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SYSTEMATIC REVIEW

Reference values for muscle strength: a systematic review with a descriptive meta-analysis

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Abstract
Background: Muscle strength is an important component of health.
Objective: To describe and evaluate the studies which have established the reference values for muscle strength on healthy individuals and to synthesize these values with a descriptive meta-analysis approach.
Methods: A systematic review was performed in MEDLINE, LILACS, and SciELO databases. Studies that investigated the reference values for muscle strength of two or more appendicular/axial muscle groups of health individuals were included. Methodological quality, including risk of bias was assessed by the QUADAS-2. Data extracted included: country of the study, sample size, population characteristics, equipment/method used, and muscle groups evaluated.
Results: Of the 414 studies identified, 46 were included. Most of the studies had adequate methodological quality. Included studies evaluated: appendicular (80.4%) and axial (36.9%) muscles; adults (78.3%), elderly (58.7%), adolescents (43.5%), children (23.9%); isometric (91.3%) and isokinetic (17.4%) strength. Six studies (13%) with similar procedures were synthesized with meta-analysis. Generally, the coefficient of variation values that resulted from the meta-analysis ranged from 20.1% to 30% and were similar to those reported by the original studies. The meta-analysis synthesized the reference values of isometric strength of 14 muscle groups of the dominant/non-dominant sides of the upper/lower limbs of adults/elderly from developed countries, using dynamometers/myometer.

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Conclusions: Most of the included studies had adequate methodological quality. The meta-analysis provided reference values for the isometric strength of 14 appendicular muscle groups of the dominant/non-dominant sides, measured with dynamometers/myometers, of men/women, of adults/elderly. These data may be used to interpret the results of the evaluations and establish appropriate treatment goals.

Introduction

Muscle strength is an important component of health and physical fitness.[1,2] Muscle strength has a relevant role in the performance of many activities of daily living,[2] and is known to be the most important predictor of function.[3] In addition, muscle weakness is related to disability.[4,5] Therefore, muscle strength is an important outcome and of great interest with regards to general health.[1]

The most common equipment or methods that provide quantitative measures of strength, such as the isokinetic[6–8] and portable dynamometers,[9–11] have been shown to provide valid and reliable measures.[9–15] Isokinetic dynamometers provide both isokinetic (concentric and eccentric) and isometric measures, while portable dynamometers provide only isometric measures. Although less used than the isokinetic and portable dynamometers, the myometer also yields isometric measures and has shown to provide reliable measures of strength of both adults and children.[16–18] An alternative method for the quantitative evaluation of isometric strength is the modified sphygmomanometer test (MST). This low-cost method also provides valid and reliable measures of strength of various populations and muscle groups.[19–21]

Since the 1980s, several studies were performed with the aim to establish reference values for muscle strength for some of these equipment or methods.[16,17,22–65] Reference values are essential for the correct interpretation of the evaluations and establishment of appropriate treatment goals.[43,66] In addition, they are useful for the evaluation of the effectiveness of interventions[30] and for the provision of important prognostic parameters, such as the possibility to return to usual activities.[43] Furthermore, reference values could also be used as motivation for patients during rehabilitation interventions.[54]

A systematic review of the reference values of muscle strength provides a comprehensive summary of the literature along with a critical analysis of the quality of the results of the included studies. This critical summary can help professionals with the clinical decision-making process. Furthermore, the results of a meta-analysis of reference values provide a better estimative of the true value of a population, since the combined sample size of the meta-analysis is larger than that of the individual studies. Two previous systematic reviews with meta-analysis were published with the aim to synthesize the reference values for the strength of the inspiratory[67] and handgrip[68] muscles. However, no systematic review has addressed the appendicular and axial muscles.

Reference values are relevant for the interpretation of the evaluation and clinical decision-making process. Since several equipment or methods that provide quantitative measures of strength are available and various studies have already established the reference values for muscle strength, the objectives of the present review were to describe and evaluate the methodological quality of these studies and synthesize, using a meta-analysis, the reference values already established for healthy individuals at any age.

Methods

Data sources and search strategy

This systematic review was reported in compliance with the PRISMA guidelines.[69–71] All the steps described below were performed by two independent examiners (PAB and LTA). A third examiner (CDCMF) was involved to solve any disagreements.

Electronic searches were conducted in the following electronic databases: Medical Literature Analysis and Retrieval System Online (MEDLINE), Latin American and Caribbean Literature in Health Sciences Literature (LILACS), and Scientific Electronic Library Online (SciELO), from the inception to December 2017, without any language restrictions. The search strategy used in the MEDLINE database was ''muscle strength'' OR ''isometric contraction'' OR ''isotonic contraction'' OR ''isokinetic contraction'' OR ''muscle force'' OR ''muscular strength'' OR ''muscular force'' AND ''reference value*'' OR ''reference range*'' OR ''normative search'' OR ''normative standard*'' OR ''normative data*'' OR ''normative score*'' OR ''normal range*'' OR ''normative value*'' OR norms OR ''average value*''. This search strategy was then modified to meet the requirements of the LILACS and SciELO databases.

Study selection and eligibility criteria

To be included, the studies had to have the objective to determine the reference strength values of two or more appendicular and/or axial muscle groups of health individuals at any age and employ any equipment or method to objectively obtain the strength measures. Studies that established reference strength values of the respiratory or facial muscles were excluded. The titles and abstracts of all the retrieved articles were screened for eligibility. Then, full-text articles were screened following the predefined criteria. The reference lists of the included studies were also manually searched.

Quality

The methodological quality of the included studies was evaluated using the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2). The QUADAS is an evidence-based tool for the evaluation of methodological quality of systematic reviews.[72] The QUADAS was already employed with the same purpose in a previous systematic review with meta-analysis for establishing the reference strength values of the inspiratory muscles.[67] The QUADAS-2 is an updated version of the QUADAS tool, which allows for a more objective and transparent rating of bias and applicability.[72] The QUADAS-2 includes four domains (patient selection, index test, reference standard, flow, and timing), which are evaluated in terms of risk of bias. In addition, the first three domains are also evaluated in terms of concerns of the applicability.[72] As the purpose of the present review was not to describe the results, based on comparisons with gold standard measures, the reference standard domain was not evaluated. Therefore, the following five QUADAS-2 criteria were evaluated: risk of bias, related to the domains of patient selection, index test, and flow/timing, and applicability regarding patient selection and index test.[72] It was considered as having adequate quality those studies that scored at least three out of five points (more than a half of the points) on the QUADAS-2.

Study characteristics

Data extraction included country, where the study was carried out; sample size; population characteristics (age and sex); equipment or method used; and muscle groups evaluated. For the population age group, the following World Health Organization classification for developed countries was used: children (0–9 years), adolescents (10–19 years), adults (20–64 years), and elderly (≥65 years).[73–75]

For the studies that had adequate methodological quality, i.e., positive greater than negative evaluation on the five QUADAS-2 criteria[72] and showed common characteristics, which allowed for the synthesis of the data, a descriptive meta-analysis was performed. The common characteristics, which were considered, included types of contraction, equipment or method of evaluation, population characteristics, age sub-groups, muscle groups, positioning of the individuals and of the equipment, descriptive statistics used, and data collection procedures. In addition, the evaluation side for the appendicular muscles, number of trials, duration of the contractions, rest intervals, familiarization with the procedures, verbal encouragement, and measurement units. The following data were extracted: sample size, descriptive statistics, and information regarding the procedures to obtain the muscle strength measures.

Data analysis

Statistical analysis of the meta-analysis was performed using the RevMan 5 software (version 5.3.5, available at https://www.statstodo.com/ ComMeans_Pgm.php). Coefficient of variation (CV) of the synthesized values was also calculated using the Excel® software. CV is a statistical measure of the dispersion of data points in a data series around the mean. It represents the ratio of the standard deviation to the mean (expressed in %), and it is a unit-free value. The CV, as a measure of variability, is considered a practical statistics for comparing the degree of variation from one data series to another, even if the means are drastically different. It also can be easily used to reflect the degree of measurement error, i.e., the lower is the obtained value, the more repeatable the method is.[66]

Results

Flow of studies and quality

Of the 414 studies identified, 95 were selected for full-text evaluation, and of those, only 46 were eligible for this review (Fig. 1). As given in Table 1, the methodological quality of the included studies ranged from two to five (median = 3 points). Most of the included studies scored at least three (58.7%)[16,22–24,26,28–31,33–38,42,44–47,52–54,59,60,64,65] out of five points on the QUADAS-2.[72] For all studies, the frequency of positive evaluation was higher than that of negative one on the five QUADAS-2 criteria[72] (Table 1).

