tiempo y de un personal entrenado para lograr una adecuada interpretación, lo cual dificultaría su implementación en la práctica clínica. En este sentido, una herramienta económica, fácilmente asequible, con una interfaz sencilla y que no requiere de un adiestramiento previo como una aplicación para teléfonos inteligentes, podría facilitar su implementación en la práctica clínica. Adicionalmente, los valores derivados de esta aplicación para discriminar los sujetos sanos de aquellos con baja velocidad de marcha, función física y sarcopenia (AUC: 0,75–0,82) fueron similares

a los valores reportados en otras investigaciones en las que se emplearon valores derivados de un test de levantarse de la silla obtenidos mediante sensores inerciales para detectar una baja velocidad de marcha (AUC: 0,86) (Park et al., 2021), o valores de fuerza de reacción contra el suelo medidas con plataforma de fuerza para determinar la presencia de sarcopenia (AUC: 0,85–0,90) (Kera et al., 2022), siendo igual de fiable pero con la ventaja de emplear una herramienta sencilla y fácilmente disponible.

Objetivo 3: Prevalencia de sarcopenia según los criterios diagnósticos recomendados por el consenso europeo EWGSOP2.

Los resultados relativos a la capacidad de una herramienta para discriminar entre las personas con presencia de sarcopenia de sus respectivos sanos podrían depender de los diferentes criterios diagnósticos que la definen. De hecho, el consenso europeo EWGSOP2 propuso un listado de herramientas para determinar la presencia de sarcopenia en ancianos. Estas recomendaciones dan como resultado un total de cuatro definiciones operativas (Cruz-Jentoft et al., 2019). Teniendo en cuenta que no existe una recomendación clara sobre la definición operativa a emplear, establecer cuál de estas definiciones operativas es la más adecuada para determinar la presencia de sarcopenia resulta de vital importancia para que el diagnóstico de esta patología se lleve a cabo de manera eficaz. Por lo tanto, el objetivo del tercer estudio de esta tesis doctoral fue determinar la prevalencia de sarcopenia en función de las diferentes recomendaciones propuestas por el consenso europeo EWGSOP2, así como determinar qué consecuencias tienen esas definiciones operativas sobre variables relacionadas con la salud.

En nuestra muestra, la prevalencia de sarcopenia analizada osciló entre el 2,1% y el 11,6% en función del criterio diagnóstico empleado. Además, los porcentajes de prevalencia más elevados se obtuvieron cuando la sarcopenia fue definida según la fuerza de los miembros inferiores y la masa muscular apendicular en valores absolutos. Estos resultados estuvieron en línea con cuanto observado por Johansson y colaboradores (2020), quienes mostraron que la prevalencia de sarcopenia definida por la fuerza de miembros inferiores fue del doble que cuando se definió por la fuerza de agarre en un total de 3498 ancianos residentes en la comunidad. Esto podría deberse al hecho de que, durante el proceso de envejecimiento, existe una tendencia a perder una mayor cantidad de fuerza en los

miembros inferiores con respecto a los miembros superiores (Candow & Chilibeck, 2005). Sin embargo, esto no sería suficiente para definir la sarcopenia únicamente como unos bajos niveles de fuerza de miembros inferiores y de masa muscular apendicular. Para que esta situación se verifique son necesarias dos condiciones esenciales: en primer lugar, que esta definición operativa de sarcopenia permita detectar exactamente los mismos casos que se detectarían definiendo la sarcopenia según otros criterios y que, además, esta definición permita detectar el mayor número de casos de sarcopenia. En términos estadísticos, la primera condición requiere que el grado de acuerdo entre las diferentes definiciones de sarcopenia sea perfecto ($\kappa = 1$), indicando un solapamiento perfecto entre los criterios diagnósticos. Sin embargo, el grado de acuerdo entre las diferentes definiciones de sarcopenia encontrado en nuestro estudio osciló entre pobre y moderado ($\kappa = 0,13-0,66$), posiblemente debido a la escasa asociación que existe entre fuerza de miembros inferiores y superiores (Johansson et al., 2020). De hecho, cuando la sarcopenia se determinó utilizando el mismo criterio de masa muscular e intercambiando el criterio diagnóstico de la fuerza, se observó un grado de acuerdo bajo ($\kappa = 0,21-0,25$). Estos resultados parecen respaldar cuanto observado en el estudio de Johansson (2023), en el que el acuerdo entre fuerza de agarre y miembros inferiores fue muy baja ($\kappa = 0,20$ y $0,19$ en mujeres y hombres, respectivamente). Dichos hallazgos podrían deberse a que el desempeño en una prueba de levantarse de la silla depende de la fuerza de miembros inferiores pero también de otros factores adicionales, tales como la movilidad, el equilibrio o el sistema propioceptivo de los individuos (Lord et al., 2002).

Adicionalmente, cuando se emplearon criterios diagnósticos diferentes tanto para definir unos bajos niveles de fuerza como de masa muscular, el grado de acuerdo fue el más bajo ($\kappa = 0,13-0,17$). Esto tiene como consecuencia que algunos individuos diagnosticados con sarcopenia según unos criterios podrían clasificarse como sanos si se emplearan criterios distintos, pudiendo dar lugar a casos de infradiagnóstico. De hecho, en nuestro estudio se observó como el 10,4% ($n=73$) de los individuos diagnosticados con sarcopenia según la forma más comúnmente empleada por la literatura; es decir, utilizando la fuerza de agarre y la masa muscular apendicular en términos relativos (Petermann-Rocha et al., 2022) fueron clasificados como sanos cuando la sarcopenia se definió según la fuerza de miembros inferiores y la masa muscular apendicular en valores absolutos.

Asimismo, el 12% de los participantes (n=66) diagnosticados con sarcopenia determinada según la fuerza de agarre y la masa muscular apendicular absoluta se clasificaron como sanos cuando la sarcopenia se definió según la fuerza de miembros inferiores y la masa muscular apendicular absoluta.

A pesar de que los criterios propuestos por el EWGSOP2 tienen el objetivo de facilitar el proceso de detección de casos de sarcopenia, es importante considerar que dichos criterios diagnósticos no deberían emplearse indistintamente, ya que cada definición operativa podría afectar a la salud de los individuos de forma distinta. Por ejemplo, como se observó en este estudio, la sarcopenia definida como bajos niveles de fuerza de miembros inferiores, independientemente del criterio de masa muscular empleado, se asoció de forma significativa con un incremento del riesgo de tener un bajo nivel socioeconómico, polifarmacia, baja salud autopercebida, depresión y hospitalización. Por otro lado, la sarcopenia definida según una baja fuerza de agarre mostro asociaciones significativas tan solo con un mayor del riesgo de estar polimedicado y de tener unos bajos niveles de salud autopercebida. Sin embargo, a pesar de que la sarcopenia definida mediante unos bajos niveles de fuerza de miembros inferiores demostró tener más consecuencias sobre la salud de los individuos y teniendo en cuenta que otros estudios mostraron resultados similares (Chew et al., 2020), la literatura actual no permite sacar conclusiones claras sobre cuál es la definición que tiene más repercusiones sobre la salud. Por ejemplo, en el estudio de Johansson (2023) se observó que una baja fuerza de agarre se asoció con un riesgo de mortalidad de casi el doble del que se observó considerando una baja fuerza de miembros inferiores (HR= 3,17 y 1,85, respectivamente). Adicionalmente, Verstraeten y colaboradores (2022) observaron que la fuerza de agarre se asoció a un incremento del riesgo de hospitalización a los tres meses (OR=1,59; IC 95%= 1,12–2,24) y de mortalidad a los tres meses (OR=2,12; IC 95% = 1,12–4,04) y al año (OR=1,67; IC 95% = 1,14–2,44), mientras que no se observaron asociaciones significativas en relación con la fuerza de miembros inferiores. La heterogeneidad encontrada en la literatura podría indicar que los criterios diagnósticos propuestos por el consenso europeo no deberían emplearse indistintamente, sino que podría ser necesaria la valoración de todos los criterios para detectar con precisión los casos de sarcopenia (Johansson et al., 2023). Por este motivo, en el planteamiento de una herramienta capaz de detectar la

sarcopenia en ancianos residentes en la comunidad, deberían tenerse en cuenta las cuatro formas de definir dicha enfermedad.

Objetivo 4: Validez de una aplicación móvil para detectar sarcopenia según los criterios diagnósticos recomendados por el consenso europeo EWGSOP2.

El cuarto estudio de esta tesis doctoral tuvo como objetivo determinar la validez de la aplicación móvil *Sit to Stand* para detectar la sarcopenia en función de cada uno de los criterios diagnósticos recomendados por el consenso europeo EWGSOP2. Adicionalmente, se analizó su validez de constructo determinando su asociación con variables relacionadas con la salud y con la fragilidad.

La aplicación *Sit to Stand*, que permite hallar los valores de tiempo, velocidad y potencia generados durante el test de levantarse de una silla, consiste en una actualización de la versión anteriormente validada tanto en la plataforma iOS como en Android, (Ruiz-Cárdenas et al., 2018; Ruiz-Cárdenas et al., 2023). La potencia muscular está considerada como un biomarcador de salud durante el proceso de envejecimiento y es capaz de distinguir los sujetos con sarcopenia de los sujetos sanos (Kera et al., 2022). Los valores de potencia se integraron con los perímetros de la pantorrilla y de la mitad superior del brazo de los individuos, indicados como sustitutos válidos de procedimientos más costosos empleados para determinar la masa muscular en personas ancianas como el DXA o la resonancia magnética (Cruz-Jentoft et al., 2019). Por lo tanto, para predecir la presencia de sarcopenia en ancianos residentes en la comunidad, se analizó la capacidad de un modelo de regresión compuesto por los valores de potencia generados en un test de levantarse de una silla, circunferencia de pantorrilla y circunferencia de la mitad superior del brazo. En los análisis de regresión que se llevaron a cabo, los valores de circunferencia de la mitad superior del brazo no se asociaron de forma significativa con la sarcopenia y, por lo tanto, fueron excluidos del modelo final.

No existiendo en la literatura disponible un consenso claro acerca de los criterios diagnóstico más adecuados a la hora de determinar la presencia de sarcopenia, la precisión del modelo se testó empleando como test de referencia las cuatro formas posibles para determinar sarcopenia propuestas por el consenso europeo.

Por lo tanto, se obtuvieron un total de ocho ecuaciones, cuatro por sexo, basadas en los valores de potencia generados durante el test de levantarse de la silla y en la circunferencia de la pantorrilla. Estas ecuaciones mostraron una excelente capacidad para discriminar entre las personas con sarcopenia y sus homólogos sanos (AUC: 80,5%–87,1%), así como una precisión diagnóstica que osciló entre el 77% y el 94%. Las puntuaciones más elevadas de AUC se observaron cuando la presencia de sarcopenia se definió empleando los valores de fuerza de los miembros inferiores: en hombres, el AUC para detectar la sarcopenia según la fuerza de miembros inferiores y la masa muscular apendicular en valores absolutos fue del 87,1% (IC 95%: 81,0–93,3), mientras que en mujeres, el AUC para detectar la sarcopenia utilizando la fuerza de miembros inferiores y la masa muscular en valores relativos fue del 85,7% (IC 95%: 76,4–95,0). Resultados parecidos se observaron en el estudio de Johansson y colaboradores (2020), quienes compararon la precisión diagnóstica de la fuerza de miembros superiores e inferiores para detectar los determinantes de sarcopenia como la velocidad de marcha, el Timed Up and Go y la masa muscular en valores relativos. Los hallazgos reportados mostraron que la fuerza de miembros inferiores tenía mejor capacidad discriminativa que la fuerza de agarre para detectar aquellos individuos con un bajo rendimiento en el Timed Up and Go (AUC: 0,86; IC 95%: 0,84–0,89 vs 0,75; IC 95% 0,69–0,83, respectivamente), y una baja velocidad marcha (AUC: 0,78; IC 95%: 0,75–0,82 vs AUC: 0,72; IC 95%: 0,65–0,79).

Adicionalmente, en nuestros resultados se observó que hasta un máximo de 21 mujeres y de 12 hombres de cada 100 podían obtener un falso positivo. En estos sujetos, el promedio de valores de potencia fue inferior al percentil 20, mientras que los de circunferencia de la pantorrilla fueron inferiores al percentil 26. Según estudios recientes, unos bajos niveles de potencia están asociados a un incremento de dos veces el riesgo de mortalidad (Losa-Reyna et al., 2022). De la misma forma, se observó que cada centímetro de incremento de la circunferencia de la pantorrilla se corresponde con una disminución del 5% al 7% del riesgo de mortalidad (Li et al., 2022). Por lo tanto, pese al sobrediagnóstico de nuestra aplicación móvil, estos individuos seguirían precisando de una intervención debido a las consecuencias que unos bajos niveles de potencia y una circunferencia de pantorrilla reducida tienen sobre la salud de los individuos.

Por otro lado, hasta un 3% de mujeres y un 2% de hombres podrían obtener un falso negativo cuando se utiliza nuestra aplicación. En estos sujetos, los resultados observados podrían verse influenciados por los valores de circunferencia promedio de pantorrilla, ya que en hombres fue mayor de 36,3 cm y en mujeres mayor a 36,2 cm. En caso de las mujeres, estos valores estuvieron por encima de la media de los valores normativos de circunferencia de pantorrilla para personas de más de 45 años (rango: 33,4–35,6 cm), mientras que en caso de los hombres se situaron en la media (rango: 35–37,1 cm) (Martone et al., 2023).

