Chapter

Sarcopenia: Technological Advances in Measurement and Rehabilitation

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Abstract

Sarcopenia is an important recently defined disease affecting people aged ≥ 65 years all over the world. Improving the assessment of loss of muscle mass is becoming mandatory. In this regard, various new technologies have been advanced. Although the gold standard is represented by magnetic resonance imaging (MRI) or magnetic resonance spectroscopy (MRS), computed tomography (CT) or dual-energy X-ray absorptiometry (DXA), followed by biological impedance analysis (BIA) compared with DXA, there are numerous correlations between sarcopenia and health domain of everyday life that must be investigated and addressed, trying to obtain the best possible outcome in the older population. In this review, we focused on all types of new technologies assessing loss of muscle mass, frailty, independence, walking, capacity to get dressed, and loss of balance or sleepiness in older people and that could improve the diagnosis of sarcopenia or the rehabilitation of sarcopenic patients to prevent possible accidents. Different technologies have been proposed to investigate the factors promoting the loss of muscle mass and weakness. Despite the standard EWGSOP 2019 guidelines defining a specific methodology for the diagnosis of sarcopenia, not all domains and devices were included, and new frontiers of prevention have been explored.

Keywords: new technologies, sarcopenia, measurement, rehabilitation, device

1. Introduction

Sarcopenia was defined by the International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM) and recognized as a disease in 2016 [1–3]. In 2019, the European Working Group on Sarcopenia in Older People (EWGSOP) published important recommendations for the diagnosis of Sarcopenia for Caucasian People [4]. These recommendations are currently used as guidelines for the assessment of sarcopenia.

The first guidelines for the diagnosis of sarcopenia were written on the occasion of the first EWGSOP Congress in 2010 [5]. They also included some criteria for the diagnosis of *pre-sarcopenia* (loss of muscle mass and its variability).

The functional and anatomical areas to investigate for diagnosis, defined in both the first and second EWGSOP Congress [4], are muscle strength (hereinafter referred to as MS); muscle quality (hereinafter referred to as MQ), and physical performance

(hereinafter referred to as PP). Nowadays, in accordance with the second EWGSOP guidelines, MS is evaluated through the assessment of grip strength (subsequently referred to as handgrip strength or HGS). The dynamometer is an inexpensive and efficient tool, but it investigates only the strength exerted by the upper limbs and has several limitations [6]. The recommended tests for MQ are magnetic resonance imaging (MRI) or magnetic resonance spectroscopy (MRS); computed tomography (CT); dual-energy X-ray absorptiometry (DXA) [4], including the alternative use of the biological impedance analysis (BIA) [7]. Regarding PP, the suggested gold standards are the short physical performance battery (SPPB) combined with the time-up and go test (TUG), or, as an alternative, the gait speed test (GS) [4].

However, the problem is that DXA, MRI, and BIA are not always available in hospitals and at the surgeries of general practitioners, and are fairly expensive.

Therefore, the aim of this review is to suggest some new and less expensive tools and technologies that may substitute the three tests mentioned above and that are able to maintain a reliable level of diagnostic accuracy. Moreover, we would like to extend the MS parameters not only to the upper limbs but also to the lower limbs and to the assessment of balance and spatial coordination. The use of these accurate and cheaper tools would favor the diagnosis of sarcopenia and, consequently, the prevention of loss of muscle mass, in a higher number of patients. Alternative tools for the evaluation of MS and PP as well as some rehabilitation tools for the prevention of bad outcomes in pre-sarcopenic and sarcopenic patients will also be proposed.

2. Methodology

This is a review of five randomized control trials (RCT), three cohort studies (CS), 13 cross-sectional studies (CSS), two systematic reviews (SR), two systematic reviews & meta-analyses (SR&M), one quasi-experimental study (Q-ES), one design and validation study (DVS), one exploratory study (ES), four randomized control studies (RCS), and four articles on new integrated technologies, some of which not yet tested on humans. The research was carried out between April 2021 and July 2021. The following libraries were searched: PubMed, Cochrane Library, Google Scholar, and Scopus.

A total of 6069 records were obtained. Of these, 5931 were discarded: 1833 were duplicates and 4098 were eliminated because of the type of population or because they focused on populations affected by cancer, or having post-operative outcomes or head and neck cancer with post-surgical outcomes affecting the tongue, or because they were studies based the use of ultrasound, MRI, CT, and DXA. Also, we excluded papers dealing with the rehabilitation of sarcopenia after a hip fracture or other similar events.

The eligibility criteria were: (1) community-dwelling older adults; (2) older adult volunteers: out-patient or hospitalized patients; (3) frail subjects according to the frailty criteria defined by Fried et al. [8]. About age, some of the studies focused on patients aged ≥50 years (middle-aged), others on patients aged ≥65 years (older), and others on patients aged 19 to an older age. Studies that did not include older adults were excluded.

Works referring to the Asian Working Group for Sarcopenia guidelines were also excluded.

Moreover, of the remaining 138 articles, 102 were discarded because they were duplicates or because they were not pertinent to the aim of the research.

The studies analyzed for this review were 36: 32 dealing with tested technologies whose results were compared with the parameters established in the EWGSOP guidelines, and four studies presenting new and not tested technologies.

