

Systematic Review

Handgrip Strength as an Indicator of Overall Strength and Functional Performance—Systematic Review

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Abstract: Reduced muscle strength can affect daily activities, so monitoring is essential. Methods such as isokinetic dynamometers assess maximum muscle force, while hand dynamometers measure hand grip strength. Research has investigated hand grip strength as a predictor of upper, lower and total strength, but the results remain unsystematic. The aim of this study was to systematize the current state of knowledge to test whether hand grip strength can be used as an indicator of overall strength and functional performance. A review of studies from 2000 to 2023 was conducted using: ScienceDirect, PubMed and GoogleScholar. The focus was on articles that examined the relationship between hand grip strength and muscle torque. The following keywords, entered in different configurations, were used in the search: ‘hand grip’, ‘muscle strength’, ‘correlation’ and ‘association’. A total of 22 studies were selected for analysis, involving 752 healthy adults, 30 physically active people, 120 ill adults, 2965 older people and 112 ill older people. The analysis looked at associations between hand grip strength and muscle moments of the trunk, limbs and knee joint. The results from the literature indicate that the value of the correlation between hand grip strength and muscle torque varies (from low to high) depending on the test method or group. Therefore, caution should be exercised when using hand grip strength as the sole measure of overall strength and functional performance.



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Keywords: handgrip strength; muscle strength; dynamometer; isokinetic contraction; isometric contraction; correlation

1. Introduction

Muscle strength is the ability to overcome an external resistance or counter it with a muscular effort. In order to put the body into motion, keep balance or control the posture and stability of joints, contractions of certain muscle groups are necessary to generate certain forces [1,2].

Evaluation methods of muscle strength can be divided into tests making use of measuring equipment (manual dynamometer, muscle force testers, medical dynamometers, isokinetic dynamometers) and motion tests (e.g., bar pull-ups, weightlifting, load tests). The application of isokinetic dynamometers is one of the most precise methods of the evaluation of maximum force moments and the determination of muscle efficiency [3–5]. Such dynamometers enable the performance of dynamic tests with a pre-set angular velocity and pre-set crank resistance, which makes it possible to conduct tests in a full motion range at a maximum contraction of muscles [4]. The measurement of muscle strength is a quite popular test and that is the reason why more and more attempts are made to develop a standardized protocol [6,7].

Measurements performed with the above-mentioned equipment enable the identification of decreased moments of muscle forces, which may result from aging processes. Such measurements make it possible to also plan and devise personalized rehabilitation blueprints, as well as assess their efficiency. However, this solution has two disadvantages: an isokinetic dynamometer is an expensive apparatus and such a test is time-consuming [5,8]. An alternative test of musculoskeletal strength capacity is the use of stands with properly fitted hand dynamometers, allowing for measurement in the target area.

Hand grip strength (abbreviated as HG or HGS in the scientific literature) is one of the simplest and most frequent methods of measuring muscle strength in clinical conditions [9–11]. For this reason, it has been the focus of interest of many scientists all over the world for a long time. As early as 1981, the American Society of Hand Therapists elaborated recommendations for the clinical assessment of hand grip strength [10]. In accordance with their guidelines, the position during the examination should be as follows: the patient should be seated with his/her shoulder adducted and neutrally rotated, elbow flexed at 90°, and the forearm and wrist in a neutral position [10]. In the above-described position, the individual tested grips the dynamometer at their maximum strength.

The hand grip strength test serves the purpose of a diagnostic indicator, providing information, for instance, on the patient's nutritional condition, or the purpose of a predictive factor, for example, of post-operative complications [12,13], injuries [14], development of diabetes [15], mineral density of bones [16,17], dementia [18], and sarcopenia [19], as well as general health prognosis, i.e., mortality rate [20] and a prophylactic means in the screening tests [21].

The examination using a dynamometer may serve as a quick screening test, enabling a regular evaluation of strength abilities [22]. In the scientific literature, one may find studies searching for the dependence between hand grip strength and moments of muscle forces [11,23–26]. The prediction of a muscle strength value on the basis of grip strength alone would be beneficial, first of all, due to its simplicity and a short time of examination, as well as a lower price of the isometric dynamometer in comparison to the isokinetic dynamometer. However, it is disputable whether the results of hand grip strength should be used as a predictor of general strength abilities. In the scientific literature, studies can be found identifying the existence of a relationship between hand grip strength and muscle force moments [11,23,24], and studies which ascertain the lack of such a dependence [25,26]. Due to the existing considerable controversies, the following objective was formulated: to systemize the current state of knowledge, enabling the verification of whether hand grip strength can be used as an indicator of overall strength and functional performance. Functional performance, understood as the ability of muscles to generate force, is measured by isokinetic dynamometers. The muscle force-generating capacity analyzed refers to the efficiency with which muscles perform a variety of force-requiring tasks relevant to daily activities and various physical and sporting activities.

2. Materials and Methods

In the period from December 2023 to January 2024, the following databases of articles were searched: Sciencedirect, PubMed and Google Scholar, in order to review the existing research which presents the relationship/dependence between hand grip strength and muscle strength or general muscle strength. The search was limited to the period between 2000 and 2023. The search algorithm used the PICOS approach (population, intervention, comparator, outcomes and study design). This systematic review was conducted according to the PRISMA guidelines [27]. During the search, the following key words were used in all of the databases using the indicated Boolean operators.

- Hand grip AND muscle strength;
- Handgrip AND muscle strength;
- Hand grip AND muscle strength AND correlation OR association;
- ((lower limb strength) OR (upper limb strength)) AND (hand grip strength).

Diagrams were elaborated for individual entries, showing a change in the number of articles published in particular years (Figure 1).

