Differences in handgrip strength protocols to identify sarcopenia and frailty - a systematic review

A. R. Sousa-Santos* and T. F. Amaral

Abstract

Background: Hand grip strength (HGS) is used for the diagnosis of sarcopenia and frailty. Several factors have been shown to influence HGS values during measurement. Therefore, variations in the protocols used to assess HGS, as part of the diagnosis of sarcopenia and frailty, may lead to the identification of different individuals with low HGS, introducing bias. The aim of this systematic review is to gather all the relevant studies that measured HGS to diagnose sarcopenia and frailty and to identify the differences between the protocols used.

Methods: A systematic review was carried out following the recommendations of The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement. PubMed and Web of Science were systematically searched, until August 16, 2016. The evidence regarding HGS measurement protocols used to diagnose sarcopenia and frailty was summarised and the most recent protocols regarding the procedure were compared.

Results: From the described search 4393 articles were identified. Seventy-two studies were included in this systematic review, in which 37 referred to sarcopenia articles, 33 to frailty and two evaluated both conditions. Most studies presented limited information regarding the protocols used.

Conclusions: The majority of the studies included did not describe a complete procedure of HGS measurement. The high heterogeneity between the protocols used, in sarcopenia and frailty studies, create an enormous difficulty in drawing comparative conclusions among them.

Keywords: Sarcopenia, Frailty, Handgrip strength, Older adults

Background

Ageing is accompanied by numerous underlying physiological changes and increasing risk of certain health conditions, such as chronic diseases. These changes that constitute and influence ageing are complex [1]. Sarcopenia and frailty are two geriatric syndromes that are frequently confounded [2].

Sarcopenia was initially proposed by Irwin Rosenberg, in 1989, to define the age-related decrease of muscle mass. It derives from the Greek words ‘sarx’, that means flesh, and ‘penia’, that means loss [3]. In 2009, the International Working Group on Sarcopenia (IWGS) provided a consensus definition describing sarcopenia as the age-associated loss of skeletal muscle mass and function. It was proposed that older patients who presented decline in physical function, strength or overall health should be considered for sarcopenia diagnosis [4]. In 2010, the European Working Group on Sarcopenia in Older People (EWGSOP) released a clinic definition and a consensus diagnostic criteria for age-related sarcopenia. They presented sarcopenia as a syndrome characterised by progressive and generalised loss of skeletal muscle mass and strength with a risk of adverse outcomes such as physical disability, poor quality of life, and death. The diagnosis should consider the presence of low muscle mass and low muscle function (strength or performance) to define conceptual stages as ‘presarcopenia’, ‘sarcopenia’ and ‘severe sarcopenia’ [2].

Frailty is a clinically recognisable state of increased vulnerability resulting from age-associated decline in reserve and function across multiple physiologic systems.
Friedness, slow gait speed and low physical activity [10]. were present: unintended weight loss, exhaustion, weakness, slow gait speed and low physical activity [10]. Fried’s frailty scale has been the most extensively tested for its validity and is the most widely used instrument in frailty research [11].

Hand grip strength (HGS) is used to diagnose both sarcopenia and frailty [2, 4, 10]. It can be quantified by measuring the amount of static force that the hand can squeeze around a dynamometer [12] and it is an indicator of overall muscle strength [13]. Age and gender are described as the strongest factors influencing HGS in healthy subjects, HGS declines with increasing age [14] and presents lower values for women [15, 16]. It has good intra- and inter-tester reliability and can be recommended the use in clinical practice [17, 18]. HGS can independently identify changes in nutritional status [19]; it responds earlier than anthropometrical measurements to nutritional deprivation and has shown to be significantly associated with sarcopenia [2] and frailty [10].

While HGS is considered a reliable measure to assess muscle strength, several factors have been shown to influence HGS values during measurement. It was reported that a different posture [20], different positions of the elbow [20] and wrist [21], the hand used to test [22] and the setting of the dynamometer [23] may affect the values of strength. It is even reinforced that certain positions can optimise the measurement and produce a maximal HGS. Therefore, variations in the protocols used to assess HGS, as part of the diagnosis of sarcopenia and frailty, may lead to the identification of different individuals with low HGS, introducing bias. This can occur even when the same cut-off points are adopted, which consequently can lead to differences in the number of individuals identified with sarcopenia and frailty. The American Society of Hand Therapists (ASHT) recommended, in 1981, that HGS should be measured with the individuals seated with their shoulders adducted, their elbows flexed 90° and their forearms in neutral position using the Jamar dynamometer [24]. This protocol has been updated with more details of the procedure in 1992 [25], and later in 2015 [26]. In 2011, a new protocol was proposed, the Southampton protocol [27], representing another step towards an improvement of the description of HGS measurement. Nevertheless, there is still a lack of consistency in the studies’ protocols to evaluate HGS used over time.

This systematic review resulted from the need to evaluate the differences between the protocols used for the HGS measurement to diagnose sarcopenia and frailty in older adults. For this reason, this revision represents a step forward towards the standardisation of the procedure. Therefore, the aim of this article is to gather all the relevant studies that measure HGS and to identify the differences between the protocols used. To this end, the proposed systematic review will answer the following questions:

1. Which dynamometer was used for measuring HGS?
2. Which hand was used?
3. What was the individual’s posture?
4. What was the arm position?
5. Which handle position was used?
6. How long did the HGS measurement take?
7. How long were the intervals between the measurements?

Methods

A systematic review was carried out following the recommendations for reporting systematic reviews and meta-analyses of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (The PRISMA Statement) [28]. PubMed and Web of Science were systematically searched until August 16, 2016, with no restriction on the year of publication. The search was limited to English, Portuguese, Spanish and French publications and to human subjects. The reference lists within the articles were scanned for any additional references missing from the databases’ search. The following search terms were used: [1] ((hand OR handgrip OR grip OR grasp) AND (force OR strength)) AND (sarcopenia OR frail elderly OR frail OR frailty). Subsequently, search results were inserted in EndNote X7 and duplicates were excluded. All the titles and abstracts were screened based on the eligibility criteria and classified as “relevant” or “not relevant”. Full texts of eligible articles were assessed and read. Those that met all criteria were included.

Eligibility criteria

Studies were included if [1] participants were aged 65 years or older within well-defined samples, with a clear description of the inclusion and exclusion criteria; [2] sarcopenia and frailty were considered as outcomes, in which HGS was used to identify this condition; [3] a description of the protocol used to measure handgrip strength was provided; [4] the outcome measures described are: type of dynamometer for the assessment of HGS, individual’s position (including shoulder, elbow, arm and handle position and posture), hand dominance,
number of repetitions, acquisition and rest time, encouragement and handgrip strength values.

Randomised control trials, cohort studies, case control studies and cross-sectional studies were included, and meta-analyses or review articles, case reports, case series, meetings’ proceedings, conference summaries and duplicate records were excluded. Articles were not included if information about either the posture of the individual, or concerning the arm position (shoulder, elbow or wrist) was absent. When the complete procedure was not described but a reference was made to another article, we searched for the missing parts of the procedure. If the article did not add more details regarding the procedure, it was still excluded. In case of disagreement about the inclusion of a study, the reviewers discussed their opinions to reach consensus. The studies were divided into two subgroups: [1] articles about sarcopenia and [2] articles about frailty. Final studies selected for inclusion in each category were independently compiled in data tables. Articles which presented the same data as an earlier study were still excluded.

**Results**

From the described search 4393 articles were identified. After removing duplicates, a total of 2753 articles remained. From these, after screening for title and abstract 2166 articles were excluded. Five hundred and eighty-seven full-text articles were assessed for eligibility and 515 references were excluded. Seventy-two studies were found eligible and, therefore, included in this systematic review. Figure 1 presents a flow diagram of the literature search and of the selection process.

The studies comprised in this systematic review were published between 2003 and 2016. Fifty-two were cross-sectional studies, 17 were cohorts, and three were clinical trials. The sample size ranged between 24 and 11,844 individuals.