Descriptions of studies

As shown in Tables 2 and 3, all studies involved samples from developed countries; the majority (95.6%) were from the Northern Hemisphere (Belgium,[53] Denmark,[35,41,58] Finland,[59,60] France,[23,37,52] Ireland,[30] Netherlands,[25,46] Norway,[39] Scotland,[51] Spain,[56] Sweden,[16,17,31,47,48,54,64] Switzerland,[28,36] Canada,[50,55] USA,[24,26,27,29,32–34,38,40,42,43,45,49,61–63,65] and China).[57] A large variation in sample size was noted: the largest sample included 3587 subjects, in a study that involved the evaluation of two muscle groups (knee flexors and extensors),[65] whereas the smallest sample included 31 subjects, which involved the evaluation of seven muscle groups of the upper limbs.[63] In only three studies (6.5%),[27,56,65] a priori sample size estimation was reported. Only eight studies (17.4%) justified the separation of the reference values into different subgroups (age, sex, or side).[23,25,31,33,34,38,53,62]

Of the 46 included studies, 91.3% ($n = 42$)[16,17,22–61] reported reference values for isometric and 17.4% ($n = 8$)[35,39,47,61–65] for isokinetic strength, whereas 75.2%[16,17,22–51] provided reference values for isometric strength of the upper limb muscles. For the evaluation of isometric strength, the most commonly employed equipment were portable dynamometers (52.3%)[22–24,26–29,31,33,34,36,38,39,41–43,45,46,51,52,56,58] followed by isokinetic dynamometers (11.9%)[32,35,40,53,61] and myometer (9.5%).[16,17,25,44] Each of the other equipment or evaluation methods used to assess isometric strength was applied by a single study (Table 2).

In the majority of the studies (93.8%), the reference values for muscle strength were reported for both men and women. The references values for isometric strength were established for the majority of the appendicular and

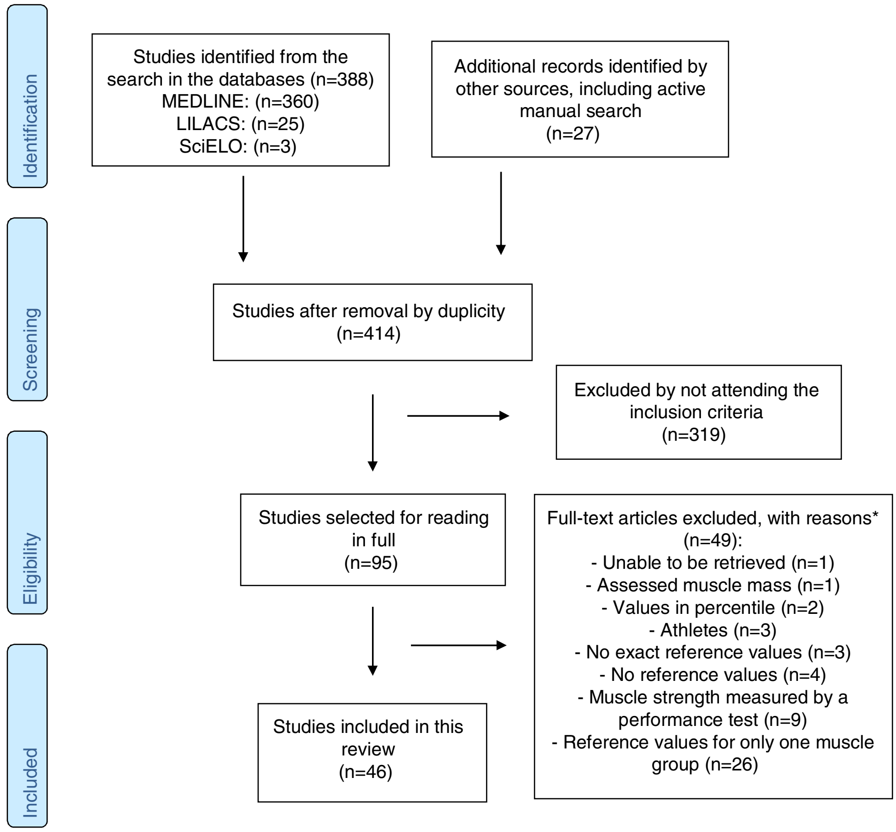

Figure 1 Flow diagram of the studies through the review. *Articles may have been excluded, for failing to meet more than one inclusion criterion.

axial muscle groups of children (21.4%)[17,22,23,25,31,39,46,47,52], adolescents (42.8%),[16,17,22,23,25,28,31,39,41,42,45–48,51,52,60,61] adults (80.9%),[16,22–24,26–28,30,32–38,40,42–45,48–61] and elderly (59.5%)[16,22,23,27–30,32–38,40,43–45,49–52,56–58] (Table 2). The reference values for isokinetic strength were established for most appendicular and axial muscle groups of adults (50%)[35,61–63] and elderly (25%)[35,62] individuals. For the children, isokinetic strength values were only found for the following muscle groups: elbow flexors and knee flexors/extensors (50%).[39,47,64,65] For the adolescents, the following muscle groups had their reference values described[39,47,61,64,65] (Table 3): elbow flexors, knee flexors/extensors, and trunk flexors/extensors.

Meta-analysis

Among the 46 studies that established reference values for muscle strength, 13% ($n=6$)[16,29,34,38,43,44] met the criteria established for synthesizing the values and performing the meta-analysis. All of these studies involved the evaluation of isometric strength. Considering that these criteria were similar, it was possible to synthesize the values of three pairs of studies, whose statistical analysis is given in Table 4. In two of these studies, the isometric strength of 10 muscle groups was evaluated, bilaterally (dominant and nondominant sides), in men and women of the following age groups: 50–59, 60–69, and 70–79 years[34,38] (reference values of muscle strength ranged from 66.73 ± 16.02 to 458.45 ± 79.73 N). In two other studies, the isometric strength of the hip flexors of the dominant side of men and women in the following age groups was evaluated: 20–29, 30–39, 40–49, 50–59, and 60–69 years[16,44] (reference values of muscle strength ranged from 167 ± 23.4 to 281.8 ± 50.7 N). Finally, two other studies evaluated the isometric strength of the handgrip muscles, as well as the lateral, palmar, and pulp-to-pulp pinches, bilaterally (right and left sides), in men and women in the 60–69 and 70–74 age groups[29,43] (reference values of muscle strength ranged from 9.5 ± 1 to 91.3 ± 18.5 Pounds). The reference values for the muscle strength presented by the meta-analysis decreased with age for men and woman. Moreover, for the same age group, men tended to have a higher muscle strength than women and the dominant side tend to have a higher muscle strength than the nondominant side. See reference values in Table 4. As given in Table 4, the CV of the combined values ranged from 15% to 29.84% and 10.6% to 32.9% for men and women, respectively, and the most common values ranged from 20.1% to 30% (56.8% for men and 69.1% for women).

Discussion

The present review described and evaluated the methodological quality of the studies, which established the reference strength values for the axial and appendicular muscles of healthy subjects. In addition, it also provided a synthesis with a descriptive meta-analysis of the previously established reference values. Most of the studies had adequate methodological quality, and reported the refer-

Table 1 Methodological quality of the included studies, according to the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) ($n = 45$).

Study	Risk of bias			Applicability		Total (5 points)
	Patient selection	Index test	Flow/ timing	Patient selection	Index test	
McKay et al.[22] 2017	No	Yes	Yes	Yes	Unclear	3
Decostre et al.[23] 2015	No	Yes	Yes	Yes	Yes	4
Harlinger et al.[24] 2015	No	Yes	Yes	Yes	Yes	4
Molenaar et al.[25] 2011	No	Unclear	Yes	Yes	Unclear	2
Riemann et al.[26] 2010	No	Yes	Yes	Yes	Yes	4
Kim et al.[27] 2009	No	Unclear	Yes	Yes	Unclear	2
Werle et al.[28] 2009	Yes	Unclear	Yes	Yes	Unclear	3
Jansen et al.[29] 2008	No	Yes	Yes	Yes	Yes	4
Meldrum et al.[30] 2007	No	Yes	Yes	Yes	Yes	4
Eek et al.[31] 2006	Unclear	Yes	Yes	Unclear	Yes	3
Hughes et al.[32] 1999	No	Unclear	Yes	Yes	Unclear	2
Boatright et al.[33] 1997	No	Yes	Yes	Yes	Yes	4
Andrews et al.[34] 1996	No	Yes	Yes	Yes	Yes	4
Danneskiold-Samsøe at al.[35] 2009	Yes	Yes	No	Yes	Yes	4
Stoll et al.[36] 2000	No	Yes	Yes	Yes	Yes	4
Hogrel et al.[37] 2007	No	Yes	Yes	Yes	Yes	4
Bohannon[38] 1997	No	Yes	Yes	Yes	Yes	4
Holm et al.[39] 2008	No	Unclear	Yes	Yes	Unclear	2
Hughes et al.[40] 1999	No	Unclear	Yes	Yes	Unclear	2
Andersen and Henckel[41] 1987	No	Unclear	Yes	Yes	Unclear	2
Backman et al.[16] 1995	Yes	Unclear	Yes	Yes	Unclear	3
Crosby et al.[42] 1994	Yes	Unclear	Yes	Yes	Unclear	3
Mathiowetz et al.[43] 1985	No	Unclear	Yes	Yes	Unclear	2
Phillips et al.[44] 2000	No	Yes	Yes	Yes	Yes	4
The National Isometric Muscle Strength (NIMS) Database Consortium[45] 1996	No	Yes	Yes	Yes	Yes	4
Beenakker et al.[46] 2001	Yes	Unclear	Yes	Yes	Unclear	3
Sunnegardh et al.[47] 1988	Yes	Unclear	Yes	Yes	Unclear	3
Backman et al.[17] 1989	Unclear	Unclear	Yes	Yes	Unclear	2
Lannersten et al.[48] 1993	Yes	Unclear	No	Yes	Unclear	2
Murray et al.[49] 1985	No	Unclear	Yes	Yes	Unclear	2
Rice et al.[50] 1989	No	Unclear	Yes	Yes	Unclear	2
Gilbertson and Barber-Lomax[51] 1994	No	Unclear	Yes	Yes	Unclear	2
Moraux et al.[52] 2013	No	Yes	Yes	Yes	Yes	4
Cagnie et al.[53] 2007	No	Yes	Yes	Yes	Yes	4
Peolsson et al.[54] 2001	Yes	Yes	Yes	Yes	Yes	5
Vernon et al.[55] 1992	No	Unclear	Yes	Yes	Unclear	2
Garcés et al.[56] 2002	No	Unclear	Yes	Yes	Unclear	2
Chiu et al.[57] 2002	No	Unclear	Yes	Yes	Unclear	2
Jordan et al.[58] 1999	No	Unclear	Yes	Yes	Unclear	2
Salo et al.[59] 2006	No	Yes	Yes	Yes	Yes	4
Paalanne et al.[60] 2009	No	Yes	Yes	Yes	Yes	4
Nordin et al.[61] 1987	No	Unclear	Yes	Yes	Unclear	2
Frontera et al.[62] 1991	No	Unclear	Yes	Yes	Unclear	2
Ivey et al.[63] 1985	No	Unclear	Yes	Yes	Unclear	2
Lundgren et al.[64] 2011	Yes	Yes	Yes	Yes	Yes	5
Wiggin et al.[65] 2006	No	Yes	Yes	Yes	Yes	4