Asimismo, se determinó la validez de constructo de la herramienta explorando la asociación que podía existir entre aquellas personas diagnosticadas con sarcopenia según la aplicación móvil *Sit to Stand*, con variables relacionadas con la salud y con el síndrome de fragilidad. En general, en los análisis ajustados por edad, sexo e índice de masa corporal, pudo observarse que todos los individuos diagnosticados con sarcopenia por la aplicación, independientemente de los criterios empleados para su definición, mostraron un incremento del riesgo de sufrir eventos adversos relacionados con la salud. Las definiciones de sarcopenia que utilizaron la fuerza de miembros inferiores como criterio de fuerza fueron aquellas que mostraron más asociaciones con la presencia de eventos adversos. Concretamente, tanto la sarcopenia definida según cualquiera de los dos criterios para determinar la masa muscular y la fuerza de miembros inferiores se asociaron con un incremento del riesgo de tener un bajo nivel educativo, un bajo nivel socioeconómico, comorbilidad, polifarmacia y unos bajos niveles de salud autopercebida. Adicionalmente, la sarcopenia definida por la fuerza de miembros inferiores y por la masa muscular apendicular en términos relativos se asoció de forma independiente con el hábito tabáquico. Como mencionado anteriormente, basándonos sobre la evidencia disponible, no queda claro cuál es la forma de medir sarcopenia que más asociaciones muestra con variables relacionadas con la salud en personas ancianas. En una investigación en la que se analizaron los datos de 764 ancianos se observó que la presencia simultánea de bajos niveles de fuerza de miembros superiores e inferiores se asoció con peores niveles de salud que cuando se analizaron de forma independiente (O. Y. A. Chan et al., 2014). De la misma forma, en otro estudio que incluyó un total de 2442 ancianos, se observó que unos bajos niveles de fuerza de miembros superiores e inferiores resultó en un riesgo de mortalidad mayor (HR = 2,06; IC 95% = 1,61–2,63) que cuando los niveles de fuerza

se analizaron de forma aislada (HR= 1,36–1,51) (Zhang et al., 2023). Sin embargo, en nuestros análisis, las cuatro definiciones de sarcopenia se asociaron de forma parecida a eventos adversos. Por ello, tener a disposición una herramienta capaz de detectar la presencia de sarcopenia de manera fiable independientemente del criterio diagnóstico que se emplee como referencia y que se asocie de manera indistinta a consecuencias relacionadas con la salud constituye una gran ventaja desde el punto de clínico.

Por último, todos los individuos con sarcopenia detectados por la aplicación, independientemente de los criterios diagnósticos que se emplearon en su definición, mostraron un incremento del riesgo para sufrir el síndrome de fragilidad. Estos valores están en línea con lo observado por Álvarez-Bustos y colaboradores (2022), en el que no solamente se observó que la sarcopenia es un predictor del desarrollo de fragilidad, sino que aquellos sujetos con sarcopenia tenían un mayor riesgo de empeorar su condición de fragilidad (Álvarez-Bustos et al., 2022).

Objetivo 5: Desarrollo y la validación de una aplicación móvil para la detección de prefragilidad y sarcopenia.

Considerada la estrecha relación que existe entre ambas condiciones, y que, además, su presencia simultánea resulta en un incremento de tres veces el riesgo de mortalidad que cuando ninguna de estas dos está presente (Thompson et al., 2021), el objetivo del último estudio de esta tesis doctoral fue determinar si la aplicación *Sit to Stand* fuese capaz de detectar de manera precoz la presencia simultánea de sarcopenia y prefragilidad o fragilidad en ancianos residentes en la comunidad.

En este estudio, en el cual se analizaron los datos de 686 participantes, un total de 232 personas se clasificaron como prefragiles, mientras que 21 individuos cumplieron con al menos tres de los cinco criterios que definen la fragilidad. Ya que la medición de la fuerza de agarre es un criterio común a ambas patologías, el empleo de este criterio como medida diagnóstica para determinar sarcopenia podría dar lugar a un incremento de la prevalencia de sujetos con ambas patologías debido a su solapamiento. De hecho, teniendo en cuenta los puntos de corte propuestos por las herramientas empleadas y siguiendo los criterios propuestos por el consenso europeo EWGSOP2, un individuo con baja fuerza de agarre

automáticamente se clasificaría como prefrágil, según los criterios de Fried. Por lo tanto, para evitar confusión entre ambos estados, la sarcopenia se definió según la fuerza de miembros inferiores. Tras la aplicación de estos criterios se detectó un total de 42 a 76 personas (6,1%–11,1% de la muestra) con sarcopenia, en función de la medida de masa muscular empleada. Adicionalmente, se identificaron entre 20 y 50 sujetos (2,9%–7,2%) que simultáneamente sufrían de sarcopenia y de un estado de prefragilidad o fragilidad.

Tras combinar las definiciones operativas de sarcopenia con la definición de fragilidad, se obtuvieron un total de cuatro ecuaciones, dos por cada sexo, basadas en los valores de potencia generados durante el gesto de levantarse de una silla y en la circunferencia de la pantorrilla para determinar la presencia simultánea de ambas condiciones. Dichas ecuaciones mostraron una capacidad aceptable para discriminar la presencia simultánea de ambas condiciones de aquellas personas que solamente sufrían una condición (rango AUC= 74%–88%). La capacidad discriminativa fue mayor cuando la aplicación se empleó para distinguir a las personas con ambas patologías de aquellas sanas (rango AUC= 84%–96%). Finalmente, cuando las ecuaciones se emplearon para discriminar entre los sujetos con la presencia simultánea de sarcopenia y prefragilidad o fragilidad del resto de los individuos (individuos sanos y/o con solamente una de las dos condiciones), los valores de AUC observados oscilaron entre aceptables y excelentes (rango AUC= 80%–92%), con unos valores de sensibilidad $\geq 75\%$, y con una especificidad de hasta el 87%. Adicionalmente, el valor predictivo positivo osciló entre el 12% y el 37,5%, mientras que el valor predictivo negativo osciló entre el 98% y el 100%, sugiriendo que la aplicación representa una mejor opción para descartar la presencia de ambas patologías que para confirmarla. Este hallazgo pudo confirmarse gracias al bajo número de test necesarios para obtener un falso negativo que se observó: en el peor de los casos, el 1,7% de las mujeres y el 0,4% de los hombres se categorizaron de forma errónea como sanos. Por el contrario, se observó que, en el peor de los escenarios, un total de hasta 17 sujetos de cada 100 tuvieron un resultado de la prueba positivo sin tener la enfermedad, dando lugar a un sobrediagnóstico. Entonces, podrá concluirse que esta herramienta sobreestimaría la presencia simultánea de ambas patologías en comparación con los criterios diagnósticos propuestos por el EWGSOP2 y el Fenotipo de Fried. Como se observó en estudios recientes, dichas herramientas diagnosticas son las más empleadas en la literatura

(Faller et al., 2019; Petermann-Rocha et al., 2022). Sin embargo, para que una herramienta pueda utilizarse en la práctica clínica tiene que ser eficaz en términos de costes-beneficios, estandarizada y replicable por distintos profesionales y en distintos ámbitos clínicos (Cruz-Jentoft et al., 2019; Dent, Morley, et al., 2019). Si bien en la literatura existe un consenso sobre los dominios a valorar en el diagnóstico de estas patologías, no existe una indicación clara sobre los test más adecuados a emplear para poder encontrar todos los casos de sarcopenia o de fragilidad (Cruz-Jentoft et al., 2019; Dent, Morley, et al., 2019). Adicionalmente, las personas erróneamente clasificadas como positivas por la aplicación mostraron niveles bajos de potencia ($< P20$) y de circunferencia de pantorrilla ($< P26$). A causa de las consecuencias que niveles reducidos de potencia y circunferencia de pantorrilla tienen sobre la salud, estos sujetos, a pesar de no sufrir estas condiciones según el test índice, no deberían en todo caso categorizarse como sanos.

Asimismo, en estos sujetos clasificados como falsos positivos los niveles de fuerza, dominio valorado por ambas patologías, se consideraron como normales. Sin embargo, estudios previos observaron como la potencia decae antes y más rápidamente que la fuerza muscular (Skelton et al., 1994). Por lo tanto, basar los criterios diagnósticos de ambas patologías sobre la potencia muscular podría permitir la identificación de casos con estas patologías en sus fases más precoces, aumentando las posibilidades de revertir estos estados (Dent, Morley, et al., 2019).

En los análisis ajustados por el sexo, la edad y el índice de masa corporal, aquellos individuos diagnosticados con la presencia simultánea de sarcopenia y prefragilidad o fragilidad según la aplicación *Sit to Stand* mostraron un mayor riesgo de sufrir eventos adversos relacionados con la salud. Independientemente del criterio diagnóstico empleado para definir la sarcopenia, los individuos con ambas patologías diagnosticados por la aplicación, respecto a sus homólogos sanos, mostraron un mayor riesgo de tener un nivel educativo bajo, comorbilidades, de estar polimedicados, de tener una baja salud autopercebida, depresión, caídas y hospitalización. Además, cuando la masa muscular se utilizó en valores absolutos, los individuos con ambas patologías mostraron un mayor riesgo de tener un bajo nivel socioeconómico y de hábito tabáquico. Los resultados de este estudio estuvieron en línea con los datos reportados en el estudio de Mori y Tokuda (2019), los cuales observaron que la coexistencia de sarcopenia y fragilidad se asoció a un

mayor riesgo de caídas (RR: 11,8; IC 95%: 2,68–52,0), bajos niveles de fuerza (RR: 8,05; IC 95%: 1,85–35,0) y a una menor funcionalidad (RR: 20,3; IC 95%: 4,54–91,2). En conjunto, los resultados de nuestro estudio confirmaron las importantes consecuencias que tienen fragilidad y sarcopenia cuando actúan de manera sinérgica sobre la salud de las personas mayores y que, los valores de potencia generados durante un test de levantarse de la silla, combinados con la circunferencia de la pantorrilla de los individuos, pueden detectar su presencia simultánea de manera precoz. Concretamente, esta herramienta representa una alternativa válida a los test de cribado propuestos en la literatura científica por su capacidad para descartar la presencia de ambas patologías de manera precisa.

Finalmente, todos los participantes reclutados para esta tesis doctoral recibieron una hoja informativa tras finalizar todas las mediciones en la que vieron reflejados los resultados obtenidos en las pruebas a las que se sometieron (Anexo 4). Adicionalmente, recibieron una explicación sobre su estado antropométrico y sobre su estado funcional y, en caso de alcanzar puntuaciones bajas o que pudieran considerarse potencialmente de riesgo para su salud, recibieron unas recomendaciones y consejos de salud con el objetivo de fomentar unos cambios de conducta favorables.

X – CONCLUSIONES

X - CONCLUSIONES

En esta tesis doctoral se encontraron los siguientes hallazgos:

- I. Se logró la publicación de un protocolo de estudio en una revista académica sobre la validez de una aplicación móvil para detectar la presencia de sarcopenia y prefragilidad en personas ancianas residentes en la comunidad. **(Artículo I)**
- II. La aplicación *Sit to Stand* para dispositivos móviles con sistemas operativos Android fue igual de fiable que la versión precedentemente validada en la plataforma iOS. Además, la reproducibilidad de la herramienta fue excelente, teniendo una capacidad de aceptable a excelente para discriminar individuos sanos de aquellos con baja función física, baja velocidad de marcha y sarcopenia. **(Artículo II)**
- III. Los valores de prevalencia de sarcopenia varían considerablemente en función de la combinación de criterios diagnósticos propuestos por el EWGSOP2 que se emplea. Estas combinaciones muestran un grado de acuerdo de bajo a moderado, por lo que estos criterios no deben intercambiarse. La definición de sarcopenia según la fuerza de miembros inferiores podría ser la más apropiada para una muestra compuesta por ancianos españoles que viven en la comunidad debido a su asociación con variables relacionadas con la salud. **(Artículo III)**
- IV. La aplicación *Sit to Stand* parece tener una buena capacidad diagnóstica para detectar sarcopenia en personas aparentemente sanas. Las personas diagnosticadas con sarcopenia por la aplicación mostraron un mayor riesgo de sufrir eventos adversos relacionados con la salud y fragilidad, comparado con quien no tiene esta enfermedad, independientemente del criterio diagnóstico utilizado. **(Artículo IV)**

- V. La aplicación *Sit to Stand* parece ser una herramienta fiable para detectar y descartar la presencia simultánea de sarcopenia y prefragilidad o fragilidad en ancianos españoles que viven en la comunidad. Adicionalmente, las personas que contemporáneamente tuvieron sarcopenia y prefragilidad o fragilidad identificados por la aplicación mostraron un mayor riesgo de sufrir eventos adversos relacionados con la salud que su contraparte sana. **(Artículo V)**

XI – CONCLUSIONS

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The following results were obtained in this doctoral thesis:

- I. Study protocol about the validity of a mobile application to detect sarcopenia and prefrailty in community-dwelling older adults was published on an academic journal. **(Article I)**
- II. The *Sit to Stand* app running on Android OS smartphones was as reliable as the previous one validated for iOS smartphones. Additionally, the reproducibility of the tool was excellent, showing acceptable to excellent ability to discriminate healthy individuals from those with low physical functioning, low gait speed and sarcopenia. **(Article II)**
- III. Sarcopenia prevalence rates vary considerably using the different combinations for sarcopenia diagnosis proposed in EWGSOP2. These combinations have weak to moderate levels of agreement and should not be used in an interchangeable way. Sarcopenia diagnosis criteria defined by lower limb muscle strength could be more suitable in Spanish community-dwelling older adults due to their associations with health-related outcomes. **(Article III)**
- IV. The *Sit to Stand* app appears to have good diagnostic performance for detecting sarcopenia in well-functioning Spanish community-dwelling older adults. Individuals with sarcopenia diagnosed by the video analysis-based app showed more odds of having health-related risk factors and frailty compared to their respective counterparts, regardless of the diagnostic criteria proposed by the EWGSOP2 guideline. **(Article IV)**
- V. The *Sit to Stand* app seems to be a reliable tool to detect and rule out the simultaneous presence of prefrailty or frailty plus sarcopenia syndromes in Spanish community-dwelling older adults. Moreover, individuals identified by the App were more likely to present health-

related risk factors compared to their healthy counterparts. (**Article V**)

XII - LIMITACIONES Y FUTURAS LÍNEAS DE INVESTIGACIÓN

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Esta tesis doctoral no estuvo exenta de limitaciones. En primer lugar, se llevó a cabo un análisis retrospectivo de los datos, con lo cual la posibilidad de extrapolar los resultados de su contexto se ve limitada. Aunque este diseño de estudio no permite detectar relaciones de tipo causa-efecto entre factores, sienta las bases para que se lleven a cabo futuros estudios de investigación de carácter longitudinal (Tofthagen, 2012).