From the articles included, 37 studies referred to sarcopenia, 33 to frailty and two evaluated both conditions. The EWGSOP and the CHS definitions were used in the majority of studies to diagnose sarcopenia and frailty.

**Description of HGS measurement**

Most studies presented limited information regarding the protocols used. As shown in both Tables 1 and 2, all 72 studies described the dynamometer used, but only five specified if it was calibrated for the study. Although, there was a wide range of equipment used, the Jamar dynamometer was the most mentioned ($n = 35$), followed by the Smedley dynamometer ($n = 10$). Sixty-
| Study details | Author | Sample | Size | Age | Dynamometer | Repetitions | Hand | Posture | Shoulder position | Elbow position | Wrist position | Handle position | Encouragement | Acquisition time | Rest time | HGS analysis | Cut-off values |
|---------------|--------|--------|------|-----|-------------|-------------|------|---------|------------------|----------------|---------------|----------------|--------------|---------------|-------------|-------------|----------------|
| Cross-sectional study | Abellan van Kan et al. [52] | Community-dwelling older women from the IPEDOS cohort | 3025 | ≥75 | Martin vigirometer, Medizin Technik, Tuttlingen, Germany | 3 | Dominant | Standing up | – | – | – | Yes | 2 min | – | – | Higher value | Lowest value |
| Cross-sectional study | Akin et al. | Community-dwelling older adults from the KPHES Study | 879 | ≥60 | Takei TKN 5401 digital handgrip dynamometer, Takei, Niigata-City, Japan | 3 | Dominant | Standing up | – | – | – | No | – | – | – | Higher value | Fried’s criteria |
| Cross-sectional study | Kan et al. | Community-dwelling older adults from the SABE Study | 1149 | ≥60 | Takei Kiki Kogyo TK 1201, Tokyo, Japan | 2 | Dominant | Sitting position | — | Resting on the table (forearms too) | Palms facing up | Adjusted to a comfortable position | – | – | 1 min | Higher value | M: >30 kgf W: <20 kgf |
| Cross-sectional study | Alexandre et al. | Consecutive patients from a specialised tertiary care center | 364 | ≥65 | DryEx digital hand dynamometer, Akern/MDS Systems, Florence, Italy | 3 | Dominant | Sitting position | – | – | – | – | – | – | – | Mean value | M: >30 kgf W: <20 kgf |
| Cross-sectional study | Bastiaanse et al. [56] | Adults with intellectual disabilities from the HA-ID study | 884 | ≥50 | Jamar hand dynamometer, Sammons Preston Rolyan, USA | 6 | Both | Sitting position | – | – | – | Yes | 2 min | – | – | Higher value | M: >30 kgf W: <20 kgf |
| Cross-sectional study | Bijlsma et al. [59] | Consecutive outpatients from an osteoporotic and geriatric department of a clinic and community-dwelling older adults | 250 | ≥65 | Hydraulic and pneumatic dynamometer Sataeh Corporation, MSD Europe, Biba, Belgium (calibrated) | 6 | Both | Sitting position | – | Forearms resting on the arms of the chair | Neutral position, over the end of the arm of the chair, thumb facing upwards | Adjusted so that the thumb is round one side of the handle and the four fingers are around the other side | Yes | – | – | Higher value | M: >30 kgf W: <20 kgf |
| Cross-sectional study | Bijlsma et al. [59] | Community-dwelling older adults from the SarcoPhAge study | 534 | ≥65 | Hydraulic and pneumatic dynamometer Sataeh Corporation, MSD Europe, Biba, Belgium (calibrated) | 6 | Both | Sitting position | – | Forearms resting on the arms of the chair | Neutral position, over the end of the arm of the chair, thumb facing upwards | Adjusted so that the thumb is round one side of the handle and the four fingers are around the other side | Yes | – | – | Higher value | M: >30 kgf W: <20 kgf |
| Cross-sectional study | Bijlsma et al. [59] | Young and healthy older Europeans from the Leiden Longevity Study | 654 | 30-82 | Jamar hand dynamometer, Sammons Preston Rolyan Inc., Bolingbrook, IL, USA | 3 | Dominant | Standing up | – | – | – | Yes | 2 min | – | – | Higher value | M: >30.3 kgf W: <19.3 kgf |
| Study details | Author | Sample | Size | Age | Dynamometer | Repetitions | Hand | Posture | Shoulder position | Elbow position | Wrist position | Handle position | Encouragement | Acquisition time | Rest time | HGS analysis | Cut-off values |
|---------------|--------|--------|------|-----|-------------|-------------|------|---------|------------------|---------------|---------------|----------------|---------------|----------------|------------|--------------|---------------|
| Cross- sectional study | Bijlsma et al. [60] | Middle to older participants from the MIOAGE study | 452 | 18–30/69–81 | Jamar hand dynamometer, Sammons Preston, Inc., Bolingbrook, IL, USA | 6 | Both | Standing upright | Abducted | – | Adjusted to hand size | – | – | – | Higher value ** |
| Cross- sectional study | Campbell et al. [61] | Assisted-living older adults | 40 | ≥65 | Vernier digital hand dynamometer and collected using LoggerPro software, Vernier, OR, USA; 60 Hz | 6 | Both | Sitting position | Adducted | 90° | Dynamometer vertical | – | Yes | Self-selected pace | – | Higher value M: <30 kgf W: <20 kgf |
| Prospective cohort study | Ceri et al. [62] | Consecutively admitted older inpatients of an Acute Geriatric Clinic, S. Gerardo University Hospital | 103 | ≥65 | Jamar hand dynamometer | 3 | Dominant | Sitting position | Adducted | 90° Forearm neutral | Between 0 and 30° extension | – | – | 1 min | Higher value M: <30 kgf W: <20 kgf |
| Cross- sectional study | Cuesta et al. [63] | Geriatric outpatients from the ELLI study | 298 | ≥70 | Jamar hand dynamometer | 3 | Dominant | Sitting position | Adducted and neutrally rotated | 90° Forearm neutral | – | 2nd | – | 1 min | Higher value M: <30 kgf W: <20 kgf |
| Cross- sectional study | Fukuda et al. [64] | Caucasian ambulatory individuals | 107 | 65–89 | DHS-176 digital handgrip dynamometer, Detecto, Webb City, MO | 3 | Dominant | Standing upright | Adducted | 90° | – | – | – | 3 to 5 s | – | Mean value ** |
| Cross- sectional study | Garatachea et al. [65] | Caucasian community-dwelling older adults from two geriatric nursing homes | 81 | 71–93 | Smedley digital hand dynamometer, Sportstek, WC, Australia | 3 | Non-dominant | Standing upright | Abducted | 180° | – | Adjusted to hand size | – | 30 to 60 s | Higher value ** |
| Prospective cohort study | Gonzalez-Montalvo et al. [66] | Consecutive patients hospitalised for hip fracture in a public 1300-bed university hospital | 509 | ≥65 | Jamar hydraulic dynamometer, Sammons Preston, Bolingbrook, IL, USA | 3 | Dominant | Sitting position | Forearms resting on the arms of the chair | Neutral, over the end of the arm of the chair, thumb facing upwards | Adjusted so that the thumb is round one side of the handle and the four fingers are around the other side | – | – | Higher value M: <30 kgf W: <20 kgf |
| Study details          | Author                  | Sample                  | Size | Age       | Dynamometer Description                                                                 | Repetitions | Hand                | Posture | Shoulder position | Elbow position | Wrist position | Handle position | Encouragement | Acquisition time | Rest time | HGS analysis | Cut-off values |
|------------------------|-------------------------|-------------------------|------|-----------|-----------------------------------------------------------------------------------------|-------------|---------------------|----------|-------------------|----------------|----------------|-----------------|---------------|----------------|--------------|--------------|
| Cross-sectional study  | Gray et al. [67]         | Community-dwelling older adults | 43   | ≥ 65      | Takei Scientific Instruments digital grip strength dynamometer, Niigata City, Japan     | 3           | Preferred hand      | Standing upright | Arms down by the side | Neutral        | Intephalangeal joint of the index finger maintained at 90° | Yes           | Minimum of 3 s | 1 min          | Higher value |
| Cross-sectional study  | Han et al. [68]          | Healthy volunteers from the Taiwan Fitness for Seniors Study | 878  | ≥ 65      | Baseline hydraulic dynamometer, Fabrication Enterprises Inc., Irvington, NY, USA        | 3           | Dominant            | Adducted         | 90° Forearm neutral | Forearm neutral | –              | –               | –             | –            | –             | Higher value |
| Cross-sectional study  | Hashemi et al. [69]      | Community-dwelling individuals from the SARIR study | 300  | ≥ 55      | Baseline pneumatic squeeze bulb dynamometer, Jamar, Inc., USA: c7489-02 Rolyan (calibrated) | 6           | Both                | Sitting position | Adducted and neutrally rotated | 90° Forearm neutral | Neutral        | 2nd             | –             | 30 s         | Mean value    | Compared with normative data from Merkies et al. [70] |
| Cross-sectional study  | Kemmler et al. [71]      | Community-dwelling German women from the FORMoSA study | 1325 | ≥ 70      | Jamar hand dynamometer, Sammons Preston Inc., Ballington, USA                           | 2           | Both                | Standing upright | Arms down by the side | –              | Adjusted to hand size | –             | –            | –             | Higher value |
| Prospective cohort study | Lee et al. [72]         | Young healthy volunteers and older adults from the H-lan Longitudinal Ageing Study | 508  | 20-40/ ≥ 65 | Smedley hand dynamometer, TTM, Tokyo, Japan                                            | 3           | Dominant            | Standing upright | Adducted and neutrally rotated | 180° | –               | –             | –             | –             | Higher value |
| Cross-sectional study  | Lee et al. [73]          | Ambulatory women from the University Hospital Menopause Clinic | 196  | ≥ 65      | Jamar hand dynamometer, Sammons Preston Inc., Bolingbrook, IL, USA                     | 3           | Dominant            | Sitting position | Adducted and neutrally rotated | 90° Forearm neutral | Between 0 and 30° dorsiflexion | 2nd             | –            | –             | Higher value |
| Cross-sectional study  | Maeda et al. [74]        | Patients admitted to acute phase wards from Tamana Regional Health Medical Center | 224  | ≥ 65      | Smedley hand dynamometer, TTM, Tokyo, Japan                                            | 2           | Dominant            | Standing or sitting position, depending on their ability | –               | –               | –             | –             | –             | –             | –             | Higher value |
| Cross-sectional study  | martinez et al. [75]     | Hospitalised elderly patients in a multi-specialty hospital | 110  | ≥ 60      | Saehan hydraulic dynamometer, Saehan Corporation, 973, Yangenk-Dong, Mean 630–728, Korea | 3           | –                   | Sitting position | –               | 90°            | –             | –             | –             | 1 min         | Higher value |