The article search was carried out by using the following word strings and the PubMed's Boolean operators: "*phase angle and sarcopenia*"; "*rehabilitation and*

sarcopenia"; "*sarcopenia and measurement*"; "*actigraphy and sarcopenia*"; "*jumping mechanography*"; "*sarcopenia and wearable devices*"; "*sarcopenia robotic measurements*". The search was restricted to the 2015–2021 period, including extremes.

To assess the quality of the paper, the Newcastle-Ottawa quality assessment scale was used [9].

3. Results

3.1 Diagnosis and rehabilitation of sarcopenia

3.1.1 Assessment of sarcopenia

3.1.1.1 Accelerometer and actigraph technology in wearable inertial sensors

Nowadays, wearable inertial sensors have the potential to assess MQ and PP (**Table 1**) [15].

In 2018, the American Academy of Sleep Medicine recommended using the actigraphy test for the diagnosis of sleep disorders [16]. Subsequently, on the basis of the ascertained association between frailty domains and functional limitations [8, 12, 17], Pana et al. investigated the relationship between sleep quality and MS among community-dwelling middle-aged and older adults [12]. The existence of a correlation between sleep disorders and sarcopenia can be expected but, until now, research in this field has been fragmented and no studies have been carried out investigating a possible direct correlation between sleep disorders and sarcopenia. For example, a study [18] has been published on the correlation between peak oxygen consumption and muscle loss. Physiological data were obtained through a feature of the actigraphy test called Actihear [19] which, however, focused on muscular functionality and not on sleep quality.

Accelerometer has been proposed in wearable devices to assess different parameters of physical activity following the "The Physical Activity Guidelines for Americans" (PAG, 2nd edition) [13], as shown in **Table 1**. However, in two studies in which the accelerometry was used, the accelerometry threshold did not prove to be indicative [10, 11]. Viecelli et al. [20] used a smartphone built-in accelerometer to obtain scientific mechano-biological descriptors of resistance exercise training. They aimed to test whether accelerometer data obtained from standard smartphone placed on the weight stack of resistance exercise machines can be used to extract single repetition, contraction-phase specific and total time-under-tension (TUT) [20]. Total time-under-tension is an important mechano-biological descriptor of resistance exercise as it was shown that it is highly positive correlated ($R2 = 0.99$) with the phosphorylation c-Jun N-terminal kinase (JNK) [21]. Activated JNK phosphorylates the transcription factor SMAD2, leading to the inhibition of myostatin [22], a potent negative regulator of muscle mass [23, 24]. The JNK/SMAD signaling axis is activated by resistance exercise and hence the molecular switch JNK stimulates muscle fiber growth, resulting in increased muscle mass [22] being a direct countermeasure of the muscle loss seen in sarcopenia.

Burd et al. [25] examined the influence of muscle time-under-tension on myofibrillar protein synthesis. Eight young men were allocated into two groups. One group performed three sets of unilateral knee extension at 30% of 1-repetion maximum involving concentric and eccentric muscle actions that were 6 s in duration to failure. The control group performed a work-matched bout that comprised concentric and eccentric actions that were 1 s in duration. As work was matched, the groups significantly differed in time-under-tension ($P < 0.001$) whereby the slow group had a time-under-tension of

Author, year, country	Study design	Sample Mean Age ± SD	Technologies employed	Data collected/ performed measurement	Session modality
Foong et al., 2016; Australia [10]	CSS	636 community-dwelling OA: 66 ± 7 years	ACC technology to assess PA	AMM S-ACC CF	Monitoring of PA at baseline, and 2.7 years, 5 years later, and last follow-up; between March 2002 and September 2004, ending on 2014
Rejeski et al., 2017; USA [11]	CSS	1.528 OA: HE (*N* = 771): 79.07 ± 5.23 and PA (*N* = 757): 78.74 ± 5.21	GT3X+ accelerometer: CPM to assess MVPA.	HE (*N* = 771) PA (*N* = 757) divided for: • Health-related variables education • SPPB • EFs	Data examined at baseline, and 6-, 12-, and 24-months of follow-up
Pana et al., 2021; Greece [12]	SR	92.363 OA ≥65 years and middle-aged adults ≥ 40 years	ASD	HGS SAss	Research from March 2020 to May 2020
Zytnick et al., 2021; USA [13]	R-CSS	1.317 healthy adults aged ≥60 years	WAM	Data collected from the fall wave of the 2015 styles database: FallStyles: PA and walking	Data monitoring, data activity carried out for more than 12 months
Kim et al., 2021; Korea [14]	CS	20 older women aged ≥65 years: 10 sarcopenic women with: 69.6 ± 3.0 and 10 normal women with: 71.1 ± 2.0	IS	GS, HGS, and walking to analyze raw data, it will be applied DL methods	Acquiring spatial-temporal parameters used in clinical practice and descriptive statistical parameters for all seven gait phases

CSS, cross-sectional studies; CS, cohort studies; SR, systematic review; R-CSS, retrospective-cross-sectional studies; OA; older adults; PA, physical activity; CPM, counts per minute; MVPA, moderate to vigorous PA; HE, health education; DH, digital handgrip; DYN, dynamometer; ACC, accelerometer; ASD, actigraphy sleep diary; WAM, wearable activity monitor; IS, inertial sensors; AMM, anthropometrics muscle mass; S-ACC, strength accelerometer; CF, cognitive function; SPPB, short physical performance battery; TUG, time-up and go test; EFs, executive functions; MS, maximal strength; RFD, rate of force development; SA, strength asymmetry; BS, bilateral strength; FSFT-ST, force steadiness fatigability task-specific tremor; HGS, hand grip strength; GS, gait speed; SAss, sleep assessment; DL, deep learning.