En segundo lugar, la muestra analizada se reclutó desde centros sociales de mayores, instituciones que tienen como objetivos fomentar la actividad física y la inclusión social de las personas mayores. Esto se reflejó en los niveles de actividad física observados de los participantes, ya que tan solo el 10% de la muestra fue sedentaria. La actividad física está reconocida hoy en día como un factor protector frente al desarrollo tanto del síndrome de fragilidad como de sarcopenia (Fried, 2016; Steffl et al., 2017). Por lo tanto, esto contribuiría a explicar los bajos niveles de prevalencia tanto de sarcopenia (2%–11%) y de fragilidad (3%) encontrados. Los niveles de prevalencia pueden influir en la sensibilidad y especificidad de una prueba, generando interpretaciones erróneas de los resultados de una investigación (Leeftang et al., 2013). Por lo tanto, los resultados de esta investigación tienen que verificarse en ulteriores estudios y, mientras tanto, han de interpretarse con cautela.

En cuanto a la validez de constructo de los estudios, la valoración de los factores de riesgo de ambas patologías se llevó a cabo a través de un cuestionario autorreportado (véase Anexo X), con lo cual las respuestas proporcionadas se vieron influenciadas por la subjetividad de las personas reclutadas. Adicionalmente, la valoración de la masa muscular de los participantes de este estudio se llevó a cabo empleando un dispositivo de BIA, que constituye una alternativa al DXA, considerado como el *gold standard* para la valoración de esta variable. Sin embargo, de acuerdo con las recomendaciones proporcionadas por el consenso europeo sobre sarcopenia EWGSOP2, para una estimación verosímil de la masa muscular de los participantes se empleó una ecuación validada en una muestra con características similares (Cruz-Jentoft et al., 2019; Sergi et al., 2015).

En relación con futuras líneas de investigación, se destaca la falta de ulteriores estudios para confirmar los hallazgos expuestos en esta tesis doctoral. Adicionalmente, estudios de validación prospectiva podrían aportar datos útiles para monitorizar la capacidad de respuesta de la herramienta, así como los cambios debidos al tratamiento experimentados por los individuos a lo largo del tiempo (Schmitt & Di Fabio, 2005). Asimismo, gracias al desarrollo tecnológico, el empleo de la inteligencia artificial en ámbito sanitario es cada vez más frecuente. En cuanto a la aplicación desarrollada por nuestro grupo de investigación, integrar un sistema de inteligencia artificial podría ayudar a todo personal clínico y/o investigador a obtener resultados precisos de forma totalmente automática, detectando los momentos exactos en los cuales el movimiento producido durante el gesto de levantarse de la silla empieza y finaliza. Actualmente, el personal clínico o el investigador que quiera hallar los valores de velocidad, tiempo y potencia alcanzados en el test de levantarse de una silla tiene que seleccionar manualmente el momento en el cual se origina y se detiene el movimiento, pudiendo incidir en la heterogeneidad de los resultados. Aunque el procedimiento de análisis de video ha mostrado una fiabilidad inter e intra observador excelente tanto en móviles con sistema Android como con sistema iOS, la integración de un sistema basado en la inteligencia artificial podría minimizar la subjetividad inherente al gesto, así como la rapidez del análisis. Adicionalmente, la inteligencia artificial podría permitir que los resultados se muestren en tiempo real, funcionando como un sistema de retroalimentación instantáneo, sin la necesidad de un análisis a posteriori.

XIII - REFERENCIAS BIBLIOGRÁFICAS

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Adamakis, M. (2021). Criterion Validity of iOS and Android Applications to Measure Steps and Distance in Adults. *Technologies*, 9(3), Article 3. <https://doi.org/10.3390/technologies9030055>

Ageing and health. (s. f.). Recuperado 13 de julio de 2023, de <https://www.who.int/news-room/fact-sheets/detail/ageing-and-health>

Álvarez-Bustos, A., Carnicero-Carreño, J. A., Davies, B., Garcia-Garcia, F. J., Rodríguez-Artalejo, F., Rodríguez-Mañas, L., & Alonso-Bouzon, C. (2022). Role of sarcopenia in the frailty transitions in older adults: A population-based cohort study. *Journal of Cachexia, Sarcopenia and Muscle*, jcs.13055. <https://doi.org/10.1002/jcs.13055>

Ambagtsheer, R. C., Beilby, J. J., Visvanathan, R., Dent, E., Yu, S., & Braunack-Mayer, A. J. (2019). Should we screen for frailty in primary care settings? A fresh perspective on the frailty evidence base: A narrative review. *Preventive Medicine*, 119, 63-69. <https://doi.org/10.1016/j.ypmed.2018.12.020>

Anabitarte-García, F., Reyes-González, L., Rodríguez-Cobo, L., Fernández-Viadero, C., Somonte-Segares, S., Díez-Del-Valle, S., Mandaluniz, E., García-García, R., & López-Higuera, J. M. (2021). Early diagnosis of frailty: Technological and non-intrusive devices for clinical detection. *Ageing Research Reviews*, 70, 101399. <https://doi.org/10.1016/j.arr.2021.101399>

Bandinelli, S., Milanese, Y., & Ferrucci, L. (2009). CHAIR STANDS TEST AND SURVIVAL IN THE OLDER POPULATION. *Journal of the American Geriatrics Society*, 57(11), 2172-2173. <https://doi.org/10.1111/j.1532-5415.2009.02544.x>

Barbosa-Silva, T. G., Menezes, A. M. B., Bielemann, R. M., Malmstrom, T. K., Gonzalez, M. C., & Grupo de Estudos em Composição Corporal e Nutrição (COCONUT). (2016). Enhancing SARC-F: Improving Sarcopenia Screening in the Clinical Practice. *Journal of the American Medical Directors Association*, 17(12), 1136-1141. <https://doi.org/10.1016/j.jamda.2016.08.004>

Baumgartner, R. N., Koehler, K. M., Gallagher, D., Romero, L., Heymsfield, S. B., Ross, R. R., Garry, P. J., & Lindeman, R. D. (1998). Epidemiology of Sarcopenia among the Elderly in New Mexico. *American Journal of Epidemiology*, 147(8), 755-763. <https://doi.org/10.1093/oxfordjournals.aje.a009520>

Beaudart, C., Zaaria, M., Pasleau, F., Reginster, J.-Y., & Bruyère, O. (2017). Health Outcomes of Sarcopenia: A Systematic Review and Meta-Analysis. *PLoS ONE*, 12(1), e0169548. <https://doi.org/10.1371/journal.pone.0169548>

Bhasin, S., Travison, T. G., Manini, T. M., Patel, S., Pencina, K. M., Fielding, R. A., Magaziner, J. M., Newman, A. B., Kiel, D. P., Cooper, C., Guralnik, J. M., Cauley, J. A., Arai, H., Clark, B. C., Landi, F., Schaap, L. A., Pereira, S. L., Rooks, D., Woo, J., ... Cawthon, P. M. (2020). Sarcopenia Definition: The Position Statements of the Sarcopenia Definition and Outcomes Consortium. *Journal of the American Geriatrics Society*, 68(7), 1410-1418. <https://doi.org/10.1111/jgs.16372>

Bian, L.-L., Lan, A.-C., Zheng, Y.-K., Xue, H.-Y., & Ye, Q. (2023). Association between calf circumference and cardiac metabolic risk factors in middle-aged and elderly women. *Heliyon*, 9(6), e17456. <https://doi.org/10.1016/j.heliyon.2023.e17456>

Biggest app stores in the world 2022. (s. f.). Statista. Recuperado 12 de diciembre de 2023, de <https://www.statista.com/statistics/276623/number-of-apps-available-in-leading-app-stores/>

Bohannon, R. W. (2015). Daily sit-to-stands performed by adults: A systematic review. *Journal of Physical Therapy Science*, 27(3), 939-942. <https://doi.org/10.1589/jpts.27.939>

Boros, K., & Freemont, T. (2017). Physiology of ageing of the musculoskeletal system. *Best Practice & Research Clinical Rheumatology*, 31(2), 203-217. <https://doi.org/10.1016/j.berh.2017.09.003>

Boss, G. R., & Seegmiller, J. E. (1981). Age-Related Physiological Changes and Their Clinical Significance. *Western Journal of Medicine*, 135(6), 434-440.

Bossuyt, P. M., Reitsma, J. B., Bruns, D. E., Gatsonis, C. A., Glasziou, P. P., Irwig, L. M., Moher, D., Rennie, D., de Vet, H. C. W., Lijmer, J. G., & Standards for Reporting of Diagnostic Accuracy. (2003). The STARD statement for reporting studies of diagnostic accuracy: Explanation and elaboration. *Annals of Internal Medicine*, 138(1), W1-12. <https://doi.org/10.7326/0003-4819-138-1-200301070-00012-w1>

Bravo-José, P., Moreno, E., Espert, M., Romeu, M., Martínez, P., & Navarro, C. (2018). Prevalence of sarcopenia and associated factors in institutionalised older adult patients. *Clinical Nutrition ESPEN*, 27, 113-119. <https://doi.org/10.1016/j.clnesp.2018.05.008>

Bruyère, O., Buckinx, F., Beaudart, C., Reginster, J.-Y., Bauer, J., Cederholm, T., Cherubini, A., Cooper, C., Cruz-Jentoft, A. J., Landi, F., Maggi, S., Rizzoli, R., Sayer, A. A., Sieber, C., Vellas, B., Cesari, M., & on behalf of ESCEO and the EUGMS frailty working group. (2017). How clinical practitioners assess frailty in their daily practice: An international survey. *Aging Clinical and Experimental Research*, 29(5), 905-912. <https://doi.org/10.1007/s40520-017-0806-8>

Burbank, C. M., Branscum, A., Bovbjerg, M. L., Hooker, K., & Smit, E. (2023). Mason. *Journal of Frailty, Sarcopenia and Falls*, 8(1), 1-8. <https://doi.org/10.22540/JFSF-08-001>

Byrne, C., Faure, C., Keene, D. J., & Lamb, S. E. (2016). Ageing, Muscle Power and Physical Function: A Systematic Review and Implications for Pragmatic Training Interventions. *Sports Medicine (Auckland, N.Z.)*, 46(9), 1311-1332. <https://doi.org/10.1007/s40279-016-0489-x>

Campbell, A. J., Borrie, M. J., & Spears, G. F. (1989). Risk Factors for Falls in a Community-Based Prospective Study of People 70 Years and Older. *Journal of Gerontology*, 44(4), M112-M117. <https://doi.org/10.1093/geronj/44.4.M112>

Candow, D. G., & Chilibeck, P. D. (2005). Differences in Size, Strength, and Power of Upper and Lower Body Muscle Groups in Young and Older Men. *The Journals of Gerontology: Series A*, 60(2), 148-156. <https://doi.org/10.1093/gerona/60.2.148>

Cederholm, T., Barazzoni, R., Austin, P., Ballmer, P., Biolo, G., Bischoff, S. C., Compher, C., Correia, I., Higashiguchi, T., Holst, M., Jensen, G. L., Malone, A., Muscaritoli, M., Nyulasi, I., Pirlich, M., Rothenberg, E., Schindler, K., Schneider, S. M., De Van Der Schueren, M. A. E., ... Singer, P. (2017). ESPEN guidelines on definitions and terminology of clinical nutrition. *Clinical Nutrition*, 36(1), 49-64. <https://doi.org/10.1016/j.clnu.2016.09.004>

Cesari, M., Landi, F., Vellas, B., Bernabei, R., & Marzetti, E. (2014). Sarcopenia and Physical Frailty: Two Sides of the Same Coin. *Frontiers in Aging Neuroscience*, 6, 192. <https://doi.org/10.3389/fnagi.2014.00192>

Cesari, M., Leeuwenburgh, C., Lauretani, F., Onder, G., Bandinelli, S., Maraldi, C., Guralnik, J. M., Pahor, M., & Ferrucci, L. (2006). Frailty syndrome and skeletal muscle: Results from the Invecchiare in Chianti study. *The American journal of clinical nutrition*, 83(5), 1142-1148.