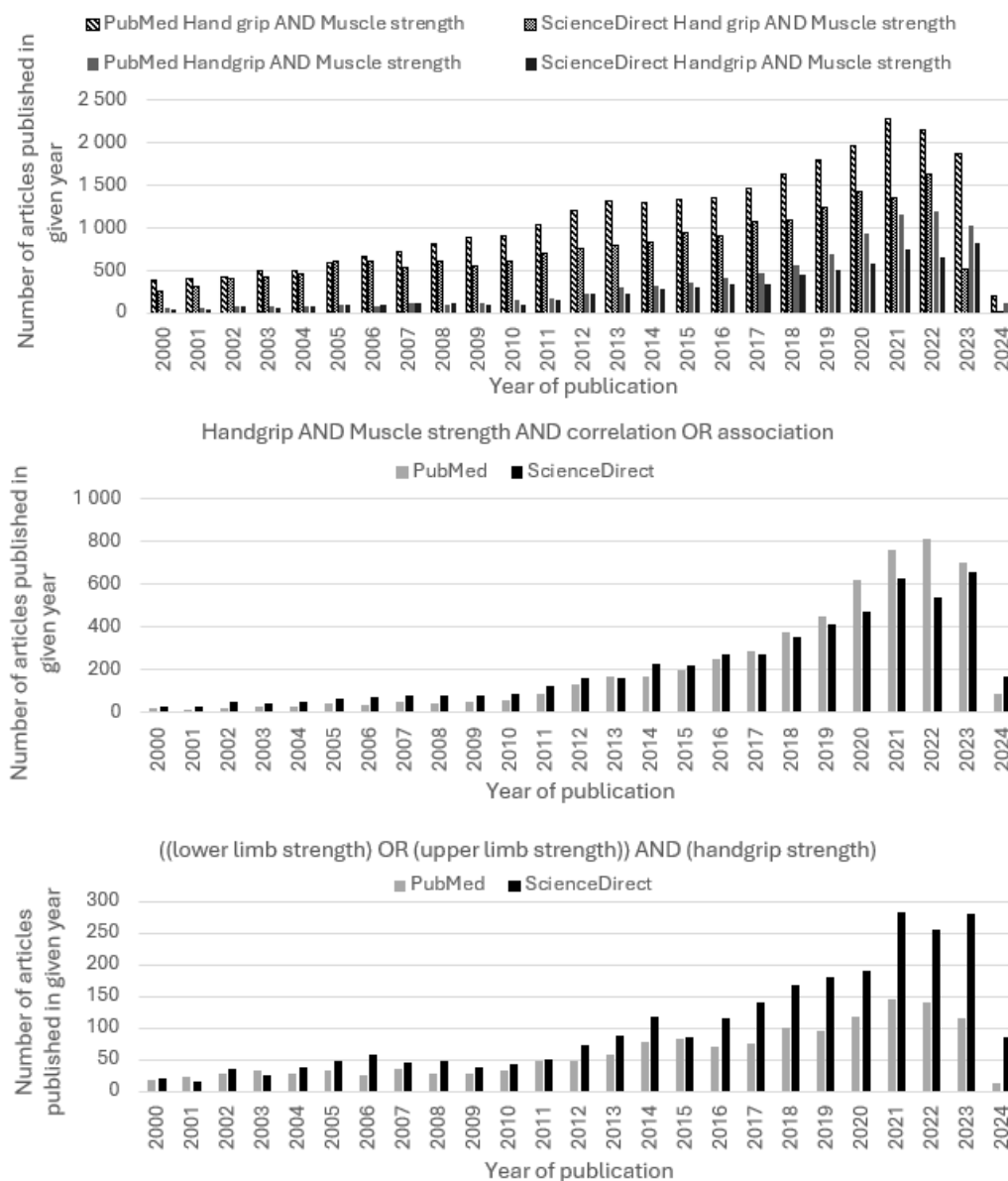


Figure 1. Number of articles published in a given year depending on a key word and the database of the articles.

Figure 2 presents subsequent steps in the search for articles, along with the number of articles which comply with the assumed criteria.

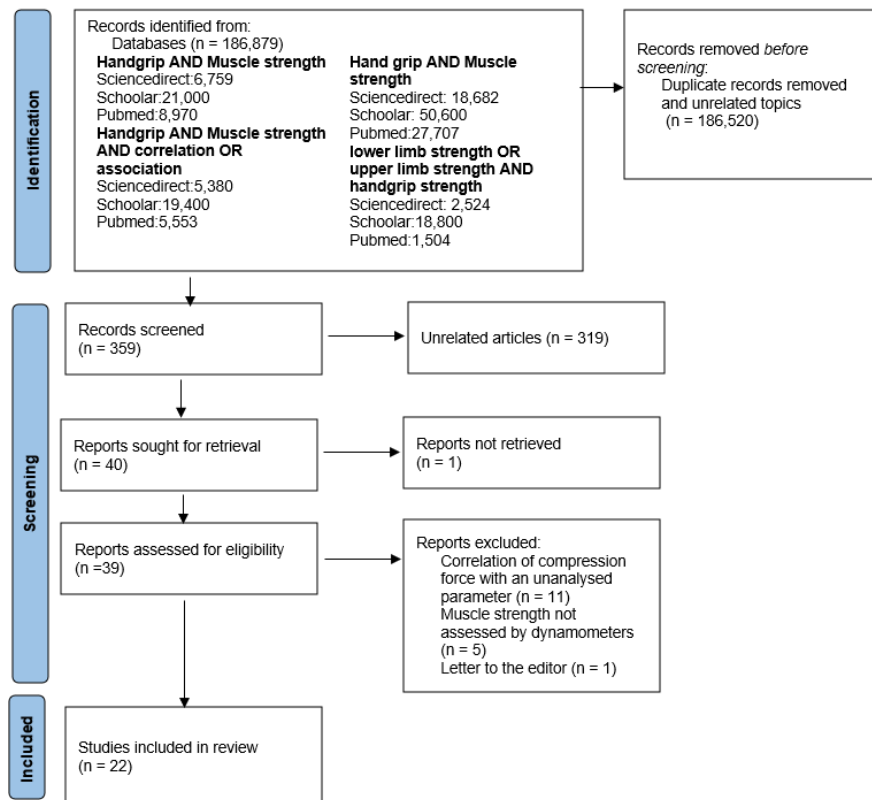


Figure 2. PRISMA flow diagram for systematic reviews.

2.1. Eligibility Criteria

The PICOS criteria were employed to select eligible studies. The inclusion and exclusion criteria for this systematic are detailed in Table 1. The focus was put on the cross-sectional studies which aim to verify the relationship between hand grip strength and the moments of muscle forces and/or assess whether hand grip strength may be a predictor of muscular strength. The study of the problem under investigation (correlation between hand grip strength and muscle force moments) does not require analysis of changes over time. Cross-sectional studies are widely used, allowing for an easier comparison of the results. In addition, the inclusion criterion was narrowed down to the search for the articles in which dynamometers (and not physiotherapeutic tests) were used for the muscle strength assessment. Two reviewers extracted the data independently, and discrepancies were identified and resolved through discussion.

Table 1. Selection criteria used according to the PICOS model.

PICOS Category	Inclusion Criteria	Exclusion Criteria
P (Population)	Participants of different ages, both healthy and with chronic diseases. Participants in studies in which HGS and the moments of muscle forces (e.g., lower or upper limb joints, trunk) were measured.	Participants in which HGS and muscle strength were not measured.
I (Intervention)	The study, which used a dynamometer to measure hand grip strength and assess the moments of muscle forces at joints.	Studies without the HGS measurement tool described or using physiotherapy tests to assess the moments of muscle forces.
C (Comparators)	Studies that determined the correlation between HGS and the moments of muscle forces.	No analysis of the correlation of HGS with the moments of muscle forces.
O (Outcomes)	Results on the relationship between HGS and the moments of muscle forces; analysis of the value of the correlation coefficient r or prediction.	Articles that did not analyze the relationship between HGS and the moments of muscle forces; no r -value or prediction was analyzed.
S (Study designs)	Cross-sectional studies, cohort studies.	Case studies (e.g., <5 participants per group), descriptive studies.

2.2. Quality Assessment

Two authors (PS and HZ) independently assessed the methodological quality of each included study using a modified version of the Downs and Black checklist [28]. The original version of the checklist consists of 27 questions, but for the purposes of this review, some questions were omitted due to the difficulty of assessment, mainly because they refer to intervention studies. Questions 1, 2, 3, 6, 7, 10, 11, 12, 18, 20, 21 and 22 were analyzed. The selected questions assess an element such as the aims, methods, data and results of the studies, external validity, internal validity and bias of the studies. Higher quality scores mean that a higher percentage of the criteria were met. Any disagreement about the methodological quality of the studies between the two authors was first discussed and consensus was sought. If consensus could not be reached, a third reviewer (KNL) made the final decision.

