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Lower limb strength assessment in healthy adults

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1. ABSTRACT

Background: The strength assessment of the lower body is a fundamental part of physical therapy clinical practice not only as an evaluation tool for detecting strength deficits but also for monitoring the patient's improvements. Currently there are many ways of assessing lower limb strength both in laboratory and non-laboratory settings. The isokinetic dynamometry is considered to be the gold standard method for assessing muscle strength in laboratory conditions whereas the 1-RM (one repetition maximum) is considered the gold standard for evaluating maximal strength in non-laboratory conditions. Many other methods are used by clinicians to assess LLS (lower limb strength) such as Jumps and Hop tests, maximum repetition tests, hand-held dynamometry, manual muscle testing and others.

Objective: The aim of this qualitative review is to explore various and different ways of assessing the lower limb strength in healthy subjects, and their possible implementation in clinical practice for musculoskeletal physical therapists.

Methods: The review was conducted by one reviewer. An electronic literature search was carried out on the following health database to identify relevant studies: PubMed, Chochrane Library and the Journal of Strength and Conditioning, supplemented by manual search. Eligibility criteria are full-text articles in English language and refer to the PIO query. Population: lower limbs of healthy subjects. Intervention: various methods of strength assessment (RM, jump, dynamometer…). Outcome: Accuracy, validity, and reliability of the tests. Study design: primary research. Articles were firstly selected based on reading title and abstract. The whole process followed the standards of the PRISMA Statement. A bias risk evaluation was performed for each study selected for this review using the QUADAS-2 tool.

Results: 29 primary studies were included in this review at the end of the screening process. Of these 8 assessed strength with hand-held or blet fixated dynamometer, 9 with jump and hop tests, 3 with repetition maximum method ,3 with portable testing devices, 2 with the evaluation of the sit to stand movement, 1 with Calf-raise Senior test, 1 using a uniaxial force transducer connected to a non-stretchable fabric strap, 1 assessed strength of the foot muscles using five different protocols performed on three different apparatus, 1 evaluated if the isometric squat. 2 of the selected studies considered the foot and ankle muscles while the others measured the strength of hip and knee muscles. 8 of the selected articles were testing athletic population and the rest of the studies considered older adults or recreationally active population with and without resistance training experience. Only 12 studies compared the assessment method with the reference standard which could be an isokinetic dynamometer or a force platform, if a jump test was performed.

Conclusion: From this review it's clear that there are various and heterogeneous ways for assessing strength in clinical practice. Given the quality of studies selected for this review, evidence does not support one method for

strength assessment over another, due to methodological limitations. Despite that, this review could offer clinical insights for strength measurement in rehabilitation musculoskeletal and sport science practice. Further studies should be encouraged in order to reduce the observed heterogeneity and make the results more comparable.

2. INTRODUCTION

2.1. Role and Definition of Strength

The role of strength in activities of daily living has been shown to be significant. For example, strength impairment, particularly in the lower extremity, has been identified as one of the factors related to increased risk of falls. Strength has also been determined to be an important factor in efficient walking, stair climbing, raising out of a chair, and other activities of daily living [1].

A General definition of muscular strength is the "ability to exert force" [2] and it's an essential function of the human body that can manifest itself in various ways. More precise definitions have been proposed in current literature such as "the ability to generate force against a resistance under a given set of conditions like body position, movement by which the force is applied, type of movement (isometric, concentric, eccentric and plyometric) and movement speed"[3]. Another way to define muscular strength is "the maximal force a muscle or muscle group can generate at a specified velocity" [4].

A much more controversial term is "power", generally associated with the ability of exerting force at higher speeds or "explosive strength", even if it contradicts the scientifical definition used in modern physics which is "the time rate of doing work" where work is the product of the force exerted on an object and the distance the object moves in the direction in which the force is exerted. Quantitatively work and power are defined as follows:

Work = Force x Displacement

Power = Work / Time

In the International System of Units force is measured in newtons (N), work in joules (J) or newton-meters (N x m) and Power in watts (W or J/s).

The discrepancies between the common and scientific definitions of power have led to misunderstandings; healthcare professionals and movement specialists should use the term power only in its scientific sense. Although the word strength is often associated with slow velocities and the word power with high velocities of movement, both variables reflect the ability to exert force at a given velocity [1,3].

2.2. Different types of Strength

When it comes to muscular performance 6 different qualities of strength can be identified:

1. Maximum Strength: highest force the neuromuscular system can produce in slow static (isometric) or dynamic contractions.
2. High-load speed-strength: highest force produced during dynamic eccentric or concentric actions under a relatively heavy load (> 30% of max) performed as rapidly as possible.
3. Low-load speed-strength: highest force produced during dynamic eccentric or concentric actions under a relatively light load (< 30% of max) performed as rapidly as possible.
4. Rate of force development (RFD): the rate at which the neuromuscular system is able to develop force measured by calculating the slope of the force-time curve on the rise to maximum force of the action
5. Reactive strength: the ability of the neuromuscular system to tolerate a stretch load and change movement from rapid eccentric to rapid concentric.
6. Skill performance: the ability of motor control system to coordinate the muscle contractions sequences to make the greatest use of the other five strength qualities.

In activities that require repeated maximal efforts such as sprinting or swimming a seventh quality termed "power endurance" should be included[5].

2.3. Why and How we should measure Strength

The assessment of muscle force output is an important clinical consideration for patients who may have a neurological, muscular, and/or skeletal illness. Such clinical information provides a baseline of information when the patient initially presents. Subsequently, if a treatment plan is followed, serial muscle force assessments may allow quantification of treatment efficacy[6].

Given these definitions it's clear that someone who is strong under a set of conditions may be considered weak on another set of conditions: different activities of daily living and different type of sports may require different types of strength [3].

Traditionally, muscle strength is measured by three different methods: isometric, isotonic, and isokinetic. In isometric strength testing, the muscle acts against an immovable resistance at a specific joint angle. Isotonic exercise allows for a complete range of motion, although maximal muscle demand occurs during only a small portion of the movement. Isokinetic strength testing does allow for full muscle tension throughout the range of motion, while holding the speed of movement constant [7].
Even if Isokinetic muscle testing is considered the "gold standard" it requires expensive laboratory equipment which is not always available in physical therapy and other clinical settings. For this reason, there is growing need for cheaper and more practical ways to evaluate the strength of a muscle or muscle group.

The most common method is the Manual Muscle Testing (MMT) which is quick, efficient, easy to learn and it doesn't require any equipment. The patient is positioned in a standardized posture for the muscle being tested while the operator applies a manual resistance to the body part avoiding any substitutional patterns or alternatively asking the patient to move against gravity force. MMT can be done in dynamic way (through the entire range of motion) or in static isometric way (the patient is instructed to resist to the force applied by the operator by the verbal command: "don't let me move you"). The result of the test can be expressed with a comparison between the two limbs (Limb Symmetry Index or LSI) or grading scales such as the Medical Research Council scale (MRC) and other comparable scoring scales. However, the reliability and accuracy of the MMT are questionable [8,9].

When greater accuracy of results is needed, instruments that provide precise readouts of the resistive force the muscle works against are available.

One example is the Handheld Dynamometer (HHD), a digital tool that is sandwiched between the hand of the operator and patient's limb; it gives a numerical value of the force expressed by the muscle and its costs are acceptable. HHD can only be used for isometric strength testing.

Some authors have pointed out that isometric strength tests are limited because they don't consider dynamic movements that are more reflective of daily life activities and sports.

Therefore, dynamic tests such as the 1RM (one repetition maximum) can be used. The 1RM test is defined as "the maximal weight that can be lifted once, while maintaining the correct lifting technique" [10].

This method has several advantages over laboratory-based tests such as testing muscles in paired eccentric and concentric actions, allows for testing in multi-joint exercises and it's highly cost-effective, given it does not require expensive equipment. 1 RM protocols consider warm up sets with submaximal loads ranging from 40% to 80% of the estimated 1RM with a 1 to 10 repetition range and some of these also include light aerobic exercise like cycling. The movements generally used for the 1RM test for lower limbs are the back squat, the mid-thigh pull and the leg extension. These protocols have shown to be safe and with no significant differences between trained and untrained subjects but some familiarization sessions prior to the testing session could be useful to participants. If there is a concern of injury or subjects to be tested and clinicians are reluctant to perform the 1RM test, then lighter weights can be used for a 7 to 10 RM test. Prediction equations can then be used to estimate the 1 RM based on the number of repetitions that are completed with a submaximal load, but their accuracy stays high only within 5 repetition maximum [5,11,12].