[67] For details on cut-off values and HGS protocols of the studies that diagnose sarcopenia, included in this systematic review.

Sousa-Santos and Amaral: BMC Geriatrics (2017) 17:238
| Study details | Author | Sample | Size | Age | Dynamometer | Repetitions | Hand | Posture | Shoulder position | Elbow position | Wrist position | Handle position | Encouragement | Acquisition time | Rest time | HGS analysis | Cut-off values |
|--------------|--------|--------|------|-----|-------------|-------------|------|---------|------------------|---------------|---------------|----------------|--------------|----------------|------------|--------------|----------------|
| Cross-sectional study | McIntosh et al. [76] | Community-dwelling older adults | 85 | ≥65 | Vernier digital hand dynamometer and collected using LoggerPro software, Vernier, OR, USA; 60 Hz | 6 | Both | Standing upright | Adducted | 90° | – | – | Yes | – | Higher value M: <30 kgf | W: <20 kgf |
| Prospective cohort study | Mijnarends et al. [77] | Community-dwelling older adults from the AGES-Reykjavik Study | 2309 | 66–93 | Good Strength software, Medtrix, Finland | 3 | Dominant | Sitting position | Relaxed | 90°, neutral | Attached by belts to a strain-gauge system thumb up | – | Yes | 4–5 s | 30 s | – | M: <30 kgf | W: <20 kgf |
| Prospective cohort study | Moon et al. [78] | Community-dwelling older adults from the Korean Longitudinal Study on Health and Aging | 297 | ≥65 | Jamar hydraulic hand dynamometer, Sammons Preston, Bolingbrook, IL, USA | 2 | Dominant | Sitting position | Adducted | 90° Forearm neutral | Adjusted to a comfortable position | – | – | 1 min | Mean value M: <26 kgf | W: <16 kgf |
| Cross-sectional study | Mosat et al. [79] | Healthy and independent living older adults from the Canadian Centre for Activity and Aging | 24 | ≥65 | Smedley hand dynamometer, TTM, Tokyo, 100 kg | 6 | Both | Standing upright | – | 90° Forearm neutral | Neutral | – | – | – | Higher value M: <30 kgf | W: <20 kgf |
| Cross-sectional study | Pagotto et al. [80] | Community-dwelling older adults | 132 | ≥65 | CROWN hydraulic dynamometer | 2 | Dominant | Sitting position | Adducted and neutrally rotated | 90° | Extended between 0 and 30° dorsiflexion | 2nd | – | 6 s | 1 min | Both values M: <30 kgf | W: <20 kgf and Fried’s criteria |
| Cross-sectional study | Patel et al. [81] | Community-dwelling older adults from the Hertfordshire Sarcopenia Study | 1890 | 68–77 | Jamar hand dynamometer | 6 | Both | Sitting position | – | Forearms resting on the arms of the chair | Neutral, over the end of the arm of the chair, thumb facing upwards | Adjusted so that the thumb is round one side of the hand and the four fingers are around the other side | – | Yes | 5 s | 1 min | Higher value M: <30 kgf | W: <20 kgf |
| Cross-sectional study | Rondanelli et al. [82] | Older adults consecutively admitted to a physical medicine and rehabilitation division, in Santa Margherita Institute | 159 | ≥65 | Jamar 5030 J1 hydraulic hand dynamometer, Sammons Preston Rolyan, Bolingbrook, IL, USA | 4 | – | Sitting position | – | Comfortable arm position | – | – | Yes | 5 s | 1 min | Mean value of the last three efforts |
| Prospective cohort study | Sanchez-Rodriguez et al. [83] | Consecutive hospitalised | 100 | ≥70 | Jamar hand dynamometer, Nottinghamshire, UK | 3 | – | Sitting position | – | Forearms resting on the arms of the chair | Neutral, over the end of the arm of the chair, thumb | Adjusted so that the thumb is round one side of the | – | – | Higher value | | Compared with normative data |
| Study details            | Author                          | Sample                                                                 | Size   | Age   | Dynamometer                      | Repetitions | Hand | Posture | Shoulder position | Elbow position | Hand position | Encouragement | Acquisition time | Rest time | HGS analysis | Cut-off values |
|-------------------------|---------------------------------|----------------------------------------------------------------------|--------|-------|----------------------------------|-------------|------|----------|------------------|---------------|---------------|---------------|-----------------|-----------|--------------|----------------|
| Retrospective cohort    | Siikamäki et al. (84)           | Finnish postmenopausal women from the OSTEPE study                     | 590    | 65-72 | Pneumatic handheld dynamometer   | 3           | –    | …        | …                | …             | …             | …             | …               | …         | …           | …              |
| Cross-sectional study   | Sousa et al. (85)               | Hospitalized adult patients from medical and surgical wards in a general and teaching hospital | 608    | ≥18 | Jamar hydraulic hand dynamometer | 3           | Non-dominant | Sitting position | Adducted and neutrally rotated | 90° | Forearm neutral | …             | 2nd        | …           | …              | …         | …           | …              |
| Cross-sectional study   | Spira et al. (86)               | Community-dwelling older adults from the BASE-II study                  | 1405   | 60-80| Smedley hand dynamometer, Scandicin, Denmark | 6           | Both | Standing upright | Adducted and neutrally rotated | 90° | Forearm neutral | …             | …         | …           | Higher value   | …         | …           | Fried’s criteria* |
| Cross-sectional study   | Verschuere et al. (87)          | Men from the European Male Ageing Study                                | 679    | 40-79| Jamar hand dynamometer, TEI Inc, Clifton, NJ | 6           | Both | Sitting position | – | Forearms resting on the arms of the chair | Neutral over the end of the arm of the chair, thumb facing upwards | Yes       | …           | Higher value   | …         | …           | Fried’s criteria* |
| Multicentre cohort study | Vetamo et al. (88)              | Older adults admitted to acute care wards of seven Italian hospitals from the CRIME study | 770    | ≥65 | North Coast hydraulic hand dynamometer, North Coast Medical Inc, Morgan Hill, CA | 4           | Both | Sitting position or lying at 30° in bed (when unable to sit) | … | 90° or with elbows supported | Neutral | … | … | Higher value | … | M: <30 kgf | W: <20 kgf |
| Cohort study            | Yalın et al. (89)               | Residents in Seyhanbaglan Nursing Home and Rehabilitation Center        | 141    | ≥65 | Takei Scientific Instruments, Nigata, Japan | 2           | Dominant | – | Abducted (30°) | 180° | Palm perpendicular to the shoulder line | … | … | 5 s | Mean value | M: <30 kgf | W: <20 kgf |
| Cross-sectional study   | Yoshida et al. (90)             | Community-dwelling older adults from OBU Study of Health Promotion for the Elderly | 4811   | ≥65 | Grip-D hand dynamometer, Takei, Nigata, Japan | 1           | Dominant | Standing upright | – | – | – | – | – | Single value | M: <28.8 kgf | W: <18.2 kgf |