Yes, low risk of bias; No, high risk of bias; Unclear, unclear risk of bias.

ence values for isometric strength of the upper limb muscles of adults and elderly of developed countries of the Northern Hemisphere, using portable dynamometers. For children and adolescents, the reference values for isometric strength of most muscle groups of the upper and lower limbs were reported. The meta-analysis synthesized the reference values of six studies, which were grouped into pairs, for 14 muscle groups of the upper and lower limbs of adults and

Table 2 Characteristics of the studies that established the reference values for isometric strength of the upper/lower limb and axial muscular groups.

UPPER LIMB MUSCLES			
Study and location	Participants (*n*; age; and sex)	Equipments or methods	Muscle groups
McKay et al.[22] 2017 Australia	*n* = 1000; 3–101 years; W/M: 500/500	Hand-held dynamometer (Citec dynamometer CT 3001; CIT Technics, Groningen, Netherlands)	Elbow flexors/extensors, shoulder internal/external rotators; grip
Decostre et al.[23] 2015 France	*n* = 345; 5–79 years; W/M:198/147	MyoWrist dynamometer	Wrist flexors/extensors
Harlinger et al.[24] 2015 USA	*n* = 180; 20–64 years; W/M:90/90	Nicholas manual muscle tester (NMMT; Lafayette Instrument, Lafayette, IN)	Wrist and elbow flexors/extensors; shoulder internal/external rotators, abductors, flexors/extensors, and horizontal abductors/adductors
Molenaar et al.[25] 2011 Netherlands	*n* = 101; 4–12 years; W/M:52/49	Rotterdam intrinsic hand myometer	Thumb flexors, oppositors and abductor; and abductors of the 2° and 5° fingers
Riemann et al.[26] 2010 USA	*n* = 181; 20–40 years; W/M:91/90	Hand-held baseline 250 hydraulic push-pull dynamometer (Baseline Corporation, Invirgton, NY)	Shoulder internal/external rotators
[a]Kim et al.[27] 2009 USA	*n* = 237; 40–86 years; W/M:93/144	Isobex dynamometer (Cursor AG, Bern, Switzerland)	Shoulder external rotators and abductors
Werle et al.[28] 2009 Switzerland	*n* = 1023; 18–96 years; W/M:507/516	Jamar dynamometer (Sammons Preston Rolyan, Bolingbrook, IL, USA); Pinch gauge (Baseline Fabrication Enterprises Inc., Irvingston, NY, USA)	Grip Lateral pinch
Danneskiold-Samsøe et al.[35] 2009 Denmark	*n* = 174; 20–80 years; W/M:121/53	Lido active (Lido Multijoint II, Loredan Biomedical, Davis, CA, USA) Hand dynamometer (Type HKRM no.: D90116; AB Detector, Göteborg, Sweden)	Wrist and elbow flexors/extensors; shoulder internal/external rotators, abductors/adductors, and flexors/extensors; Grip (only men)
Holm et al.[39] 2008 Norway	*n* = 376; 7–12 years; W/M:191/185	Jamar dynamometer (Jamar, Bolingbrook, IL, USA)	Grip
Jansen et al.[29] 2008 USA	*n* = 224; 65–92 years; W/M:140/84	Jamar dynamometer; B & L pinch gauge	Grip; lateral, palmar, and pulp-to-pulp pinch
Meldrum et al.[30] 2007 Ireland	*n* = 494; 19–76 years; W/M:259/235	Quantitative muscle assessment system	Elbow flexors/extensors; shoulder abductors/adductors
Hogrel et al.[37] 2007 France	*n* = 315; 20–80 years; W/M:168/147	Quantitative muscle testing	Elbow flexors/extensors; shoulder internal/external rotators, abductors, flexors/extensors; grip
Eek et al.[31] 2006 Sweden	*n* = 149; 5–15 years; W/M:73/76	Hand-held electronic dynamometer (Adapted Chatillon dynamometer; Axel Ericson Medical AB, S Vägen 12, 412 54 Gothenburg, Sweden)	Wrist extensors; elbow flexors/extensors; shoulder abductors
Beenakker et al.[46] 2001 Netherlands	*n* = 270; 4–16 years; W/M:131/139	Hand-held dynamometer type CT 3001 (C.I.T. Technics, Groningen, The Netherlands)	Palmar pinch; Wrist extensors; elbow flexors/extensors; shoulder abductors;

Table 2 (*Continued*)

Upper limb muscles			
Study and location	Participants (*n*; age; and sex)	Equipments or methods	Muscle groups
Stoll et al.[36] 2000 Switzerland	*n* = 543, 20–82 years; W/M:290/253	Hand-held pull gauge Martin vigorimeter	Wrist and elbow flexors/extensors; shoulder internal/external rotators, abductors/adductors, flexors/extensors; grip
Phillips et al.[44] 2000 Australia	*n* = 200; 20–69 years; W/M:100/100	Penny and Giles hand-held myometer (Penny & Giles Instrumentation Ltd., 4 Airfield Way, Christchurch, Dorset BH233TS, England)	Wrist extensors; elbow flexors/extensors; shoulder external rotators and abductors
Hughes et al.[32] 1999 USA	*n* = 120; 20–78 years; W/M:60/60	Modified Cybex II dynamometer (Cybex, Ronkonkoma, New York)	Shoulder internal/external rotators, abductors/adductors and flexors/extensors
Hughes et al.[40] 1999 USA	*n* = 120; 20–78 years; W/M:60/60	Cybex II dynamometer	Shoulder internal/external rotators, abductors/adductors, and flexors/extensors
Bohannon[38] 1997 USA	*n* = 231; 20–79 years; W/M:125/106	Ametek digital hand-held dynamometer	Wrist extensors; elbow flexors/extensors; shoulder abductors and extensors
Boatright et al.[33] 1997 USA	*n* = 309; 20–97 years; W/M:208/101	Jamar dynamometer (Asimow Engineering, Los Angeles, CA); Pinch gauge (B&L Engeneering, Santa Fe Springs, CA); Thumb abduction strength testing device	Grip Lateral pinch Thumb abductors
Andrews et al.[34] 1996 USA	*n* = 156; 50–79 years; W/M:70/77	Chatillon CSD400C hand-held dynamometer	Wrist extensors; elbow flexors/extensors; shoulder internal/external rotators, abductors and flexors/extensors
The National Isometric Muscle Strength (NIMS) Database Consortium,[45] 1996 USA	*n* = 493; 18–80 years; W/M:273/220	Interface SM-250 electronic strain gauge (Interface, Inc., 7401 E. ButtherusDr., Scottsdale, AZ 85260) Jamar model 2A (Asimow Engineering Co., Santa Monica, CA.)	Elbow and shoulder flexors/extensors Grip
Backman et al.[16] 1995 Sweden	*n* = 128; 17–70 years; W/M:63/65	Portable electronic dynamometer (Myometer, Penny & Giles Transducers Ltd, Dorset, England) Strain gauge (Rank Stanley Cox)	Wrist extensors; elbow flexors; shoulder abductors Grip
Crosby et al.[42] 1994 USA	*n* = 214; 16–63 years; W/M:109/105	Jamar Dynamometer (Asimow Engineering, Los Angeles, CA). Pinch gauge (B& L Engineering, Santa Fe, CA)	Grip Lateral and pulp-to-pulp pinch
Gilbertson and Barber-Lomax[51] 1994 Scotland	*n* = 260; 15–92; W/M:130/130	Jamar dynamometer (Asimov Engineering Co., Los Angeles, CA) B+L hydraulic pinch gauge (B+L Engeneering, Santa Fe Springs, CA)	Grip Lateral, palmar, and pulp-to-pulp pinch
Lannersten et al.[48] 1993 Sweden	*n* = 186; 19–65 years; W/M:90/96	Electromechanical force transducer (Bofors, Suécia)	Shoulder external rotators, abductors, and flexors;