Many authors agree that 1RM has good to excellent test-retest reliability regardless of age, sex, previous training experience, the inclusion of familiarization sessions and the complexity of the movement required for the test (single or multi-joint movement).

In fact, 1RM test is currently considered the “gold standard” of dynamic strength.

Another category of tests are the vertical jumps and hop tests. These test are particularly useful for evaluating lower limb “explosive strength” defined as the ability which varies according to the ratio between movement velocity and the developed strength by the specific muscle groups (Newton and Kraemer, 1994; Stone et al., 2003). Jumping test can be performed by using jump platforms (JP) which is the “gold standard” or on field tests like the Sargent Jump test (SJT) [13].

The most common Hop tests used in rehabilitation facilities are the single, triple and crossover, often used for return to sport criteria comparing the injured vs non-injured limb. Hop test are functional manoeuvres that simulate athletic activities and provide objective information for existing neuromuscular deficits [14,15].

3. MATERIALS AND METHODS

3.1. *Eligibility criteria*

Research strategy and eligibility criteria that were adopted refer to PIO model as follows:

- **P**opulation: lower limbs of healthy adults
- **I**ntervention: strength assessment methods
- **O**utcome: accuracy, validity and reliability of the tests and their possible implementation in clinical practice

Only articles written in English language with full text available were considered.

Only primary studies have been selected for this narrative review, therefore systematic reviews were excluded.

Lower limbs of healthy adults are the considered population; the pre-set filter "+19 years old" of PubMed was used for this search.

These other inclusion and exclusion criteria were then applied:

- When analysing the population for this review all the studies that were assessing the lower body strength of non-healthy population were excluded. Studies that considered the assessment of other muscles rather than the lower limbs were excluded. People who are 19 years old or more, with no history of pathology were included in this review, including older people and athletes.

- For the intervention were considered various methods of strength assessment like hop and jump tests, "repetition maximum" (RM) approach and even the use of modern cost-effective technological devices such as the hand-held dynamometer, the accelerometer, linear transducers or smartphone apps. All the studies that were assessing the lower body strength in laboratory-setting or by the use of expensive equipment such as isokinetic dynamometer, were excluded.

- The main interventions considered were the ones that gave a quantitative and direct measure of strength and power. For this reason, some assessment methods like the jump and hop tests or the linear transducers, who can obtain force-velocity values from other parameters such as jump height or time of flight, were addressed with a lower relevance in comparison to dynamometer and RM methods.

- The main outcome analysed for this study was the usefulness and practicality of the techniques used for testing strength and their possible implementation in clinical practice. Other outcomes considered for this review are the accuracy, validity, repeatability and reliability of the assessment methods.

- Finally, the study types included were only primary studies, including randomized controlled trials and other experimental studies. Therefore, systematic reviews were excluded.

3.2. Search strategy

Firstly, a preliminary research was carried out on PubMed (August- October 2022) Google Scholar and other books of strength and conditioning, in order to have a general idea about the strength assessment methods of the lower limbs used by clinicians around the world, and to identify the keywords needed for query strings. From January 2023 the literature strategy was conducted on several databases: PubMed, Cochrane Library and The Journal of Strength and Conditioning have been examined. The main starting string was formulated on PubMed and then adapted for each other database. A single search string has been formulated for each database. Keywords, Boolean operators that were adopted for query strings and their timeline are shown below in table 1. No time limits were set. The filter “+19 years old” of PubMed was used for this search. Furthermore, bibliographic references of all included studies and other pertinent systematic reviews were checked for other relevant articles.

Table 1. *Research strategies*

Database	*Query strings, keywords and Boolean operators*
Pubmed	("adult"[MeSH Terms]) OR ("healthy volunteers"[MeSH Terms])) OR ("lower extremity"[MeSH Terms])) OR ("leg"[MeSH Terms])) OR ("thigh"[MeSH Terms])) OR ("athletes"[MeSH Terms])) OR ("lower limbs"[Title/Abstract])) OR ("lower body"[Title/Abstract])) OR ("knee"[Title/Abstract])) OR ("hip"[Title/Abstract])) OR ("ankle"[Title/Abstract])) OR ("foot"[Title/Abstract])) OR ("lower extremity"[Title/Abstract])) OR ("leg"[Title/Abstract])) OR ("healthy volunteers"[Title/Abstract])) OR ("healthy subjects"[Title/Abstract])) OR ("normal volunteers"[Title/Abstract])) OR ("athletes"[Title/Abstract])) OR ("healthy population"[Title/Abstract]) **AND** ("muscle strength dynamometer"[MeSH Terms]) OR ("1 RM"[Title/Abstract])) OR ("1-RM"[Title/Abstract])) OR ("1 repetition maximum"[Title/Abstract])) OR ("one repetition maximum"[Title/Abstract])) OR ("jump"[Title/Abstract])) OR ("vertical jump"[Title/Abstract])) OR ("jump platform"[Title/Abstract])) OR ("force platform"[Title/Abstract])) OR ("force plate"[Title/Abstract])) OR ("hop"[Title/Abstract])) OR ("single hop"[Title/Abstract])) OR ("triple hop"[Title/Abstract])) OR ("jump test"[Title/Abstract])) OR ("hop test"[Title/Abstract])) OR ("RM test"[Title/Abstract])) OR ("manual muscle testing"[Title/Abstract])) OR ("squat"[Title/Abstract])) OR ("back squat"[Title/Abstract])) OR ("single leg squat"[Title/Abstract])) OR ("single-leg squat"[Title/Abstract])) OR ("leg press"[Title/Abstract])) OR ("leg extension"[Title/Abstract])) OR ("sit to stand"[Title/Abstract])) OR ("sit-to-stand"[Title/Abstract])) OR ("jump squat"[Title/Abstract])) OR ("squat jump"[Title/Abstract])) OR ("counter movement jump"[Title/Abstract])) OR ("CMJ"[Title/Abstract])) OR ("mid thigh pull"[Title/Abstract])) OR ("deadlift"[Title/Abstract])) OR ("calf raise"[Title/Abstract])) OR ("handheld dynamometer"[Title/Abstract])) OR ("HHD"[Title/Abstract]) **AND** ("patient outcome assessment"[MeSH Terms]) OR ("muscle strength"[MeSH Terms])) OR ("torque"[MeSH Terms])) OR ("assessment"[Title/Abstract])) OR ("assessment method"[Title/Abstract])) OR ("measurement"[Title/Abstract])) OR ("measure"[Title/Abstract])) OR ("test"[Title/Abstract])) OR ("testing"[Title/Abstract])) OR ("evaluation"[Title/Abstract])) OR ("muscle strength"[Title/Abstract])) OR ("torque"[Title/Abstract])) OR ("peak torque"[Title/Abstract])) OR ("strength"[Title/Abstract])) OR ("power"[Title/Abstract])) OR ("dynamic strength"[Title/Abstract])) OR ("isometric strength"[Title/Abstract])) OR ("isotonic strength"[Title/Abstract])) OR ("reactive strength"[Title/Abstract])) OR ("rate of force development"[Title/Abstract])) OR