3. Results

Following the literature review, 22 articles were selected for the analysis. Quality assessment scores for the included studies ranged from 9 to 12. The percentage scores ranged from 75 to 100% (mean = 85.61%, SD = 6.73). All articles analyzed had a clearly defined aim and hypothesis, and were of high methodological quality. In 16 articles, the main results of the study were clearly described. A detailed breakdown of the results was presented in 18 articles. In half of the articles analyzed, there was no information about the time of recruitment of the study group (Table 2).

Their analysis process was divided into three parts: dependence between hand grip strength and the values of moments of muscle forces in upper limbs (Table 3), dependence between hand grip strength and the values of moments of muscle forces in lower limbs and the trunk (Table 4), and dependence between hand grip strength and the values of moments of muscle forces in the knee joint in isokinetic and isometric conditions (Table 5).

3.1. Dependence Between Hand Grip Strength and the Values of the Moments of Muscle Forces in Upper Limbs

The authors sought dependences between hand grip strength and the moments of muscle forces in upper limbs [23,29–33]. The tests were performed in various positions: in a sitting position with an elbow flexed [23,30,33] or extended [31], in a standing position with an upper limb hanging by the side of the body [29,32], and an upper limb elevated [29]. In their research, the authors took into consideration different groups of individuals. The dependences between hand grip strength and muscle strength were sought after, for instance, in a group of patients with chronic hemiparesis due to stroke [30], healthy athletes [29], volleyball players of the national representation of Brazil [23], people with shoulder pain, weakness, MRI-confirmed RC tears [31] and patients with spinal cord injury, with the time since the injury of at least 6 months [33]. The tests also included healthy individuals, both at a young and elderly ages [32].

Mandalidis et al. [29] checked at which position of the upper limb, during the measurement of hand grip strength, the highest values of correlation with the moments of muscle forces were achieved in the joints of upper limbs. They also investigated which value obtained from the measurements, the mean value of the highest moments of muscle forces or the value of the highest single moment, was more strongly correlated with the values of hand grip strength. The results of their research showed that the highest values of the Pearson correlation were reached when the correlation was performed between the mean values of the moments of muscle forces and hand grip strength when the elbow was flexed at an angle of 90 degrees. This position produced correlation coefficient R for the limbs dominating in the range from 0.42 to 0.71 in the case of shoulder abductors, from

0.45 to 0.66 in the case of elbow flexors, and from 0.4 to 0.54 in the case of shoulder rotators. The results of the correlation were statistically significant ($p < 0.05$), except for the results obtained in the case of internal rotators of the shoulder. The authors ascertained that hand grip strength could be used as a strength indicator of shoulder stabilizers (with a certain caution). Ahmadi et al. [23] also pointed out that hand grip strength is linearly correlated with the values of force moments of internal and external rotators of the shoulder measured in isokinetic conditions (R from 0.23 to 0.72). It was also confirmed by Nascimento et al. [30] by obtaining higher values of the Pearson correlation, i.e., from 0.6 to 0.82 (all results statistically significant $p < 0.05$). On the basis of this range, authors came to the conclusion that in the case of a lack of isokinetic dynamometers, the measurement of hand grip strength could be used to monitor the strength of stabilizers. Team Manske et al. [31], on the basis of analyses, obtained the Pearson correlation values for abductors amounting to 0.378, whereas the value of the rotator cuff (RC) was slightly higher and amounted to 0.421. The authors drew attention to a weak linear correlation between the loss of hand grip strength and abduction strength ($r = 0.27$), and RC ($r = 0.193$). No dependences were found between hand grip strength and the rotator cuff dysfunction. The researchers assessed that hand grip strength should not be used solely for the diagnosis of the RC injuries. On the basis of the conducted tests, Roman-Liu et al. [32] pointed out changes in the muscle strength values of upper and lower limbs occurring with increasing age in a group of men and women. The values of the Pearson correlation obtained by the researchers between hand grip strength and the values of muscle force moments equaled 0.3–0.6 in the case of women and 0.35–0.65 in the case of men (all coefficients were statistically significant $p < 0.01$). The researchers found that in most cases, hand grip strength was weakly correlated with the moments of forces in upper and lower limbs.

Table 2. Quality assessment scores for the included studies.

Study	1	2	3	6	7	10	11	12	18	20	21	22	Total	%
Mandalidis et al. (2010) [29]	1	1	1	1	0	1	1	1	1	1	1	1	11	91.67%
Nascimento et al. (2012) [30]	1	1	1	0	1	1	0	1	1	1	1	1	10	83.33%
Ahmadi et al. (2020) [23]	1	1	1	1	1	1	1	0	1	1	1	1	11	91.67%
Manske et al. (2021) [31]	1	1	1	1	0	1	1	1	1	1	1	0	10	83.33%
Roman-Liu et al. (2021) [32]	1	1	1	0	0	1	1	1	1	1	1	1	10	83.33%
Neto et al. (2021) [33]	1	1	1	1	1	1	1	1	1	1	1	0	11	91.67%
Strandkvist et al. (2021) [11]	1	1	1	0	1	0	1	1	1	1	1	1	10	83.33%
Mello Porto et al. (2019) [34]	1	1	1	1	1	1	1	1	1	1	1	1	12	100.00%
Samuel and Rowe(2012) [35]	1	1	1	0	1	1	1	1	1	1	0	0	9	75.00%
Rodacki et al. (2020) [26]	1	1	1	1	1	1	1	1	1	1	1	0	11	91.67%
Wind et al. (2010) [36]	1	1	1	0	1	1	1	1	1	1	0	0	9	75.00%
Felício et al. (2021) [37]	1	1	1	1	1	1	1	1	1	1	1	0	11	91.67%
Alonso et al. (2018) [38]	1	1	1	0	1	1	1	1	1	1	0	1	10	83.33%
Felicio et al. (2014) [24]	1	1	1	1	1	1	0	1	1	1	1	1	11	91.67%
Jenkins et al. (2014) [39]	1	1	1	1	1	1	1	0	1	1	0	1	10	83.33%
Bohannon (2012) [40]	1	1	1	1	1	1	1	1	1	1	1	0	11	91.67%
Bohannon et al. (2012) [41]	1	1	0	1	1	1	1	1	1	1	1	0	10	83.33%
Yeung et al. (2018) [25]	1	1	1	1	1	0	1	1	1	1	0	0	9	75.00%
Yeung et al. (2018) [42]	1	1	1	1	1	1	0	1	1	1	1	1	11	91.67%
Buendía-Romero et al. (2021) [8]	1	1	1	1	1	1	0	1	1	1	1	0	10	83.33%
Chan et al. (2014) [43]	1	1	1	1	0	1	1	1	1	1	0	0	9	75.00%
Samuel et al. (2012) [44]	1	1	1	1	1	1	1	0	1	1	0	1	10	83.33%

Table 3. Measurement methodology of hand grip strength and muscle strength in the upper limb, the mean values of the parameters tested and correlation values, and the conclusions drawn.