Table 1.
General overview of the paper focused on the accelerometer in wearable devices and the actual use of actigraphy to assess sarcopenia in primary prevention.

407 ± 23 s and the control group a time-under-tension 50 ± 3, respectively. Myofibrillar protein synthetic rate was higher in the slow condition versus the control condition after 24–30 h recovery ($P < 0.001$). Therefore, a longer time-under-tension increased myofibrillar protein synthesis longer and to a greater extent than under the control condition.

As evident, time-under-tension is not only an important mechano-biological descriptor of resistance exercise but also of high clinical relevance.

Lastly, a very recent article [14] aimed at identifying and elaborating parameters from gait signals produced by the sensors in order to develop a screening and classification method for sarcopenia. In the study were used specific parameters that they interpreted through an artificial intelligence (AI) model called SHAP (*Shapley Additive Explanations*). The input that applied the SHAP to the descriptive statistical parameters

Author, year, country	Study design	Sample Mean Age ± SD	Technologies employed	Data collected/ performed measurement	Session modality
Swiecicka et al., 2019; UK [17]	RCT	86 older men aged 74 ± 5.	EMG (DS7AH; Digitimer, Welwyn Garden City, UK); AAE (Dermatrode, Farmadomo, The Netherlands); S2S (v.8.1; Cambridge Electronic Designs).	L&NBRM determined relationship between FP and FI with CMAP and MUP sizes before and after adjustments for age and BMI.	The femoral nerve was stimulated maximally and the resulting CMAP measured over the vastus lateralis. MUP size assessed in voluntary contractions using (iEMG).
Habenicht et al., 2020; Vienna [26]	CSS	86 VHP between 18 and 90 years of age.	BED and EMG (DAVID®, Helsinki, Finland); EMG (Model Trigno, DelSys®, Boston, MA, USA) and TXACC-SI.	Anthropometric measurements, IPAQ, warm-up and MVC, HGS, and EMG.	Measurement obtained during training session: first session at baseline, second session 2 days after, and third session 6 weeks later.
Marshall et al., 2020 [27]	CSS	15 HY: 25 ± 3 years; and 15 OA: 70 ± 5 years.	BIA (mBCA 525, SECA, Hamburg, Germany); EMG (Mbody, Myontec Ltd., Kuopio, Finland).	Indices of QM EMG activity in response to different modes of RET and ADL.	In 4 days, participants completed a MVC of the KE, followed by a 15mWT, SCT (i.e., ADL) and BW-RET and MN-RET or EB-RET.
Gennaro et al., 2020; Switzerland [28]	ES	198 community-dwelling volunteers: 73 ± 6 years.	EMG: FREEEMG 1000, BTS Bioengineering, Milan, Italy; EEG: eego sport, ANT Neuro, Enschede, The Netherlands.	EEG and EMG samples in sarcopenic participants.	Acquired during walking, then processed.
Hu et al., 2021; Taiwan [29]	CSS	Five risk-sarcopenia (age: 66.20 ± 4.44), five healthy (age: 69.00 ± 2.35), and 20 young (age: 21.33 ± 1.15).	EMG (EMGworks® 4.0 Acquisition software, Delsys Inc., Boston, MA, USA).	EMG parameters as: MN_{RT}, MFR_{RT}, y-intercept, FRU, and mean MFR extracted to analyze MFD. HGS, GS, PASE, and IPAQ.	Not defined.

RCT, randomized control trials; CSS, cross-sectional studies; ES, exploratory study; VHP, voluntary health people; HY, healthy young; OA, older adults; BIA, biological impedance analysis; HGS, hand grip strength; EMG, electromyography; EEG, electroencephalogram; L&NBRM, logistic & negative binomial regression models; BED, back extension dynamometer; RET, resistance exercise training; KE, knee extension; SCT, stair climbing task; MVC, maximal voluntary contraction; 15mWT, 15 minutes walking task; TXACC-SI, triaxial accelerometer-sensor integrated; QM, quadriceps muscle; BW-RET, lower-limb RET through body-weight squats; MN-RET, seated knee extensions on machine; AAE, adhesive anode electrode; EB-RET, seated knee extensions via elastic bands; S2S, Spike2 Software; FP, frailty phenotype; FI, frailty index; CMAP, compound muscle action potential; MUP, motor unit potential; MN_{RT}, motor unit number-recruitment threshold; MFR_{RT}, motor unit firing rate-recruitment threshold; FRU, firing rate per unit force; MFR, motor unit firing rate; MFD, muscle fiber discrimination; PASE, physical activity of senior elder; IPAQ, International Physical Activity Questionnaire.

Table 2.
General overview of the paper focused on new tools for the assessment of sarcopenia with electromyography (EMG).

yielded the best performance; showing that the signal of the inertial sensor contained abundant information on gait parameters. However, the deep learning did not extract effective features from inertial signals; further data and greater cohorts, respectively, with additional clinical evaluations should be collected and studied [14].

3.1.1.2 Electromyography

In **Table 2**, an interesting new technology capable of evaluating variations in muscle activity is shown: the EMG.

It was demonstrated [17] that some electrophysiological sarcopenic variables were associated with the frailty phenotype [8, 17], but frailty in older men was associated with lower CMAP and MUP, which however were not related to age and BMI.