	("explosive strength"[Title/Abstract])) OR ("peak force"[Title/Abstract])) OR ("maximal strength"[Title/Abstract])) OR ("force"[Title/Abstract]) **AND** ("validity"[Title/Abstract]) OR ("reliability"[Title/Abstract])) OR ("repeatability"[Title/Abstract]) **FILTERS:** Adult: 19+ years Time: 15/01/2023
Chochrane Library	MeSH descriptor: [Lower Extremity] OR MeSH descriptor: [Healthy Volunteers] OR (thigh OR leg OR hip OR knee OR foot OR ankle) OR (adults OR "healthy adults" OR "healthy subjects" OR athletes OR "healthy population") **AND** MeSH descriptor: [Muscle Strength Dynamometer] OR (rm OR "repetition maximum" OR jump OR hop OR dynamometer OR sphygmomanometer OR "manual muscle testing" OR squat OR "rm test" OR "jump test" OR "hop test" **AND** ("strength assessment" OR "strength test" OR "strength measure" OR assess OR test OR assessment OR testing OR measurement OR evaluation OR validity OR reliability OR ability) **AND** MeSH descriptor: [Reproducibility of Results] Time: 15/01/2023
Journal of strength and Conditioning	*(strength assessment) (strength test) (strength testing) (strength evaluation) (maximal strength test) (dynamic strength assessment) (isometric strength test) (isometric strength assessment) (maximal strength assessment) (dynamic strength assessment) (muscle strength assessment)(lower limb) (lower body) (leg) (knee) (hip) (foot) (ankle)* ***AND*** *(RM) (jump) (hop) (handheld dynamometer) (one repetition maximum) (manual); (reliability) (validity) (ability); (strength assessment) (strength test) (strength testing) (strength evaluation) (maximal strength test) (dynamic strength assessment) (isometric strength test) (isometric strength assessment) (maximal strength assessment) (dynamic strength assessment) (muscle strength assessment)(lower limb) (lower body) (leg) (knee) (hip) (foot) (ankle); (RM) (jump) (hop) (handheld dynamometer) (one repetition maximum) (manual); (reliability) (validity) (ability)* Time: 15/01/2023

3.3. Study selection

The review was conducted by one reviewer (L.G.), who extracted each research result, selecting independently the useful articles to be included, but submitting any uncertainty to the supervisor (G.M.). The selection process consisted of several steps: firstly, duplicate references were removed from the search results; then the reviewer screened the identified articles based on title and abstract, and, lastly, examined the remaining articles by reading full text and comparing them to the eligibility criteria. Only articles written in English language with available full text were considered. Studies that met inclusion and exclusion criteria after reading the full text were included in the review. In case the full text was not available, the article was discarded. These steps can be seen in the PRISMA flow diagram (*Figure 1*).

3.4. Assessment of methodological quality

A bias risk evaluation was performed for each article selected for this review using the QUADAS-2 tool. This tool was originally designed for the assessment of methodological quality for the diagnostic accuracy studies, and it was adapted to evaluate the completeness and the potential bias in all included studies. This tool is composed with four domains; for each of these areas there is a set of criteria for assessing protection from bias ranked as High, Low or Unclear. In the end each of the included articles was classified in high, unclear or low risk of bias according to the original ratings of the QUADAS-2 tool.

4. RESULTS

4.1. Data extraction

The original search, carried out on 15 January 2023, identified 1715 results across the selected databases: in particular, 1499 from PubMed, 164 from Cochrane Library, 52 from the Journal of Strength and Conditioning. After duplicates removal (n=67), the remaining articles were 1648. Of these, 1443 results were eliminated after reading the title and the abstract, as they did not meet the established eligibility criteria and considered not relevant to the PIO query, reducing the number of studies still eligible to 205. The full text of these articles was read and assessed for eligibility: 33 studies were excluded as the full text was not available; 72 articles were eliminated because they considered strength testing with expensive equipment which is not commonly available in physical therapy facilities (such as isokinetic dynamometer); 10 articles were excluded because they also tested for other muscle rather than lower limb muscles (studies that considered also upper limb strength or trunk muscle strength); 96 studies were eliminated because they did not consider healthy population which was the aim of this narrative review (studies that included people with surgical interventions or had a pathology). At the end of the selection process, the articles included in the review were 29. All the steps just described are displayed in *Figure 1*, in which is shown the flow diagram adapted from the guidelines of PRISMA Statement.

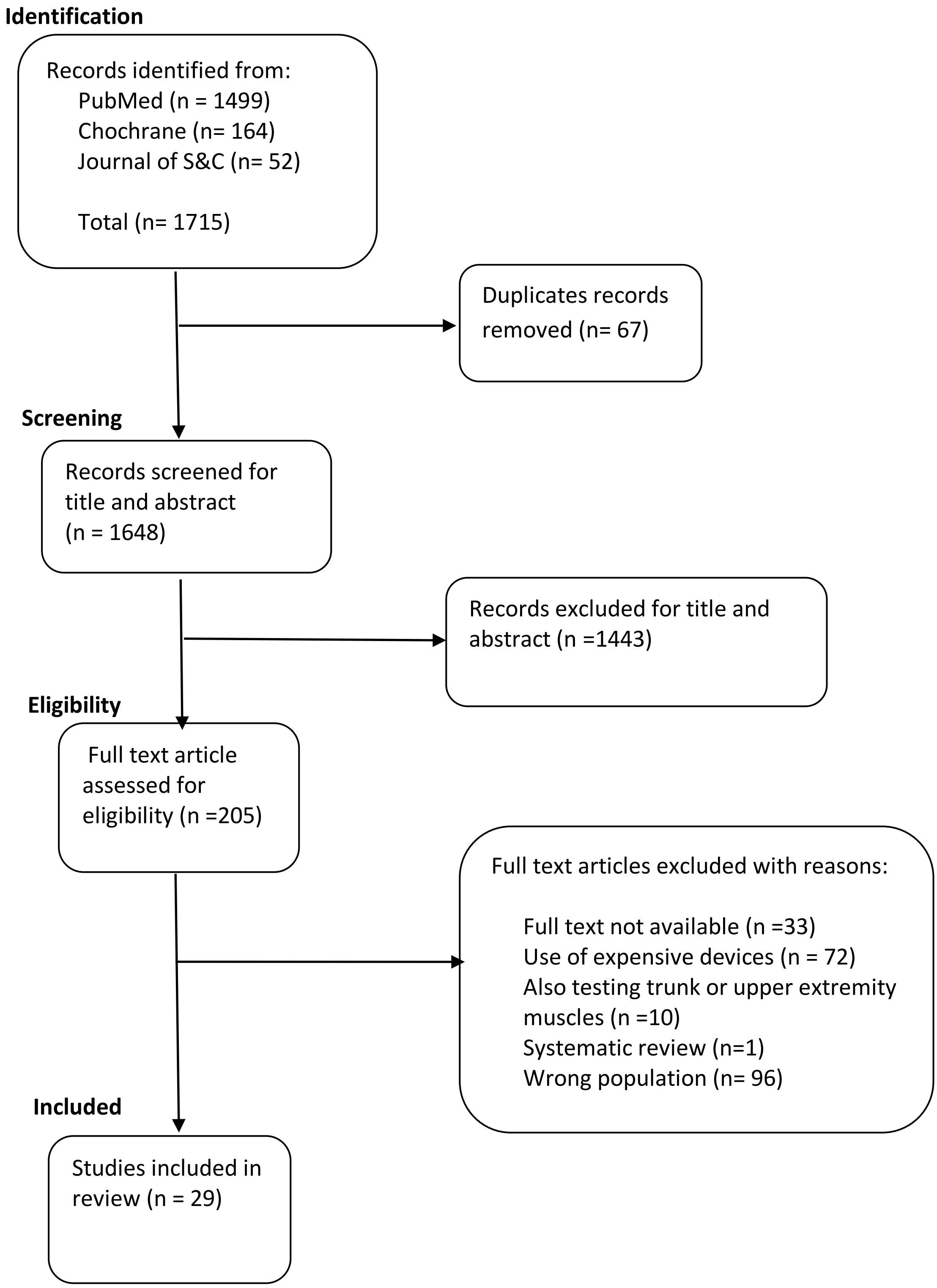

Figure 1. Flowchart of study inclusion, adapted from PRISMA statement.

4.2. *Characteristics of included studies*

After establishing which articles to embed in this review, data of interest were extracted from full texts and summarized in the synoptic table, displayed below. The characteristics and results of each study selected are described in detail in Table 1 and refer to PIO query. Articles are presented in chronological order, according to publication date. For each paper are reported the following characteristics: Author, Year, Population (subdivided into Participants, presented with sex, personal and anthropometric data), Intervention (description of the examined test, execution mode and, if any, self-reported questionnaires. Table contents were discussed with the supervisor (G.M.) to resolve any doubts.