Author and Year	Participants + Characteristics	Device and Position for Measuring Hand Grip Strength	Torque Measurement Device and Position	Hand Grip Force Values	Hand Grip Force Values Recalculated by the Authors	Moments of Strength				Conclusions
						Correlation Value				
Mandalidis et al. (2010) [29]	18 healthy male athletes (mean age 25.7 years)	Lafayette, standing, the shoulder at 0°, 90°, and 180° of flexion and the elbow in full extension	Kin Com II, dominant and non-dominant internal and external rotators and abductors of the shoulder as well as the flexors of the dominant and non-dominant elbow examination with velocity 60°/s	Dominant 90° 42.7 ± 6.3 [kg]; Non-dominant 90° 41.7 ± 6.6 [kg];	Dominant 90° 418.74 ± 61.78 [N]; Non-dominant 90° 408.95 ± 64.72 [N];	Average moment Shoulder internal rotation 60°/s [Nm]	Average moment Shoulder external rotation 60°/s [Nm]	Average moment Shoulder abductors 60°/s [Nm]	Average moment Elbow flexors 60°/s [Nm]	The tests showed a positive correlation between squeeze force and isokinetic torque. According to the authors, HG isometric force can be used to monitor the isokinetic strength of certain muscle groups (with some caution).
						dominant 35.1 ± 7.4 non-dominant 33.2 ± 9.1	dominant 24.0 ± 4.9 non-dominant 23.1 ± 4.3	dominant 54.2 ± 7.9 non-dominant 52.2 ± 8.4	dominant 44.6 ± 10.1 non-dominant 43 ± 6.9	
						Pearson correlation				
						dominant r = 0.29 non-dominant r = 0.34	dominant r = 0.54 (p < 0.05) non-dominant r = 0.33	dominant r = 0.62 (p < 0.01) non-dominant r = 0.61 (p < 0.01)	dominant r = 0.51 (p < 0.05) non-dominant r = 0.52 (p < 0.05)	
Nascimento et al. (2012) [30]	12 with chronic hemiparesis due to stroke (6 man, 6 woman—age mean 52 ± 10.5 years)	Jamar, sit on a chair with their elbows flexed at a 90° angle	Biodex System-3 Pro, Isokinetic measures of peak torque and work during shoulder rotations and scapular protraction-retraction movements were obtained with the isokinetic dynamometer at a speed of 60°/s.	Paretic: 15.0 ± 10.4 [Nm] Non-paretic: 33.0 ± 9.3 [Nm]	----	Shoulder internal rotation—60°/s [N/kg × 100]	Shoulder external rotation—60°/s [N/kg × 100]	Scapular protraction—60°/s [N/kg × 100]	Scapular retraction—60°/s [N/kg × 100]	The test indicated statistically positive association between isometric HG force and isokinetic peak torque. The authors suggest that in the absence of isokinetic dynamometers or isometric HG force measurements can be used clinically to monitor the strength level of shoulder stabilizers.
						Paretic: 18.6 ± 7.3 Non-paretic: 31.6 ± 7.6	Paretic: 18.2 ± 7.3 Non-paretic: 31.0 ± 5.8	Paretic: 172.0 ± 71.9 Non-paretic: 311.8 ± 95.6	Paretic: 214.0 ± 75.1 Non-paretic: 334.8 ± 99.2	
						Pearson correlation				
						Paretic: r = 0.82 (p = 0.001) Non-paretic: r = 0.81 (p = 0.001)	Paretic: r = 0.61 (p = 0.035) Non-paretic: r = 0.74 (p = 0.007)	Paretic: r = 0.60 (p = 0.039) Non-paretic: r = 0.67 (p = 0.039)	Paretic: r = 0.72 (p = 0.008) Non-paretic: r = 0.71 (p = 0.010)	
Ahmadi et al. (2020) [23]	12 players of the Brazilian national sitting volleyball team (6 F/6 M) aged between 20 and 40 years (mean age: 33.2 ± 6.1)	Jamar, sit on a chair with their elbows flexed at a 90° angle	Biodex System 4 Pro, The shoulder internal rotation (IR) and external rotation (ER)—According to the manufacturer’s recommendations examination with velocity 60°/s and 180°/s	Dominant: 47 ± 12.6 [kgf] Non-dominant: 40.1 ± 9.4 [kgf]	Dominant: 460.91 ± 123.56 [N] Non-dominant: 393.24 ± 92.18 [N]	Shoulder internal rotation 60°/s [Nm]	Shoulder external rotation 60°/s [Nm]	Shoulder internal rotation 180°/s [Nm]	Shoulder external rotation 180°/s [Nm]	HG strength is correlated with isokinetic data on shoulder external rotator strength in Brazilian Sitting Volleyball players. The authors conclude that in the absence of isokinetic dynamometers, isometric HG force measurements could be used to monitor shoulder external rotator muscle strength levels.
						Dominant: 57.1 ± 17.2 Non-dominant: 50.4 ± 11.3	Dominant: 43.5 ± 12.8 Non-dominant: 38.5 ± 7.8	Dominant: 57.4 ± 15.7 Non-dominant: 53.7 ± 11.3	Dominant: 40.9 ± 10.6 Non-dominant: 35.8 ± 6.6	
						Pearson correlation				
						Dominant: r = 0.42 Non-dominant: r = 0.42	Dominant: r = 0.67 (p < 0.05) Non-dominant: r = 0.33	Dominant: r = 0.23 Non-dominant: r = 0.5	Dominant: r = 0.51 Non-dominant: r = 0.58 (p < 0.05)	
Manske et al. (2021) [31]	47 patients The average age of all patients was 59.8 years, ranging from 34–74, presenting with shoulder pain, weakness, and MRI-confirmed RC tears	Jamar, seated upright in a chair with the arm hanging straight down	Lafayette Instrument Company, Lafayette, Abduction strength was measured while the subject was seated with the shoulder in 90° of abduction, or within available range of motion, and 90° of elbow flexion. External rotation (ER) force was measured when the patient was sitting with the shoulder in a neutral position and the elbow in 90° flexion and 0° pronation/supination	Hand grip strength (affected), 27.8 ± 11.0 [kg] Hand grip strength (healthy) 30.2 ± 10.4 [kg]	Hand grip strength (affected), 272.62 ± 107.87 [N] Hand grip strength (healthy) 296.16 ± 101.98 [N]	Shoulder external rotation—neutral position (affected) [kg]	Shoulder external rotation—neutral position(healthy) [kg]	Shoulder Abduction strength (affected) [kg]	Shoulder Abduction strength (healthy) [kg]	It was found that hand grip strength did not correlate with rotator cuff (RC) strength. Grip force should not be used to diagnose RC failures.
						6.9 ± 3.4	8.7 ± 3.5	5.2 ± 2.9	6.8 ± 2.7	
						Pearson correlation				
						r = 0.421 (Statistical significance)	Not performed	r = 0.378 (Statistical significance)	Not performed	
Roman-Liu et al. (2021) [32]	240 persons, (4 groups of 60 persons each: two groups of women and men (18–30 years old) and two groups of older women and men (55–67 years old))	VETEK, neutral position, standing upright, with the upper limb straightened along the body and the elbow fully extended (0 degrees)	Biodex Medical Systems, izometric, moments of: flexion and extension in the elbow, pronation and supination of the forearm, flexion and extension in the wrist joint, flexion and extension in the hip, flexion and extension in the knee and plantar flexion and dorsiflexion in the ankle (in a body position appropriate for the maximum strength capabilities of a given type of force)	No data available	No data available	No data available (values presented only in the graph)				In most cases, hand grip strength is poorly correlated with upper and lower limb strength moments. The best correlation is for pronation and supination of the forearm. The best approximation of the models developed is knee strength.
						Multivariate regression analysis was performed using generalized linear and nonlinear (GLZ) models with a power link function, with continuous age and hand grip strength predictors. The Pearson correlation coefficient was also calculated. No data available (values presented only in the graph).				