On the basis of the data obtained by Habenicht et al. [26] in their study on back extension, a diagnostic algorithm for assessing the first signs of muscle weakness

Author, year, country	**Study design**	**Sample Mean Age ± SD**	**Technologies employed**	**Data collected/ performed measurement**	**Session modality**
Dietzel et al., 2015; Germany [32]	CSS	Total of 293 C-D women (146) and men (147): aged 60–85 years.	Leonardo Mechanograph® (Novotec Medical, Pforzheim, Germany); plateDXA.	DXA data, ADL, JM, EFI, HF, CRT_V. MF: muscle power per $2LJ_{Prel}$ and the CRT_{Prel} on a force.	30 subjects in each 5-year.
Siglinsky et al., 2015, Madison (USA) [33]	CS	USA OA (213 women/119 men), mean: 65.4 ± 17.4 years.	DXA, Leonardo Mechanograph®	BMI, ALM/Ht2, HGS, GS, CRT, JH, JRP, Vel. (m/s) APT.	Randomly.
Hannam et al., 2017; Bristol, UK [34]	CSS	463 C-D of which: 300 76.4 ± 2.6, and 163 with 77.7 ± 3.6 years.	Jumping Mechanography (Leonardo Mechanograph).	JM, SPPB, HGS.	Re-recruited participants from an earlier population-based cohort study, during 2015 for 1 years.
Minett et al., 2020; Germany [35]	RCT	94 OA: 46 users to the WALK: mean 75.8 years and 48 to the W + EX: mean 77.1 years.	DXA and JM.	F&C, weekly meetings, DI&EH, BIA, MD, M-CSA, IMAT, MF, and MM, JM.	3-month exercise intervention, measured performed at baseline and at the third month. 09-12/2016.
Alvero-Cruz et al., 2021; Málaga, Spain [36]	CSS	256 MATH of these, 240 ATH aged between 35 and 91 years; mean 58 ± 12 years.	BIA, JM.	Anthropometric, BIA, JM.	Between 4th and 15th September 2018, during the 23rd-WMAC held in Málaga; 40–60 minutes for athlete.

CSS, cross-sectional studies; CS, cohort studies; RCT, randomized control trials; OA, older adult; C-D, community-dwelling; JM, jumping mechanography; BIA, biological impedance analysis; DXA, dual-energy X-ray absorptiometry; BMI, body mass index; EFI, Esslinger fitness index; HF, history falls; MF, muscle function; $2LJP_{rel}$, maximum 2 leg jump power per kg body mass; $CRTP_{rel}$, maximum chair rise test power per kg body mass; CRT_V, the max velocity of the CRT; HGS, hand-grip strength; GS, gait speed; SPPB, short physical performance battery; JRP, jumping relative power; APT, acceptability; W or WALK, walking; EX, exercises; F&C, feasibility & compliance; DI&EH, dietary intakes & eating habits; MD, muscle density; M-CSA, muscle cross-sectional area; IMAT, intramuscular adipose tissue; MM, mobility measures; MATH, masters athletes; ATH, athletes; 23RD-WMAC, 23rd-World Masters Athletics Championships.

Table 3.
General overview of papers based on jumping mechanography.

related to back extension may be developed [26]. Subsequently, Gennaro et al. [28], in their ES, defined "*corticomuscular coherence*" (CMC), obtained during locomotion by simultaneously measuring EEG and EMG, and suggested it as a new feature for the diagnosis of sarcopenia [28], reporting that it has a high sensitivity and specificity.

Marshall et al. [27] compared BW-RET with MN-RET and EB-RET in a group of healthy younger adults and a group of older adults: BW-RET proved less effective than MN-RET and EB-RET. The EMG parameters were defined by studying a population composed of young adults, healthy and at-risk older adults [29] (as shown in **Table 2**). In the article, they concluded that it was not clear if EMG difference correlates with MS loss or mere loss of muscle mass [29].

3.1.1.3 Jumping mechanography

The association between the jumping mechanography (JM) and sarcopenia starts with Buehring et al. [30, 31], who gave "operational definitions of the variables available through muscle mechanography" with the aim to propose muscle mechanography as a tool for what we defined as MQ parameter [31], supporting the reproducibility of JM in older people [30, 32].

To assess muscle function and, at the same time, the MQ and PP parameters, JM can be considered an interesting new tool. It was first described by Dietzel et al., Siglinsky et al., Hannam et al., and Gangnon et al. [30, 32–34]; in all of these studies, JM was performed by Leonardo Mechanograph® (**Table 3**). JM measures the peak of muscle power by a vertical jump, as this practice is considered safe and useful to assess not only MQ and PP parameters but also different geriatric outcomes clearly important in primary prevention.

In all previous studies, participants were tested in accordance with the first EWGSOP guidelines [32, 33] and showed a better correlation between ADL and JM performance. Such correlation gives useful indications for the prevention of falls and fractures. In another work [34], the feasibility and acceptability of JM were evaluated: JM was considered comfortable and the comfort was related to one's own JM performance.

Also, in the work by Alvero-Cruz et al. [36], sarcopenia was diagnosed according to the first EWGSOP guidelines. They did not use JM but studied highly trained track and field athletes to explain the age-related decline in vertical jumping performance, obtaining data from the Redcap, Leonardo, and BIA data merging [36].