Table 1. *Synoptic Table: characteristics of included studies*

Author	Year	Population	Intervention
Kea J, Kramer J, Forwell L, Birmingham T	2001	27 male professional or elite amateur hockey player (mean age 20 ± 3 yrs)	computerized dynamometer and Hop tests for distance (medial and laterla directions)
Kollock RO Jr, Onate JA, Van Lunen B	2010	37 participants recruited in 2 phases :1, 11 healthy college graduate students (2 men, 9 women) 2, 26 healthy college undergraduate students (7 men, 19 women)	portable fixed Hand Held dynamometer
Hansen KT, Cronin JB, Newton MJ	2011	25 male, professional rugby union players aged between 18 and 34 years; mean age and height were 23.6 ± 4.8 years and 1.8 ± 0.1 m, and body weight on days 1 and 2 was 98.6 ± 12.0 and 98.8 ± 11.9 kg, respectively	linear position transducer and force plate during a loaded squat jump
Lu YM, Lin JH, Hsiao SF, Liu MF, Chen SM, Lue YJ	2011	Sixteen healthy young adults (8 men and 8 women; mean ± SD: age = 22.7 ± 2.1 years, height = 167.2 ± 8.1 cm, and body weight = 55.9 ± 8.0 kg	Hand held dynamometer

Thorborg K, Bandholm T, Hölmich P	2013	Twenty-one healthy athletes	hand-held dynamometer with external belt-fixation
Reeve TC, Tyler CJ	2013	Twenty-three healthy untrained adults (men: n = 15, age = 26 ± 6 years, stature = 179 ± 7 cm, body mass = 81.1 ± 11.2 kg; women: n = 8, age = 26 ± 9 years, stature = 166 ± 3 cm, 60.1 ± 5.9 kg)	Smart Jump Contact Mat using 3 different jump types (countermovement jump [CMJ], countermovement with arms [CMJA], and squat jump [SJ])
Lee SP, Powers C	2013	Twenty individuals (10 women, 10 men) between 24 and 42 years	uniaxial force transducer connected to a nonstretchable fabric strap in a weight-bearing position
Castagna Carlo; Ganzetti Marco; Ditroilo Massimiliano; Giovannelli Marco; Rocchetti Alessandro; Manzi Vincenzo	2013	Twenty (age 15.5 ± 0.8 years, height 176.5 ± 5.8 cm, body mass 77 ± 18.1 kg) regional-level young male rugby players	optical mat (Optojump) and an accelerometer based (Myotest) system
Cuk I, Markovic M, Nedeljkovic A, Ugarkovic D, Kukolj M, Jaric S	2014	10 healthy and physically active male participants (age 23.4 ± 3.0; body weight 77.3 ± 8.0 kg; body height 182.6 ± 4.2 cm; data shown as mean ± SD)	loaded and unloaded vertical jumps (CMJ and SJ) with a Force Plate

Kockum B, Heijne AI	2015	Eighteen healthy athletes (nine women and nine men), average age 23.4 years (SD:2.4), average weight 72.1 kg (SD:15.3) and average height 172 cm (SD:11.0)	vertical jump (jump mat), one-leg hop for distance, side hop, single-leg squat jump, knee-flexion and knee-extension power tests
Bazyler CD, Beckham GK, Sato K	2015	17 college-aged males with at least 1 year of resistance training experience	isometric squat
Urquhart BG, Moir GL, Graham SM, Connaboy C	2015	Fourteen men (mean ± SD: age = 23 ± 1.18 years; height = 1.81 ± 0.05 m; mass = 79.96 ± 6.48 kg) non–resistance-trained, recreationally active	1RM Squat and Split Squat
André HI, Carnide F, Borja E, Ramalho F, Santos-Rocha R, Veloso AP	2016	Forty-five subjects aged 65 years and older, of both sexes	Calf-raise senior test
Jackson SM, Cheng MS, Smith AR Jr, Kolber MJ	2017	Fifteen asymptomatic adult runners	Handheld dynamometer with a PVC pipe stabilization device
Martins J, da Silva JR, da Silva MRB, Bevilaqua-Grossi D	2017	26 healthy participants (13 men, 13 women; age = 23.5 ± 2.8 years, height = 1.7 ± 0.1 m, mass = 68.6 ± 12.4 kg)	belt stabilized HHD

Clark NC, Reilly LJ, Davies SC	2019	Thirteen athletes participated (male n = 6; female n = 7; age 25.6 ± 5.5 years; height 171.4 ± 8.4 cm; mass 71.8 ± 13.4 kg; SARS 93.5 ± 8.0; football n = 7; rugby n = 2; netball n = 4)	one repetition maximum (1RM) single-leg leg-press (LP), knee-flexion (KF), and knee-extension (KE)
Helme M, Bishop C, Emmonds S, Low C	2019	26 well trained male (age = 23.8 ± 4.6 years [age range: 19-36 years], mass = 88.1 ± 10.7 kg, and height = 1.79 ± 0.1 m)	5 RM Rear foot eleveted Split Squat
Florencio LL, Martins J, da Silva MRB, da Silva JR, Bellizzi GL, Bevilaqua-Grossi D	2019	Twenty-four participants (12 male and 12 female) without reported hip or knee dysfunction, aged 18–28 years (mean age: 23.1 ± 3 years, mean height: 170 ± 10 cm, and mean weight: 68.5 ± 13 kg)	Handheld dynamometer and Belt-stabilized dynamometer
Sung KS, Yi YG, Shin HI	2019	39 Healthy adults, 19 male and 20 female, aged 30.08 ± 4.16 y	Portable dynamometer anchoring system
Seko T, Mori M, Ohnishi H, Himuro N, Takahashi Y, Kumamoto T, Ito T	2019	40 older adults	HHD device was used in 3 postures (sitting, standing, and prone positions)

Bruening DA, Ridge ST, Jacobs JL, Olsen MT, Griffin DW, Ferguson DH, Bassett KE, Johnson AW	2019	Forty healthy participants (20 M, 20 F) height = 172.2 ± 9.8 cm, weight = 72.3 ± 13.1 kg, age = 25.3 ± 6.2 yrs	Five strength testing protocols were performed on three different apparatus: custom toe flexion dynamometer (seated), custom doming dynamometer (standing), and a pressure mat (standing)
Bazett-Jones DM, Squier K	2020	Thirty healthy participants (16 females, age = 21.5 ± 2.4 yrs, mass = 76.7 ± 24.1 kg, height = 1.7 ± 0.1 m)	Hand held dynamometer
Piche E, Chorin F, Gerus P, Jaafar A, Reneaud N, Guerin O, Zory R	2021	46 participants (6men, 40women) were included in this study (mean age = 73.7 +/− 7.7 years; mean height = 161.8 +/− 8.2 cm; mean weight = 61.5 +/− 11.4 kg; mean BMI = 23.5 +/− 4.2 kg/m2)	Sit-to-stand protocol (with no additional load, with 10kgs load and with 5 kg)
Hartog J, Dijkstra S, Fleer J, van der Harst P, Mariani MA, van der Woude LHV	2021	22 healthy middle-aged to elderly adults (gender: 11/11, age: 59.4 ± 8.7 years, BMI: 25.0 ± 3.1 kg/m2)	Q-Force II portable testing device
Balachandran AT, Vigotsky AD, Quiles N, Mokkink LB, Belio MA, Glenn JM	2021	51 community-dwelling adults, 65 years or older	chair and a linear transducer to assess peak power during a sit-to-stand test

Montalvo Samuel; Gonzalez Matthew P.; Dietze-Hermosa Martin S.; Eggleston, Jeffrey D.; Dorgo, Sandor	2021	Thirty recreationally trained young adult subjects (17 males and 13 females; age ± SD: 23.37 ± 1.87 years)	vertical jumps through CMJ, SQJ, and DJ assessed by 4 field-test devices (Optojump, Push-Band 2.0, MyJump2, and What'sMyVert mobile applications)
Grootswagers P, Vaes AMM, Hangelbroek R, Tieland M, van Loon LJC, de Groot LCPGM	2022	258 older adults (≥65 years)	Hand Held dynamometer
Montoro-Bombú R, de la Paz Arencibia L, Buzzichelli C, Miranda-Oliveira P, Fernandes O, Santos A, Rama L	2022	22 athletes 17 volleyball athletes (12 men and 5 women), and 3 track and field triple jump specialists (3 men) (mean ± SD; age: 20.75 ± 1.67 (year), height: 1.74 ± 0.06 (m), weight 64.76 ± 9.67 (kg), and BMI 20.52 ± 2.93)	Push Band 2.0 (PB2.0) wereable device during Drop Jumps
Vieira A, Ribeiro GL, Macedo V, de Araújo Rocha Junior V, Baptista RS, Gonçalves C, Cunha R, Tufano J	2023	Ten physically active university-aged men (20 ± 3 years, 176 ± 6 cm, 68 ± 9 kg)	Jumpo 2 and MyJump 2 apps