Table 2 (*Continued*)

Upper limb muscles			
Study and location	Participants (*n*; age; and sex)	Equipments or methods	Muscle groups
Rice et al.[50] 1989 Canada	*n* = 118; 62–92; W/M:81/37	Modified sphygmomanometer Hand-grip Stoelting dynamometer (Stoelting Co., 1350 South Kosner Ave, Chicago, IL 60651)	Elbow flexors/extensors; shoulder abductors and flexors Grip
Backman et al.[17] 1989 Sweden	*n* = 217; 3.5–15 years; W/M:104/113	Portable electronic dynamometer (Myometer, Penny and Gyles Transducers Ltd., Dorset, England)	Wrist extensors; elbow flexors/extensors; and shoulder abductors
Sunnegardh et al.[47] 1988 Sweden	*n* = 124; 8–13 years; W/M:65/59	Pressure transducers (Presductor ®, ASEA)	Grip
Andersen and Henckel[41] 1987 Denmark	*n* = 293; 6–19 years; W/M:165/128	Strain gauge dynamometers	Elbow flexors
Murray et al.[49] 1985 USA	*n* = 40; 25–36 (young)/55–66 years (elderly); W/M:20/20	U-shaped deflection-beam force gauges (Model X-T-KG, W. C. Dillon & Co., Inc., Van Nuys, California)	Shoulder internal/external rotators, abductors/adductors, and flexors/extensors
Mathiowetz et al.[43] 1985 USA	*n* = 628; 20–94 years; W/M:318/310	Jamar dynamometer (Asimov Engineering Co.Los Angeles, CA) B & L pinch gauge (B&L Engineering, Tustin. CA)	Grip Lateral, palmar, and pulp-to-pulp pinch

LOWER LIMB MUSCLES			
Study and location	Participants (*n*; age; and sex)	Equipments or methods	Muscle groups
McKay et al.[22] 2017 Australia	*n* = 1000; 3–101 years; W/M: 500/500	Hand-held dynamometer (Citec dynamometer CT 3001; CIT Technics, Groningen, Netherlands) Fixed dynamometry (CSMi; HUMAC NORM, Stoughton, MA)	Ankle dorsiflexors/plantarflexors; knee flexors/extensors; hip internal and external rotators, and abductors
Moraux et al.[52] 2013 France	*n* = 345; 5–80 years; W/M:198/147	Ankle dynamometer	Ankle dorsiflexors/plantarflexors
Danneskiold-Samsøe et al.[35] 2009 Denmark	*n* = 174; 20–80 years; W/M:121/53	Lido active (Lido Multi Joint II, Loredan Biomedical, Davis, CA, USA)	Ankle dorsiflexors/plantarflexors; knee flexors/extensors; hip internal/external rotators, abductors/adductors, and flexors/extensors
Meldrum et al.[30] 2007 Ireland	*n* = 494; 19–76 years; W/M:259/235	Quantitative muscle assessment system	Ankle dorsiflexors; knee flexors/extensors; and hip flexors
Hogrel et al.[37] 2007 France	*n* = 315; 20–80 years; W/M:168/147	Quantitative muscle testing	Ankle dorsiflexors; knee and hip flexors/extensors
Eek et al.[31] 2006 Sweden	*n* = 149; 5–15 years; W/M:73/76	Hand-held eletronic dynamometer (Adapted Chatillon dynamometer; Axel Ericson Medical AB, S Vägen 12, 412 54 Gothenburg, Sweden)	Ankle dorsiflexors/plantarflexors; knee flexors/extensors; hip abductors/adductors and flexors/extensors
Beenakker et al.[46] 2001 Netherlands	*n* = 270; 4–16 years; W/M:131/139	Hand-held dynamometer type CT 3001 (C.I.T. Technics, Groningen, The Netherlands)	Ankle dorsiflexors; knee flexors/extensors; hip abductors and flexors

Table 2 (*Continued*)

Lower limb muscles			
Study and location	Participants (*n*; age; and sex)	Equipments or methods	Muscle groups
Stoll et al.[36] 2000 Switzerland	*n* = 543, 20–82 years; W/M:290/253	Hand-held pull gauge	Ankle dorsiflexors/plantarflexors; knee flexors/extensors; hip internal/external rotators, abductors/adductors, and flexors/extensors
Phillips et al.[44] 2000 Australia	*n* = 200; Age:20–69 years; F:100/M:100	Penny and Gileshand-held myometer (Penny & Giles Instrumentation Ltd., 4 Airfield Way, Christchurch, Dorset BH233TS, England)	Ankle dorsiflexors; hip abductors and flexors
Bohannon[38] 1997 USA	*n* = 231; 20–79 years; W/M:125/106	Ametek digital hand-held dynamometer	Ankle dorsiflexors; knee extensors; hip abductors and flexors
Andrews et al.[34] 1996 USA	*n* = 147; 50–79 years; W/M:70/77	Chatillon CSD400C hand-held dynamometer	Ankle dorsiflexors; knee flexors/extensors; hip, abductors and flexors
The National Isometric Muscle Strength (NIMS) Database Consortium[45] 1996 USA	*n* = 493; 18–80 years; W/M:273/220	Interface SM-250 electronic strain gauge (Interface, Inc., 7401 E. ButtherusDr., Scottsdale, AZ 85260)	Ankle dorsiflexors; knee and hip flexors/extensors
Backman et al.[16] 1995 Sweden	*n* = 128; 17–70 years; W/M:63/65	Portable electronic dynamometer (Myometer, Penny & Giles Transducers Ltd, Dorset, England)	Ankle dorsiflexors; knee flexors/extensors; hip abductors and flexors
Backman et al.[17] 1989 Sweden	*n* = 217; 3.5–15 years; W/M:104/113	Portable electronic dynamometer (Myometer, Penny and Gyles Transducers Ltd., Dorset, England)	Ankle dorsiflexors; knee flexors/extensors; hip abductors and flexors/extensors
Rice et al.[50] 1989 Canada	*n* = 118; 62–92 years; W/M:81/37	Modified sphygmomanometer	Ankle dorsiflexors/plantarflexors; knee extensors; hip flexors/extensors
Sunnegardh et al.[47] 1988 Sweden	*n* = 124; 8–13 years; W/M: 65/59	Pressure transducers (Presductor ®, ASEA)	Knee extensors
Andersen and Henckel[41] 1987 Denmark	*n* = 293; 16–19 years; W/M:165/128	Strain gauge dynamometers	Knee extensors

AXIAL MUSCLES			
Study and location	Participants (*n*; age; and sex)	Equipments or methods	Muscle groups
Paalanne et al.[60] 2009 Finland	*n* = 874; 19 ± 0.2 years; W/M:493/381	Computerized strain gauge dynamometer (New Test, Co., Oulu, Finland)	Trunk flexors/extensors and rotators
Danneskiold-Samsøe et al.[35] 2009 Denmark	*n* = 174; 20–80 years; W/M:121/53	Lido active (Lido Multi Joint II, Loredan Biomedical, Davis, CA, USA)	Trunk flexors/extensors
Cagnie et al.[53] 2007 Belgium	*n* = 96; 20–59 years; W/M:48/48	Biodex isokinetic dynamometer	Neck flexors/extensors
Meldrum et al.[30] 2007 Ireland	*n* = 494; 19–76 years; W/M:259/235	Quantitative muscle assessment system	Neck flexors
Hogrel et al.[37] 2007 France	*n* = 315; 20–80 years; W/M:168/147	Quantitative muscle testing	Neck flexors

Table 2 (*Continued*)

Axial muscles			
Study and location	Participants (*n*; age; and sex)	Equipments or methods	Muscle groups
Salo et al.[59] 2006 Finland	*n* = 220; 20–59 years; W:220	Specially designed measurement system	Neck flexors/extensors and rotators
[a]Garcés et al.[56] 2002 Spain	*n* = 94; 20->60 years; W/M:43/51	Kin-Con ® computerized dynamometer	Neck flexors/extensors
Chiu et al.[57] 2002 China	*n* = 91; 20–84 years; W/M:46/45	Multi cervical rehabilitation unit (Hanoun Medical Inc., Ontario, Canada)	Neck flexors/extensors; lateral flexors; protractors/retractors
Peolsson et al.[54] 2001 Sweden	*n* = 101; 25–63 years; W/M:50/51	David back clinic 140 (DCB 140)	Neck flexors/extensors and lateral flexors
Beenakker et al.[46] 2001 Netherlands	*n* = 270; 4–16 years; W/M:131/139	Hand-held dynamometer type CT 3001 (C.I.T. Technics, Groningen, The Netherlands)	Neck flexors
Stoll et al.[36] 2000 Switzerland	*n* = 543, 20–82 years; W/M:290/253	Hand-held pull gauge	Neck flexors/extensors; trunk flexors and rotators
Phillips et al.[44] 2000 Australia	*n* = 200; 20–69 years; W/M:100/100	Penny and Gileshand-held myometer (Penny & Giles Instrumentation Ltd., 4 Airfield Way, Christchurch, Dorset BH233TS, England)	Neck flexors
Jordan et al.[58] 1999 Denmark	*n* = 100; 20–70 years; W/M:50/50	Strain-gauge dynamometer (Neck Exercise Unit, Norway)	Neck flexors/extensors
Vernon et al.[55] 1992 Canada	*n* = 40; 25 ± 2 years; M:40	Modified sphygmomanometer dynamometer (Magnatec Co. Ltd. Concord, Ontario, Canada)	Neck flexors/extensors; lateral flexors and rotators
Sunnegardh et al.[47] 1988 Sweden	*n* = 124; 8–13 years; W/M:65/59	Pressure transducers (Presductor ®, ASEA)	Trunk flexors/extensors
Andersen and Henckel[41] 1987 Denmark	*n* = 193; 16–19 years; W/M:165/28	Strain gauge dynamometer	Trunk flexors/extensors
Nordin et al.[61] 1987 USA	*n* = 101; 18–48 years; W:101	Cybex II isokinetic dynamometer	Trunk flexors/extensors