Chan, A.-W., Hróbjartsson, A., Haahr, M. T., Gøtzsche, P. C., & Altman, D. G. (2004). Empirical Evidence for Selective Reporting of Outcomes in Randomized Trials Comparison of Protocols to Published Articles. *JAMA*, 291(20), 2457-2465. <https://doi.org/10.1001/jama.291.20.2457>

Chan, O. Y. A., van Houwelingen, A. H., Gussekloo, J., Blom, J. W., & den Elzen, W. P. J. (2014). Comparison of quadriceps strength and handgrip strength in their association with health outcomes in older adults in primary care. *AGE*, 36(5), 9714. <https://doi.org/10.1007/s11357-014-9714-4>

Chen, L.-K., Woo, J., Assantachai, P., Auyeung, T.-W., Chou, M.-Y., Iijima, K., Jang, H. C., Kang, L., Kim, M., Kim, S., Kojima, T., Kuzuya, M., Lee, J. S. W., Lee, S. Y., Lee, W.-J., Lee, Y., Liang, C.-K., Lim, J.-Y., Lim, W. S., ... Arai, H. (2020). Asian Working Group for Sarcopenia: 2019 Consensus Update on Sarcopenia Diagnosis and Treatment. *Journal of the American Medical Directors Association*, 21(3), 300-307.e2. <https://doi.org/10.1016/j.jamda.2019.12.012>

Cheng, Y.-Y., Wei, S.-H., Chen, P.-Y., Tsai, M.-W., Cheng, I.-C., Liu, D.-H., & Kao, C.-L. (2014). Can sit-to-stand lower limb muscle power predict fall status? *Gait & Posture*, 40(3), 403-407. <https://doi.org/10.1016/j.gaitpost.2014.05.064>

Chew, J., Yeo, A., Yew, S., Lim, J. P., Tay, L., Ding, Y. Y., & Lim, W. S. (2020). Muscle Strength Definitions Matter: Prevalence of Sarcopenia and Predictive Validity for Adverse Outcomes Using the European Working Group on Sarcopenia in Older People 2 (EWGSOP2) Criteria. *The Journal of Nutrition, Health & Aging*, 24(6), 614-618. <https://doi.org/10.1007/s12603-020-1371-y>

Chi, J., Chen, F., Zhang, J., Niu, X., Tao, H., Ruan, H., Wang, Y., & Hu, J. (2021). Impacts of frailty on health care costs among community-dwelling older adults: A meta-analysis of cohort studies. *Archives of Gerontology and Geriatrics*, 94, 104344. <https://doi.org/10.1016/j.archger.2021.104344>

Clegg, A., & Young, J. (2011). The frailty syndrome. *Clinical Medicine (London, England)*, 11(1), 72-75. <https://doi.org/10.7861/clinmedicine.11-1-72>

Clegg, A., Young, J., Iliffe, S., Rikkert, M. O., & Rockwood, K. (2013). Frailty in elderly people. *The Lancet*, 381(9868), 752-762. [https://doi.org/10.1016/S0140-6736\(12\)62167-9](https://doi.org/10.1016/S0140-6736(12)62167-9)

Closs, V. E., Ziegelmann, P. K., Flores, J. H. F., Gomes, I., & Schwanke, C. H. A. (2017). Anthropometric Measures and Frailty Prediction in the Elderly: An Easy-to-Use Tool. *Current Gerontology and Geriatrics Research*, 2017, e8703503. <https://doi.org/10.1155/2017/8703503>

Cohen, J. F., Korevaar, D. A., Altman, D. G., Bruns, D. E., Gatsonis, C. A., Hooft, L., Irwig, L., Levine, D., Reitsma, J. B., Vet, H. C. W. de, & Bossuyt, P. M. M. (2016). STARD 2015 guidelines for reporting diagnostic accuracy studies: Explanation and elaboration. *BMJ Open*, 6(11), e012799. <https://doi.org/10.1136/bmjopen-2016-012799>

Cooper, R., Kuh, D., Hardy, R., Mortality Review Group, & FALCon and HALCyon Study Teams. (2010). Objectively measured physical capability levels and mortality: Systematic review and meta-analysis. *BMJ (Clinical Research Ed.)*, 341, c4467. <https://doi.org/10.1136/bmj.c4467>

Cruz-Jentoft, A. J., Baeyens, J. P., Bauer, J. M., Boirie, Y., Cederholm, T., Landi, F., Martin, F. C., Michel, J.-P., Rolland, Y., Schneider, S. M., Topinková, E., Vandewoude, M., & Zamboni, M. (2010). Sarcopenia: European consensus on definition and diagnosis. *Age and Ageing*, 39(4), 412-423. <https://doi.org/10.1093/ageing/afq034>

Cruz-Jentoft, A. J., Bahat, G., Bauer, J., Boirie, Y., Bruyère, O., Cederholm, T., Cooper, C., Landi, F., Rolland, Y., Sayer, A. A., Schneider, S. M., Sieber, C. C., Topinkova, E., Vandewoude, M., Visser, M., & Zamboni, M. (2019). Sarcopenia: Revised European consensus on definition and diagnosis. *Age and Ageing*, 48(1), 16-31. <https://doi.org/10.1093/ageing/afy169>

Cruz-Jentoft, A. J., & Sayer, A. A. (2019). Sarcopenia. *The Lancet*, 393(10191), 2636-2646. [https://doi.org/10.1016/S0140-6736\(19\)31138-9](https://doi.org/10.1016/S0140-6736(19)31138-9)

Daly, R. M., Rosengren, B. E., Alwis, G., Ahlborg, H. G., Sernbo, I., & Karlsson, M. K. (2013). Gender specific age-related changes in bone density, muscle strength and functional performance in the elderly: A-10 year prospective population-based study. *BMC Geriatrics*, 13(1), 71. <https://doi.org/10.1186/1471-2318-13-71>

Davies, B., García, F., Ara, I., Artalejo, F. R., Rodríguez-Mañas, L., & Walter, S. (2018). Relationship Between Sarcopenia and Frailty in the Toledo Study of Healthy Aging: A Population Based Cross-Sectional Study. *Journal of the American Medical Directors Association*, 19(4), 282-286. <https://doi.org/10.1016/j.jamda.2017.09.014>

Davies, B., Walter, S., Rodríguez-Laso, A., Carreño, J. A. C., García-García, F. J., Álvarez-Bustos, A., & Rodríguez-Mañas, L. (2022). Differential Association of Frailty and Sarcopenia With Mortality and Disability: Insight Supporting Clinical Subtypes of Frailty. *Journal of the American Medical Directors Association*, 23(10), 1712-1716.e3. <https://doi.org/10.1016/j.jamda.2022.03.013>

Dehling, T., Gao, F., Schneider, S., & Sunyaev, A. (2015). Exploring the Far Side of Mobile Health: Information Security and Privacy of Mobile Health Apps on iOS and Android. *JMIR mHealth and uHealth*, 3(1), e3672. <https://doi.org/10.2196/mhealth.3672>

Demography of Europe—An ageing population. (s. f.). Demography of Europe. Recuperado 14 de julio de 2023, de <https://www.ine.es/prodyser/demografia UE/bloc-1c.html>

Dent, E., Martin, F. C., Bergman, H., Woo, J., Romero-Ortuno, R., & Walston, J. D. (2019). Management of frailty: Opportunities, challenges, and future directions. *The Lancet*, 394(10206), 1376-1386. [https://doi.org/10.1016/S0140-6736\(19\)31785-4](https://doi.org/10.1016/S0140-6736(19)31785-4)

Dent, E., Morley, J. E., Cruz-Jentoft, A. J., Woodhouse, L., Rodríguez-Mañas, L., Fried, L. P., Woo, J., Aprahamian, I., Sanford, A., Lundy, J., Landi, F., Beilby, J., Martin, F. C., Bauer, J. M., Ferrucci, L., Merchant, R. A., Dong, B., Arai, H., Hoogendijk, E. O., ... Vellas, B. (2019). Physical Frailty: ICFSR International Clinical Practice Guidelines for Identification and Management. *The Journal of Nutrition, Health & Aging*, 23(9), 771-787. <https://doi.org/10.1007/s12603-019-1273-z>

Diaz, R., Hernandez-Vaquero, D., Alvarez, R., Moris, C., & Silva, J. (2015). Frailty Plays a Key Role after Cardiac Surgery. *Heart, Lung & Circulation*, 24(9), 940. <https://doi.org/10.1016/j.hlc.2015.03.022>

Dinarello, C. A. (2000). Proinflammatory Cytokines. *Chest*, 118(2), 503-508. <https://doi.org/10.1378/chest.118.2.503>

Dodds, R., & Sayer, A. A. (2015). Sarcopenia and frailty: New challenges for clinical practice. *Clinical Medicine (London, England)*, 15 Suppl 6, s88-91. <https://doi.org/10.7861/clinmedicine.15-6-s88>

Em, R., Mc, T., Gj, B., S, V., Ma, de van der S., Cg, M., & Ab, M. (2016). Common Ground? The Concordance of Sarcopenia and Frailty Definitions. *Journal of the American Medical Directors Association*, 17(4). <https://doi.org/10.1016/j.jamda.2016.01.013>

Eriksrud, O., & Bohannon, R. W. (2003). Relationship of Knee Extension Force to Independence in Sit-to-Stand Performance in Patients Receiving Acute Rehabilitation. *Physical Therapy*, 83(6), 544-551. <https://doi.org/10.1093/ptj/83.6.544>

Esteves, C. L., Ohara, D. G., Matos, A. P., Ferreira, V. T. K., Iosimuta, N. C. R., & Pegorari, M. S. (2020). Anthropometric indicators as a discriminator of sarcopenia in community-dwelling older adults of the Amazon region: A cross-sectional study. *BMC Geriatrics*, 20(1), 518. <https://doi.org/10.1186/s12877-020-01923-y>

Evans, W. J. (1996). Reversing sarcopenia: How weight training can build strength and vitality. *Geriatrics*, 51(5), 46-47, 51-53; quiz 54.

Faller, J. W., Pereira, D. do N., Souza, S. de, Nampo, F. K., Orlandi, F. de S., & Matumoto, S. (2019). Instruments for the detection of frailty syndrome in older adults: A systematic review. *PLOS ONE*, 14(4), e0216166. <https://doi.org/10.1371/journal.pone.0216166>

Fernandes, D. P. de S., Juvanhol, L. L., Lozano, M., & Ribeiro, A. Q. (2022). Calf circumference is an independent predictor of mortality in older adults: An approach with generalized additive models. *Nutrition in Clinical Practice*, 37(5), 1190-1198. <https://doi.org/10.1002/ncp.10780>

Ferrari, A. U., Radaelli, A., & Centola, M. (2003). Invited Review: Aging and the cardiovascular system. *Journal of Applied Physiology*, 95(6), 2591-2597. <https://doi.org/10.1152/jappphysiol.00601.2003>

Fielding, R. A., Vellas, B., Evans, W. J., Bhasin, S., Morley, J. E., Newman, A. B., Abellan van Kan, G., Andrieu, S., Bauer, J., Breuille, D., Cederholm, T., Chandler, J., De Meynard, C., Donini, L., Harris, T., Kannt, A., Keime Guibert, F., Onder, G., Papanicolaou, D., ... Zamboni, M. (2011). Sarcopenia: An undiagnosed condition in older adults. Current consensus definition: prevalence, etiology, and consequences. International working group on sarcopenia. *Journal of the American Medical Directors Association*, 12(4), 249-256. <https://doi.org/10.1016/j.jamda.2011.01.003>

Fried, L. P. (2016). Interventions for Human Frailty: Physical Activity as a Model. *Cold Spring Harbor Perspectives in Medicine*, 6(6), a025916. <https://doi.org/10.1101/cshperspect.a025916>

Fried, L. P., Ferrucci, L., Darer, J., Williamson, J. D., & Anderson, G. (2004). Untangling the concepts of disability, frailty, and comorbidity: Implications for improved targeting and care. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, 59(3), 255-263. <https://doi.org/10.1093/gerona/59.3.m255>

Fried, L. P., Tangen, C. M., Walston, J., Newman, A. B., Hirsch, C., Gottdiener, J., Seeman, T., Tracy, R., Kop, W. J., Burke, G., McBurnie, M. A., & Cardiovascular Health Study Collaborative Research Group. (2001). Frailty in older adults: Evidence for a phenotype. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, 56(3), M146-156. <https://doi.org/10.1093/gerona/56.3.m146>

Frontera, W. R., Hughes, V. A., Fielding, R. A., Fiatarone, M. A., Evans, W. J., & Roubenoff, R. (2000). Aging of skeletal muscle: A 12-yr longitudinal study. *Journal of Applied Physiology*, 88(4), 1321-1326. <https://doi.org/10.1152/jappl.2000.88.4.1321>

García-Nogueras, I., Aranda-Reneo, I., Peña-Longobardo, L. M., Oliva-Moreno, J., & Abizanda, P. (2017). Use of Health Resources and Healthcare Costs associated with Frailty: The FRADEA Study. *The Journal of Nutrition, Health & Aging*, 21(2), 207-214. <https://doi.org/10.1007/s12603-016-0727-9>

Gilbert, S. F. (2000). Aging: The Biology of Senescence. En *Developmental Biology*. 6th edition. Sinauer Associates. <https://www.ncbi.nlm.nih.gov/books/NBK10041/>

Gobbens, R. J., Luijkx, K. G., Wijnen-Sponselee, M. T., & Schols, J. M. (2010). Toward a conceptual definition of frail community dwelling older people. *Nursing Outlook*, 58(2), 76-86. <https://doi.org/10.1016/j.outlook.2009.09.005>

Gordon, E. H., Reid, N., Khetani, I. S., & Hubbard, R. E. (2021). How frail is frail? A systematic scoping review and synthesis of high impact studies. *BMC Geriatrics*, 21(1), 719. <https://doi.org/10.1186/s12877-021-02671-3>

Gort-van Dijk, D., Weerink, L. B. M., Milovanovic, M., Haveman, J.-W., Hemmer, P. H. J., Dijkstra, G., Lindeboom, R., & Campmans-Kuijpers, M. J. E. (2021). Bioelectrical Impedance Analysis and Mid-Upper Arm Muscle Circumference Can Be Used to Detect Low Muscle Mass in Clinical Practice. *Nutrients*, 13(7), 2350. <https://doi.org/10.3390/nu13072350>

Guillamón-Escudero, C., Diago-Galmés, A., Tenías-Burillo, J. M., Soriano, J. M., & Fernández-Garrido, J. J. (2020). Prevalence of Sarcopenia in Community-Dwelling Older Adults in Valencia, Spain. *International Journal of Environmental Research and Public Health*, 17(23), Article 23. <https://doi.org/10.3390/ijerph17239130>