4.3. *Synthesis of results*

As shown in the synoptic table the articles considered [17-45] covered a period from 2001 to 2023, while the type of studies is only observational (cross-sectional and/or repeated measures studies). All the studies have a population consisting of healthy subjects ranging from elite level athletes to older, physically inactive, community-dwelling adults. Considering the totality of included articles, the population surveyed is composed of 985 subjects of which 234 were athletes or physically active subjects with training experience while 751 were non-trained or inactive subjects. The age of considered population ranged from 15 to 65 years old. Each article fulfilled the inclusion and exclusion criteria for this review: every participant was injury and pathology free and had no history of surgical intervention that could interfere with the testing procedures. Subjects were selected by convenience from colleges, sport societies and communities. The studies that assessed muscle strength and power with the use of expensive equipment were excluded because the aim of this review is to identify accurate and cost-effective methods that can be implemented in every day clinical practice.

As for analysed intervention 9 studies [17-25] focused on dynamometer devices that were stabilized either manually by the operator or externally with a belt (non-stretchable fabric strap) or with other stabilization methods. 2 studies [17, 18] assessed validity and reliability comparing the Handheld Dynamometer (HHD) with the Gold Standard Isokinetic dynamometer. 1 study [19] compared the HHD in three different positions (sitting, standing, and prone positions) for the assessment of hip extensors. 1 study [20] evaluated the inter-tester reliability of hip and knee strength test utilizing the HHD with the external belt fixation. 1 study [21] used the HHD for the assessment of hip muscles across different ranges of motion and compared the results with the Gold Standard Isokinetic dynamometer. 1 study [22] focused on the relative and absolute interrater reliability of HHD for hip and knee muscles tested by 2 physiotherapists. Another study [23] considered the reliability and the standard error of measurement (SEM) comparing the dynamometer stabilized manually and an external belt fixation. Jackson SM, et al. [24] utilized a portable stabilization device consisting of a PVC pipe and verified the intra-rater reliability of this particular method. The last study [25] assessing strength with a portable fixed dynamometer evaluated the reliability of this device in knee and hip muscles.

9 studies [26-34] utilized jump testing methods for the strength evaluation; Kockum et al. [26] correlate the hop performance with leg muscle power tests by the use of a test battery; 1 study [27] assessed the force-velocity curve using loaded and unloaded jumps on a Force Platform; another one [28] assessed 3 different types of jumps (countermovement jump [CMJ], countermovement with arms [CMJA], and squat jump [SJ]) with a contact mat; in 1 study [29] a linear position transducer and a force plate are compared; 1 study [30] evaluated the subjects jumping with 2 mobile smartphone applications; 1 study [31] tested medial and lateral hop for distance and its relationship with the computerized dynamometer strength performance; 1 study [32] focused

on the validity of optical mat (Optojum) and accelerometer based Myotest system; 1 article [33] compared 4 different field methods (two mobile apps, Optojump system and Pushband 2.0 devices) through Counter Movement Jump (CMJ), Squat Jump (SJ) and Drop Jump (DJ); 1 study [34] focused entirely on the Push Band 2.0 wearable device when assessing for the Drop Jump (DJ).

3 studies [35-37] considered RM testing protocols for the assessment of strength. One of these [35] assessed the 5RM RFESS (Rear Foot Elevated Spilt Squat) while the other two used a 1RM protocol, one [37] with the Squat and the other one [36] with Leg press, Knee flexion and Knee extension exercises.

2 studies utilized the Sit-to-stand (STS) assessment protocol [38,39] to assess force-velocity profile, of which one used a chair and a linear transducer to assess peak power during a sit-to-stand test and the other one used simple STS method with and without an external load.

2 studies [40,41] examined portable testing devices: a portable anchoring system [40] and the Q-Force II portable testing device [41], both assessing knee extensor with an isometric maximal voluntary contraction.

2 studies [42,43] were evaluating the foot muscle strength with different methods. Bruening et al. [42] assessed strength of the foot muscles using five different protocols performed on three different apparatus custom toe flexion dynamometer (seated), custom doming dynamometer (standing), and a pressure mat (standing). The other one [43] used the Calf-raise senior test (CRSt) to assess the plantar flexor muscle strength in older adults.

1 study [44] described a new way to assess hip abductor and external rotator muscles in a weight bearing position using a uniaxial force transducer connected to a non-stretchable fabric strap.

1 study [45] evaluated if the isometric squat could be an efficient method for measuring strength and explosiveness in relationship with the conventional 1RM squat and partial squat tests.

As for the analysed outcome measures the majority of the studies [17-27,29-31,33,35-37,39-45] included focused on inter and intra-session reliability and as well as intra and inter-session reliability, with a test-retest repeated measures study design. The main statistical outcome measures considered in these articles are the Interclass Correlation Coefficient (ICC), Standard Error of Measurement (SEM), Minimal Detectable Change (MCD), Pearson Correlation Coefficient (r). As a whole every study showed moderate to excellent reliability for the intervention proposed, with an ICC ranging from 0,75 to 0,98. Only one study [21] showed poor reliability for the isometric strength testing with a dynamometer when assessing hip internal rotation and another one [33], who found out that the Optojum system is not reliable for detection of the Reactive Strength Index (RSI). 4 studies [28,32,34,38] focused on the validity only, and sometimes the correlation analysis between different testing methods was performed.

All the included articles are observational studies as there were no randomized control trials that suited the eligibility criteria of the initial research.

4.4. *Risk of bias assesment*

The bias risk assessment of the included articles is summarized in Table 2 it shows the score for each item of the 4 domains of the QUADAS-2 tool and at the end the overall rating for each study. In particular the overall ratings are made up of the total of the domains' scores: studies have been classified as HIGH, LOW or UNCLEAR risk of bias, according to the aforementioned criteria (Assessment of methodological quality).

From the analysis and the interpretation of the overall rating, it is shown that 8 studies [23-26,29,35-37] have an unclear risk of bias, 9 studies [19,20,22,27,39,41,42,44,45] have a high risk of bias, and 12 studies [17,18,21,28,30-34,38,40,43] have low risk of bias. Deepening in detail each domain, it emerges that, for the patient selection one study [42] has an unclear risk of bias and another one [32] has a high risk of bias; for the remaining 27 studies [17-31,33-41,43-45] all scored as a low risk of bias. For the index test 18 studies [17,18,21,23,25,26,28-36,38,40,43] have a low risk of bias whether 8 studies [19,20,22,27,37,42,44,45] have a high risk of bias and only 3 articles [24,39,41] presented an unclear risk of bias. Regarding the reference standard 12 of the selected articles [17,18,21,27,28,30,31-33,38,40,43] compared the index test with the Gold standard and were considered with a low risk of bias; 3 studies [34,35,39] have an unclear risk of bias because the reference standard was inadequate while the rest of the articles [19,20,22-26,29,36,37,41,42,44,45] were addressed with a high risk of bias for the absence of a compared test that could validate the index test examined. Only 9 studies [17,28,30,32-34,37,38,40] were appropriately respecting the flow and timing domain, assessing the index test and reference standard simultaneously or with adequate timing between the first and the second one. 11 studies [22,23,25,27,29,31,35,36,39,41,42] are at high risk of bias for the flow and timing domain and 9 [18-21,24,26,43-45] are reported as unclear.