*HGS analysis* from Luna-Hernández et al. (16)
Table 1 Details and HGS protocols of the studies that diagnose sarcopenia, included in this systematic review (Continued)

| Study details | Author | Sample | Size | Age | Dynamometer | Repetitions | Hand | Posture | Shoulder position | Elbow position | Wrist position | Handle position | Encouragement | Acquisition time | Rest time | HGS analysis | Cut-off values |
|---------------|--------|--------|------|-----|-------------|-------------|------|---------|-------------------|----------------|---------------|----------------|--------------|---------------|------------|--------------|----------------|
| Cohort study  | Yu et al. [91] | Community-dwelling individuals, from the CASA, FAMAS and NWAHS studies | 1123 | ≥18 | Lafayette Instrument Company, IN, USA (CASA and NWAHS), Smedley, Chicago, IL (FAMAS) | 3 | Dominant | Sitting position | – | Arm supported by a horizontal surface | – | – | – | – | Mean value | M: <30 kgf; W: <20 kgf |

[57] Seconds; [Min] Minutes; [M] Men; [W] Women
[60] Study cited the ASHT 1981 protocol
[61] Study cited the ASHT 1992 protocol
[62] Study cited the ASHT protocol, without specifying which protocol year was used
[63] Study cited the Southampton protocol
* Fried’s criteria (Cut-off points for handgrip strength) Men: ≤29 kgf (BMI ≤ 24 kg/m²); ≤30 kgf (BMI 24.1–26 kg/m²); ≤30 kgf (BMI 26.1–28 kg/m²); ≤32 kgf (BMI > 28 kg/m²) / Women: ≤17 kgf (BMI ≤ 23 kg/m²); ≤17.3 kgf (BMI 23.1–26 kg/m²); ≤18 kgf (BMI 26.1–29 kg/m²); ≤21 kgf (BMI > 29 kg/m²)
** Not defined due to the type of analysis conducted by the study
| Study details                        | Author | Sample | Size | Age | Dynamometer | Repetitions | Hand | Posture | Shoulder position | Elbow position | Wrist position | Handle position | Encouragement | Acquisition time | Rest time | HGS analysis | Cut-off values |
|-------------------------------------|--------|--------|------|-----|-------------|-------------|------|---------|------------------|----------------|---------------|----------------|--------------|----------------|-----------|--------------|----------------|
| Multicentric prospective cohort study | Abizanda et al. [92] (c) | Institutionalised older adults, in four nursing homes from the ACTIVNES study | 91 | 97 | Jamar hand dynamometer, Sammons Preston Rolyan, Bolingbrook, IL | 2 | Sitting position | Adducted and neutrally rotated | 90° Forearm neutral | 2nd | – | – | Higher value | Fried’s criteria* |
| Cross-sectional study Alexandria, Egypt | Abou-Raya et al. [93] | Consecutive patients with congestive heart failure | 126 | 265 | Jamar hand dynamometer | 2 | Dominant Sitting position | Adducted | 90° | Between 0 and 30° dorsiflexion and 0 and 15° ulnar deviation | 2nd | Yes | – | Higher value | Fried’s criteria* |
| Cross-sectional study USA | Bandeen-Roche et al. [94] | Older adults from the 2011 baseline of the National Health and Aging Trends Study | 7439 | 265 | Jamar digital hand dynamometer | 2 | Dominant Sitting position | Adducted | 90° | Dynamometer or forearm resting on the table | 2nd | Yes | – | Higher value | Lowest 20% within BMI categories |
| Cross-sectional study The Netherlands | Bastiaanse et al. [50] (b) | Adults with intellectual disabilities from the HA-ID study | 884 | 265 | Jamar hand dynamometer, Sammons Preston Rolyan, USA | 6 | Both | Sitting position | Adducted and neutrally rotated | 90° Forearm neutral | 2nd | – | – | 1 min | Higher value | Fried’s criteria* |
| Cross-sectional study Liège, Belgium | Beaudart et al. [58] (d) | Community-dwelling older adults from the SarcoPhAge study | 534 | 265 | Hydraulic dynamometer | 6 | Both | Sitting position | – | Forearms resting on the arms of the chair | Neutral position, over the end of the arm of the chair, thumb facing upwards | Adjusted so that the thumb is round one side of the handle and the four fingers are around the other side | Yes | – | – | Higher value | Fried’s criteria* |
| Cross-sectional study England | Buttery et al. [95] | Consecutively patients from three elderly care wards of an urban teaching hospital | 44 | 67–91 | Jamar isometric hand dynamometer, Sammons Preston, Bolingbrook, Illinois, USA | 6 | Both | Sitting position | Adducted and neutrally rotated | 90° Forearm neutral | Between 0 and 30° dorsiflexion and 0 and 15° ulnar deviation | 2nd | Yes | – | Higher value | Compared with normative data from Bohannon et al. [96] |
| Cross-sectional study Germany | Buttery et al. [97] | Community-dwelling older adults from the DEGS1 | 1843 | 65–79 | Smedley hand dynamometer | 4 | Both | Standing upright | – | – | – | – | – | – | Higher value | Fried’s criteria* |
| Cross-sectional study Urban administrative section of Taipei, Taiwan | Chang et al. [98] | Community-dwelling older adults | 234 | 265 | Hand grip dynamometer, Fabrication Enterprises, Inc., Livingston, NY | – | Both | Adducted | 90° | – | – | Yes | – | – | Lowest 20% at baseline | Fried’s criteria* |
Table 2 Details and HGS protocols of the studies that diagnose frailty, included in this systematic review (Continued)