Of interest, in 2020 a complete and well-designed RCT was carried out [35]. It consisted of an intervention program based on physical exercises to evaluate outcomes in anthropometrics, body composition, muscle function, mobility measures, JM, and dietary habits. It showed that the program could be feasible in a population of older adults and that JM detected differences in MS and MQ using the chair-rise test rather than the TUG test [35].

All the above-mentioned studies were carried out on the basis of the first EWGSOP guidelines. However, it is now necessary to perform studies comparing results with the second EWGSOP guidelines. Wiegmann et al. defined a diagnostic algorithm on the basis of the 2nd EWGSOP guidelines [37].

3.1.1.4 Sarcopenia and BIA's phase angle

The BIA's phase angle (PhA) was mentioned, not for the first time, in a work by Heymsfield et al. [7]. Biological impedance analysis (BIA) was considered a useful tool for sarcopenic patients who were unable to perform a handgrip test or to walk [4, 38, 39]. Nowadays, BIA is used to confirm the diagnosis of sarcopenia (**Table 4**).

Author, year, country	Study design	Sample Mean Age ± SD	Technologies employed	Data collected/ performed measurement	Session modality
Pessoa et al., 2019; Brazil [40]	CSS	94 physically active older women: Tercile 1 (n = 31): 73.5 ± 7.6 Terciles 2 and 3 (n = 63): 69.6 ± 5.7	BIA (Biodynamics® 450, version 5.1).	BIA and PhA; 4-mWST, HGS, following 1st EWGSOP criteria.	Not specified.
Rosas-Carrasco et al., 2021; Mexico [41]	CS	498 Mexican older adults with over 50 years of age 71.1 ± 9.5.	BIA (SECAR model mBCA 514.), DXA and DYN.	BIA and PhA; HGS, DXA, CES, MMSE, MNA-SF.	Cohort of adults living in the community of two municipalities of Mexico City consisting of men and women over 50 years of age.

CSS, cross-sectional studies; CS, cohort studies; BIVA, bioelectrical impedance vector analysis; BIA, biological impedance analysis; DXA, dual-energy X-ray absorptiometry; 4-mWST, 4-m walking speed test; HGS, hand-grip strength; CES, center for epidemiologic studies, DS, depression scale (Mexican version); MMSE, mini-mental state examination; MNA-SF, mini nutritional assessment-short form; PhA, phase angle; NRS-2002, Nutritional Risk Screening 2002; DT, drawing test.

Table 4.
General overview of the relationship between the assessment of sarcopenia and BIA's phase angle.

Author, year, country	Study design	Sample Mean Age ± SD	Technologies employed	Data collected/ performed measurement	Session modality
Beveridge et al., 2018, Scotland, UK [42]	RCT	SC-D people >65 years, Study 1: 77.6 ± 6.2; for study 2, and data of study 1.	Magstim 200 system (Magstim Company Ltd., Whitland, UK).	6 MW, QMVC, SPPB, HGS and TwQ compared with population of Study 2.	Stimulation at baseline and 2 weeks along with 6 MW, QMVC, SPPB and HG.
Lera et al., 2020; Chile [43]	DVS	430 C-D people 60 years and older: 68.2 ± 4.9	Mobile devices (Android, IOS) and software HTSMayor.	EWGSOP parameters compared with software.	A comparison between clinical diagnosis and software diagnosis, with a median follow-up of 4.8 years.
Bachasson et al., 2021; France [44]	CSS	40 of which 20 HP: 8 women, aged 37 ± 9 years, and 12 men, age 35 ± 10 years; and 20 SP: 10 men, aged 63 ± 7 years and 10 women, aged 68 ± 10 years.	MRI using a 3 T Scanner (PrismaFit, Siemens, Healthineers, Erlangen, Germany), BIA (Z-Scan, Bioparhom, France).	Lean thigh muscle volume from MRI (IV_{MRI}) compared with lean thigh muscle volume from BIA (IV_{BIA}).	IV_{MRI} was computed, subsequently, multifrequency acquired. Values of the muscle electrical conductivity constant were computed using data from S_{BIA} and MRI.

CSS, cross-sectional study; RCT, random controlled trial; SC-D, sarcopenic community-dueling; C-D, community-dueling; DVS, design and validation study; HP, healthy participants; SP, sarcopenic participants; BIA, biological impedance analysis; MRI, magnetic resonance imaging; 6 MW, six minutes walking; QMVC, maximum voluntary quadriceps contraction; TwQ, maximum quadriceps twitch tension.

Table 5.
General overview of the paper focused on the assessment of sarcopenia: New tools and software.

According to a study carried out in Mexico [40] on active older women, there seems to be no correlation between PhA and sarcopenia parameters, but PhA seems to be associated, with a doubtful biological meaning, with speed walking [40] (or PP). In a recent paper [41], they analyzed sarcopenia on the basis of the parameters defined by the second EWGSOP guidelines, and physical frailty, according to the parameters defined by Fried et al. [8], both adjusted to the Mexican population.

Studies on more homogeneous populations may clarify the usefulness of BIA's PhA.

3.1.1.5 New technologies tested

Magstim 200 system: Magnetic nerve stimulation was tested on older sarcopenic people [42]. The study reports several limitations in the execution and screening of sarcopenic patients whose functions were not highly compromised. Despite this and the fact that it is an expensive technique, this methodology is still considered acceptable and feasible. More tests on sarcopenic patients with highly impaired functionality would be needed (**Table 5**).