Table 2. *Assessment of methodological quality: QUADAS-2 tool.*

Article	Patient Selection	Index Test	Reference Standard	Flow and Timing	Overall Decision
Martins J, Reliability and Validity of the Belt-Stabilized Handheld Dynamometer in Hip- and Knee-Strength Tests. J Athl Train. 2017	LOW	LOW	LOW	LOW	LOW
Bruening DA, Functional assessments of foot strength: a comparative and repeatability study. BMC Musculoskelet Disord. 2019	UNCLEAR	HIGH	HIGH	HIGH	HIGH
Piche E, Validity of a simple sit-to-stand method for assessing force-velocity profile in older adults. Exp Gerontol. 2021	UNCLEAR	LOW	LOW	LOW	LOW
Grootswagers P, Relative Validity and Reliability of Isometric Lower Extremity Strength Assessment in Older Adults by Using a Handheld Dynamometer. Sports Health. 2022	LOW	LOW	LOW	UNCLEAR	LOW
Kockum B, Hop performance and leg muscle power in athletes: Reliability of a test battery. Phys Ther Sport. 2015	LOW	LOW	HIGH	UNCLEAR	UNCLEAR

Cuk I, Force-velocity relationship of leg extensors obtained from loaded and unloaded vertical jumps. Eur J Appl Physiol. 2014	LOW	HIGH	LOW	HIGH	HIGH
Seko T, Reliability and Validity of Seated Hip Extensor Strength Measurement by Handheld Dynamometer in Older Adults. J Geriatr Phys Ther. 2019	LOW	HIGH	HIGH	UNCLEAR	HIGH
Thorborg K, Hip- and knee-strength assessments using a hand-held dynamometer with external belt-fixation are inter-tester reliable. Knee Surg Sports Traumatol Arthrosc. 2013	LOW	HIGH	HIGH	UNCLEAR	HIGH
Sung KS, Reliability and validity of knee extensor strength measurements using a portable dynamometer anchoring system in a supine position. BMC Musculoskelet Disord. 2019	LOW	LOW	LOW	LOW	LOW
Reeve TC, The validity of the SmartJump contact mat. J Strength Cond Res. 2013	LOW	LOW	LOW	LOW	LOW
Bazett-Jones DM, Measurement properties of hip strength measured by handheld dynamometry: Reliability and validity across the range of motion. Phys Ther Sport. 2020	LOW	LOW	LOW	UNCLEAR	LOW
Lee SP, Description of a weight-bearing method to assess hip abductor and external rotator muscle performance. J Orthop Sports Phys Ther. 2013	LOW	HIGH	HIGH	UNCLEAR	HIGH

Lu YM, The relative and absolute reliability of leg muscle strength testing by a handheld dynamometer. J Strength Cond Res. 2011	LOW	HIGH	HIGH	HIGH	HIGH
Florencio LL, Knee and hip strength measurements obtained by a hand-held dynamometer stabilized by a belt and an examiner demonstrate parallel reliability but not agreement. Phys Ther Sport.	LOW	LOW	HIGH	HIGH	UNCLEAR
Jackson SM, Intrarater reliability of hand held dynamometry in measuring lower extremity isometric strength using a portable stabilization device. Musculoskelet Sci Pract. 2017	LOW	UNCLEAR	HIGH	UNCLEAR	UNCLEAR
Helme M, Validity and Reliability of the Rear Foot Elevated Split Squat 5 Repetition Maximum to Determine Unilateral Leg Strength Symmetry. J Strength Cond Res. 2019	LOW	LOW	UNCLEAR	HIGH	UNCLEAR
Hartog J, A portable isometric knee extensor strength testing device: test-retest reliability and minimal detectable change scores of the Q-Force II in healthy adults. BMC Musculoskelet Disord. 2021	LOW	UNCLEAR	HIGH	HIGH	HIGH

Clark NC, Intra-rater reliability, measurement precision, and inter-test correlations of 1RM single-leg leg-press, knee-flexion, and knee-extension in uninjured adult agility-sport athletes: Considerations for right and left unilateral measurements in knee injury control. Phys Ther Sport. 2019	LOW	LOW	HIGH	HIGH	UNCLEAR
André HI, Calf-raise senior: a new test for assessment of plantar flexor muscle strength in older adults: protocol, validity, and reliability. Clin Interv Aging. 2016	LOW	LOW	LOW	UNCLEAR	LOW
Hansen KT, The reliability of linear position transducer and force plate measurement of explosive force-time variables during a loaded jump squat in elite athletes. J Strength Cond Res. 2011	LOW	LOW	HIGH	HIGH	UNCLEAR
Bazyler CD, The use of the isometric squat as a measure of strength and explosiveness. J Strength Cond Res. 2015	LOW	HIGH	HIGH	UNCLEAR	HIGH
Vieira A, Evidence of validity and reliability of Jumpo 2 and MyJump 2 for estimating vertical jump variables. PeerJ. 2023	LOW	LOW	LOW	LOW	LOW
Kollock RO Jr, The reliability of portable fixed dynamometry during hip and knee strength assessments. J Athl Train. 2010	LOW	LOW	HIGH	HIGH	UNCLEAR
Urquhart BG, Reliability of 1RM Split-Squat Performance and the Efficacy of Assessing Both Bilateral Squat and Split-Squat 1RM in a Single Session for Non-	LOW	HIGH	HIGH	LOW	UNCLEAR

Resistance-Trained Recreationally Active Men. J Strength Cond Res. 2015					
Balachandran AT, Validity, reliability, and measurement error of a sit-to-stand power test in older adults: A pre-registered study. Exp Gerontol. 2021	LOW	UNCLEAR	UNCLEAR	HIGH	HIGH
Kea J, Hip abduction-adduction strength and one-leg hop tests: test-retest reliability and relationship to function in elite ice hockey players. J Orthop Sports Phys Ther. 2001	LOW	LOW	LOW	HIGH	LOW
Castagna, Concurrent Validity of Vertical Jump Performance Assessment Systems. Journal of Strength and Conditioning Research March 2013.	HIGH	LOW	LOW	LOW	LOW
Montoro-Bombú R, The Validity of the Push Band 2.0 on the Reactive Strength Index Assessment in Drop Jump. Sensors (Basel). 2022	LOW	LOW	UNCLEAR	LOW	LOW
Montalvo, Common Vertical Jump and Reactive Strength Index Measuring Devices: A Validity and Reliability Analysis. Journal of Strength and Conditioning Research 2021	LOW	LOW	LOW	LOW	LOW

5. DISCUSSION

5.1 Summary of evidence

Overall, it is reasonable to affirm that nowadays there are many cost-effective ways to assess muscle strength and power qualities in healthy subjects. These methods could be easily applicated in clinical practice for musculoskeletal practitioners and in the sport science filed.

Considering the articles included in this review, the emerged results are affected by the heterogeneity in the population observed, in the characteristics of different types of intervention and in the outcome measures. Therefore, the evidence described should be interpreted taking into account these specificities.

Firstly, as displayed in the results section, some studies [17,21-23,25,27,28,30,33,35,37,40,42,44,45] considered young adults, often defined as physically active or with training experience, while other studies [20,24,26,29,31,32,34,36] assessed strength in athletes and only a few studies [18,19,38,39,41,43], tested non-active population up to 65 years old of age and older. The variety of analysed population on one hand is a limitation for the interpretation of the results of this research but on the other hand it reflects the heterogeneity of patients that are commonly seen in rehabilitation settings, particularly in the musculoskeletal area.

Some studies are only describing new methods to assess strength with the purpose of exploring different ways to make testing more accurate but their transferability into practice is not clear. However, they can be considered as a starting point to encourage researchers to investigate these interesting methods and to verify their applicability.

The majority of articles selected are assessing the absolute and relative reliability of the applied interventions both intra and inter operator. The highest quality of design in these terms is provided by those studies who compare the intervention to a reference standard who has previously proven to be a reliable method for strength assessment or, even better, the Gold Standard.

From now on the discussion section is divided by type of intervention used to assess strength.