| Study details | Author | Sample | Size | Age | Dynamometer | Repetitions | Hand | Posture | Shoulder position | Elbow position | Wrist position | Handle position | Encouragement | Acquisition time | Rest time | HGS analysis | Cut-off values |
|---------------|--------|--------|------|-----|-------------|-------------|------|---------|------------------|---------------|---------------|----------------|--------------|----------------|-----------|-------------|----------------|
| Cross-sectional study | Da Camara et al. [99] | Community-dwelling older adults | 124 | 65-74 | Jamar hand dynamometer, Jamar, Irvington, NY, USA | 3 | – | Sitting position | Adducted and neutrally rotated | 90° | Forearm neutral | – | Adjusted to a comfortable position between the 2nd or 3rd handle | – | – | 1 min | Mean value | Fried’s criteria* |
| Cross-sectional study | Danilovich et al. [100] | Convenience sample of older adults | 42 | ≥70 | Jamar hand hydraulic dynamometer | 4 | Both | Sitting position | Adducted and neutrally rotated | 90° | Between 0 and 30° dorsiflexion | 2nd | – | – | – | Higher value | M: <30 kgf W: <20 kgf |
| Cross-sectional study | Dato et al. [101] | Community-dwelling older adults | 3719 | ≥70 | Smedley hand dynamometer TTM | 3 | Dominant | Sitting position | Adducted | – | – | – | – | – | Higher value | ** |
| Cross-sectional study | Evenhuis et al. [102] | Individuals with borderline to profound intellectual disabilities of three care provider services from the HA-ID Study | 848 | 90° | Jamar hand dynamometer, 5030 J1, Sammons Preston Rolyan, Dolgeville, NY | 6 | Both | Sitting position | Adducted and neutrally rotated | 90° | Between 0 and 30° dorsiflexion | 2nd | Yes | – | – | Fried’s criteria |
| Prospective cohort study | Fried et al. [10] | Community-dwelling older adults from the Cardiovascular Health study | 5317 | ≥70 | Jamar hand dynamometer | 3 | Dominant | Sitting position | – | 90° | – | 2nd | Yes | – | – | Mean value | Fried’s criteria* |
| Cross-sectional study | Gurina et al. [103] | Community-dwelling older adults from the "Crystal" Study | 611 | 265 | Carpal dynamometer (DK-50, Nizhni Tagi, Russian Federation) | 6 | Both | Standing upright | Arms hanging down at the sides | – | – | – | – | – | 30 s | Mean value | Lowest 20%, adjusted for sex and BMI |
| Cross-sectional study | Heider et al. [104] | Pre-frail and frail community-dwelling older adults | 83 | 265 | Jamar hydraulic hand dynamometer, Lafayette, Louisiana | 6 | Both | Sitting position | – | Forearms resting on the arms of the chair | Neutral, over the end of the arm of the chair, thumb facing upwards | Adjusted so that the thumb is round one side of the handle and the four fingers are around the other side | Yes | – | 1 min | Higher value | ** |
| Cross-sectional and prospective cohort study | Hoogendijk et al. [105] | Older adults from the Longitudinal Aging Study Amsterdam | 1115 | ≥70 | Takei TRK 5001, Takei Scientific Instruments, Tokyo, Japan | 4 | Both | Standing upright or sitting position when the participant was not able to stand | – | 180° | – | – | – | Sum of the highest values of each hand | Fried’s criteria |
| Study details                        | Author             | Sample Details                                                                 | Study Size | Age | Dynamometer Type and Brand | Repetitions | Hand Position | Elbow Position | Wrist Position | Handgear Position | Encouragement | Acquisition Time | Rest Time | HGS Cut-off Values |
|-------------------------------------|--------------------|-------------------------------------------------------------------------------|------------|-----|-----------------------------|-------------|---------------|----------------|----------------|-------------------|---------------|------------------|-----------|-------------------|
| Cross-sectional study, Seoul, Korea | Kang et al.        | Female outpatients from the department of family medicine at Kangbuk Samsung Hospital | 121        | ≥65 | Electronic hand grip dynamometer | 265         | Right         | Abducted 180° | –              | –                 | –             | –                | –         | 14.5 kgf          |
| Cross-sectional study, Seoul and Gyeonggi province, Korea | Kim et al. | Older adults who registered at six senior welfare centers | 486        | ≥65 | Hydraulic hand dynamometer | 265         | –             | Abducted 180° | –              | –                 | –             | –                | –         | Lowest 20%, adjusted for sex and BMI |
| Cross-sectional study, Beaver Dam, Wisconsin | Klein et al. | Adults and older adults from the Beaver Dam Eye Study | 2962       | ≥53 | Hand dynamometer | 265         | Both | Standing upright | Abducted 180° | –                 | Adjusted to hand size | –         | –                | –         | Mean value for the dominant hand |
| Randomised controlled trial, Itabashi Ward, Tokyo, Japan | Kwon et al. | Pre-frail community-dwelling older women | 89         | ≥70 | Hydraulic hand dynamometer | 265         | Dominant | Standing upright | Ams hanging naturally at their sides | –          | –                | –         | Higher value at baseline |
| Cohort study, Korea | Lee et al. | Community-dwelling older adults from the Living profiles of Older People Survey | 11,844     | ≥65 | Hydraulic hand dynamometer | 265         | Both | – | Elbow by the side of the body | 90°          | –                | –         | Highest value – 3 kgf at baseline |
| Prospective cohort study, Boston, Massachusetts, USA | Mohr et al. | Community-dwelling men from the Massachusetts Male Aging study | 646        | 50–86 | Hydraulic hand dynamometer | 265         | Dominant | Sitting position | Arms at their sides | 90° Forearm neutral | Adjusted to hand size | 3 s        | 1 min             | Higher value |
| Prospective cohort study, Barcelona, Spain | Mora et al. | Community-dwelling women from the Mataró Ageing Study | 110        | ≥70 | Hydraulic hand dynamometer | 265         | Non-dominant | Sitting position | Adducted and neutrally rotated | 90° Forearm neutral | Between 0 and 30° dorsiflexion and between 0 and 15° ulnar deviation | Yes         | –                | Mean value |
| Cross-sectional study | Moreira et al. | Community-dwelling older | 99         | 65–89 | Hydraulic hand dynamometer | 265         | Dominant | Sitting position | Adducted and neutrally rotated | 90° Forearm neutral | Between 0 and 30° dorsiflexion | Yes         | –                | Mean value | Fried’s criteria |

*Sousa-Santos and Amaral BMC Geriatrics (2017) 17:238*
Table 2 Details and HGS protocols of the studies that diagnose frailty, included in this systematic review (Continued)