Software HTSMavor: In South America, accessibility to DXA is very difficult. With the purpose to facilitate the assessment of sarcopenia, a screening algorithm for the diagnosis of sarcopenia, following the second EWGSOP guidelines, was developed. The results are very promising, but software accuracy for different populations should be implemented [43].

Bioelectrical impedance analysis to estimate the lean muscle volume: Serial bioelectrical impedance analysis (S_{BIA}) was compared with magnetic resonance imaging (MRI) [44]. As a strong agreement between IV_{BIA} and IV_{MRI} was found, a specific conductivity constant ($\boldsymbol{\sigma}$) was computed in order to assess the reliability of S_{BIA} as a possible alternative to MRI. Despite the study limitations, the technique appears to be very promising.

3.1.2 Rehabilitation in sarcopenia

Sarcopenic patients are not usually followed in the daily routine, therefore it would be advisable to develop rehabilitation programs to keep the progression of the disease under control. Rehabilitation programs usually contain enhanced physical exercises and dietary increased amounts of protein intake [45]. In the absence of these rehabilitation programs, physicians give advice on physical exercises and dietary habits to patients. However, these recommendations are rarely observed by the patients [46].

In the following part of this manuscript, we talk about new proposals on rehabilitation. Such proposals include new or old technologies that could be used in planned therapies for pre-sarcopenic and sarcopenic patients.

3.1.2.1 Virtual reality and laser therapy

Thousands of articles on rehabilitation protocols that use virtual reality in different research fields have been produced [47, 48], but there are still few studies applying virtual reality to sarcopenia. The patients on whom the usability was tested were older patients with varied pathologies. The results were promising; therefore, it is hoped that it will be applicable to sarcopenic patients (**Table 6**).

In the work by Chen et al. [50], the virtual reality-based progressive resistance training was tested on patients residing in a nursing home, over a period of 12 weeks. The outcomes were different, but the training determined an improvement especially of the upper limb strength, in other words, MS and MQ but not PP. An increase of ASMM was present but was not statistically significant [50]. Further studies are required.

Author, year, country	Study design	Sample Mean Age ± SD	Technologies employed	Data collected/ performed measurement	Session modality
Toma et al., 2016; Brazil [49]	RCT-DB	38 elderly women: -CG = 15; 63.64 ± 2.11- TG = 17; mean: 63.31 ± 2.66- TLG = 16; mean: 64.07 ± 2.87.	An infrared AsGaAl laser (λ = 808 nm) (Photon Lase III; DMC® São Carlos, SP, Brazil).	6-MWT, SEMG, 1-RM, BS, IP.	STS was performed by TG and TLG groups for 8 consecutive weeks. Placebo or active LLLT for CG at the end of each STS.
Chen et al., 2020; Taiwan, China [50]	Q-ES	30 residents: 74.57.	VR-RHE; ORH; one constellation; LMS.	HGS, GS, BIA.	Measurements at baseline, and at 4, 8, and 12 weeks. Session took place twice per week, 30 minutes per session.
Tuena et al., 2021; Portugal [47]	SR	405 OA and YA and other specific disease patients.	VR: 3D simulator environment system.	SUS, other questionnaires, and physical impairments.	Variable

RTC-DB, randomized control trial-double blinded; Q-ES, quasi-experimental study; SR, systematic review; VR-RHE, virtual reality-based progressive resistance training; ORH, oculus rift headset; LMS, leap motion sensor; VR, virtual reality; CG, control group; LLLT, low-level laser therapy; TG, strength training associated with placebo LLLT; TLG, strength training associated with active LLLT; BS, blood sample; HGS, hand grip strength; GS, gait speed; BIA, biological impedance analysis; OA, older adult; YA, young adult; SUS, system usability scale; 6-MWT, 6-min walk test; SEMG, isokinetic protocol in isokinetic dynamometry; 1-RM, 1-repetition maximum; STS, strength training session.

Table 6.
General overview of papers focused on rehabilitation with virtual reality and laser therapy in sarcopenia.

3.1.2.2 Electrostimulation included whole-body vibration

It is well-known, from previous studies, that electrostimulation can favor the increase of muscle fibers thus improving MS, MQ, and PP and today confirmed in different works [51]. In 2016, Wittman et al. [52] and then Klemmer et al. [53–55] evaluated the parameters linked to sarcopenia and the WB-EMS effects, according to sex: the FORMOsA trial was conducted on women and the FranSO trial was conducted on men (**Table 7**).

The FORMOsA study concluded that the WB-EMS did not improve MS or PP nor decrease the fat mass, compared to the conventional physical activity [52], but it improved muscle mass. For this reason, it is advisable to use it in cases where the patient is unable to perform conventional resistance training [52, 53]. The FranSO study, on the other hand, showed that in men WB-EMS succeeded in increasing muscle mass and lowering fat mass (in sarcopenic obesity), confirming its use in the case of older people unable to move or unmotivated [54, 55].

To understand the effects of EMS intervention, Nishikawa et al. [56] made three measurements over a period of 12 weeks; then the results were compared with SEMG. Although their conclusions were closely related to a short group of individuals with the locomotive syndrome, the results suggested that EMS was able to increase MS and MQ. However, further studies would have to be performed [56] to obtain more conclusive results.

In the article by Jandova et al. [57], the EMS activity was completed in lumbar multifidus (LM) and vastus lateralis (VL). The results suggested an increase in muscle mass and mobility.