W: women; M: men; USA: United States of America.
[a] Reported sample calculation.

elderly individuals of both sexes, using portable dynamometers and myometer. The CVs of the combined values of these studies ranged mainly from 20.1% to 30% and were also similar to those of the original studies.

Establishing criteria is also important to determine possible subgroups (e.g., age, sex, side) for reporting the results of the descriptive statistics of the reference values. Of the 46 included studies, only 17.4% (*n* = 8) justified the subgroups, while reporting the results of the descriptive statistics,[23,25,31,33,34,38,53,62] of which 62.5% (*n* = 5) did not clearly justify the reasons to support the applied criteria.[25,31,33,53,62] Between-group comparisons,[23,25,33,34,53,62] correlations,[34,38] and regression[25,31,34,38] were the types of statistical analyses used to justify the subgroup divisions.

Regarding the age subgroups, most of the studies, which established reference strength values for children and adolescents, reported their subgroup results in 1-year intervals.[25,28,31,39,41,46,64,65] This is probably justified by the rapid changes in the development of these subjects. For adults and elderly, the results for the subgroups were described per decades.[16,23,27,30,32,34,35,38,40,44,52–54,58,59,62] Pessoa et al.,[67] in a systematic review with meta-analysis for the reference strength values of the inspiratory muscles in adults and elderly, reported the age subgroup results per decade.[67] On the other hand, Bohannon et al.,[68] in their systematic review with meta-analysis for the reference values of handgrip strength for the same population, provided the subgroup results in 5-year intervals.[68] Perhaps, the definition of age subgroups in these two previous meta-analyses[67,68] followed the definition adopted by the majority of the studies, which were included in the reviews. As the population groups were similar (adults and elderly) between the two reviews[67,68] associated with the results of the present study, it is possible to conclude that there is no clear criterion, neither a consensus regarding the age range to group the subjects, when reporting reference values of muscle strength.

Table 3 Characteristics of the studies that established the reference values for isokinetic strength.

Study and location	Participants (*n*; age; and sex)	Instrumentation	Muscular groups
Lundgren et al.[64] 2011 Sweden	*n* = 436; 6–12 years; W/M:190/246	Computerized dynamometer (Biodex System 3®, Biodex Medical Systems, Inc., Shirley, NY, USA)	Knee flexors/extensors
Danneskiold-Samsøe et al.[35] 2009 Denmark	*n* = 174; 20–80 years; W/M:121/53	Lido active (Lido Multi Joint II, Loredan Biomedical, Davis, CA, USA)	Shoulder, elbow, wrist, hip, knee and trunk flexors/extensors; shoulder and hip abductors/adductors, external/internal rotators; ankle dorsiflexors/plantarflexors
Holm et al.[39] 2008 Norway	*n* = 376; 7–12 years; W/M:191/185	Cybex 6000 (Cybex-Lumex Inc, Ronkonkoma, NY,USA)	Knee flexors/extensors
[a]Wiggin et al.[65] 2006 USA	*n* = 3587; 6–13 years; W/M: 2030/1557	Biodex system II and III isokinetic dynamometers	Knee flexors/extensors
Frontera et al.[62] 1991 EUA	*n* = 200; 45–78 years; W/M:114/86	Cybex II isokinetic dynamometer	Elbow and knee flexors/extensors
Sunnegardh et al.[47] 1988 Sweden	*n* = 124; 8–13 years; W/M:65/59	Cybex II with a modified lever	Elbow flexors and knee flexors/extensors
Nordin et al.[61] 1987 USA	*n* = 101; Age: 18–48 years; W:101	Cybex II isokinetic dynamometer	Trunk flexors/extensors
Ivey et al.[63] 1985 USA	*n* = 31; 21–50 years; W/M:13/18	Cybex II isokinetic dynamometer	Shoulder flexors/extensors, abductors/adductors, external/internal rotators

W: women; M: men; USA: United States of America.
[a] Reported sample calculation.

Table 4 Meta-analysis results: Reference values (means ± SD) and coefficients of variation (%) of the strength measures, in Newton or Pounds, that resulted from the combination of the values of the studies with similar characteristics.

Studies	Muscular groups	Age groups	Sex	Side	n	Mean ± SD	CV	Side	n	Mean ± SD	CV	Position	Procedure
Andrews et al.[34] 1996 and Bohannon[38] 1997	Shoulder extensors	50-59	W	D	46	186.95±37.96	20.30	ND	45	181.45±43.84	24.16	Shoulder extensors: supine, shoulder flexed 90°, elbow flexed; Resistance: just proximal to the epicondyles of humerus; Stabilization: superior aspect of shoulder	Two trials; six to seven seconds of contraction; Rest time of at least one minute; Make test; Record: peak force; Instrument: Dynamometer; Unit of measurement: Newton
			M	D	47	326.04±56.75	17.41	ND	47	302.97±51.99	17.16		
		60-69	W	D	47	153.42±35.40	23.07	ND	47	152.08±30.79	20.25		
			M	D	44	276.34±57.44	20.79	ND	43	271.11±51.59	19.03		
		70-79	W	D	45	155.29±34.45	22.19	ND	45	138.00±29.03	21.04		
			M	D	48	269.12±50.21	18.66	ND	48	255.12±49.61	19.44		
	Shoulder abductors	50-59	W	D	46	136.06±24.29	17.85	ND	45	129.57±27.59	21.29	Shoulder abductors: supine, shoulder abducted 45°, elbow extended; Resistance: just proximal to the lateral epicondyle of humerus; Stabilization: superior aspect of shoulder	
			M	D	45	239.01±55.81	23.35	ND	44	222.28±42.75	19.23		
		60-69	W	D	47	120.06±26.04	25.69	ND	47	110.12±19.24	17.47		
			M	D	43	201.49±44.94	22.30	ND	42	194.31±42.71	21.98		
		70-79	W	D	44	101.95±21.89	21.47	ND	44	105.46±21.05	19.96		
			M	D	48	191.96±34.86	18.16	ND	46	186.75±31.58	16.91		
	Shoulder external rotators	50-59	W	D	46	103.82±19.86	19.13	ND	45	101.57±22.22	21.88	Shoulder external rotators: supine, shoulder abducted 45°, elbow at 90°; Resistance: just proximal to styloid processes; Stabilization: elbow	
			M	D	47	160.96±37.86	23.52	ND	40	152.30±31.29	20.54		
		60-69	W	D	47	87.94±18.93	21.52	ND	47	85.94±18.57	21.60		
			M	D	43	143.63±31.28	21.78	ND	42	132.51±26.22	19.78		
		70-79	W	D	45	81.97±11.65	14.21	ND	44	79.58±14.81	18.61		
			M	D	48	136.25±26.61	19.53	ND	47	131.49±29.05	22.09		
	Elbow flexors	50-59	W	D	46	161.50±27.34	16.93	ND	46	158.31±24.63	15.56	Elbow flexors: supine, shoulder at neutral, elbow flexed 90°. forearm supinated; Resistance: just proximal to the styloid process; Stabilization: superior aspect of shoulder or arm	
			M	D	45	289.78±43.48	15.00	ND	47	270.43±51.96	19.21		
		60-69	W	D	47	146.70±29.38	20.02	ND	47	144.44±25.05	17.34		
			M	D	43	259.22±47.36	18.27	ND	43	246.45±38.21	15.50		
		70-79	W	D	45	134.62±26.49	19.68	ND	45	136.47±26.08	19.11		
			M	D	48	236.70±39.64	16.75	ND	48	234.20±39.07	16.68		
	Elbow extensors	50-59	W	D	46	148.81±41.16	27.66	ND	46	105.45±21.87	20.74	Elbow extensors: supine, shoulder in neutral, elbow flexed 90°, forearm neutral; Resistance: just proximal to the styloid process; Stabilization: anterior aspect of shoulder or arm	
			M	D	47	192.01±34.95	18.20	ND	47	181.58±36.03	19.84		
		60-69	W	D	47	94.87±21.87	23.06	ND	47	96.10±21.89	22.78		
			M	D	44	165.49±41.07	24.82	ND	44	160.33±33.19	20.70		
		70-79	W	D	45	90.67±17.55	19.36	ND	45	89.64±15.79	17.63		
			M	D	48	158.11±34.50	21.82	ND	47	160.74±33.22	20.66		
	Wrist extensors	50-59	W	D	45	94.95±20.61	21.71	ND	46	89.87±19.87	22.08	Wrist extensors: supine, shoulder at neutral, elbow flexed 90°, wrist at neutral, and fingers relaxed; Resistance: just proximal to the metacarpophalangeal joints; Stabilization: distal forearm	
			M	D	46	149.01±32.66	21.92	ND	47	141.77±31.43	22.17		
		60-69	W	D	46	80.68±16.21	20.09	ND	47	76.13±17.60	23.11		
			M	D	44	134.28±28.88	21.50	ND	43	123.30±23.97	19.44		
		70-79	W	D	49	75.24±17.83	23.70	ND	45	66.73±16.02	24.00		
			M	D	48	127.28±20.82	16.36	ND	47	122.99±21.19	17.23		