5.1.1 Dynamometer

Martins J. et al. [17] compare the belt stabilized HHD to the isokinetic dynamometer in the hip and knee muscle groups. The correlation between these two instruments was high and, even if the absolute values did not agree, it remains a reliable way for strength assessment. Also Grootswagers P. et al. [18] confronted a Microfet HHD to the isokinetic gold standard and again a high correlation was found between the two methods; although HHD systematically overestimated torque as compared with Biodex System 4, it represents a valid alternative to rank individuals on leg strength, or to assess within-person changes in leg strength over time. Sung KS. et al. [40] proposed a new portable anchoring HHD system which was designed to test knee extensor strength in a supine position; this could be useful in practice for those patients who are not able to assume the sitting position required for knee extensors isokinetic test. The comparison between the GS and this instrument showed promising results in the healthy population (39 healthy subjects aged from 20 to 40 years old) and future clinical feasibility studies are needed to determine if this equipment can be applied to post-surgery patients or painful conditions.

Bazett-Jones DM. et al. just like Martins J. et al. [21,17] examined the reliability and validity of the belt-stabilized HHD comparing it to the isokinetic, but, in this study [21], hip muscles were tested across multiple angles and positions to see if that could influence the results. This is extremely useful for clinicians who are willing to standardize the testing position and avoid error of measurement. Usually, the muscles are tested in an intermediate articular position, to test knee extension and flexion for example, a seated or prone position of the patient with the joint at 90 degree of flexion is preferred. Isometric dynamometers are extremely useful in clinical practice, but the clinician must be aware of the potential risk of bias when assessing strength with these devices. Kollock RO Jr. et al. [25] in their study demonstrated a good intrarater reliability for all hip and knee movements, except from hip internal rotation, whereas another study by Lu YM. et al. [22] found out poor results for knee extensor HHD testing. This error of measurement can occur when the subject attempting the test is exerting force compensating with trunk or other counter movement. Another element that could affect the results of the test is a considerable imbalance between the operator and the subject strength. To overcome these two potential errors, when assessing with the manual dynamometer, compensatory movements can be limited fixating the patient on the chair or table and giving proper instruction prior to the test execution. To eliminate strength mismatches bias, external stabilization tools can be used. Even though one study [23] concluded that the HHD was better than the belt stabilized dynamometer, Thorborg K. et al. [20] affirm that belt fixation is a valid way to overcome hand fixation especially if we're testing athletes or the operator has too little strength. Another portable stabilization device proposed by Jackson SM. et al. [24] is a PVC pipe positioned between the subject limb and a wall. When the subject is not able to assume a prone position, which might be the case of some older patients, we can take into consideration the study of Seko T. et al. [19] who affirms that it is possible to assess hip extensors also in a seated position. Isometric strength assessment was also performed by Hartog J. et al.[41] who utilized a device that works in a similar way to the dynamometer and another article [44] who used a force transducer in standing position attached to a non-stretchable fabric strap positioned around distal ends of both thighs for testing the hip external rotator and abductor muscles.

5.1.2 Hop and Jump

When it comes to hop or jump performance, the reference criteria for a proper reliability comparison should be the Force Plate/Platform or alternatively the IKD, which are currently considered the two main Gold Standards. For example, the idea behind the study of Kea J. et al. [31] is to determine if the hip adduction and abduction torques and the medial and lateral hop tests are test-retest reliable and if there is any relationship between the hop distance and the isokinetic values. The people tested for this study are elite ice hockey players, and even though the correlations were really low, it reasonable to think the IKD is an objective measure of muscular strength under a certain set of conditions, but it should be carefully relied upon when it comes to sport performance and readiness to return to activity. This aspect has a huge impact on the rehabilitation process of all athletes who suffer from an injury and are tested before they return to the filed: musculoskeletal practitioners should assess this type of patients taking into consideration both jumping tests and maximum voluntary contractions (MVC).

Cuck I. et al. [27] explored the Force-Velocity relationship (F-V) with loaded and unloaded vertical jumps comparing it with the Force Plate. They found out that the method is valid, reliable and strong. They even hypothesised that the assessment of maximum Force and Power could be somewhat more reliable and valid than the assessment of maximum Velocity. Even if the subjects tested are only ten, this study suggests that use of vertical jumps with an external load should be implemented in clinical practice.

Other articles [30,33,34] focused on the vertical jump as a strength measure with different instruments and comparing several methods with an appropriate reference standard (Force Platform). Montalvo S. et al. and Viera A. et al. [30,33] both evaluate the use of mobile applications for determining jump height, mean values of force, velocity, power produced [30] and Reactive Strength Index (RSI) obtained with the flight time method [33]. Specifically, the apps used for these two studies are MyJump2, What'sMyVert and Jumpo 2. The subjects tested were recorded with a slow-motion smartphone camera while performing different vertical jump modalities (Squat Jump, SJ, Counter Movement Jump, CMJ, and Drop Jump, DJ) on a Force Platform. Overall, the results confirm that mobile applications may provide physiotherapists and coaches with a cost-effective and reliable measurement of various vertical jumps. The most precise value was obtained for jump height and RSI, but the remaining variables provided by these apps must be viewed with caution since the validity of force depends on jump type, while velocity (and as consequence power) could not be well estimated form apps. Since the availability of smartphones nowadays, these types of apps are a valid and easy-to-use tool which can be used in clinical settings by practitioners.

In the study of Montalvo S. et al. [33] other two devices were used synchronously during the jump testing session: the Optojum and the Push-Band 2.0.

The first one is a device consisting of a photoelectric cell transmitting and a receiving bar placed in a parallel position, which uses signal interruption technology to record flight time during the vertical jump. The second device is an inertial measuring unit (IMU) to estimate velocity, power and position of the object to which is attached to (typically a barbell). In the end both devices showed system and proportional bias for several jump modalities, with the Optojump the reliability was poor even for the SJ which was good for all other devices.

The Push Band 2.0, for what we can extrapolate from these two studies [33,34] is not the best choice when it comes to RSI evaluation or Peak Power (PP) because of his poor reliability over the compared Gold Standard (the force plate was used as a reference in both studies).

Of the remaining studies who consider jump testing reliability in comparison with the reference standard one study[32] assessed flight times with the Optojump and the Myotest, an accelerometer-based system, in rugby players while performing a CMJ. These instruments can be used under field conditions and used both as a screening tool in pre-season or in a rehabilitation program to track the athlete's improvement. Reeve TC. et al.[28] used the Smartjump contact mat which is a less expensive instrument to calculate vertical jump height (VJH) if we compare it to the force platform. This instrument has several limitations: it can only obtain VJH and peak power (PP) values from other variables like take off velocity (TOV) and time in air (TIA) using a validated equation and it tents to overestimate these data against the force platform.

Other authors [29] describe a linear position transducer compared to a force plate with loaded jump squat in elite athletes. Again, the problem with this technology is the variation of measurement which is generally greater when using position data to calculate force. Another article [26] assessed a jump battery test for his reliability. This time three hop tests and jump test were combined in a cluster together with leg power tests. The protocol used was efficient in detecting strength deficits in athletes and authors conclude that it could be used in late rehabilitation process.

5.1.3 RM

The study from Urquhart BG. et al. [37] is trying to see if it is possible to assess bilateral squat and split squat in the same session. The fact that the selected population are subjects that are not familiar with these type of movements is really interesting from this review's perspective. In fact, people in this study underwent a familiarization session prior to the testing session. For physical therapists who are interested in assessing strength with maximal repetition method it is important that they introduce the patient to the exercise selected for the test. This will influence the motor learning component of the subject and will guarantee a better and more reliable performance in the test. From this kind of assessment (RM) the clinician should obtain the maximal strength output that the patient is capable to exert; generally, the closer it gets to the one repetition maximum (1RM), the more is reflective of strength level of the patient. However, the 1RM is not always the best choice in clinical practice because patients might be reluctant to do that and because of safety reasons. To overcome this problem, we can use multiple repetition test which are reliable within the 5 repetitions (5RM) and then calculate the 1RM with a validated equation. Other tow studies [35,36] focused on unilateral leg strength symmetry. One [36] is using the leg press, leg curl and leg extension machines, while the second one [35] is assessing the 5RM with the rear foot elevated split squat. Investigating strength symmetry is a fundamental concept in rehabilitation and is critical for between-limb clinical decision making. The results of these studies showed good reliability and physiotherapists who are treating lower limb (LL) musculoskeletal conditions should always monitor strength deficits with this method. When treating LL tendinopathies or post-surgical patients (like anterior cruciate ligament reconstruction) protocols often refer to limb symmetry index (LSI): the RM, together with the isometric dynamometer, is the most immediate way to track progresses and detect imbalances comparing the affected vs the non-affected leg. Bazyler CD. et al. [45] examine the relationship between isometric squat kinetic variables and isoinertial strength measures. The isometric squat was performed at 90° and 120° of knee flexion. This approach can provide strong indication of changes in strength and explosiveness and has the advantage of using a static muscle contraction. This is useful in clinical practice because it eliminates the potential errors of an isotonic squat which can be affected by bad technique, inability of the patient to reach the bottom position and tracking of the knee and hip range of motion.