Gul, R., Nazir, I., Amirzada, M. I., Jahan, F., Naseer, F., Baig, T. A., Gul, R., Nazir, I., Amirzada, M. I., Jahan, F., Naseer, F., & Baig, T. A. (2024). Aging and Synovial Joint Function: Changes in Structure and Implications for Mobility. En *Advancements in Synovial Joint Science—Structure, Function, and Beyond*. IntechOpen. <https://doi.org/10.5772/intechopen.1003866>

Guralnik, J. M., Cawthon, P. M., Bhasin, S., Fielding, R., Magaziner, J., Cruz-Jentoft, A. J., Vellas, B., Clarke, L., Lattimer, L., & Evans, W. (2023). Limited physician knowledge of sarcopenia: A survey. *Journal of the American Geriatrics Society*, 71(5), 1595-1602. <https://doi.org/10.1111/jgs.18227>

Hogan, D. B. (2018). Models, Definitions, and Criteria for Frailty. En *Conn's Handbook of Models for Human Aging* (pp. 35-44). Elsevier. <https://doi.org/10.1016/B978-0-12-811353-0.00003-8>

Hu, F.-J., Liu, H., Liu, X.-L., Jia, S.-L., Hou, L.-S., Xia, X., & Dong, B.-R. (2021). Mid-Upper Arm Circumference as an Alternative Screening Instrument to Appendicular Skeletal Muscle Mass Index for Diagnosing Sarcopenia. *Clinical Interventions in Aging*, 16, 1095-1104. <https://doi.org/10.2147/CIA.S311081>

Huang, J. Y., Liu, L., Lo, K., Yu, Y., Chen, C. L., Shen, G., Zhang, B., Huang, Y. Q., & Feng, Y. Q. (2021). The association of calf circumference and all-cause, cardiovascular and cerebrovascular mortality: Results from the National Health and Nutrition Examination Surveys. *Archives of Medical Science*. <https://doi.org/10.5114/aoms/118575>

Hughes, V. A., Frontera, W. R., Wood, M., Evans, W. J., Dallal, G. E., Roubenoff, R., & Fiatarone Singh, M. A. (2001). Longitudinal muscle strength changes in older adults: Influence of muscle mass, physical activity, and health. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, 56(5), B209-217. <https://doi.org/10.1093/gerona/56.5.b209>

Hwang, A.-C., Lee, W.-J., Huang, N., Chen, L.-Y., Peng, L.-N., Lin, M.-H., Chou, Y.-J., & Chen, L.-K. (2021). Longitudinal changes of frailty in 8 years: Comparisons between physical frailty and frailty index. *BMC Geriatrics*, 21, 726. <https://doi.org/10.1186/s12877-021-02665-1>

Ito, A., Ishizaka, M., Kobayashi, K., Sawaya, Y., Hara, T., Nagasaka, Y., Yakabi, A., Watanabe, M., & Kubo, A. (2021). Changes in the screening efficacy of lower calf circumference, SARC-F score, and SARC-CalF score following update from AWGS 2014 to 2019 sarcopenia diagnostic criteria in community-dwelling older adults. *Journal of Physical Therapy Science*, 33(3), 241-245. <https://doi.org/10.1589/jpts.33.241>

Janssen, I. (2010). Evolution of sarcopenia research. *Applied Physiology, Nutrition, and Metabolism = Physiologie Appliquee, Nutrition Et Metabolisme*, 35(5), 707-712. <https://doi.org/10.1139/H10-067>

Janssen, I., Shepard, D. S., Katzmarzyk, P. T., & Roubenoff, R. (2004). The healthcare costs of sarcopenia in the United States. *Journal of the American Geriatrics Society*, 52(1), 80-85. <https://doi.org/10.1111/j.1532-5415.2004.52014.x>

Johansson, J., Grimsgaard, S., Strand, B. H., Sayer, A. A., & Cooper, R. (2023). Comparing associations of handgrip strength and chair stand performance with all-cause mortality—implications for defining probable sarcopenia: The Tromsø Study 2015–2020. *BMC Medicine*, 21(1), 451. <https://doi.org/10.1186/s12916-023-03172-3>

Johansson, J., Strand, B. H., Morseth, B., Hopstock, L. A., & Grimsgaard, S. (2020). Differences in sarcopenia prevalence between upper-body and lower-body based EWGSOP2 muscle strength criteria: The Tromsø study 2015–2016. *BMC Geriatrics*, 20(1), 461. <https://doi.org/10.1186/s12877-020-01860-w>

Kandinata, S. G., Widajanti, N., Ichwani, J., Firdausi, H., Aryana, I. G. P. S., & Alkaff, F. F. (2023). Diagnostic performance of calf circumference, SARC-F, and SARC-CalF for possible sarcopenia screening in Indonesia. *Scientific Reports*, 13(1), 9824. <https://doi.org/10.1038/s41598-023-36585-4>

Kera, T., Kawai, H., Takahashi, J., Hirano, H., Watanabe, Y., Fujiwara, Y., Ihara, K., Kim, H., & Obuchi, S. (2020). Association between ground reaction force in sit-to-stand motion and falls in community-dwelling older Japanese individuals. *Archives of Gerontology and Geriatrics*, 91, 104221. <https://doi.org/10.1016/j.archger.2020.104221>

Kera, T., Kawai, H., Takahashi, J., Hirano, H., Watanabe, Y., Fujiwara, Y., Ihara, K., Kim, H., & Obuchi, S. (2022). Development of a screening formula for sarcopenia using ground reaction force during sit-to-stand motion. *Gait & Posture*, 93, 177-182. <https://doi.org/10.1016/j.gaitpost.2022.02.001>

Khezrian, M., Myint, P. K., McNeil, C., & Murray, A. D. (2017). A Review of Frailty Syndrome and Its Physical, Cognitive and Emotional Domains in the Elderly. *Geriatrics (Basel, Switzerland)*, 2(4), 36. <https://doi.org/10.3390/geriatrics2040036>

Kiebzak, G. M. (1991). Age-related bone changes. *Experimental Gerontology*, 26(2), 171-187. [https://doi.org/10.1016/0531-5565\(91\)90010-J](https://doi.org/10.1016/0531-5565(91)90010-J)

Kim, G.-M., Song, S., Park, J.-H., Tak, Y. J., Wang, I. J., Huh, U., & Cho, J. S. (2022). Diagnostic significance of calf circumference in sarcopenia of healthy korean adult males. *Frontiers in Physiology*, 13. <https://www.frontiersin.org/articles/10.3389/fphys.2022.973265>

Kim, S. Y. (2022). Why do journals publish research protocols? *Science Editing*, 9(2), 146-148. <https://doi.org/10.6087/kcse.280>

Kojima, G. (2019). Increased healthcare costs associated with frailty among community-dwelling older people: A systematic review and meta-analysis. *Archives of Gerontology and Geriatrics*, 84, 103898. <https://doi.org/10.1016/j.archger.2019.06.003>

Kojima, G., Liljas, A., & Iliffe, S. (2019). Frailty syndrome: Implications and challenges for health care policy. *Risk Management and Healthcare Policy, Volume 12*, 23-30. <https://doi.org/10.2147/RMHP.S168750>

Kubben, P. (2019). Mobile apps. *Fundamentals of Clinical Data Science*, 171-179.

Laird, C. E., & Rozier, C. K. (1979). Toward understanding the terminology of exercise mechanics. *Physical Therapy*, 59(3), 287-292. <https://doi.org/10.1093/ptj/59.3.287>

Landi, F., Liperoti, R., Fusco, D., Mastropaolo, S., Quattrociocchi, D., Proia, A., Russo, A., Bernabei, R., & Onder, G. (2012). Prevalence and Risk Factors of Sarcopenia Among Nursing Home Older Residents. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 67A(1), 48-55. <https://doi.org/10.1093/gerona/qlr035>

Landi, F., Russo, A., Liperoti, R., Pahor, M., Tosato, M., Capoluongo, E., Bernabei, R., & Onder, G. (2010). Midarm muscle circumference, physical performance and mortality: Results from the aging and longevity study in the Sirente geographic area (ilSIRENTE study). *Clinical Nutrition*, 29(4), 441-447. <https://doi.org/10.1016/j.clnu.2009.12.006>

Lang, P.-O., Michel, J.-P., & Zekry, D. (2009). Frailty syndrome: A transitional state in a dynamic process. *Gerontology*, 55(5), 539-549. <https://doi.org/10.1159/000211949>

Leeftang, M. M. G., Rutjes, A. W. S., Reitsma, J. B., Hooft, L., & Bossuyt, P. M. M. (2013). Variation of a test's sensitivity and specificity with disease prevalence. *CMAJ*, 185(11), E537-E544. <https://doi.org/10.1503/cmaj.121286>

Levis, B., Benedetti, A., Levis, A. W., Ioannidis, J. P. A., Shrier, I., Cuijpers, P., Gilbody, S., Kloda, L. A., McMillan, D., Patten, S. B., Steele, R. J., Ziegelstein, R. C., Bombardier, C. H., de Lima Osório, F., Fann, J. R., Gjerdingen, D., Lamers, F., Lotrakul, M., Loureiro, S. R., ... Thombs, B. D. (2017). Selective Cutoff Reporting in Studies of Diagnostic Test Accuracy: A Comparison of Conventional and Individual-Patient-Data Meta-Analyses of the Patient Health Questionnaire-9 Depression Screening Tool. *American Journal of Epidemiology*, 185(10), 954-964. <https://doi.org/10.1093/aje/kww191>

Li, X., Lang, X., Peng, S., Ding, L., Li, S., Li, Y., Yin, L., & Liu, X. (2022). Calf Circumference and All-Cause Mortality: A Systematic Review and Meta-Analysis Based on Trend Estimation Approaches. *The Journal of Nutrition, Health & Aging*, 26(9), 826-838. <https://doi.org/10.1007/s12603-022-1838-0>

Lin, J.-R., Kao, E. H.-C., Weng, S.-C., & Rouyer, E. (2019). A Study of Frailty, Mortality, and Health Depreciation Factors in Older Adults. *International Journal of Environmental Research and Public Health*, 17(1), 211. <https://doi.org/10.3390/ijerph17010211>

López-Otín, C., Blasco, M. A., Partridge, L., Serrano, M., & Kroemer, G. (2013). The Hallmarks of Aging. *Cell*, 153(6), 1194-1217. <https://doi.org/10.1016/j.cell.2013.05.039>

Lord, S. R., Murray, S. M., Chapman, K., Munro, B., & Tiedemann, A. (2002). Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, 57(8), M539-543. <https://doi.org/10.1093/gerona/57.8.m539>

Losa-Reyna, J., Alcazar, J., Carnicero, J., Alfaro-Acha, A., Castillo-Gallego, C., Rosado-Artalejo, C., Rodríguez-Mañas, L., Ara, I., & García-García, F. J. (2022). Impact of Relative Muscle Power on Hospitalization and All-Cause Mortality in Older Adults. *The Journals of Gerontology: Series A*, 77(4), 781-789. <https://doi.org/10.1093/gerona/glab230>

Malmstrom, T. K., Miller, D. K., Simonsick, E. M., Ferrucci, L., & Morley, J. E. (2016). SARC-F: A symptom score to predict persons with sarcopenia at risk for poor functional outcomes: SARC-F. *Journal of Cachexia, Sarcopenia and Muscle*, 7(1), 28-36. <https://doi.org/10.1002/jcsm.12048>

Martin, F. C., & Ranhoff, A. H. (2021). Frailty and Sarcopenia. En P. Falaschi & D. Marsh (Eds.), *Orthogeriatrics: The Management of Older Patients with Fragility Fractures* (pp. 53-65). Springer International Publishing. https://doi.org/10.1007/978-3-030-48126-1_4

Martone, A. M., Ciciarello, F., Galluzzo, V., Calvani, R., Zazzara, M. B., Tosato, M., Coelho-Junior, H. J., Marzetti, E., & Landi, F. (2023). A simple medical device development according to normative values of calf circumference across ages: Results from the Italian Longevity Check-up 7+ (Lookup 7+) project. *Journal of Cachexia, Sarcopenia and Muscle*, jcsm.13286. <https://doi.org/10.1002/jcsm.13286>

Masanés Toran, F., Culla, A., Navarro-Gonzalez, M., Navarro-Lopez, M., Sacanella, E., Torres, B., & Lopez-Soto, A. (2012). Prevalence of sarcopenia in healthy community-dwelling elderly in an urban area of Barcelona (Spain). *The Journal of Nutrition, Health & Aging*, 16(2), 184-187. <https://doi.org/10.1007/s12603-011-0108-3>

McGauran, N., Wieseler, B., Kreis, J., Schüler, Y.-B., Kölsch, H., & Kaiser, T. (2010). Reporting bias in medical research—A narrative review. *Trials*, 11(1), 37. <https://doi.org/10.1186/1745-6215-11-37>

Mello, A. de C., Engstrom, E. M., & Alves, L. C. (2014). Health-related and socio-demographic factors associated with frailty in the elderly: A systematic literature review. *Cadernos de Saúde Pública*, 30, 1143-1168. <https://doi.org/10.1590/0102-311X00148213>

Mesquita, W. dos R., & Ricci, N. A. (2022). What do Brazilian health professionals know about the frailty syndrome? A cross-sectional study. *BMC Geriatrics*, 22(1), 232. <https://doi.org/10.1186/s12877-022-02927-6>

Metter, E. J., Conwit, R., Tobin, J., & Fozard, J. L. (1997). Age-associated loss of power and strength in the upper extremities in women and men. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, 52(5), B267-276. <https://doi.org/10.1093/gerona/52a.5.b267>