| Study details                      | Author                      | Sample                                         | Size | Age       | Dynamometer                     | Repetitions | Hand          | Posture | Shoulder position | Elbow position | Wrist position | Handle position | Encouragement | Acquisition time | Rest time | HGS analysis | Cut-off values          |
|------------------------------------|-----------------------------|------------------------------------------------|------|-----------|---------------------------------|-------------|---------------|---------|-------------------|----------------|----------------|-----------------|---------------|------------------|-----------|--------------|-------------------------|
| Belo Horizonte, Brazil             | Muller et al. [114]         | women with type 2 diabetes                      | 100  | ≥70       | Jamar hand dynamometer, Horsham, PA | 3           | Non-dominant   | Sitting position | neutrally rotated | Adducted and neutrally rotated | 90° Forearm neutral | Between 0 and 30° dorsiflexion and between 0 and 15° ulnar deviation | – | Yes | – | – | Mean value ** |
| Double-blind, randomised, controlled trial Rotterdam, The Netherlands | Parentoni et al. [115] (c)  | Convenienc sample of older women                | 106  | 65–85     | Saehan dynamometer, SH5001 (calibrated) | 3           | Dominant      | Sitting position | Adducted and neutrally rotated | 90° Forearm neutral | Neutral | 2nd | Yes | – | 1 min | Mean value Fried’s criteria ** |
| Cross-sectional study Dimantina, Brazil | Parentoni et al. [115] (c)  | Community-dwelling older adults                 | 369  | 65–85     | Smedley hand dynamometer TTM        | 2           | Dominant      | Sitting position | – | Resting on the table | Palm facing up | Adjusted to a comfortable position | Yes | – | Higher value |
| Cross-sectional study Dimantina, Brazil | Parentoni et al. [115] (c)  | Community-dwelling older adults                 | 1370 | ≥32–105   | Jamar hydraulic hand dynamometer, Lafayette, IN | 2           | Dominant      | Sitting position | – | – | – | – | – | – | Mean value Fried’s criteria ** |
| Cohort study Texas, New Mexico, Colorado, Arizona and California, USA | Sanders et al. [118]         | Non-institutionalised Mexican Americans from the Hispanic Established Population for the Epidemiological Study of the Elderly | 4875 | ≥32–105   | Jamar hydraulic hand Dynamometer, Lafayette, IN | 2           | Dominant      | Sitting position | – | – | – | – | – | – | Mean value Fried’s criteria ** |
| Cohort study United States and Denmark | Sanders et al. [118]         | Community-dwelling individuals from Long Life Family Study | 3112 | ≥65–70    | Jamar hand dynamometer, Lafayette Instrument Company, Lafayette, IN | 3           | Dominant      | Sitting position | – | Forearm resting on arm of the chair | Neutral, over the end of the arm of the chair, thumb facing upwards | Adjusted so that the thumb is round one side of the handle and the four fingers are around the other side | Yes | – | Higher value M: <30 kgf; W: <20 kgf | Fried’s criteria |
| Cross-sectional study Saarland, Germany | Saum et al. [119] (18)      | Community-dwelling adults from ESTHER study      | 861  | 65–70     | Baseline hydraulic dynamometer      | 3           | Right         | Sitting position | Adducted and neutrally rotated | 90° Forearm neutral | Between 0 and 30° dorsiflexion and 0 and 15° ulnar deviation | 2nd | Yes | – | – | Higher value Fried’s criteria |
| Cross-sectional study Lausanne, Switzerland | Seematter-Bignoud et al. [120] | Community-dwelling older adults from the LC65+ study | 62   | 65–70     | Jamar hydraulic dynamometer         | 3           | Right         | Sitting position | Adducted and neutrally rotated | 90° Forearm neutral | Between 0 and 30° dorsiflexion and 0 and 15° ulnar deviation | 2nd | Yes | – | – | Higher value Fried’s criteria |
| Cross-sectional study Lausanne, Switzerland | Seematter-Bignoud et al. [120] | Community-dwelling older adults from the LC65+ study | 861  | 65–70     | Baseline hydraulic dynamometer      | 3           | Right         | Sitting position | Adducted and neutrally rotated | 90° Forearm neutral | Between 0 and 30° dorsiflexion and 0 and 15° ulnar deviation | 2nd | Yes | – | – | Higher value Fried’s criteria |
| Randomised, Double-Blind, Placebo-Controlled Trial The Netherlands | Tieland et al. [121]         | Frail older adults                              | 62   | ≥65       | Jamar hand dynamometer, Jackson, MI, USA | 6           | Both          | Sitting position | – | – | – | – | – | – | Fried’s criteria |

**Mean values calculated using Fried’s criteria."
Table 2 Details and HGS protocols of the studies that diagnose frailty, included in this systematic review (Continued)

| Study details  | Author | Sample | Size | Age | Dynamometer | Repetitions | Hand | Posture | Shoulder position | Elbow position | Wrist position | Handle position | Encouragement | Acquisition time | Rest time | HGS analysis | Cut-off values |
|---------------|--------|--------|------|-----|-------------|-------------|------|---------|------------------|---------------|---------------|----------------|---------------|-----------------|-----------|----------|----------------|
| Cross-sectional study | Vieira et al. [122] (c) | Institutionalised older adults from three urban residential homes | 50 | 68-99 | Jamar hydraulic hand dynamometer, J00105 | 3 | Dominant Sitting position | Adducted and in extension | 90° Forearm neutral | Extended between 0 and 30° | – | – | 10 s | 1 min | – | M:<30 kgf W:<18 kgf |
| Cross-sectional study | Walston et al. [123] | Community-dwelling women from the Women’s Health and Aging Studies I and II | 463 | 70-79 | Jamar hand dynamometer, model BK-74978, Fred Sammons, Inc., Burr Ridge, IL | 6 | Both Sitting position | Adducted | 90° | – | – | Yes | – | – | Higher value of the non-dominant hand | Fried’s criteria* |
| Cross-sectional study | Wu et al. [124] | Community-dwelling older adults and outpatients from a hospital-based outpatient clinic | 90 | ≥65 | Jamar hand dynamometer, Sammons Preston, Bolingbrook, IL | – | Dominant Sitting position | – | – | – | – | – | – | – | Fried’s criteria* |

S Seconds; Min Minutes; M Men; W Women

(a) Study cited the ASHT 1981 protocol
(b) Study cited the ASHT 1992 protocol
(c) Study cited the ASHT protocol, without specifying which protocol year was used
(d) Study cited the Southampton protocol

* Fried’s criteria (Cut-off points for handgrip strength) Men: ≤29 kgf (BMI ≤ 24 kg/m²); ≤30 kgf (BMI 24.1–26 kg/m²); ≤30 kgf (BMI 26.1–28 kg/m²); ≤32 kgf (BMI > 28 kg/m²) / Women: ≤17 kgf (BMI ≤ 23 kg/m²); ≤17.3 kgf (BMI 23.1–26 kg/m²); ≤18 kgf (BMI 26.1–29 kg/m²); ≤21 kgf (BMI > 29 kg/m²)

** Not defined due to the type of analysis conducted by the study
six studies described the posture of the individual, in which the majority was measured in a sitting position \((n = 47)\), and 19 were in a standing position. Three studies mentioned variations regarding the posture, depending on the ability of the individuals.

Most studies chose to measure HGS only in the dominant hand \((n = 33)\), in four studies measurement was obtained from the non-dominant, and in 25 in both dominant and non-dominant. In one study HGS was measured using the preferred hand while the right hand was used in two other studies. In seven articles information about the chosen limb was absent. The position of the shoulder and the elbow was indicated in 46 and 62 studies, respectively, and the wrist position was described in 39 studies. The dynamometer’s handle was referred in 37 articles, while the second handle position was mentioned in 16 articles. Encouragement during the procedure was reported in 26 studies, only nine studies indicated the data acquisition time and, 19 studies specified the rest time. Most studies \((n = 42)\) used the higher HGS value for the analysis. The ASHT protocol was mentioned in 11 studies, of which the 1981 protocol was referred twice and the 1992 protocol was cited in five studies. The others did not specify the ASHT protocol used. The Southampton protocol was alluded to in eight studies.

**Discussion**

The aim of this systematic review is to identify the HGS protocols used to diagnose sarcopenia and frailty. The heterogeneity in HGS protocols, the wide variability in the criteria used to identify either sarcopenia and frailty and the different inclusion and exclusion criteria in the evaluated studies is an issue in this research field. Indeed, these differences hinder comparison between the studies and hamper progress of the study of these conditions.

We observed that most studies which diagnose these conditions did not mention the protocol used in the measurement of HGS, or did not include a full description of it. Although the ASHT and Roberts et al. proposed standardised protocols, the results of the present review showed high heterogeneity of the chosen procedure. Studies concerning sarcopenia and frailty did not differ in standardised protocols used. Plus, the complete description of the procedure is lacking in most studies. In trying to overcome this problem, some authors raise an additional difficulty when they cite the previous publication of their study protocol.

The parameters regarding the HGS procedure that were presented in the Tables 1 and 2 and its influence in HGS values were evaluated in several studies. As shown below, in spite of some results being similar between the studies, others present contradictory results.

**Dynamometer**

The ASHT recommends a calibrated Jamar dynamometer in the second handle position for the measurement of HGS [24–26]. While, the Southampton protocol suggested the handle should be adjusted so that the thumb is round one side of the handle and the four fingers are around the other side and the instrument should feel comfortable in the hand [27].

The Jamar hydraulic dynamometer presents higher intra and inter-individual reliability [17]. Despite this being referred to as the most widely used and tested dynamometer [27], this review shows a great variability in the dynamometers used, regardless of Jamar’s predominance. Present results exhibit a great number of studies which failed to describe if the instruments were properly calibrated for the measurements. A correctly calibrated dynamometer is highly reliable. Nevertheless, it should be recalibrated regularly [29].