5.1.4 Sit-to-Stand

Two studies [38,39] compare the STS to a reference standard, the first [38] with a Isokinetic dynamometer and the second [39] with a Force Platform and the aid of a 3D camera system (Optojump system). For the Sit-to-Stand assessment we can say that the test is quick, relatively inexpensive, safe, and portable and thus should be considered for use in aging research. However, this test is more suitable for older patients who are experiencing a power declination as often happens in elderly people. The results of these two studies are very promising in terms of validity and reliability in measuring lower body power in community-dwelling older adults.

5.1.5 Other

Two studies [42,43] only described foot muscle assessment. Bruening et al. [42] used three different devices (custom toe flexion dynamometer; custom doming dynamometer; pressure mat) both in seated and standing position. Authors suggest that these devices and protocols can be duplicated in the clinic to evaluate and monitor rehabilitation progress in clinical populations associated with foot muscle weakness, however, the availability of such instruments is not common in physiotherapy facilities, except for the pressure mat. Therefore, this study remains an interesting starting point for further research and perhaps a distribution of these tools for the foot strength assessment.

A useful method to test plantar flexors was proposed in Andre et al. study [43]. For this test no equipment is required as it consists of a 30 second timed test where the subject is instructed to execute as many calf raise repetitions as possible, reaching the same height every time. This is an immediate and effective method to quantify ankle-foot strength and can be adapted to patients who have suffered from an ankle sprain, Achilles tendinopathy or ankle foot surgery. In this article a bilateral calf raise is performed but in rehabilitation we can assess the difference of the affected vs non-affected side using the single leg variation and then calculate the limb symmetry index (LSI) to detect strength and quality of movement deficits. This method was confronted with IKD and showed great validity and the tested population are older adults: this confirms even more the applicability of this kind of assessment in clinical practice.

5.2Limitations

Some methodological limitations should be recognized in this review. First of all, the heterogeneity in the study population did not allow a proper comparison among the included articles. Another factor regarding population that can affect the results of some studies is the inadequate sample size: most of the studies selected are assessing strength in small groups of participants and their validity is therefore limited. Moreover, studies differ in some characteristics of the examined intervention and in the observed outcome.

Another limitation of the review is that it analyses only observational studies, which are qualitatively inferior in the context of primary studies. RCTs and systematic reviews could not be included since they did not meet the eligibility criteria of the research.

Another constraint is the use of QUADAS-2 Tool to assess the risk of bias of included studies. This tool was originally proposed to assess the quality of primary diagnostic accuracy studies, but it is used in this review, since there is not a specific gold standard for the assessment of risk of bias for observational studies. As this checklist has been validated for diagnostic accuracy studies, some items of the tool were not applicable and were considered incorrect. Therefore, the methodological quality scores may not entirely reflect the quality of articles included in this review.

Finally, acknowledged the already mentioned heterogeneities and methodological inaccuracies, it has not been possible to perform a meta-analysis for this narrative review.

6. CONCLUSION

From the literature reviewed in this study regarding strength assessment we can affirm that there are many and various ways to test muscles in healthy subjects. Even if the validity of these methods applied with patients in clinical practice is yet to be confirmed, we can make some practical considerations.

The studies that considered isometric testing with digital dynamometer showed good consistency and reliability: they offer standardized protocols for testing, ensuring consistency across different individuals and testing sessions. These devices have been tested in population of different ages, from the older inactive adults to young athletes: this suggests that they could be used with any kind of patient in clinical practice. Another advantage of the dynamometer is its versatility because it can be used in a wide range of applications and assessment options. Moreover, they are portable and easy to use, making them convenient for use in various settings such as clinics, research laboratories and even at home. They are generally user-friendly and require minimal training to operate. That been said, the stabilized dynamometer has several limitations. Even if it gives quantitative data, providing objective numerical values for strength levels, it has a limited functional relevance: it can only measure strength in specific muscle groups, not giving any information of the overall strength of the subject, and does not always correlate with functional performance in daily activities or sports. It is also important for clinicians willing to use this method in practice to understand that positioning and technique used during strength assessments can influence the results. It may be challenging to ensure consistent standardized positioning across different testers or testing sessions, which could introduce some variability in the measurements. It's important to note that digital dynamometers can be a valuable tool in assessing strength in clinical and rehabilitation setting. However, they should be used in conjunction with other assessment methods and interpreted within the context of specific goals and requirements of the assessment.

The studies that considered jump and hop tests have more functional relevance compared to the static strength tests because they simulate real-life movements that involve force production and power generation. They have a direct applicability to activities like sports, where explosive lower body strength is crucial. Assessing strength through these tests can provide insights into an individual's ability to generate force and power in functional movements. However, the main limitation of jump tests is that their applicability with patients can only be implemented in young athletic population because of the higher forces exerted on the lower body. If performed incorrectly, they may pose a risk of injury, particularly for individuals who are untrained, have underlying musculoskeletal conditions, or lack proper guidance and supervision. For these reasons it makes sense to use this approach in the late stage of rehabilitation or in return to sport programs. Another factor that clinicians should take into account when assessing with jump and hop tests is that the performance is influenced by factors other than strength. Jump and hop tests ca be affected by technique, flexibility, balance, and coordination. While strength is a critical component, these additional factors can impact an individual's performance, making it challenging to isolate and measure strength alone.

The repetition maximum (RM) approach is a well-established and widely used method in strength training and exercise science. It provides a standardized protocol for measuring and comparing strength levels across individuals and studies, making it easier to establish norms and benchmarks. Some of the studies selected for this review used this method with good results in older subjects or people who are unfamiliar to resistance training; this suggests that physiotherapists could use this approach for the assessment of strength in a wide variety of patients. However, individuals with limited experience or inadequate technique may not achieve their true maximum strength, leading to potential underestimation or overestimation of their abilities. For this reason, submaximal loads, preferably within a five-repetition range, can be used with musculoskeletal patients instead. In summary, while RM strength assessment can be suitable in certain cases within physical therapy, it should be used judiciously, with consideration of the individual's condition, goals, and safety. Physical therapists should assess each patient on an individual basis, taking into account their specific needs and abilities, and utilize a range of assessment methods to gain a comprehensive understanding of the individual's functional capacity and progress.

As for the other testing procedures evaluated in this review, the sit-to-stand method is interesting from this review perspective. It is simple, accessible, and cost effective, making it suitable for clinical or resource-limited settings. Its relevance in terms of functional activity is high since it reflects the ability to rise from a seated position. Although there are general guidelines for performing the STS test, the main concern for practitioners is the lack of standardized protocols regarding chair height, arm position and test duration. This lack of standardization may affect the consistency and comparability of results across different studies or settings.

Other types of intervention were evaluated by studies included like linear transducers, accelerometers, and smartphone mobile applications. However, the use of these methods is relatively new and yet is not possible to recommend its implementation in clinical practice. Further studies should deepen the validity and applicability of such technologies in physical therapy facilities.

In conclusion, evidence is not sufficiently strong to support the use of a method over another one, but it is possible to combine these approaches with patients, considering pros and cons, to have a more complete strength-velocity profile.

7. KEY POINTS

- There are many valid and reliable methods to assess strength in healthy subjects that could possibly be implemented in clinical practice for musculoskeletal practitioners willing to test their patients.
- Different types of tests are assessing different strength qualities and that should be considered when applying these interventions to healthy and unhealthy population.
- Direct measures of strength levels, such as dynamometer and RM method, are more reliable in older or untrained subjects, whereas jump and hop tests are more suitable for young athletic population.
- To make strength assessment more objective and reliable, physical therapists should stop using manual muscle testing and instead use more valid and scientific approach.

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