Miljkovic, N., Lim, J.-Y., Miljkovic, I., & Frontera, W. R. (2015). Aging of Skeletal Muscle Fibers. *Annals of Rehabilitation Medicine*, 39(2), 155-162. <https://doi.org/10.5535/arm.2015.39.2.155>

Millor, N., Lecumberri, P., Gómez, M., Martínez, A., Martinikorena, J., Rodríguez-Mañas, L., García-García, F. J., & Izquierdo, M. (2017). Gait Velocity and Chair Sit-Stand-Sit Performance Improves Current Frailty-Status Identification. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 25(11), 2018-2025. <https://doi.org/10.1109/TNSRE.2017.2699124>

Ministerio de Sanidad—Profesionales—Prevención de fragilidad y caídas. (s. f.). Recuperado 17 de septiembre de 2023, de <https://www.sanidad.gob.es/areas/promocionPrevencion/envejecimientoSaludable/fragilidadCaídas/home.htm>

Mitnitski, A. B., Mogilner, A. J., & Rockwood, K. (2001). Accumulation of Deficits as a Proxy Measure of Aging. *The Scientific World Journal*, 1, 323-336. <https://doi.org/10.1100/tsw.2001.58>

Mobasheri, A., & Mendes, A. (2013). Physiology and pathophysiology of musculoskeletal aging: Current research trends and future priorities. *Frontiers in Physiology*, 4. <https://doi.org/10.3389/fphys.2013.00073>

Moloney, E., O'Donovan, M. R., Sezgin, D., McGrath, K., Timmons, S., & O'Caoimh, R. (2023). Frailty Knowledge, Use of Screening Tools, and Educational Challenges in Emergency Departments in Ireland: A Multisite Survey. *Journal of Emergency Nursing*. <https://doi.org/10.1016/j.jen.2023.08.008>

Mori, H., & Tokuda, Y. (2019). Differences and overlap between sarcopenia and physical frailty in older community-dwelling Japanese. *Asia Pacific Journal of Clinical Nutrition*, 28(1), 157-165. [https://doi.org/10.6133/apjcn.201903_28\(1\).0021](https://doi.org/10.6133/apjcn.201903_28(1).0021)

Morley, J. E., Abbatecola, A. M., Argiles, J. M., Baracos, V., Bauer, J., Bhasin, S., Cederholm, T., Stewart Coats, A. J., Cummings, S. R., Evans, W. J., Fearon, K., Ferrucci, L., Fielding, R. A., Guralnik, J. M., Harris, T. B., Inui, A., Kalantar-Zadeh, K., Kirwan, B.-A., Mantovani, G., ... Anker, S. D. (2011). Sarcopenia With Limited Mobility: An International Consensus. *Journal of the American Medical Directors Association*, 12(6), 403-409. <https://doi.org/10.1016/j.jamda.2011.04.014>

Morley, J. E., Baumgartner, R. N., Roubenoff, R., Mayer, J., & Nair, K. S. (2001). Sarcopenia. *The Journal of Laboratory and Clinical Medicine*, 137(4), 231-243. <https://doi.org/10.1067/mlc.2001.113504>

Mosa, A. S. M., Yoo, I., & Sheets, L. (2012). A Systematic Review of Healthcare Applications for Smartphones. *BMC Medical Informatics and Decision Making*, 12(1), 67. <https://doi.org/10.1186/1472-6947-12-67>

Murao, Y., Ishikawa, J., Tamura, Y., Kobayashi, F., Iizuka, A., Toba, A., Harada, K., & Araki, A. (2023). Association between physical performance during sit-to-stand motion and frailty in older adults with cardiometabolic diseases: A cross-sectional, longitudinal study. *BMC Geriatrics*, 23(1), 337. <https://doi.org/10.1186/s12877-023-04011-z>

Navaratnarajah, A., & Jackson, S. H. D. (2017). The physiology of ageing. *Medicine*, 45(1), 6-10. <https://doi.org/10.1016/j.mpmed.2016.10.008>

O'Caoimh, R., Galluzzo, L., Rodríguez-Laso, Á., Van der Heyden, J., Ranhoff, A. H., Lamprini-Koula, M., Ciutan, M., López-Samaniego, L., Carcaillon-Bentata, L., Kennelly, S., Liew, A., & Work Package 5 of the Joint Action ADVANTAGE. (2018). Prevalence of frailty at population level in European ADVANTAGE Joint Action Member States: A systematic review and meta-analysis. *Annali Dell'Istituto Superiore Di Sanita*, 54(3), 226-238. https://doi.org/10.4415/ANN_18_03_10

O'Caoimh, R., Sezgin, D., O'Donovan, M. R., Molloy, D. W., Clegg, A., Rockwood, K., & Liew, A. (2021). Prevalence of frailty in 62 countries across the world: A systematic review and meta-analysis of population-level studies. *Age and Ageing*, 50(1), 96-104. <https://doi.org/10.1093/ageing/afaa219>

Offord, N. J., Clegg, A., Turner, G., Dodds, R. M., Sayer, A. A., & Witham, M. D. (2019). Current practice in the diagnosis and management of sarcopenia and frailty – results from a UK-wide survey. *Journal of Frailty, Sarcopenia and Falls*, 4(3), 71-77. <https://doi.org/10.22540/JFSF-04-071>

Ofori-Asenso, R., Chin, K. L., Mazidi, M., Zomer, E., Ilomaki, J., Zullo, A. R., Gasevic, D., Ademi, Z., Korhonen, M. J., LoGiudice, D., Bell, J. S., & Liew, D. (2019). Global Incidence of Frailty and Prefrailty Among Community-Dwelling Older Adults: A Systematic Review and Meta-analysis. *JAMA Network Open*, 2(8), e198398. <https://doi.org/10.1001/jamanetworkopen.2019.8398>

Ohtake, P. J., & Childs, J. D. (2014). Why Publish Study Protocols? *Physical Therapy*, 94(9), 1208-1209. <https://doi.org/10.2522/ptj.2014.94.9.1208>

Orange, S. T., Metcalfe, J. W., Liefelth, A., & Jordan, A. R. (2020). Validity of various portable devices to measure sit-to-stand velocity and power in older adults. *Gait & Posture*, 76, 409-414. <https://doi.org/10.1016/j.gaitpost.2019.12.003>

Park, C., Sharafkhaneh, A., Bryant, M. S., Nguyen, C., Torres, I., & Najafi, B. (2021). Toward Remote Assessment of Physical Frailty Using Sensor-based Sit-to-stand Test. *Journal of Surgical Research*, 263, 130-139. <https://doi.org/10.1016/j.jss.2021.01.023>

Petermann-Rocha, F., Balntzi, V., Gray, S. R., Lara, J., Ho, F. K., Pell, J. P., & Celis-Morales, C. (2022). Global prevalence of sarcopenia and severe sarcopenia: A systematic review and meta-analysis. *Journal of Cachexia, Sarcopenia and Muscle*, 13(1), 86-99. <https://doi.org/10.1002/jcsm.12783>

Peters, J., & Mengersen, K. (2008). Selective Reporting of Adjusted Estimates in Observational Epidemiology Studies: Reasons and Implications for Meta-analyses. *Evaluation & the Health Professions*, 31(4), 370-389. <https://doi.org/10.1177/0163278708324438>

Reid, K. F., & Fielding, R. A. (2012). Skeletal Muscle Power: A Critical Determinant of Physical Functioning In Older Adults. *Exercise and sport sciences reviews*, 40(1), 4-12. <https://doi.org/10.1097/JES.0b013e31823b5f13>

Reid, K. F., Pasha, E., Doros, G., Clark, D. J., Patten, C., Phillips, E. M., Frontera, W. R., & Fielding, R. A. (2014). Longitudinal decline of lower extremity muscle power in healthy and mobility-limited older adults: Influence of muscle mass, strength, composition, neuromuscular activation and single fiber contractile properties. *European Journal of Applied Physiology*, 114(1), 29-39. <https://doi.org/10.1007/s00421-013-2728-2>

Reijnierse, E. M., Schueren, M. A. E., Trappenburg, M. C., Doves, M., Meskers, C. G. M., & Maier, A. B. (2017). Lack of knowledge and availability of diagnostic equipment could hinder the diagnosis of sarcopenia and its management. *PloS One*, 12(10), 0185837. <https://doi.org/10.1371/journal.pone.0185837>

Rifai, N., Altman, D. G., & Bossuyt, P. M. (2008). Reporting Bias in Diagnostic and Prognostic Studies: Time for Action. *Clinical Chemistry*, 54(7), 1101-1103. <https://doi.org/10.1373/clinchem.2008.108993>

Roberts, H. C., Denison, H. J., Martin, H. J., Patel, H. P., Syddall, H., Cooper, C., & Sayer, A. A. (2011). A review of the measurement of grip strength in clinical and epidemiological studies: Towards a standardised approach. *Age and Ageing*, 40(4), 423-429. <https://doi.org/10.1093/ageing/afr051>

Roberts, S., Colombier, P., Sowman, A., Mennan, C., Rölfig, J. H. D., Guicheux, J., & Edwards, J. R. (2016). Ageing in the musculoskeletal system. *Acta Orthopaedica*, 87(Suppl 363), 15-25. <https://doi.org/10.1080/17453674.2016.1244750>

Rockwood, K., & Howlett, S. E. (2018). Fifteen years of progress in understanding frailty and health in aging. *BMC Medicine*, 16(1), 220. <https://doi.org/10.1186/s12916-018-1223-3>

Rockwood, K., Song, X., MacKnight, C., Bergman, H., Hogan, D. B., McDowell, I., & Mitnitski, A. (2005). A global clinical measure of fitness and frailty in elderly people. *CMAJ: Canadian Medical Association Journal*, 173(5), 489-495. <https://doi.org/10.1503/cmaj.050051>

Rosenberg, I. H. (1989). Summary comments. *The American Journal of Clinical Nutrition*, 50(5), 1231-1233. <https://doi.org/10.1093/ajcn/50.5.1231>

Rosenberg, I. H. (1997). Sarcopenia: Origins and clinical relevance. *The Journal of Nutrition*, 127(5 Suppl), 990S-991S. <https://doi.org/10.1093/jn/127.5.990S>

Ruiz Comellas, A., Pera, G., Baena Díez, J. M., Mundet Tudurí, X., Alzamora Sas, T., Elosua, R., Torán Monserrat, P., Heras, A., Forés Raurell, R., Fusté Gamisans, M., & Fàbrega Camprubí, M. (2012). Validación de una versión reducida en español del cuestionario de actividad física en el tiempo libre de Minnesota (VREM). *Revista Española de Salud Pública*, 86(5), 495-508.

Ruiz-Cárdenas, J. D., Rodríguez-Juan, J. J., Smart, R. R., Jakobi, J. M., & Jones, G. R. (2018). Validity and reliability of an iPhone App to assess time, velocity and leg power during a sit-to-stand functional performance test. *Gait & Posture*, 59, 261-266. <https://doi.org/10.1016/j.gaitpost.2017.10.029>

Ruiz-Cárdenas, J. D., Montemurro, A., Martínez-García, M. del M., & Rodríguez-Juan, J. J. (2023). Concurrent and discriminant validity and reliability of an Android App to assess time, velocity and power during sit-to-stand test in community-dwelling older adults. *Aging Clinical and Experimental Research*. <https://doi.org/10.1007/s40520-023-02451-6>

Rutjes, A. W. S., Reitsma, J. B., Di Nisio, M., Smidt, N., van Rijn, J. C., & Bossuyt, P. M. M. (2006). Evidence of bias and variation in diagnostic accuracy studies. *CMAJ: Canadian Medical Association Journal = Journal de l'Association Médicale Canadienne*, 174(4), 469-476. <https://doi.org/10.1503/cmaj.050090>

Santos, L. P., Gonzalez, M. C., Orlandi, S. P., Bielemann, R. M., Barbosa-Silva, T. G., Heymsfield, S. B., & COCONUT Study Group. (2019). New Prediction Equations to Estimate Appendicular Skeletal Muscle Mass Using Calf Circumference: Results From NHANES 1999-2006. *JPEN. Journal of Parenteral and Enteral Nutrition*, 43(8), 998-1007. <https://doi.org/10.1002/jpen.1605>

Schmitt, J., & Di Fabio, R. P. (2005). The Validity of Prospective and Retrospective Global Change Criterion Measures. *Archives of Physical Medicine and Rehabilitation*, 86(12), 2270-2276. <https://doi.org/10.1016/j.apmr.2005.07.290>

Scott-Warren, V., & Maguire, S. (2017). Physiology of ageing. *Anaesthesia & Intensive Care Medicine*, 18(1), 52-54. <https://doi.org/10.1016/j.mpaic.2016.10.015>

Sergi, G., De Rui, M., Veronese, N., Bolzetta, F., Berton, L., Carraro, S., Bano, G., Coin, A., Manzato, E., & Perissinotto, E. (2015). Assessing appendicular skeletal muscle mass with bioelectrical impedance analysis in free-living Caucasian older adults. *Clinical Nutrition (Edinburgh, Scotland)*, 34(4), 667-673. <https://doi.org/10.1016/j.clnu.2014.07.010>

Simera, I., Moher, D., Hoey, J., Schulz, K. F., & Altman, D. G. (2009). The EQUATOR Network and reporting guidelines: Helping to achieve high standards in reporting health research studies. *Maturitas*, 63(1), 4-6. <https://doi.org/10.1016/j.maturitas.2009.03.011>

Skelton, D. A., Greig, C. A., Davies, J. M., & Young, A. (1994). Strength, Power and Related Functional Ability of Healthy People Aged 65–89 Years. *Age and Ageing*, 23(5), 371-377. <https://doi.org/10.1093/ageing/23.5.371>