Table 4 (*Continued*)

	Hip flexors	50-59	W	D	46	126.20±16.21	24.28	ND	46	122.33±24.87	20.33	Hip flexors: supine, hip flexed 90°, knee relaxed, contralateral limb in eutral; Resistance: femoral condyles; Stabilization: pelvis	
			M	D	47	198.71±59.29	29.84	ND	47	204.59±54.20	26.49		
		60-69	W	D	47	115.27±26.11	22.65	ND	47	112.58±24.84	22.06		
			M	D	44	177.02±46.99	26.54	ND	44	177.47±44.83	25.26		
		70-79	W	D	45	98.54±26.87	27.27	ND	45	97.36±27.06	27.80		
			M	D	48	104.96±39.88	24.18	ND	48	161.50±41.60	25.76		
	Hip abductors	50-59	W	D	46	208.12±40.36	19.39	ND	46	203.27±38.37	18.87	Hip abductors: supine, both lower limbs in neutral; Resistance: lateral femoral condyles; Stabilization: contralateral lower limb held in neutral	
			M	D	47	305.97±68.79	22.48	ND	47	298.49±67.64	22.66		
		60-69	W	D	47	192.30±44.11	24.20	ND	47	178.45±41.94	23.50		
			M	D	44	260.02±51.59	19.84	ND	44	265.06±64.18	24.21		
		70-79	W	D	44	162.95±36.54	23.65	ND	45	154.66±33.11	21.41		
			M	D	48	251.2±48.64	19.38	ND	48	242.64±48.94	20.17		
	Knee extensors	50-59	W	D	46	314.75±82.98	26.36	ND	46	305.22±75.68	24.79	Knee extensors: seated, hips and knee flexed 90°, hands resting in lap; Resistance: just proximal to malleoli; Stabilization: on the shoulders by an assistant	
			M	D	47	458.45±79.73	17.39	ND	47	452.54±86.52	19.12		
		60-69	W	D	47	263.48±66.92	25.40	ND	46	255±73.06	28.65		
			M	D	43	372.71±81.81	21.95	ND	41	377.57±67.75	17.94		
		70-79	W	D	44	218.55±46.71	21.37	ND	44	215.72±48.55	22.51		
			M	D	48	358.57±76.13	21.23	ND	47	365±71.21	19.51		
	Ankle dorsiflexors	50-59	W	D	46	221.11±63.44	28.69	ND	46	212.38±54.91	25.86	Ankle dorsiflexors: supine, hip, knee and ankle at 0°; Resistance: just proximal to metatarsophalangeal joints; Immobilization: knee maintained in full extension, leg supported with foot off the table	
			M	D	47	306.02±87.41	28.56	ND	47	296.64±70.91	23.90		
		60-69	W	D	47	195.96±64.53	32.93	ND	47	197.92±58.43	29.52		
			M	D	43	249.41±68.60	27.51	ND	42	255.39±61.72	24.17		
		70-79	W	D	45	162.59±45.73	28.12	ND	45	153.36±35.91	23.42		
			M	D	46	230.35±52.56	22.82	ND	46	227.48±52.75	23.19		
Backman et al.[16] 1995 and Phillips et al.[44] 2000	Hip flexors	20-29	W			—		ND	30	193.3±36.9	19.07	Supine. hip and knee flexed 90°; Resistance: lateral aspect of the distal third of the thigh; Stabilization: iliac crests	Three trials; Break test; Record: peak force; Instrument: Myometer Unit of measurement: Newton
			M			—		ND	32	281.8±50.7	18		
		30-39	W			—		ND	30	198±34.4	17.38		
			M			—		ND	31	270.1±64.1	23.72		
		40-49	W			—		ND	33	190.5±36.9	19.34		
			M			—		ND	30	269.3±55.7	20.69		
		50-59	W			—		ND	30	177±37.2	21		
			M			—		ND	30	268±53.4	19.92		
		60-69	W			—		ND	30	167±23.4	13.99		
			M					ND	32	242.2±47.7	19.67		
Jansen et al.[29] 2008 and Mathiowetz et al.[43] 1985	Grip Strength	65-69	W	R	61	52.5±10.2	19.42	L	61	46.7±10.3	22.8	Seated with shoulder adducted, elbow flexed at 90°, forearm in neutral position, and wrist between 0° and 30° extension and 0° and 15° ulnar deviation. The dynamometer handle was set in the second position	Three trials; Instrument: Dynamometer; Unit of measurement: Pounds
			M	R	46	91.3±18.5	20.24	L	46	81.5±18.5	22.68		
		70-74	W	R	66	51.2±10.5	20.57	L	66	45.3±10.8	23.92		
			M	R	45	79.1±20.1	25.41	L	45	71.8±19.8	27.62		
Jansen et al.[29] 2008 and Mathiowetz et al.[43] 1985	Lateral pinch	65-69	W	R	61	14.1±2.8	19.85	L	61	13.4±2.8	20.59	Seated with shoulder adducted and neutrally rotated, elbow flexed at 90°, forearm in neutral position, and wrist between 0° and 30° extension and 0° and 15° ulnar deviation	Three trials; Instrument: Dynamometer; Unit of measurement: Pounds
			M	R	46	22.9±4.1	17.69	L	46	21.5±4.2	19.58		
		70-74	W	R	66	13.9±2.8	20.33	L	66	12.8±2.9	22.88		
			M	R	45	19.3±3.5	18.14	L	45	18.9±3.7	19.52		
	Palmar pinch	65-69	W	R	60	13.8±3.1	22.76	L	60	13.2±3.2	23.97		
			M	R	46	20.6±3.9	18.74	L	46	20.4±4.3	21.08		
		70-74	W	R	64	13.4±2.8	20.76	L	64	13.2±2.6	19.47		
			M	R	45	18.2±4.2	23.05	L	45	18.3±3.9	21.31		
	Pulp-to-pulp pinch	65-69	W	R	60	10.3±2.6	25.68	L	60	10.1±2.3	22.94		
			M	R	46	16.5±4.3	25.91	L	46	15.4±3.3	21.48		
		70-74	W	R	64	10±2.5	24.62	L	64	9.5±1	10.56		
			M	R	45	14.3±3.5	24.70	L	45	13.6±3.3	24.26		

W: women; M: men; D: dominant; ND: non-dominant; R: right; L: left; SD: standard deviation; CV: coefficient of variation.

The lack of description and differences in methods and evaluation procedures limited the number of studies included in the present meta-analysis, i.e., only six out of 46 studies (13%). Among the 41 evaluated muscle groups, only 14 (34.1%) had their results synthesized in the meta-analysis. In addition, only the hip flexor muscle group of the dominant side was evaluated in two pairs of studies, one that employed a portable dynamometer[34,38] and the other a myometer,[16,44] and both evaluated isometric strength. Data from four[16,34,38,44] of the six studies, which were included in the meta-analysis, could have been grouped, if the adopted procedures were similar. Similar results were found in two previous systematic reviews with meta-analysis of inspiratory[67] and handgrip[68] muscle strength, i.e., differences in methods and evaluation procedures also limited the number of the included studies.[67,68]

The CVs were similar to those calculated with the descriptive statistics reported by all of the studies, except for values related to the hip flexor muscles of the non-dominant side reported by the studies of Backman et al.[16] and Phillips et al.[44]: the CVs of the present meta-analysis ranged from 14% (see Table 4, CV = 23.4/167) to 23.7% (see Table 4, CV = 64.1/270.1), whereas those reported by Backman et al.[16] and Phillips et al.[44] ranged from 10.9% (CV = 20/183) to 26% (CV = 84/323) and 6.6% (CV = 16/241) to 13.5% (CV = 25/185), respectively. In general, these results indicate adequacy of reference values reported in the present meta-analysis, since they are mostly similar to those of the original studies.

The reference values for muscle strength have already been established for subjects from developed countries, most of them from the Northern Hemisphere, who have specific ethnic characteristics, which may interfere with strength measures, such as body fat mass and muscle mass indices, height, and weight.[76] The possible differences in strength among ethnic groups[77] confirm the importance of determining reference values for population groups, who have specific demographic characteristics. For professionals on developing countries, no information is available on the reference strength values for the appendicular and axial muscles. Therefore, the interpretations of the evaluation of strength and, consequently, the clinical decision-making within clinical settings are limited. In addition, specifically for children and adolescents, the reference values for the following muscles groups have not been established: shoulder and hip external/internal rotators, shoulder adductors, neck and trunk lateral flexors, and lateral rotators.