Other dynamometers, such as Smedley dynamometer (mechanical) and Martin vigorimeter (pneumatic), measure HGS by a different mechanism [30]. Concerning the Smedley dynamometer, it has shown excellent results regarding its laboratory tested accuracy but, when applied among older adults, it did not produce comparable results to the Jamar hydraulic [31]. Low agreement between Jamar dynamometer and Takei dynamometer was observed [32]. Otherwise, the results of the comparison between the Jamar dynamometer and the Martin vigorimeter in a healthy elderly population, indicate a very high correlation between the two HGS data values [33]. When the hydraulic dynamometers, Baseline and Sae-han, were tested they shown to be valid, reliable and comparable to the Jamar dynamometer [34, 35].

**Hand**

A summary of the studies comparing HGS in dominant and non-dominant limbs, revealed that it is reasonable to expect greater grip strength in the dominant upper extremity in right-handed individuals [36]. Yet, it is important to consider that the difference between sides varies widely among studied samples and in a significant proportion of individuals the opposite is observed [37, 38].

**Posture and arm position (shoulder, elbow and wrist)**

Most studies revised here, a standing or sitting position was selected. In some cases, the position was adapted to the individual’s physical function. The influence of the standing versus sitting posture in HGS values was evaluated and no significant differences were found by several studies [39–41]. When comparing standing versus sitting position, Balogun et al. observed significant differences only between sitting with elbow at 90 degrees and standing with elbow at full extension [20]. These results were
in agreement with one study that showed that grip strength is significantly greater when measured with the elbow in the fully extended position [42]. Additionally, even though the posture alone did not significantly influence HGS values, combined with the elbow position it could indicate the presence of an interaction between the elbow position at 180 degrees and a standing position. On the other hand, other results showed a stronger grip strength measurement in the 90 degrees elbow flexed position than in the fully extended position [41, 43].

Su et al. also evaluated different shoulder and elbow positions. They observed that when the shoulder was positioned at 180 degrees of flexion with elbow in full extension the highest mean grip strength measurement was recorded; whereas the position of 90 degrees elbow flexion with shoulder in zero degrees of flexion produced the lowest grip strength score [44]. While, De et al. did not find significant differences when shoulder joints varied between 90 and 180 degrees [41].

Regarding the wrist position, one study suggested that a minimum of 25 degrees of wrist extension was required for optimum grip strength [21]. Later, it was shown that HGS measured with wrist in a neutral position was significantly higher than that in the wrist ulnar deviation [41] and, in another study that the mean grip strength scores were higher for all the tested six positions when wrist was positioned in neutral than in extension position [45].

Handle position
Some researchers opted for HGS measurement in a standard handle position. However, in others, researchers adapted the handle to hand size or to a comfortable position for the individual. It was suggested that hand size and optimal grip span only correlated in women [46]. Other studies results have shown that the second handle position was the best position for the majority of the participants. Therefore, the authors suggested the use of a standard handle position (second setting) over multiple different positions [23, 47]. This would provide accurate results and increase the comparability of the results [47].

Repetitions
Mathiowetz et al. suggested that the mean of three trials is a more accurate measure than one trial or even the highest score of three trials [48], while the latter was the most widely adopted by the studies included in this systematic review. In contrast, it was suggested that muscle fatigability might occur with each attempt and one trial is sufficient for the measurement of grip strength [49]. In another study, it was observed that the mean values of grip strength generated for each method of grip strength testing (one trial, the mean of three trials, and the best of three trials) produced comparable results [50].

Encouragement
To our knowledge, only one research described the effects of the encouragement during HGS measurement. It showed that instruction, verbal encouragement, and visual feedback had critical effects on the handgrip strength and, therefore it should be mentioned in the articles [51]. More than half of the articles included here did not provide a full description of if and how the encouragement was made during the trials.

Analysis
As described above, most studies used the higher value for the HGS analysis, however other forms of HGS values chosen by the authors, such as the mean or the sum of the values obtained during the measurements was also observed. Hence, the diagnosis of sarcopenia and frailty between the studies is even less comparable.

Comparison of the protocols
Although the most recent ASHT protocol presents more details regarding the HGS measurement, this protocol has not been adopted by any of the studies included in this revision. Almost every aspect was described in the protocol, making the variations between the studies almost impossible, but also increasing the complexity of the measurement, and therefore the duration of the procedure. Despite the fact that the Southampton protocol referred to all the aforementioned aspects in Table 3, it did not describe in detail the joints position, which could lead to variations in HGS values between the studies.

Due to the great variability in the studies concerning sarcopenia and frailty, namely in the inclusion and exclusion criteria, and in the definition and procedures used to identify these conditions, it is difficult to evaluate the impact of each parameter of the procedure in HGS values. Therefore, to diminish the heterogeneity observed in the studies, the most recent ASHT protocol should be adopted. Variations in the procedure are strongly discouraged, however when it is impossible to fully implement this protocol, namely due to the individuals’ health conditions, any variation should be reported.

Main topics
The mixed results above discussed reinforce the need to standardise HGS measurement. The difference between the protocols can influence the HGS results and, consequently, affect the comparability between the studies. A common approach would be not only important for research purposes but also for clinical practice. For both
sarcopenia and frailty, the major studies that suggested a diagnosis using HGS did not recommend a protocol for its measurement, neither referred to the protocols used to estimate the outlined cut-off points. There is a necessity to include guidelines concerning a standardised protocol in the consensus made by European and International societies. That will allow the results of the studies to be more comparable and more suitable for the application in clinical practice.

In order to describe with precision the handgrip strength protocol used, researchers should always make reference to which protocol was adopted (when applied). For a complete description of the protocol, we suggest that all the points addressed in Table 3 should be mentioned in the methods section of the articles, and therefore include the description of the posture, arm position (including shoulder, elbow and wrist positions), number of trials, characteristics of the dynamometer (brand, model, resolution, calibration and handle position), acquisition and rest time, the applied instructions and the HGS values used in the analysis. The cut-off points to identify low HGS for sarcopenia or frailty should also be stated.

Additionally, deviations to the protocol must be described.

**Strengths and limitations**

Some strengths of this systematic review can be highlighted. Besides the original search, we additionally handsearched the references of the included articles for a broader research. Plus, for our knowledge there is no other review of literature that comprises a detailed description of the methods of HGS in observational and experimental studies about sarcopenia and frailty in older adults and that considered the most recent protocols proposed for HGS measurement.

This article also had a few limitations. Data was only searched in two databases (Pubmed and Web of Science) and the inclusion of other databases could increase the range of articles found. In addition, we identified three articles in which we could not locate the references made for the full procedure. The focus of the present revision was to gather information regarding HGS methods, hence, we have not evaluated the methodologic quality of the included studies. In our opinion, we do not consider that the limitations would substantially alter our results.

**Table 3** Recent HGS protocols proposed

| Posture | ASHT protocol – 2015 [26] | Southampton protocol – 2011 [27] |
|---------|--------------------------|----------------------------------|
| Arm position | | |
| -Shoulder | Adducted and neutrally rotated | Forearms rested on the arms of the chair |
| -Elbow | Flexed to 90°, the forearm should be in midprone (neutral) | – |
| -Wrist | Between 15 and 30° of extension (dorsiflexion) and 0–15° of ulnar deviation | Just over the end of the arm of the chair, in a neutral position, thumb facing upwards |
| Trials | Three trials | Three trials on each side, alternating sides (start with the right hand) |
| Dynamometer | | |
| -Model | Jamar dynamometer | Jamar hydraulic hand dynamometer |
| -Calibration | Yes | – |
| -Handle position | 2nd | Thumb is round one side of the handle and the four fingers are around the other side |
| Acquisition time | At least 3 s | – |
| Rest time | At least 15 s | – |
| Instructions | ‘This test will tell me your maximum grip strength. When I say go, grip as hard as you can until I say stop. Before each trial, I will ask you ‘Are you ready?’ and then tell you ‘Go’. Stop immediately if you experience any unusual pain or discomfort at any point during testing. Do you have any questions? Are you ready? Go!’. ‘Harder... harder... harder...Relax’ | ‘I want you to squeeze as hard as you can for as long as you can until I say stop. Squeeze, squeeze, squeeze, stop’ (when the needle stops rising) |
| HGS analysis | Mean of three trials | Maximal grip score from all six trials |

Sousa-Santos and Amaral BMC Geriatrics (2017) 17:238 Page 17 of 21
Conclusion
In conclusion, the majority of the studies included did not describe a complete procedure of HGS measurement. The high heterogeneity between the protocols used, in sarcopenia and frailty related studies, create an enormous difficulty in drawing comparative conclusions among them. Even though, there are suggested standardised procedures, present results reinforce the need to uniform the procedure not only in the studies that diagnose these conditions but also in studies which present normative data. Further studies should evaluate which factors contribute to higher HGS values. Meanwhile, we suggest the adoption of the most recent ASHT protocol. In our opinion, this is the most detailed one and, thus, it is less probable to generate differences in HGS values between the studies. Nevertheless, we embrace that the complexity of this protocol may increase the difficulty in its application, especially in clinical practice. Future studies of these issues should include a complete description of the procedure, mentioning the deviations to the protocol.