Table 3. Cont.

Author and Year	Participants + Characteristics	Device and Position for Measuring Hand Grip Strength	Torque Measurement Device and Position	Hand Grip Force Values	Hand Grip Force Values Recalculated by the Authors	Moments of Strength				Conclusions
						Correlation Value				
						Shoulder abduction [Nm]	Shoulder adduction [Nm]	Trunk flexion [Nm]	Trunk extension [Nm]	
Neto et al. (2021) [33]	108 patient with spinal cord injury time since injury of at least 6 months (20 Female, 88 Male) age—31.7 years	Saehan Corporation, with participants seated, shoulder adducted, elbow flexed to 90°, wrist in a neutral position, and the distal phalanges of the hand resting on the dynamometer handle	Biodex System 4 Pro, isokinetic shoulder abduction/adduction at 60°/s, isometric trunk flexion/extension—tests were performed at 55° and 105° in the sagittal plane for hip flexion and extension, respectively	Whole group 100.5 [kgf], Female 60.5 [kgf], Male 103.0 [kgf]	Whole group 985.56 [N], Female 593.3 [N], Male 1010.12 [N]	Whole group 61.1, Female 44.9, Male 63.8	Whole group 87.8, Female 62.3, Male 92.0	Whole group 48.4, Female 40.7, Male 52.6	Whole group 42.3, Female 38.2, Male 43.3	In this survey hand grip strength was a significant predictor only for maximum shoulder abduction/adduction moment.
						Linear multiple regression model				
						Whole group: r = 0.75 (p ≤ 0.05)	Whole group: r = 0.77 (p ≤ 0.05)	Whole group: r = 0.61 (p ≤ 0.05)	Whole group: r = 0.54 (p ≤ 0.05)	

Table 4. Measurement methodology of hand grip strength and muscle strength in the lower limb, mean values of the parameters tested and correlation values, and the conclusions drawn.

Author and Year	PARTICIPANTS + Characteristics	Device and Position for Measuring Hand Grip Strength	Torque Measurement Device and Position	Hand Grip Force Values	Hand Grip Force Values Recalculated by the Authors	Moments of Strength								Conclusions				
						Correlation Value												
Strandkvist et al. (2021) [11]	45 people, each over 70 years old (27 K/18 M)	E-LINK, sit on a chair with their elbows flexed at a 90° angle and to hold the dynamometer in a neutral position of the lower arm and hand	Biodex 3, Isometric, hip position—laying position with the knee joint at 90, abduction—laying down on the side and lower limb in a neutral position (0° hip and knee), knee (flexion/extension—seated position with the knee joint at a 30° flexion), ankle (plantar flexion and dorsiflexion)	All: Left: 279.5 ± 91.5 [N] Right: 293.8 ± 101.5 [N] Women: Left: 221.0 ± 42.4 [N] Right: 233.2 ± 40.3 [N] Men: Left: 367.5 ± 73.1 [N] Right: 389.9 ± 95.1 [N]	All: Left: 28.5 ± 9.33 [kgf] Right: 29.95 ± 10.35 [kgf] Women: Left: 22.53 ± 4.32 [kgf] Right: 22.78 ± 4.11 [kgf] Men: Left: 37.45 ± 7.45 [kgf] Right: 39.76 ± 9.69 kgf]	Hip extension 90° [Nm]	Hip abduction 90° [Nm]	Knee extension 30° [Nm]	Knee flexion 30° [Nm]	Ankle dorsal flexion -neutral position (0° ankle) [Nm]	Ankle plantar flexion neutral position (0° ankle) [Nm]	All muscle groups tested were significantly correlated with handgrip strength, meaning that there was a strong and valid model showing a relationship between hand grip strength and lower limb strength.						
						All: Left: 62.6 ± 19.9 Right: 70.6 ± 22.7 Women: Left: 37.1 ± 12.5 Right: 39.1 ± 12.5 Men: Left: 367.3 ± 73.1 Right: 389.9 ± 95.1	All: Left: 51.2 ± 24 Right: 55.5 ± 25.2 Women: Left: 37 ± 15.3 Right: 41.9 ± 15 Men: Left: 72.5 ± 18.2 Right: 75.9 ± 23.7	All: Left: 86.6 ± 29.4 Right: 84.2 ± 30.2 Women: Left: 69.1 ± 19 Right: 66.2 ± 19.5 Men: Left: 112.8 ± 21.6 Right: 111.3 ± 22	All Left: 67.8 ± 24.8 Right: 70.5 ± 27.2 Women Left: 51.7 ± 11.2 Right: 53.2 ± 13.8 Men Left: 91.9 ± 19.4 Right: 96.3 ± 21	All Left: 21.8 ± 8 Right: 23.5 ± 8.5 Women Left: 18.3 ± 5.6 [Nm] Right: 19.6 ± 5.3 Men Left: 27 ± 8.4 Right: 28.2 ± 8.9	All Left: 85.5 ± 35.6 Right: 81.8 ± 32.9 Women Left: 64.9 ± 21.9 Right: 64 ± 19 Men Left: 116.4 ± 29.5 Right: 108.5 ± 31.4							
						Orthogonal projection to latent structures (OPLS) regression model.												
						No data available (values presented only in the graph)												
Mello Porto et al. (2019) [34]	150 people, age range 60–80	Jamar, with the recommendations of the American Society of Hand Therapy	Biodex System 4 Pro, isometric, trunk extensors and flexors (at semi-standing position), hip abductors and adductors (lateral decubitus position, with the limb to be tested upward at 15° of hip abduction), hip flexors and extensors (positioned at 60° of hip flexion), knee flexors and extensors (positioned at 60° of knee flexion), ankle plantar flexors and dorsiflexors. The global muscle strength determined is the sum of the peak rotational moments of the trunk and the dominant muscle groups of the lower limbs—the joints studied.	25.5 ± 8.1 [kgf]	250.17 ± 79.14 [N]	Global muscle strength [Nm]	Ankle dorsal flexion, R—neutral position (0° ankle) [Nm]	Ankle plantar flexion, R—neutral position (0° ankle) [Nm]	Trunk extensor PT -semi-standing position [Nm]	Hip extensor PT—60° flex [Nm]	Hip flexor PT—60° flex [Nm]	Hip abductor PT—15° [Nm]	Hip adductor PT—15° [Nm]	Knee extensor PT—60° flex [Nm]	Knee flexor PT—60° flex [Nm]	The research showed that hand grip strength can be used to represent the global muscle strength of younger and older people living in the community, even when taking into account variables that may interfere with the relationship between measurements. However, hand grip strength alone does not eliminate the need to test different muscle groups if necessary.		
						684.31 ± 223.40	25.39 ± 9.25	57.11 ± 27.31	171.53 ± 59.13	63.88 ± 31.91	72.21 ± 26.95	34.68 ± 14.33	51.08 ± 17.43	48.68 ± 18.64	106.89 ± 37.94		52.86 ± 23.13	
						Pearson correlation												
						r = 0.69 (p < 0.05)	r = 0.369 (p < 0.05)	r = 0.557 (p < 0.05)	r = 0.528 (p < 0.05)	r = 0.7 (p < 0.05)	r = 0.476 (p < 0.05)	r = 0.673 (p < 0.05)	r = 0.627 (p < 0.05)	r = 0.511 (p < 0.05)	r = 0.615 (p < 0.05)		r = 0.68 (p < 0.05)	

Table 5. Measurement methodology of hand grip strength and muscle strength in the knee joint, mean values of the parameters tested and correlation values, and the conclusions drawn.