Author, year, country	Study design	Sample Mean Age ± SD	Technologies employed	Data collected/performed measurement	Session modality
Wittmann et al., 2016; Germany [52] **I** & Kemmler et al., 2016; Germany [53] **II**	RCS	75 SC-D women with MetS • WB-EMS: 77.3 ± 4.9 • WB-EMS&P: 76.4 ± 2.9 • CG: 77.4 ± 4.9	WB-EMS equipment (miha bodytec®, Gersthofen, Germany).	**I** *POP*: Change of the MetS *Z*-score. *SOP*: WC, MAP, TGs, FPG, HDL-C. **II** *POP*: Change in sarcopenia *Z*-score (EWGSOP). *SOP*: Change TBF from baseline to 26 weeks follow-up, HGS, GS, SMI.	Stratified for age, randomly assigned to: (a) n = 25 WB-EMS; (b) n = 25 WB-EMS&P and (c) n = 25 non-training CG. 6 months.
Kemmler et al., 2017; Germany [54] **I** & Kemmler et al., 2018; Germany [55] **II**	RCS	100 SC-D men with MetS: • WB-EMS: 77.1 ± 4.3 • WB-EMS&P: 78.1 ± 5.1 • CG: 76.9 ± 5.1	WB-EMS equipment (miha bodytec®, Gersthofen, Germany).	**I** *POP*: Change of the sarcopenia *Z*-score (FNIH criteria). *SOP*: (at baseline and after 16 weeks): TBF, SMI refers to FNIH, HGS. **II** *POP*: Changes in TBF. *SOP*: (from baseline to 16 weeks' follow-up): Changes in: TF, WC, TOT. cholesterol/HDL, cholesterol ratio, TAG.	Stratified for age, they were randomly assigned to: (a) n = 33 WB-EMS; (b) n = 33 WB-EMS&P and (c) n = 34 non-training CG. 16 weeks.
Nishikawa et al., 2019; Japan [56]	RCT	19 older women divided in: IG: n = 10; age = 75.6 ± 3.7 years; CG: n = 9; age = 77.3 ± 3.9 years.	Multi-channel SEMG (ELSCH064RS3; OT Bioelettronica, Torino, Italy); EMS.	Antropometric data and comparison with the two-step test and 25-question risk assessment between two group.	A portable EMS device to stimulate the bilateral quadriceps muscles for 8 weeks (23 minutes/5 days/week). Measurements were made at baseline, 8 weeks, and 12 weeks:
Jandova et al., 2020, Italy [57]	CSS	16 HOV of which NMES = 8, 69.3 ± 3.2 years and CG = 8, 68.0 ± 2.3 years.	NMES (Genesy 1200Pro; Globus Srl, Cologne, Italy), Muscle ultrasound.	*FT*: TUG, FTSST, VL muscle architecture, MT, PA, FL, along with VL-CSA, LM-CSA before and after by ultrasound.	3 times/week for 8 weeks.
Wu et al., 2020; China [58]	SR&M	223 participants in 7 papers: 5 with WB-VT, while 2 with L-VT.	WB-VT and L-VT	Muscle mass, muscle strength, or physical function.	8–20 minutes/12–60 Hz in L-VT; 15 minutes/300 Hz in WB-VT; 1–3 times/week for 8–12 weeks.

Author, year, country	Study design	Sample Mean Age ± SD	Technologies employed	Data collected/performed measurement	Session modality
Šarabon et al., 2020; Austria, Slovenia [59]	SR&M of RCT	2017 participants with RT, 606 with WBV, and 192 with EMS. Pooled mean age: 73.5 ± 4.8.	RT, WBV, and EMS.	(a) baseline and post-intervention mean and SD; (b) baseline demographics (c) intervention characteristics.	Typical time of intervention was 12 weeks (28) some shorter (12) and others longer (23).
Yamazaki et al., 2020; Japan [60]	CSS	64 Older adults: • NLMM (n = 51):70.6 ± 3.4 • LMM (n = 13):71.5 ± 1.9	DXA (Lunar DPX, Madison, WI, USA), SYNAPSE (Fujifilm Medical Co., Ltd., Tokyo, Japan).	Anthropometric measurements and RPW variables at 30, 60, and 240 Hz.	Measurement time was 30s, divided into two intervals of 15 s each. VS applied to the users during the last 15 s.

CSS, cross-sectional study; RCT, randomized control trials; RCS, randomized control study; MetS, metabolic syndrome; SC-D, sarcopenic community-dwelling; POP, primary outcome parameter; SOP, secondary outcome parameter; SR&M, systematic review & metanalysis; HGS, hand-grip strength; GS, gait speed; SMI, skeletal muscle mass index; EMS, electromyostimulation; DXA, dual-energy X-ray absorptiometry; WB-EMS, whole-body electromyostimulation; NMES, neuromuscular electrical stimulation; SEMG, surface electromyography; WB-EMS&P, whole-body electromyostimulation and protein supplementation; WC, waist circumference; WB-VT, whole-body vibration therapy; IG, intervention group; CG, control group; FT, functional tests; CWBV, continuous whole-body vibration; IWBV, intermittent whole-body vibration; BPP, bench press power; VJ, vertical jump (height); MAP, mean arterial pressure; TGs, triglycerides; FPG, fasting plasma glucose; HDL-C, high-density lipoprotein cholesterol; WPS, whey protein supplementation; TBF, total body fat mass; TF, trunk fat mass; TAG, triglycerides; HOV, healthy older volunteer; TUG, timed up and go test; FTSST, five times sit-to-stand test; MT, muscle thickness; PA, pennation angle; FL, fiber length; LM, lumbar multifidus; VL, vastus lateralis; VL-CSA, VL cross-sectional area; LM-CSA, LM cross-sectional area; RPW, relative proprioceptive weighting ratio VS, vibratory stimulation.