Sobhani, A., Fadayevatan, R., Sharifi, F., Kamrani, A. A., Ejtahed, H.-S., Hosseini, R. S., Mohamadi, S., Fadayevatan, A., & Mortazavi, S. (2021). The conceptual and practical definitions of frailty in older adults: A systematic review. *Journal of Diabetes and Metabolic Disorders*, 20(2), 1975-2013. <https://doi.org/10.1007/s40200-021-00897-x>

Sousa, A. S., Guerra, R. S., Fonseca, I., Pichel, F., Ferreira, S., & Amaral, T. F. (2016). Financial impact of sarcopenia on hospitalization costs. *European Journal of Clinical Nutrition*, 70(9), Article 9. <https://doi.org/10.1038/ejcn.2016.73>

Steffl, M., Bohannon, R. W., Sontakova, L., Tufano, J. J., Shiells, K., & Holmerova, I. (2017). Relationship between sarcopenia and physical activity in older people: A systematic review and meta-analysis. *Clinical Interventions in Aging*, Volume 12, 835-845. <https://doi.org/10.2147/CIA.S132940>

Sternberg, S. A., Schwartz, A. W., Karunanathan, S., Bergman, H., & Mark Clarfield, A. (2011). The Identification of Frailty: A Systematic Literature Review. *Journal of the American Geriatrics Society*, 59(11), 2129-2138. <https://doi.org/10.1111/j.1532-5415.2011.03597.x>

Studenski, S. A., Peters, K. W., Alley, D. E., Cawthon, P. M., McLean, R. R., Harris, T. B., Ferrucci, L., Guralnik, J. M., Fragala, M. S., Kenny, A. M., Kiel, D. P., Kritchevsky, S. B., Shardell, M. D., Dam, T.-T. L., & Vassileva, M. T. (2014). The FNIH Sarcopenia Project: Rationale, Study Description, Conference Recommendations, and Final Estimates. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 69(5), 547-558. <https://doi.org/10.1093/gerona/glu010>

Tan, L. F., Lim, Z. Y., Choe, R., Seetharaman, S., & Merchant, R. (2017). Screening for Frailty and Sarcopenia Among Older Persons in Medical Outpatient Clinics and its Associations With Healthcare Burden. *Journal of the American Medical Directors Association*, 18(7), 583-587. <https://doi.org/10.1016/j.jamda.2017.01.004>

Thompson, M. Q., Yu, S., Tucker, G. R., Adams, R. J., Cesari, M., Theou, O., & Visvanathan, R. (2021). Frailty and sarcopenia in combination are more predictive of mortality than either condition alone. *Maturitas*, 144, 102-107. <https://doi.org/10.1016/j.maturitas.2020.11.009>

Tofthagen, C. (2012). Threats to Validity in Retrospective Studies. *Journal of the Advanced Practitioner in Oncology*, 3(3), 181-183.

Travers, J., Romero-Ortuno, R., Bailey, J., & Cooney, M.-T. (2019). Delaying and reversing frailty: A systematic review of primary care interventions. *The British Journal of General Practice*, 69(678), e61-e69. <https://doi.org/10.3399/bjgp18X700241>

Uppstad, P. H., & McTigue, E. (2020). A rationale for publishing peer-reviewed study protocols in the Nordic Journal of Literacy Research in order to increase scientific rigour. *Nordic Journal of Literacy Research*, 6(1), Article 1. <https://doi.org/10.23865/njlr.v6.2010>

Valdivieso, R., Azevedo, L. F., Moreira, E., Ataíde, R., Martins, S., Fernandes, L., Silva-Cardoso, J., & Borges, N. (2021). Frailty phenotype and associated nutritional factors in a sample of Portuguese outpatients with heart failure. *Nutrition, Metabolism and Cardiovascular Diseases*, 31(8), 2391-2397. <https://doi.org/10.1016/j.numecd.2021.03.028>

Valenzuela, P. L., Castillo-García, A., Morales, J. S., Izquierdo, M., Serra-Rexach, J. A., Santos-Lozano, A., & Lucia, A. (2019). Physical Exercise in the Oldest Old. En *Comprehensive Physiology* (pp. 1281-1304). John Wiley & Sons, Ltd. <https://doi.org/10.1002/cphy.c190002>

Ventola, C. L. (2014). Mobile Devices and Apps for Health Care Professionals: Uses and Benefits. *Pharmacy and Therapeutics*, 39(5), 356-364.

Verstraeten, L. M. G., de Haan, N. J., Verbeet, E., van Wijngaarden, J. P., Meskers, C. G. M., & Maier, A. B. (2022). Handgrip strength rather than chair stand test should be used to diagnose sarcopenia in geriatric rehabilitation inpatients: RESStORing health of acutely unwell adults (RESORT). *Age and Ageing*, 51(11), afac242. <https://doi.org/10.1093/ageing/afac242>

Wagner, K.-H., Cameron-Smith, D., Wessner, B., & Franzke, B. (2016). Biomarkers of Aging: From Function to Molecular Biology. *Nutrients*, 8(6), 338. <https://doi.org/10.3390/nu8060338>

Wilson, D., Jackson, T., Sapey, E., & Lord, J. M. (2017). Frailty and sarcopenia: The potential role of an aged immune system. *Ageing Research Reviews*, 36, 1-10. <https://doi.org/10.1016/j.arr.2017.01.006>

Wong, E. K., Lachance, C. C., Page, M. J., Watt, J., Veroniki, A., Straus, S. E., & Tricco, A. C. (2019). Selective reporting bias in randomised controlled trials from two network meta-analyses: Comparison of clinical trial registrations and their respective publications. *BMJ Open*, 9(9), e031138. <https://doi.org/peter>

Xue, Q.-L. (2011). The Frailty Syndrome: Definition and Natural History. *Clinics in Geriatric Medicine*, 27(1), 1-15. <https://doi.org/10.1016/j.cger.2010.08.009>

Yang, M., Hu, X., Xie, L., Zhang, L., Zhou, J., Lin, J., Wang, Y., Li, Y., Han, Z., Zhang, D., Zuo, Y., Li, Y., & Wu, L. (2018). Screening Sarcopenia in Community-Dwelling Older Adults: SARC-F vs SARC-F Combined With Calf Circumference (SARC-CalF). *Journal of the American Medical Directors Association*, 19(3), 277.e1-277.e8. <https://doi.org/10.1016/j.jamda.2017.12.016>

Yao, X. M., Liu, B. B., Deng, W. Y., & Wang, X. H. (2022). The Awareness and Knowledge Regarding Sarcopenia among Healthcare Professionals: A Scoping Review. *The Journal of Frailty & Aging*, 11(3), 274-280. <https://doi.org/10.14283/jfa.2022.7>

Yeung, S. S. Y., Reijnierse, E. M., Trappenburg, M. C., Meskers, C. G. M., & Maier, A. B. (2020). Current knowledge and practice of Australian and New Zealand health-care professionals in sarcopenia diagnosis and treatment: Time to move forward! *Australasian Journal on Ageing*, 39(2), 185-193. <https://doi.org/10.1111/ajag.12730>

Yoshimura, N., Muraki, S., Iidaka, T., Oka, H., Horii, C., Kawaguchi, H., Akune, T., Nakamura, K., & Tanaka, S. (2019). Prevalence and co-existence of locomotive syndrome, sarcopenia, and frailty: The third survey of Research on Osteoarthritis/Osteoporosis Against Disability (ROAD) study. *Journal of Bone and Mineral Metabolism*, 37(6), 1058-1066. <https://doi.org/10.1007/s00774-019-01012-0>

Yuan, S., & Larsson, S. C. (2023). Epidemiology of sarcopenia: Prevalence, risk factors, and consequences. *Metabolism: Clinical and Experimental*, 144, 155533. <https://doi.org/10.1016/j.metabol.2023.155533>

Zanker, J., Sim, M., Anderson, K., Balogun, S., Brennan-Olsen, S. L., Dent, E., Duque, G., Girgis, C. M., Grossmann, M., Hayes, A., Henwood, T., Hirani, V., Inderjeeth, C., Iuliano, S., Keogh, J., Lewis, J. R., Lynch, G. S., Pasco, J. A., Phu, S., ... Scott, D. (2023). The Australian and New Zealand Society for Sarcopenia and Frailty Research (ANZSSFR) sarcopenia diagnosis and management task force: Findings from the consumer expert Delphi process. *Australasian Journal on Ageing*, 42(1), 251-257. <https://doi.org/10.1111/ajag.13164>

Zech, A., Steib, S., Sportwiss, D., Freiburger, E., & Pfeifer, K. (2011). Functional muscle power testing in young, middle-aged, and community-dwelling nonfrail and prefrail older adults. *Archives of Physical Medicine and Rehabilitation*, 92(6), 967-971. <https://doi.org/10.1016/j.apmr.2010.12.031>

Zhang, C., Li, J., Shi, H., Liu, Y., Cui, J., Luo, X. M., Zeng, L. T., Fan, G. Q., Chang, X. M., Zhang, P. J., & Shen, J. (2023). Independent and combined associations of upper and lower limb strength with all-cause mortality in community-based older adults: Findings from the Chinese Longitudinal Healthy Longevity Survey. *Public Health*, 220, 57-64. <https://doi.org/10.1016/j.puhe.2023.04.023>

XIV – ANEXOS



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ANEXO 1. Aprobación del Comité Ético.



COMITÉ DE ÉTICA DE LA UCAM

DATOS DEL PROYECTO

Título:	“Validez y fiabilidad de una aplicación móvil para detectar el síndrome de fragilidad y la sarcopenia en personas mayores”	
Investigador Principal	Nombre	Correo-e
Dr.	Juan Diego Ruiz Cárdenas	jdruiz@ucam.edu

INFORME DEL COMITÉ

Fecha	26/02/2021	Código	CE022108
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Tipo de Experimentación

Investigación experimental clínica con seres humanos	
Investigación experimental no clínica con seres humanos	
Utilización de tejidos humanos procedentes de pacientes, personas sanas, tejidos embrionarios o fetales	
Utilización de tejidos humanos, tejidos embrionarios o fetales procedentes de bancos de muestras o tejidos	
Investigación observacional, psicológica o comportamental en humanos	X
Uso de datos personales, información genética, etc.	X
Experimentación animal	
Utilización de agentes biológicos de riesgo para la salud humana, animal o las plantas	
Uso de organismos modificados genéticamente (OMGs)	

Comentarios Respecto al Tipo de Experimentación

Nada Obsta

Comentarios Respecto a la Metodología de Experimentación

Nada Obsta





COMITÉ DE ÉTICA DE LA UCAM

Sugerencias al Investigador

A la vista de la solicitud de informe adjunto por el Investigador y de las recomendaciones anteriormente expuestas el dictamen del Comité es:

Emitir Informe Favorable	X
Emitir Informe Desfavorable	
Emitir Informe Favorable condicionado a Subsanación	
MOTIVACIÓN	
Incrementará conocimientos en su área	

Vº Bº El Presidente,

Fdo.: José Alberto Cánovas Sánchez

El Secretario,

Fdo.: José Alarcón Teruel

ANEXO 2. Hoja informativa para los sujetos de estudio.**DOCUMENTO DE INFORMACIÓN PARA SUJETOS SOMETIDOS A ESTUDIO
(HOJA INFORMATIVA)****1. EN QUÉ CONSISTE Y PARA QUÉ SIRVE:**

El estudio consiste en realizar una valoración funcional en pacientes ancianos en pacientes ancianos. El objetivo es desarrollar una aplicación móvil para detectar el síndrome de fragilidad y la sarcopenia, así como determinar la validez y la fiabilidad de la misma.

2. COMO SE REALIZA:

La valoración funcional se realiza mediante los siguientes test:

- (i) El gesto de levantarse de una silla: Consiste en levantarse de una silla lo más rápidos posible con los brazos cruzados sobre el pecho.
- (ii) El gesto de levantarse de una silla cinco veces: Consiste en levantarse de una silla cinco veces lo más rápidos posible con los brazos cruzados sobre el pecho.
- (iii) El test de marcha de 4 metros: Consiste en caminar a ritmo normal en una distancia de 4 metros.
- (iv) Prueba de presión manual: Consiste en presionar lo más fuerte posible un dinamómetro de mano. La prueba se realizará dos veces con cada mano.
- (v) Prueba de equilibrio estático: Consiste en mantener la posición de pie y con un pie delante del otro por un tiempo de 10 segundos.

3. QUÉ EFECTOS LE PRODUCIRÁ:

Ninguno conocido.

4. EN QUÉ LE BENEFICIARÁ:

Podrá contribuir al avance científico sobre las enfermedades Sarcopenia y Síndrome de Fragilidad.

5. QUÉ RIESGOS TIENE:

Ningún riesgo conocido.

6. SITUACIONES ESPECIALES QUE DEBEN SER TENIDAS EN CUENTA:

No participará en el estudio si usted sufre o tiene problemas cardiovasculares graves, desfibriladores o marcapasos implantados, si podrá clasificarse como no totalmente independiente y si cumplirá con los criterios diagnósticos de demencia senil.

7. OTRAS INFORMACIONES DE INTERÉS (a considerar por el/la profesional)

Ninguna.

8. OTRAS CUESTIONES PARA LAS QUE LE PEDIMOS SU CONSENTIMIENTO

Usted será grabado en video durante el test de levantarse de una silla. Las imágenes de video no grabarán su rostro en la medida de lo posible. Además, estas imágenes no serán utilizadas para otro fin distinto al de la presente investigación. Los investigadores se comprometen a eliminar todos los registros de video después de su análisis.