This systematic review with meta-analysis has both strengths and limitations that need to be considered. First, the electronic searches were conducted in only three databases (MEDLINE, LILACS, and SciELO), which may have prevented the inclusion of some relevant studies. Considering that the MEDLINE database is one of the most complete bibliographic databases[78] of biomedical literature records[79]; that LILACS and SciELO databases also comprise articles published in Portuguese or Spanish that may not be found at MEDLINE; and that the reference list of the included articles was screened to identify further ones, it can be considered that a comprehensive systematic review was performed. A strength of this study is the analysis of the methodological quality of the studies and the comparison of the CV of the results of the meta-analysis with the CV of the original studies. In addition, another strength of this systematic review is the applicability of the results for the measurement of different muscle groups.

In conclusion, the studies, that reported reference values of strength for the appendicular and axial muscles, showed, in general, adequate methodological quality and provided both isometric and isokinetic measures for all age groups, mainly adults and elderly. Establishing the reference values is still necessary for other muscle groups of children and adolescents and other methods of evaluation, such as the MST, whose data are scarce. Furthermore, no study was found that provided reference values of strength of the axial and appendicular muscles of people from developing and undeveloped countries. The present meta-analysis provided normative data for the isometric strength of 14 appendicular muscle groups of the dominant and nondominant sides of both men and women, aged 20–79 years. It is necessary to adapt the procedures and methods for the evaluation of reference values in future studies to carry out a more comprehensive meta-analysis including children and adolescents and some muscle groups for adults and the elderly. In general, the CV values that resulted from the meta-analysis were similar to those reported by the original studies. This indicates adequacy of reference values reported in the present meta-analysis. These data may be used to interpret the results of the evaluations and establish appropriate treatment goals.

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Conflicts of interest

The authors report no conflict of interest.

References

1. Volaklis KA, Halle M, Meisinger C. Muscular strength as a strong predictor of mortality: a narrative review. *Eur J Intern Med*. 2015;26:303–310.
2. Weigent DA, Bradley LA, Blalock JE, Alarcon GA. Current concepts in the pathophysiology of abnormal pain perception in fibromyalgia. *Am J Med Sci*. 1998;315:405–412.
3. Hislop HJ, Avers D, Brown M. *Daniels and Worthingham's Muscle Testing Techniques of Manual Examination and Performance Testing*. 9th ed. St. Louis: Elsevier Sanders; 2014.
4. Oliveira VHF, Wiechmann SL, Narciso AMS, Deminice R. Knee extension and flexion strength asymmetry in Human Immunodeficiency Virus positive subjects: a cross-sectional study. *Braz J Phys Ther*. 2017;21:434–439.
5. Rabelo NDDA, Lucareli PRG. Do hip muscle weakness and dynamic knee valgus matter for the clinical evaluation and decision-making process in patients with patellofemoral pain? *Braz J Phys Ther*. 2018;22:105–109, http://dx.doi.org/10.1016/j.bjpt.2017.10.002.
6. Guihem G, Cornu C, Guevel A. Neuromuscular and muscle-tendon system adaptions to isotonic and isokinetic eccentric exercise. *Ann Phys Rehab Med*. 2010;53:319–341.
7. Lewis VM, Merritt JL, Piper SM, Sinaki M. Correlations between isotonic and isometric measurements of trunk muscle strength. *Arch Phys Med Rehabil*. 1987;68:639–640.
8. Tiffreau V, Ledoux I, Eymard B, et al. Isokinetic muscle testing for weak patients suffering from neuromuscular disorders: a reliability study. *Neuromusc Dis*. 2007;17:524–531.
9. Stark T, Walker B, Phillips JK, Fejer R, Beck R. Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: a systematic review. *Crit Rev*. 2011;3: 472–479.
10. Andrews AW, Bohannon RW. Distribution of muscle strength impairments following stroke. *Clin Rehabil*. 2000;14:79–87.
11. Bohannon RW, Andrews AW. Interrater reliability of hand-held dynamometry. *Phys Ther*. 1987;67:931–933.
12. Lund H, Sondergaard K, Zachariassen T, et al. Learning effect of isokinetic measurements in healthy subjects, and reliability and comparability of Biodex and Lido dynamometer. *Clin Physiol Funct Imaging*. 2005;25:75–82.
13. Ordway NR, Hand N, Briggs G, Ploutz-Snyder LL. Reliability of knee and ankle strength measures in an older adult population. *J Strength Cond Res*. 2006;20:82–87.
14. Blacker SD, Fallowfield JL, Bilzon JLJ, Willems MET. Within-day and between-days reproducibility of isokinetic parameters of knee, trunk and shoulder movements. *Isokinet Exerc Sci*. 2010;18:45–55.
15. Impellizzeri FM, Bizzini M, Rampinini E, Cereda F, Maffiuletti NA. Reliability of isokinetic strength imbalance ratios measured using the Cybex NORM dynamometer. *Clin Physiol Funct Imaging*. 2008;28:113–119.
16. Backman E, Johansson V, Hãger B, Sjoblom P, Henriksson KG. Isometric muscle strength and muscular endurance in normal persons aged between 17 and 70 years. *Scand J Rehab*. 1995;27:109–117.
17. Backman E, Odenrick P, Henriksson KG, Ledin T. Isometric muscle force and anthropometric values in normal children aged between 3.5 and 15 Years. *Scand J Rehab Med*. 1989;21:105–114.
18. Edwards RHT, Chapman SJ, Newman DJ, Jones DA. Practical analysis of variability of muscle function measurements in Duchenne Muscular. *Muscle Nerve*. 1987;10:6–14.
19. Souza LA, Martins JC, Teixeira-Salmela LF, Godoy MR, Aguiar LT, Faria CD. Evaluation of muscular strength with the modified sphygmomanometer test: a review of the literature. *Fisioter Mov*. 2013;26:437–452.