Author and Year	Participants + Characteristics	Device and Position for Measuring Hand Grip Strength	Torque Measurement Device and Position	Hand Grip Force Values	Hand Grip Force Values Recalculated by the Authors	Moments of Strength				Conclusions
						Correlation Value				
Felício et al. (2021) [37]	220 women over 65 years of age; division into groups according to the duration of TUG (over 10 s) over 10 s n = 127—group age: 71.2 ± 4.8; below n = 93—group age 70.6 ± 5.0;	Jamar, with the recommendations of the American Society of Hand Therapy	Biodex System 3 Pro, isokinetic; knee extensors was measured with the angular velocity selected was 60°/s	TUG > 10 s—20.4 ± 4.7 [kgf] TUG < 10 s-22.0 ± 4.2 [kgf]	TUG > 10 s—200.06 ± 46.09 [N] TUG < 10 s-215.75 ± 41.19 [N]	No data available				Knee extension strength and hand grip strength can be particularly useful indicators in screening for functional fitness in older people.
						Reduced backward linear regression model				
						Model 1 for TUG ≥ 10 s: r = 0.2 (p < 0.001)		Model 2 for TUG < 10 s: r = 0.06 (p = 0.03)		
Alonso et al. (2018) [38]	110 older women over 60	Jamar, with the recommendations of the American Society of Hand Therapy	Biodex Multi-Joint System 3, isokinetic; 60°/s knee	No data available	No data available	Knee extensor—dominant [Nm/Bw %]	Knee flexor—dominant [Nm/Bw %]	Knee extensor—Non dominant [Nm/Bw %]	Knee flexor—Non dominant [Nm/Bw %]	HG can be used as a substitute indicator of overall strength capacity for screening among older women.
						No data available				
						Spearman's correlation				
						Dominant: 0.43 (p < 0.001) Non Dominant: 0.39 (p < 0.001)	Dominant: 0.13 (p = 0.21) Non Dominant: 0.16 (p = 0.12)	Dominant: 0.35 (p < 0.001) Non Dominant: 0.38 (p < 0.001)	Dominant: 0.1 (p = 0.36) Non Dominant: 0.16 (p = 0.13)	
Felicio et al. (2014) [24]	221 older women, age: 71.07 ± 4.93	Jamar, with the recommendations of the American Society of Hand Therapy	Biodex System 3 Pro, isokinetic; knee -velocities selected were 60°/s with five repetitions and 180°/s	21.2 ± 4.6 [kgf]	207.41± 45.01 [N]	Knee 60°/s [Nm]	Knee 180°/s [Nm]	Knee 60°/s [%—normalized to body weight]	Knee 180°/s [%—normalized to body weight]	For healthy adults, isometric measurements of hand grip strength and knee extension reflect a common relationship, namely limb muscle strength.
						No data available				
						Spearman's correlation				
						Extensor: r = 0.26 (p = 0.101) Flexor: r = 0.16 (0.017)	Extensor: r = 0.15 (p = 0.025) Flexor: r = 0.09 (p = 0.172)	Extensor: r = 0.12 (p = 0.0.058) Flexor: r = 0.07 (0.288)	Extensor: r = 0.03 (p = 0.603) Flexor: r = 0.01 (0.790)	
Jenkins et al. (2014) [39]	16 man (72.1 ± 7.1 age)	TSD121C, Biopac Systems; with the recommendations of the American Society of Hand Therapy	Biodex System 3, isometric leg was flexed to 90°; isokinetic muscle actions of the leg extensors at 1.05 rad/s and 3.14 rad/s; (60°/s and 180°/s)	35.4 ± 0.1 [kg]	346.66 ± 1.17 [N]	Isometric knee extension	Isokinetic knee 60°/s	Isokinetic knee 180°/s		Isometric hand grip strength were not reliable and should not be used as outcome variables in older men. Therefore, hand grip strength may not be an adequate substitute for lower body strength.
						130.93 ± 1.43 [Nm]	118.48 ± 0.4 [Nm]	72.17 ± 3.12 [Nm]		
						Pearson correlation				
						r = 0.363 (not statistically significant)	r = 0.382 (not statistically significant)	r = 0.467 (not statistically significant)		
Bohannon (2012) [40]	34 people (61–93 age M-80.2 ± 8.1) (25 woman, 10 man) with coexisting diseases	Jamar, with the recommendations of the American Society of Hand Therapy	MicroFET2 hand-held dynamometer, isometric patients sat with their knees at 90° of flexion and their legs dependent	Left 157.0 ± 70.9 [N] Right 163.3 ± 74.2 [N]	Left 16 ± 7.23 [kgf] Right 16.65 ± 7.56 [kgf]	Left knee extension [N]		Right knee extension [N]		Grip and knee extension strength appear to reflect a common underlying construct (limb muscle strength) among patients treated in a home-care setting. When the intention of testing is to characterize limb muscle strength, either one might be used.
						141.8 ± 41.9		158.6 ± 44.1		
						Pearson correlation				
						Left Grip: r = 0.68 (p < 0.001) Right Grip: r = 0.56 (p < 0.001)		Left Grip: r = 0.61 (p < 0.001) Right Grip: r = 0.58 (p < 0.001)		
Bohannon et al. (2012) [41]	164 participants, 106 were women (50.6 ± 22.4) and 58 were men (45.6 ± 20.2) (age range 18–85 years mean age of the whole group 48.8 ± 21.7)	Jamar, with the recommendations of the American Society of Hand Therapy	Biodex, isometric with knees at 90 degrees	Left 326.0 ± 113.4 [N] Right 349.9 ± 119.6 [N]	Left 33.24 ± 11.56 [kgf] Right 35.68 ± 12.2 [kgf]	Left knees at 90° [Nm]		Right knees at 90° [Nm]		Isometric measurements of hand grip strength and knee extension in healthy adults reflect a common underlying construct.
						170.4 ± 73.1 (52.5–420.0)		171.7 ± 71.8 (39.7–416.4)		
						Pearson correlation				
						Left Grip: r = 0.782 (p<0.001) Right Grip: r = 0.772 (p<0.001)		Left Grip: r = 0.805 (p<0.001) Right Grip: r = 0.805 (p<0.001)		

Table 5. Cont.