Table 7.
General overview of papers focused on electrostimulation and whole-body vibration as a sarcopenia rehabilitation tool.

On the other hand, vibration therapy (VT) was considered a close relative of EMS and showed the potential to improve MS and PP in sarcopenic older adults [58].

Initially, whole-body vibration was tested both on Asiatic and European middle-aged and older postmenopausal women [61]. Later, other studies tried to determine the optimal rate of frequency per time [62]; patients were enrolled if the diagnosis of sarcopenia was assessed by skeletal mass index. Therefore, there were some discrepancies due to the type of population and the criteria used to establish the diagnosis of sarcopenia, the point of stimulation, the type of exercises, and the measurements [58, 61]. It was compared [59] RT, WBV, and EMS and concluded that the combined use of the three techniques had the capability to improve MS and functional performance. However, more studies would be necessary to obtain more evidence that the combined use of EMS, RT, and WBV is effective in improving MS [59]. In the same year, Wu et al. [58] published a systematic review and meta-analysis showing the efficacy of WBV in improving sarcopenia and important results demonstrating an increase in MS, MQ, and PP after treatment.

Finally, Yamazaki et al. evaluated proprioception in pre-sarcopenia in a group of 64 patients [60]. However, a limitation of the study was the absence of the diagnosis of sarcopenia. Nevertheless, the results suggested that the proprioception could be linked to the decline of lower leg skeletal muscle spindles in older adults with lower muscle mass.

3.1.3 New-born technologies (not yet been tested)

Addante et al. [63] proposed new wearable devices incorporating the Arduino software to gain HGS, GS, and EMG data at the same time. Data acquisition was possible through the activation of a mobile application linked to the REST server, which was connected with the PostgreSQL database stored on a web application.

Concurrently, McGrath et al. [6] proposed a new dynamometer. It integrates the basic functionalities of any dynamometer with those of an accelerometer allowing a doubling of the features measured, obtaining a complete evaluation of the muscular capacities, integrating the parameters of MS, MQ, and PP, but only of the upper limbs.

Given the functional connection between brain activity and muscles driving the whole gait cycle, Gennaro et al. [64] proposed a mobile wireless recording device of brain activity combined with several other body behavioral variables [28, 64]. Through statistical methods based on blind source separation, they managed to segregate non-cerebral/artefactual sources from cerebral sources of activity: this system is called "*mobile brain/body imaging*" (MoBI) [64]. The obtained data were founded on coupled EEG-EMG analysis, in an interval from 0 to 1 named "*cortico-muscular coherence*" (CMC) [28, 64].

Friedrich et al. [65] introduced the MyoRobot technology (a full description is available on the biomechatronic platform [66]) designed for assessing the patho-physiologic mechanisms of muscle biomechanics. Nowadays, the technology is still being tested.

4. Discussion and conclusions

Sarcopenia is a disease that cannot be underestimated, given the impact it has on out-patient or hospitalized patients: complications, length of hospitalization, mortality, and possible problems that may occur in everyday life. In order to define target strategies or personalized therapies against sarcopenia, the diagnosis in older sarcopenic patients should be achieved through qualitative and quantitative measurements of muscle loss. Such measurements could be facilitated by the use, during hospitalization, of wearable devices capable of providing important data in a very short period of time.

In order to assess the reliability of the novel technologies proposed, a comparison on homogeneous populations should be made between the parameters obtained by using the second EWGSOP guidelines instructions and the parameters acquired through the technologies applied. Thereafter, it will be possible to define a diagnostic algorithm that would be able:

- To distinguish pre-sarcopenia from sarcopenia and severe sarcopenia, as defined by the first EWGSOP guidelines;

- On the basis of the MQ, MS, and PP parameters defined by the second EWGSOP guidelines, to build pre-sarcopenia cut-offs through the use of low-cost, safe, and useful technologies to assess pre-sarcopenia.

In conclusion, the proposed technologies are: (a) accelerometer and actigraph technology in wearable inertial sensors (**Table 1**), focused on sleep quality and loss of muscle strength, and physical activity in older adults related to PP assessment; (b) EMG for diagnostic purposes (**Table 2**); (c) JM (**Table 3**), (d) a short overview about the correlation between the PhA and muscle loss (**Table 4**); (e) a new frontier of virtual reality (**Table 6**) designed for rehabilitation programs for sarcopenic patients; (f) EMS and WBV (**Table 7**) technologies that are being studied for rehabilitation for pre-sarcopenia and sarcopenia; (g) IoT technologies, dynamometer, MoBI, and Myorobot Fiber System, which have not been yet evaluated on patients, and tools and software proposed and already tested (**Table 5**) (cfr. 3.1.3).

Devices promoting active aging could be used to design rehabilitation and prevention programs in severe sarcopenic and pre-sarcopenic patients, respectively. It would be desirable that these devices were available in hospitals, occupational medicine physicians' offices, or at general practitioner's surgeries.

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Conflict of interest

The authors have no conflicts of interest to declare.

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