Abbreviations
ASHT: American Society of Hand Therapists; CHS: Cardiovascular Health Study; EWGSOP: European Working Group on Sarcopenia in Older People; HGS: Handgrip strength; IWGS: International Working Group on Sarcopenia; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

Acknowledgements
Not applicable.

Funding
Not applicable.

Availability of data and materials
The datasets analysed during the current study available from the corresponding author on reasonable request.

Authors’ contributions
RS and TA conceived of the study, and participated in its design and coordination and helped to draft the manuscript. Both authors read and approved the final version of the manuscript.

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Received: 8 December 2016 Accepted: 8 October 2017 Published online: 16 October 2017

References
1. WHO. World report on ageing and health. Luxembourg: World Health Organization; 2015.
2. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, et al. Sarcopenia: European consensus on definition and diagnosis: report of the European working group on sarcopenia in older people. Age Aging. 2010; 39(4):412–23.
3. Rosenberg IH. Sarcopenia: origins and clinical relevance. J Nutr. 1997;127(Suppl):990s–15.
4. Fielding RA, Vellas B, Evans WJ, Bhasin S, Morley JE, Newman AB, et al. Sarcopenia: an undisagnosed condition in older adults. Current consensus definition, prevalence, etiology, and consequences. International working group on sarcopenia. J Am Med Dir Assoc. 2011;12(4):249–56.
5. Xue QL. The frailty syndrome: definition and natural history. Clin Geriatr Med. 2011;27(1):1–15.
6. Woods NF, LaCroix AZ, Gray SL, Aagåker A, Cochrane BB, Brunner RL, et al. Frailty: emergence and consequences in women aged 65 and older in the Women’s Health Initiative observational study. J Am Geriatr Soc. 2005;53(8):1321–30.
7. Ensrud KE, Ewing SK, Taylor BC, Fink HA, Stone KL, Cauley JA, et al. Frailty and risk of falls, fracture, and mortality in older women: the study of osteoporotic fractures. J Gerontol A Biol Sci Med Sci. 2007;62(2):74–51.
8. Cawthon PM, Marshall LM, Michael Y, Dam TT, Ensrud KE, Barrett-Conner E, et al. Frailty in older men: prevalence, progression, and relationship with mortality. J Am Geriatr Soc. 2007;55(8):1216–23.
9. Wong CH, Weiss D, Sourial N, Karunanithan S, Quail JM, Wolfson C, et al. Frailty and its association with disability and comorbidity in a community-dwelling sample of seniors in Montreal: a cross-sectional study. Aging Clin Exp Res. 2010;22(1):54–62.
10. Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gotttdiener J, et al. Frailty in older adults: evidence for a phenotype. J Gerontol A Biol Sci Med Sci. 2001;56(3):M146–56.
11. Bouillon K, Kvismaki M, Hamer M, Sabia S, Fransson EL, Singh-Manoux A, et al. Measures of frailty in population-based studies: an overview. BMC Geriatr. 2013;13:64.
12. Massy-Westropp NM, Gill TK, Taylor AW, Bohannon RW, Hill CL. Hand grip strength: age and gender stratified normative data in a population-based study. BMC Res Notes. 2011;4:127.
13. Rantanen T, Volpato S, Ferrucci L, Heikkinen E, Fried LP, Guralnik JM. Handgrip strength and cause-specific and total mortality in older disabled women: exploring the mechanism. J Am Geriatr Soc. 2003;51(5):636–41.
14. Frederiksen H, Hjelmborg J, Mortensen J, McGue M, Vaupel JW, Christensen K. Age trajectories of grip strength: cross-sectional and longitudinal data among 8,342 Danes aged 46 to 102. Ann Epidemiol. 2006;16(7):554–62.
15. Budzíałack MB, Pureza Duarte RR, Barbosa-Silva MC. Reference values and determinants for handgrip strength in healthy subjects. Clin Nutr. 2008;27(3):357–62.
16. Luna-Heredia E, Martin-Pena G, Ruiz-Galiana J. Handgrip dynamometry in healthy adults. Clin Nutr. 2005;24(2):250–8.
17. Bohannon RW, Schaubert KL. Test-retest reliability of grip-strength measures obtained over a 12-week interval from community-dwelling elders. J Hand Ther. 2005;18(4):426–7.
18. Pedisson A, Hedlund R, Oberg B. Intra- and inter-tester reliability and reference values for hand strength. J Rehabil Med. 2001;33(1):36–41.
19. Flood A, Chung A, Parker H, Kearns V, O’Sullivan TA. The use of hand grip strength as a predictor of nutrition status in hospital patients. Clin Nutr. 2014;33(1):106–14.
20. Balogun JA, Akomolafe CT, Armou LO. Grip strength: effects of testing posture and elbow position. Arch Phys Med Rehabil. 1991;72(5):280–3.
21. O’Driscoll SW, Hori E, Ness R, Cahalan TD, Richards RR, An K-N. The relationship between wrist posture, grasp size, and grip strength. J Hand Surg Am. 1992;17(1):169–77.
22. Incel NA, Ceceli E, Durukan PB, Erdem HR, Yorgancioğlu ZR. Grip strength: effect of hand dominance. Singapore Med. 2002;43(5):234–7.
23. Firrell JC, Cram GM. Which setting of the dynamometer provides maximal grip strength? J Hand Surg Am. 1996;21(3):397–401.
24. Fess E, Morin C. Clinical assessment recommendations. 1st ed. Indianapolis: American Society of Hand Therapists; 1981.
25. Fess E. Clinical assessment recommendations. Chicago: American Society of Hand Therapists; 1992.
26. MacDermid J, Solomon G, Fedorczyk J, Valdes K. Clinical assessment recommendations 3rd edition: impairment-based conditions. American Society of Hand Therapists. 2015.
27. Roberts HC, Denison HJ, Martin HJ, Patel HP, Syddall H, Cooper C, et al. A review of the measurement of grip strength in clinical and epidemiological studies: towards a standardised approach. Age Ageing. 2011;40(4):423–9.
criteria in elderly people: a cross sectional observational study. Arch Gerontol Geriatr. 2016;66:73–81.

123. Walston J, Arking DE, Fallin D, Li T, Beamer B, Xue Q, et al. IL-6 gene variation is not associated with increased serum levels of IL-6, muscle, weakness, or frailty in older women. Exp Gerontol. 2005;40(4):344–52.

124. Wu IC, Shiesh SC, Kuo PH, Lin XZ. High oxidative stress is correlated with frailty in elderly chinese. J Am Geriatr Soc. 2009;57(9):1666–71.

Submit your next manuscript to BioMed Central and we will help you at every step:

- We accept pre-submission inquiries
- Our selector tool helps you to find the most relevant journal
- We provide round the clock customer support
- Convenient online submission
- Thorough peer review
- Inclusion in PubMed and all major indexing services
- Maximum visibility for your research

Submit your manuscript at www.biomedcentral.com/submit