Author and Year	Participants + Characteristics	Device and Position for Measuring Hand Grip Strength	Torque Measurement Device and Position	Hand Grip Force Values	Hand Grip Force Values Recalculated by the Authors	Moments of Strength					Conclusions
						Correlation Value					
Yeung et al. (2018) [25]	Research from various projects: MyoAge cohort: 181 young healthy individuals (aged 18–30 years) and 320 older healthy individuals (aged 69–81 years) Manchester Metropolitan University cohort: 42 young healthy individuals (aged 18–40 years) and 108 older healthy individuals (aged 60–90 years) Dehydroepiandrosterone in older individuals cohort: 68 healthy individuals: female and male individuals aged 60–80 years, Geriatric outpatients 163 older healthy individuals, Promoting Mobility after Hip Fracture cohort: 78 individuals with mobility problems	MyoAge cohort and geriatric outpatients: JAMAR Sammons Preston, Inc, Bolingbrook, IL position: upright standing position with their arms along the side while holding the dynamometer; MMU cohort: JAMAR Patterson Medical, Warrenville, IL position: upright standing position with their arms along the side while holding the dynamometer; DHEAge cohort: Baseline dynamometer, position: American Society of Hand Therapists instructions; ProMo cohort: Good Strength dynamometer, Metitur Ltd., Palokka, Finland, position: seated with supported and flexed at 90 degrees elbow	MMU cohort: custom-built dynamometer; DHEAge cohort: an isokinetic dynamometer (Biodex Medical Systems Inc, Shirley, NY, USA); geriatric outpatients: Forcelink B.V. (Culemborg, The Netherlands); ProMo cohort: a Good Strength dynamometer chair (Metitur Ltd., Palokka, Finland) MyoAge cohort: custom-built devices in the United Kingdom, Estonia, and Finland; Forcelink B.V. (Culemborg, The Netherlands) in The Netherlands, and an isokinetic dynamometer (Biodex system 3 Pro, Biodex Medical System Inc., Shirley, NY, USA) in France; isometric knee extension strength at 90° extension	Young male 52.7 ÷ 53.2 [kg] Young female 33 [kg] Old male 28.5 ÷ 40.3 [kg] Old female 17.1 ÷ 26.7 [kg]	Young male 516.81 ÷ 521.71 [N] Young female 323.62 [N] Old male 279.48 ÷ 395.21 [N] Old female 261.84 [N]	Knee extension strength [Nm]					HG scores and knee extension strength showed a low to moderate correlation, regardless of age and health status. HG alone should not be taken as a proxy for overall muscle strength.
Yeung et al. (2018) [42]	n = 163, geriatric patients (64 Males, 99 Woman) age: 81.7 ± 7.2	Jamar, in an upright standing position with the arms along the side, while holding the dynamometer in one hand	Forcelink Inc., Culemborg, knee extension strength (KES) was measured in a seated position, with hips and knees in 90 degrees, by a force transducer mounted in a chair	Male: 33.0 ± 5.5 [kg] Female: 21.5 ± 4.9 [kg]	Male: 323.62 ± 53.9 [N] Female: 210.85 ± 48 [N]	Knee extension strength [Nm]					The findings support the view that measuring HGS alone may not be sufficient in clinical practice as a measure of muscle strength.
Buendía-Romero et al. (2021) [8]	13 older people (mean age 87.0 ± 10.9 years)	TKK 5101, Grip-D, Takeji, Tokio, Japonia, participants seated, shoulder adducted, elbow flexed to 90°, wrist in a neutral position	Chronojump, Barcelona, Hiszpania, Isometric Knee Extension (knee joint flex under 110–120 degree)	Dominant handgrip/BM (kg·kg ^{−1}) 0.23 ± 0.06Non-dominant handgrip/BM (kg·kg ^{−1}) 0.21 ± 0.06	---	Dominant IKE/BM (N·kg ^{−1})					The authors did not conclude whether there was a correlation high enough to use squeeze force as a surrogate for lower limb muscle strength. In contrast, they determined that knee extension strength is reproducible and that it is an appropriate assessment for screening lower limb strength in older people.
						Non-dominant IKE/BM (N·kg ^{−1})					
						2.37 ± 0.89					
						Dominant handgrip/BM: r = 0.47					
						Non-dominant handgrip/BM: r = 0.68 (p ≤ 0.05)					
						2.60 ± 0.91					
						Dominant handgrip/BM: r = 0.67 (p ≤ 0.01)					
						Non-dominant handgrip/BM: r = 0.68 (p ≤ 0.01)					

Table 5. Cont.

Author and Year	Participants + Characteristics	Device and Position for Measuring Hand Grip Strength	Torque Measurement Device and Position	Hand Grip Force Values	Hand Grip Force Values Recalculated by the Authors	Moments of Strength		Conclusions
						Correlation Value		
Chan et al. (2014) [43]	Total n = 764—age 83 yers; Men-243—age 82 yers; Woman-521—age 83 yers; everyone over 75 years of age	Jamar, stand up and hold the dynamometer in the dominant hand with the arm parallel to the body without squeezing the arm against the body	Microfet2, isometric, knees flexed at an angle 90°	Total 20 [kg] Man 30 [kg] Woman 18 [kg]	Total 196 [N] Man 294 [N] Woman 176 [N]	Quadriceps strength (kg)		In the older population, quadriceps thigh muscle strength and hand grip strength are only moderately associated, and that quadriceps strength and hand grip strength are independently associated with several health outcomes.
						Total 25 Man 32 Woman 23		
						using linear or logistic regression models adjusting for age and sex		
Samuel et al. (2012) [44]	Young adults (10 M age: 24 ± 4.2 and 10 K age: 24 ± 2.5) Elderly individuals (9 M age: 71.2 ± 6.6 and 9 K age: 72.4 ± 8.3)	Biometrics DataLink software (Biometrics Ltd., Wales, UK), with the recommendations of the American Society of Hand Therapy	Quadriceps strength was assessed with the participant seated in a strength testing chair, with the hips and knees at 90°	Young adults M:444 ± 92 [N] Young adults K: 298 ± 60 [N] Elderly individuals M: 410 ± 57 [N] Elderly individuals K: 229 ± 37 [N]	Young adults M: 45.27 ± 9.38 [kgf] Young adults K: 30.39 ± 6.12 [kgf] Elderly individuals M: 41.80 ± 5.8 [kgf] Elderly individuals K: 23.35 ± 3.77 [kgf]	Quadriceps Strength (N)		The authors concluded that expressing lower limb strength and squeeze strength as a ratio may be a sensitive method of distinguishing relative differences between young and older people. They note the need for further research to determine whether squeeze strength is dependent on quadriceps strength in relation to the rate of strength decline.
						Young Males: 585 ± 123 [N] Young Females: 434 ± 139 [N] Older Males: 399 ± 99 [N] Older Females: 225 ± 88 [N]		
						Pearson correlation		
						Young Males: r = 0.63 Young Females: r = 0.83 (p < 0.05) Older Males: r = 0.35 Older Females: r = 0.05		

Neto et al. [33] performed isokinetic tests of adduction and abduction in the shoulder joint, as well as the isometric flexion and extension of the trunk. They applied a multiple linear regression model and developed four predictive equations. The regression equations obtained for the trunk flexion and extension were statistically significant. The authors found that predictive equations calculated for the shoulder joint may constitute an alternative method to the measurement of hand grip strength.