20. Martins JC, Teixeira-Salmela LF, Castro e Souza LA, et al. Reliability and validity of the modified sphygmomanometer test for the assessment of strength of upper limb muscles after stroke. *J Rehabil Med*. 2015;57:697–705.
21. Aguiar LT, Lara EM, Martins JC, et al. Modified sphygmomanometer test for the assessment of strength of the trunk, upper and lower limbs muscles in subjects with subacute stroke: reliability and validity. *Eur J Phys Rehab Med*. 2016;52:637–649.
22. McKay MJ, Baldwin JN, Ferreira P, Simic M, Vanicek N, Burns J. 1000 Norms Project Normative reference values for strength and flexibility of 1,000 children and adults. *Neurology*. 2017;88:36–43.
23. Decostre V, Canal A, Ollivier G, et al. Wrist flexion and extension torques measured by highly sensitive dynamometer in healthy subjects from 5 to 80 years. *BMC Musculoskelet Disord*. 2015;16:1–10.
24. Harlinger WV, Blalock L, Merritt JL. Upper limb strength: study providing normative data for a clinical handheld dynamometer. *PM R*. 2015;7:135–140.
25. Molenaar HM, Selles RW, Willemsen SP, Hovius SER, Stam HJ. Growth diagrams for individual finger in children measured with the RIHM. *Clin Orthop Relat Res*. 2011;469:868–876.
26. Riemann BL, Davies GJ, Ludwig L, Gardenhour H. Hand-held dynamometer testing of the internal and external rotater musculature based on selected positions to establish normative data and unilateral ratios. *J Shoulder Elbow Surg*. 2010;19:1175–1183.
27. Kim HM, Teefey SA, Zelig A, Galatz LM, Keener JD, Yamaguchi K. Shoulder strength in asymptomatic individuals with intact compared with torn rotator cuffs. *J Bone Joint Surg Am*. 2009;91:289–296.
28. Werle S, Goldhahn J, Drerup S, Simmen BR, Sprott H, Herren DB. Age- and gender-specific normative data of grip and pinch strength in a healthy adult Swiss population. *J Hand Surg*. 2009;34:76–84.
29. Jansen CWS, Niebuhr BR, Coussirat DJ, Hawthorne D, Moreno L, Phillip M. Hand force of men and women over 65 years of age as measured by maximum pinch and grip force. *J Aging Phys Act*. 2008;16:24–41.
30. Meldrum D, Cahalane E, Conroy R, Fitzgerald D, Hardiman O. Maximum voluntary isometric contraction: reference values and clinical application. *Amyotroph Lateral Scler*. 2007;8:47–55.
31. Eek MN, Kroksmark A-K, Beckung E. Isometric muscle torque in children 5 to 15 years of age: normative data. *Arch Phys Med Rehabil*. 2006;87:1091–1099.
32. Hughes RE, Johnson ME, Driscoll O, An SWK-N. Age-related changes in normal isometric shoulder strength. *Am J Sports Med*. 1999;27:651–657.
33. Boatright JR, Kiebzak GM, Neil O, Peindl DMRD. Measurement of thumb abduction strength: normative data and a comparison with grip and pinch strength. *J Hand Surg*. 1997;22:843–848.
34. Andrews AW, Thomas MW, Bohannon RW. Normative values for isometric muscle force measurements obtained with hand-held dynamometers. *Phys Ther*. 1996;76:248–259.
35. Danneskiold-Samsoe B, Bartels EM, Bulow PM, et al. Isokinetic and isometric muscle strength in a healthy population with special reference to age and gender. *Acta Physiol*. 2009;197:1–68.
36. Stoll T, Huber E, Seifert B, Michel BA, Stucki G. Maxinal isometric muscle strength: normative values and gender-specific relation to age. *Clin Rheumatol*. 2000;19:105–113.
37. Hogrel J, Payan CA, Ollivier G, et al. Development of a French isometric strength normative database for adults using quantitative muscle testing. *Arch Phys Med Rehabil*. 2007;88:1289–1297.
38. Bohannon RW. Reference values for extremity muscle strength obtained by hand-held dynamometry from adults aged 20 to 79 years. *Arch Phys Med Rehabil*. 1997;78:26–32.
39. Holm I, Fredriksen PM, Fosdahl M, Vollestad N. A normative sample of isotonic and isokinetic muscle strength measurements in children 7 to 12 years of age. *Acta Paediatr*. 2008;97:602–607.
40. Hughes RE, Johnson ME, O'Driscoll SW, An K-N. Normative values of agonist-antagonist shoulder strength ratios of adults aged 20 to 78 years. *Arch Phys Med Rehabil*. 1999;80:1324–1326.
41. Andersen LB, Henckel P. Maximal voluntary isometric strength in Danish adolescents 16–19 years of age. *Eur J Appl Physiol*. 1987;56:83–89.
42. Crosby CA, Wehbé MA, Mawr B. Hand strength: normative values. *J Hand Surg*. 1994;19A:665–670.
43. Mathiowetz V, Kashman N, Volland G, et al. Grip and pinch strength: normative data for adults. *Arch Phys Med Rehabil*. 1985;66:69–72.
44. Phillips BA, Lo SK, Mastaglia FL. Muscle force measured using ''break'' testing with a hand-held myometer in normal subjects aged 20 to 69 years. *Arch Phys Med Rehabil*. 2000;81:653–661.
45. The National Isometric Muscle Strength (NIMS) Database Consortium. Muscular weakness assessment: use of normal isometric strength data. *Arch Phys Med Rehabil*. 1996;77:1251–1255.
46. Beenakker EAC, Van Der Hoeven JH, Fock JM, Maurits NM. Reference values of maximum isometric muscle force obtained in 270 children aged 4–16 years by hand-held dynamometry. *Neuromuscul Disord*. 2001;11:441–446.
47. Sunnegardh J, Bratteby L-E, Nordesjo L-O, Nordgren B. Isometric and isokinetic muscle strength, anthropometry and physical activity in 8 and 13 year old Swedish children. *Eur J Appl Physiol*. 1988;58:291–297.
48. Lannersten L, Harms-Ringdahl K, Schuldt K, Ekholm J. Isometric strength in flexors, abductors, and external rotators of the shoulder. *Clin Biomech*. 1993;8:235–242.
49. Murray MP, Gore DR, Gardner GM, Mollinger LA. Shoulder motion and muscle strength of normal men and women in two groups. *Clin Orthop Relat Res*. 1985;192:268–273.
50. Rice CL, Cunningham DA, Paterson DH, Rechnitzer PA. Strength in an elderly population. *Arch Phys Med Rehabil*. 1989;70:391–397.
51. Gilbertson L, Barber-Lomax S. Power and pinch strength recorded using the hand-held jamar® dynamometer and B+L hydraulic pinch gauge: British normative data for adults. *Br J Occup Ther*. 1994;57:438–483.
52. Moraux A, Canal A, Ollivier G, et al. Ankle dorsi- and plantar-flexion torques measured by dynamometry in healthy subjects from 5 to 80 years. *BMC Musculoskelet Disord*. 2013;14:1–10.
53. Cagnie B, Cools A, Loose D, Cambier D, Danneels L. Differences in isometric neck muscle strength between healthy controls and women with chronic neck pain: the use of a reliable measurement. *Arch Phys Med Rehabil*. 2007;88:1441–1445.
54. Peolsson A, Oberg B, Hedlund R. Intra- and inter-tester reliability and reference values for isometric neck strength. *Physiother Res Int*. 2001;6:15–26.
55. Vernon HT, Aker P, Aramenko M, Battershill D, Alepin A, Penner T. Evaluation of neck muscle strength with a modified sphygmomanometer dynamometer: reliability and validity. *J Manipulative Physiol Ther*. 1992;15:343–349.
56. Garcés GL, Medina D, Milutinovic L, Garavote P, Guerado E. Normative database of isometric cervical strength in a healthy population. *Med Sci Sports Exerc*. 2002;33:464–470.
57. Chiu TTW, Lam T, Hedley AJ. Maximal isometric muscle strength of the cervical spine in healthy volunteers. *Clin Rehabil*. 2002;16:772–779.

58. Jordan A, Mehlsen J, Bulow PM, Ostergaard K, Danneskiold-samsoe B. Maximal isometric strength of the cervical musculature in 100 healthy volunteers. *Spine*. 1999;24:1343–1348.
59. Salo PK, Ylinen JJ, Mãlkiã EA, Kautiainen H, Hãkkinen AH. Isometric strength of the cervical flexor, extensor, and rotator muscles in 220 healthy females aged 20 to 59 years. *J Orthop Sports Phys Ther*. 2006;36:495–503.
60. Paalanne NP, Korpelainen R, Taimela SP, Remes J, Salakka M, Karppinen JI. Reproducibility and reference values of inclinometric balance and isometric trunk muscle strength measurements in Finnish young adults. *J Strength Cond Res*. 2009;23:1618–1626.
61. Nordin M, Kahanovitz N, Verderame R, et al. Normal trunk muscle strength and endurance in women and the effect of exercises and electrical stimulation. *Spine*. 1987;12: 105–111.
62. Frontera WR, Hughes VA, Lutz KJ, Evans WJ. A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women. *J Appl Physiol*. 1991;71:644–650.
63. Ivey FM, Calhoun JH, Rusche K, Bierschenk J. Isokinetic testing of shoulder strength: normal values. *Arch Phys Med Rehabil*. 1985;66:384–386.
64. Lundgren SS, Nilsson JA, Ringsberg KAM, Karlsson MK. Normative data for tests of neuromuscular performance and DXA-derived lean body mass and fat mass in pre-pubertal children. *Acta Paediatr*. 2011;100:1359–1367.
65. Wiggin M, Wilkinson K, Habetz S, Chorley J, Watson M. Percentile values of isokinetic peak torque in children six through thirteen years old. *Pediatr Phys Ther*. 2006:3–18.
66. Portney LG, Watkins MP. *Foundations of Clinical Research: Applications to Practice*. 3rd ed. New Jersey: Prentice-Hall; 2009.
67. Pessoa IMB, Franco VF, Fregonezi GAF, Sheel AW, Chung F, Reid WD. Reference values for maximal inspiratory pressure: a systematic review. *Can Respir J*. 2014;21:43–50.
68. Bohannon RW, Peolsson A, Massy-Westropp N, Desrosiers J, Bear-Lehman J. Reference values for adult grip strength measured with Jamar dynamometer: a descriptive meta-analysis. *Physiotherapy*. 2006;92:11–15.
69. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analysis: the PRISMA statement. *PLoS Med*. 2009;6:e100097.
70. Liberati A, Alman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analysis of studies that evaluate healthcare interventions: explanation and elaboration. *PLoS Med*. 2009;6:e1000100.
71. Mancini MC, Cardoso JR, Sampaio RF, Costa LCM, Cabral CMN, Costa LOP. Tutorial for writing systematic reviews for the Brazilian Journal of Physical Therapy (BJPT). *Braz J Phys Ther*. 2014;18:471–480.
72. Whiting PF, Rutjes AWS, Westwood ME, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. *Ann Intern Med*. 2011;155:529–536.
73. World Health Organization. *World report on ageing and health*. Geneva: World Health Organization; 2015.
74. World Health Organization. *Department of Maternal, Newborn, Child and Adolescent Health (MCA)*. Geneva: World Health Organization; 2016.
75. United Nations Children's Fund. *The State of the Word's Children. Adolescence: An Age of Opportunity*. New York: United Nations Children's; 2011.
76. Backer JF, Davis M, Alexander R, et al. Associations between body composition and bone density and structure in men and women across the adult age spectrum. *Bone*. 2013;53:34–41.
77. Zengin A, Prentice A, AnnaWard K. Ethnic differences in bone health. *Front Endocrinol*. 2015;6:1–6.
78. Michaleff ZA, Costa LO, Moseley AM, et al. Central, pedro, pubmed, and embase are the most comprehensive database indexing randomized controlled trials of physical therapy interventions. *Phys Ther*. 2011;91:190–197.
79. Plikus MV, Zhang Z, Chuong CM. PubFocus: semantic MEDLINE/PubMed citations analytics through integration of controlled biomedical dictionaries and ranking algorithm. *BMC*. 2006;7:1–15.