ANEXO 3. Hoja de registro de datos.**Nombre**_____ **Cod**_____**Telefono**_____ **Fecha**_____**Datos antropométricos****Sexo:** H M**Altura:** _____ cm**Longitud del fémur:** _____ cm**Circunferencia brazo:** _____ cm**Peso:** _____ Kg**Reactancia:** _____ Ohm**Índice de resistencia:** _____ Ohm

Mediciones y test

1-STTS: _____ seg _____ seg _____ seg

Fuerza de agarre: _____ Kg _____ Kg _____ Kg _____ Kg

Equilibrio en bipedestación: 1 punto

Equilibrio en semi-tándem: 1 punto

Equilibrio en tándem: _____ seg

Velocidad de marcha 4m: _____ seg _____ seg

5-STTS SPPB: _____ seg

5-STTS: _____ seg

Altura silla: _____ cm

Nombre _____ Cod# _____

Tel _____ Fecha _____

Estado clínico

Entre las siguientes opciones, marque la casilla correspondiente con su último nivel de estudios cursados:

- ☐ Menos que primaria
- ☐ Educación primaria
- ☐ Primera etapa educación secundaria
- ☐ Segunda etapa educación secundaria
- ☐ Enseñanzas de formación profesional de grado superior y similares
- ☐ Diplomado universitario y similares
- ☐ Licenciado y similares
- ☐ Doctor universitario

Indique la franja que se corresponde con su nivel socioeconómico anual

- ☐ 0-10.000 €
- ☐ 10.000-20.000 €
- ☐ 20.000-30.000 €
- ☐ 30.000-40.000 €
- ☐ > 40.000 €

¿Tiene usted diagnosticada alguna de estas enfermedades crónicas?

- ☐ Hipertensión arterial
- ☐ Diabetes tipo II
- ☐ Enfermedades cardiovasculares
- ☐ Enfermedad Pulmonar Obstructiva Crónica
- ☐ Infartos agudos de miocardio
- ☐ Cánceres
- ☐ Asma
- ☐ Artritis/Artrosis
- ☐ Bronquitis crónica
- ☐ Incontinencia urinaria/fecal
- ☐ Anemia

- Otras

¿Es usted fumador? SI NO

¿Toma usted más de 5 medicamentos? SI NO

¿Cómo juzgaría en general su nivel de salud? Marque una de las siguientes opciones:

- Muy malo
- Malo
- Regular
- Bueno
- Excelente

Depresión: "Le voy a hacer una serie de preguntas y usted debe responder SÍ o NO."

¿Se siente básicamente satisfecho con su vida? SI NO

¿Se encuentra a menudo aburrido? SI NO

¿Se siente a menudo abandonado? SI NO

¿Prefiere quedarse en casa a salir y hacer cosas nuevas? SI NO

¿Le cuesta iniciar nuevos proyectos? SI NO

Caídas y hospitalización

¿Ha sufrido usted 2 o más caídas en el último año? SI NO

Fenotipo de Fried

¿Ha sufrido usted una pérdida de peso importante en el último año? Una pérdida de 5% o 4,5 Kg.

SI

NO

Indique la frecuencia con la que experimenta estos estados en la última semana: (0-3 puntos)

Si le digo la siguiente frase: “No tenía ganas de hacer nada; siento que todo lo que hago me supone un esfuerzo”. ¿Cuántas veces se ha sentido así en la última semana?

- Nunca o casi nunca (menos de 1 día)
- A veces (1-2 días)
- Con frecuencia (3-4 días) *
- Siempre o casi siempre (5-7 días) *

(*) Criterio de fragilidad.

Versión Reducida en Español del cuestionario de actividad física en el tiempo libre de Minnesota (VREM)

Nombre: _____ Edad: _____

¿Qué actividad física ha realizado durante su tiempo libre en el **ÚLTIMO MES O MES HABITUAL**?

1.- **Caminar.** Días/mes _____ Minutos/día _____ Meses/año _____

2.- **Trabajar en el huerto.** Días/mes _____ Minutos/día _____ Meses/año _____

3.- **Hacer deporte o bailar.** ¿Qué tipo de deporte o baile?

Tipo de deporte/baile: _____ Días/mes _____ Minutos/día _____ Meses/año _____

Tipo de deporte/baile: _____ Días/mes _____ Minutos/día _____ Meses/año _____

Tipo de deporte/baile: _____ Días/mes _____ Minutos/día _____ Meses/año _____

4.- **Subir escaleras.** Días/mes _____ Pisos/día _____

En **LA ÚLTIMA SEMANA O SEMANA HABITUAL**

5.- ¿Cuánto tiempo dedica a **ir a comprar a PIE**? Minutos/semana _____

6.- ¿Cuánto tiempo dedica a **LIMPIAR la casa**? Minutos/semana _____

Nombre _____ Cod _____

Teléfono _____ Fecha _____

MINI COG TEST (Exclusión: < 3 puntos)**Paso 1. Registro de tres palabras.**

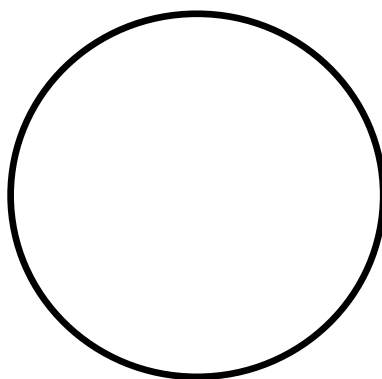
Escuche con atención. Voy a decir tres palabras que quiero que usted repita ahora y trate de recordar. Las palabras son:

Versión 1	Versión 2	Versión 3	Versión 4	Versión 5	Versión 6
Plátano	Líder	Pueblo	Río	Capitán	Hija
Amanecer	Temporada	Cocina	Nación	Jardín	Cielo
Silla	Mesa	Bebé	Dedo	Retrato	Montaña

"Ahora repita las palabras."

Paso 2. Test del reloj.

"Ahora, quiero que me dibuje un reloj. Primero, coloque los números donde van". Una vez que el cliente haya terminado, diga: "Ahora, ponga las manecillas del reloj en la posición que indiquen las 11:10".



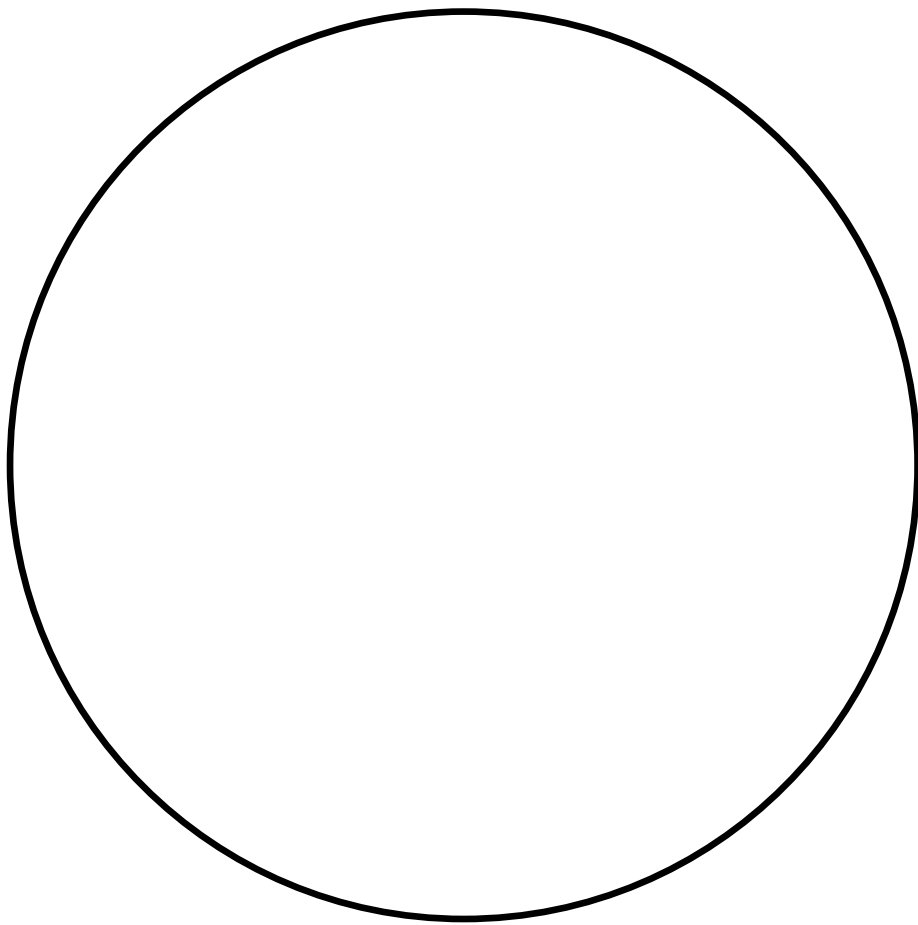
Números: 1 punto

Agujas: 1 punto

Paso 3. Test de memoria.

¿Cuáles fueron las tres palabras que le pedí que recordara?" Registre el número de versión de lista de palabras y las respuestas de la persona a continuación.

Versión _____ Respuestas _____



ANEXO 4. Ejemplar de informe de resultados obtenidos en las mediciones.

Grupo de Investigación ECOFISTEM
Universidad Católica de Murcia

Informe de valoración

Nombre: _____ Edad: _____ años

Peso: _____ Kg

Talla: _____ m

Índice de Masa Corporal (IMC)

92	43	42	41	40	39	38	37	36	35	34	33	33	32	31	30	30	29	28	28	27	27	26	25
90	42	41	40	39	38	37	36	35	34	33	33	32	31	30	30	29	28	28	27	27	26	25	25
88	41	40	39	38	37	36	35	34	34	33	32	31	30	30	29	28	28	27	27	26	25	25	24
86	40	39	38	37	36	35	34	34	33	32	31	30	30	29	28	28	27	27	26	25	25	24	24
84	39	38	37	36	35	35	34	33	32	31	30	30	29	28	28	27	27	26	25	25	24	24	23
82	38	37	36	35	35	34	33	32	31	30	30	29	28	28	27	26	26	25	25	24	24	23	23
80	38	37	36	35	34	33	32	31	30	30	29	28	28	27	26	26	25	25	24	24	23	23	22
78	37	36	35	34	33	32	31	30	30	29	28	28	27	26	26	25	25	24	24	23	23	22	22
76	36	35	34	33	32	31	30	30	29	28	28	27	26	26	25	25	24	23	23	22	22	22	21
74	35	34	33	32	31	30	30	29	28	28	27	26	26	25	24	24	23	23	22	22	21	21	20
72	34	33	32	31	30	30	29	28	27	27	26	26	25	24	24	23	23	22	22	21	21	20	20
70	33	32	31	30	30	29	28	27	27	26	25	25	24	24	23	23	22	22	21	21	20	20	19
68	32	31	30	29	29	28	27	27	26	25	25	24	24	23	22	22	21	21	21	20	20	19	19
66	31	30	29	29	28	27	26	26	25	25	24	23	23	22	22	21	21	20	20	19	19	19	18
64	30	29	28	28	27	26	26	25	24	24	23	23	22	22	21	21	20	20	19	19	18	18	18
62	29	28	28	27	26	25	25	24	24	23	22	22	21	21	20	20	20	19	19	18	18	18	17
60	28	27	27	26	25	25	24	23	23	22	22	21	21	20	20	19	19	19	18	18	17	17	17
58	27	26	26	25	24	24	23	23	22	22	21	21	20	20	19	19	18	18	18	17	17	16	16
56	26	26	25	24	24	23	22	22	21	21	20	20	19	19	18	18	18	17	17	17	16	16	16
54	25	25	24	23	23	22	22	21	21	20	20	19	19	18	18	17	17	17	16	16	16	15	15
52	24	24	23	23	22	21	21	20	20	19	19	18	18	18	17	17	16	16	16	15	15	15	14
50	23	23	22	22	21	21	20	20	19	19	18	18	17	17	17	16	16	15	15	15	14	14	14
48	23	22	21	21	20	20	19	19	18	18	17	17	17	16	16	15	15	15	14	14	14	14	13
46	22	21	20	20	19	19	18	18	18	17	17	16	16	16	15	15	15	14	14	14	13	13	13
44	21	20	20	19	19	18	18	17	17	16	16	16	15	15	15	14	14	14	13	13	13	12	12
42	20	19	19	18	18	17	17	16	16	16	15	15	15	14	14	14	13	13	13	12	12	12	12
40	19	18	18	17	17	16	16	16	15	15	15	14	14	14	13	13	13	12	12	12	11	11	11
	1,46	1,48	1,5	1,52	1,54	1,56	1,58	1,6	1,62	1,64	1,66	1,68	1,7	1,72	1,74	1,76	1,78	1,8	1,82	1,84	1,86	1,88	1,9

Nota: Este documento es meramente informativo y no sustituye la valoración de un profesional sanitario. Este documento carece de validez médica. Para una valoración más detallada consulte con su médico.

Grupo de Investigación ECOFISTEM
Universidad Católica de Murcia

Informe de valoración

Circunferencia de brazo (cm)

18	18,5	19	19,5	20	20,5	21	21,5	22	22,5	23	23,5	24	24,5	25	25,5	26
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Circunferencia de pantorrilla (cm)

28	28,5	29	29,5	30	30,5	31	31,5	32	32,5	33	33,5	34	34,5	35	35,5	36
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Tiempo de marcha en 4 metros (seg)

5,6	5,4	5,2	5	4,8	4,6	4,4	4,2	4	3,8	3,6	3,4	3,2	3	2,8	2,6	2,4
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Fuerza de agarre (Kg)

Mujeres																
P10	P25			P50						P75			P90			P95
14	18	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Hombres																
P10	P25			P50						P75			P90			P95
29	34	36	38	40	42	43	44	45	46	47	49	51	54	55	57	58

Fuerza de piernas (seg)

18	17,5	17	16	15,1	14	13,7	13	12,5	12	11,2	10,5	10,2	10	9,8	9,6	9,5
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