3.2. Dependence Between Hand Grip Strength and the Values of Moments of Muscle Forces in the Trunk and Lower Limbs

Scientific literature features investigations searching for the dependences between hand grip strength and the moments of muscle forces in the trunk and lower limbs [11,26,34–36]. Such studies focus on the testing of muscle force moments in isometric conditions [23,34] and isokinetic conditions [26] in the scope of the hip, knee and tarsal joints [11,34], as well as on the measurements of moments of forces in the trunk muscles [34]. One can also find studies which search for the dependence between hand grip strength and global muscle strength, which was defined as the total sum of force moments of the muscle groups tested [34,36]. Hand grip strength was most often tested in a sitting position [11,26,34,35]. The tests were performed mainly with the participation of elderly individuals and focused on the comparison of the correlation coefficient values between age groups of elderly people [11,26,34,35], for instance, in the following age ranges: 60–70 and 71–86 years of age [26], or 60–69, 70–79, 80 years of age and more [35]. As a result of the literature review, only one article was found where the study group was in the age range from 8 to 20 years of age [36]. Only Strandkvist et al. [11], seeking out dependences, decided to apply Orthogonal Projection to Latent Structures, i.e., the OPLS regression model. Other authors used the Pearson linear correlation for the assessment of dependences [26,34–36]. Strandkvist et al. [11] showed that there exists a strong and valid model demonstrating the relationship between hand grip strength and lower limb strength. Porto et al. [34] tested not only the dependence between hand grip strength and the moments of muscle forces exerted on the joints in the lower limb and the trunk, but also calculated global muscle strength, defined as the total sum of all measured moments of muscle forces. Value R of the Pearson linear correlation was within the range of 0.369 to 0.7 (all values statistically significant). The authors observed that hand grip strength may be applied to show global muscle strength in elderly people (HG and global muscle strength— $R = 0.69$, $p < 0.05$). The researchers noticed that the dependence between hand grip strength and all muscle groups reached low-to-moderate values. The authors think that positive linear dependence eliminates the necessity of testing different muscle groups, if necessary.

Samuel and Rowe [35] obtained different results while testing the extensors and flexors of the knee and hip, as well as the adductors and abductors of hips. On the basis of the results obtained by the authors, it was possible to determine the range within which correlation values fall, i.e., from 0.56 to 0.78 ($p < 0.01$). On the grounds of their results, they came to the conclusion that hand grip strength poorly reflects the changes in the muscle forces of lower limbs. The researchers suggested that a better alternative method was the measurement of the maximum isometric moment in the knee joint. Additionally, within the scope of their research, they estimated how strength decreases in the age groups of octogenarians in relation to sexagenarians, and found that the relative reduction in muscle strength falls into the range from 14.3% to 27%.

Rodacki et al. [26] also obtained the Pearson correlation coefficients between hand grip strength and the moments of muscle forces of lower limbs in isometric and isokinetic conditions. However, they were deemed scarce or low (r from -0.067 to 0.391), and most of them did not show any statistical significance. The authors drew a conclusion that the

generalization of hand grip strength and its application as a simple measurement of lower limb strength should be treated with caution.

Wind et al. [36] observed that, in children, the values of the Pearson correlation coefficient between hand grip strength and the total muscle strength in the upper limb joints are high, i.e., boys showed 0.9 ($p < 0.01$), whereas girls showed 0.7 ($p < 0.01$) for the right and left side of the body. However, when the correlation between hand grip strength and the total muscle strength controlled for weight was performed, the values of correlation were lower, i.e., boys showed 0.5 ($p < 0.01$) for the right and left hand, whereas girls 0.6 ($p < 0.01$) for the right hand and 0.5 ($p < 0.01$) for the left hand. The researchers showed that there was a strong correlation between hand grip strength and the moments of muscle forces expressed in N, and decided that hand grip strength could be used as an indicator of global muscle strength.

3.3. Dependence Between Hand Grip Strength and the Values of Muscle Force Moments in the Knee Joint in Isokinetic and Isometric Conditions

The greatest interest among researchers is aroused by the dependence between hand grip strength and the moments of forces which are exerted by the muscles responsible for the extension and flexion of the knee joint. The tests were performed in isokinetic and isometric conditions.

3.3.1. Tests in Isokinetic Conditions

Tests in isokinetic conditions were performed by Felicio et al. [24,37], Alonso et al. [38], Rodacki et al. [26] and Jenkins et al. [39]. All of them performed tests at an angular velocity of $60^\circ/\text{s}$. In addition, Felicio et al. [24], Rodacki et al. [26] and Jenkins et al. [15] performed tests at an angular velocity of $180^\circ/\text{s}$. Each of the above researchers performed hand grip strength tests in accordance with the recommendations of the American Society of Hand Therapy using the Jamar dynamometer [24,37,38] or TSD121C, Biopac Systems [39]. In each case, the Biodex 3 System Pro was used to test muscle force moments. The study group in each article consisted of older people; in the case of Alonso et al. [38], Felicio et al. [24], Rodacki et al. [26] and Felicio et al. [37], it was older women, whereas in the case of Jenkins et al. [39], it was only men. Felicio et al. [37] used a backward linear regression model. The following variables were used in its development: work performed by the extensors during the test at a speed of $60^\circ/\text{s}$ related to the subject's body mass and hand grip strength. Based on this, the researchers concluded that knee extension strength and hand grip strength can be useful indices in screening tests to assess functional fitness in older people. However, where possible, the tests should be used in a complementary way.

Alonso et al. [38] pointed out to the non-linear Spearman correlation between hand grip strength and the moments of forces of knee joint extensors (values referred to the body weight) values r from 0.35 to 0.43 (all values statistically significant $p < 0.05$). No correlation was shown in the case of flexors of the knee joint. The authors found that lower hand grip strength was significantly related to the strength of lower limbs in adult women, and thanks to that, it may be used as a substitute indicator.

On the other hand, in their studies Felicio et al. [24] did not show a linear, statistically significant correlation between hand grip strength and the moments of forces of extensors and flexors in the knee joint. Due to this fact, their conclusions differed from Alonso et al. [38] and Felicio et al. [37]. They reached the conclusion that it is necessary to be cautious about the generalization that hand grip strength may be used as an indicator of global muscle strength in elderly women. A lack of statistically significant linear correlation between hand grip strength and the moments of muscle forces in the knee joint measured in isokinetic conditions (at a velocity of $180^\circ/\text{s}$ — $r = 0.467$, and $60^\circ/\text{s}$ — $r = 0.382$) and isometric

conditions ($r = 0.363$) was also reported by Jenkins et al. [39]. These authors found that hand grip strength may not be a proper substitute of global muscle strength.

3.3.2. Tests in Isometric Conditions

The dependences between hand grip strength and the moments of muscle forces in the knee joint during an isometric contraction were searched for also by Bohannon [40], Bohannon et al. [41], Yeung et al. [25], Buendía-Romero et al. [8], Yeung et al. [42], Chan et al. [43], Rodacki [26] and Samuel et al. [44]. The above-mentioned authors studied hand grip strength in a sitting position with the elbow flexed [8,26,40,41,44], and also in a standing position with the limb hanging on the side of the body [25,42,43]. In each of the analyzed articles, the study group consisted of elderly individuals [8,25,26,40–44]. Only in three articles were young participants also additionally tested [25,41,44]. The majority of the authors decided to search for the Pearson linear correlation.

Bohanon [40] determined the range of correlation values between hand grip strength and the moments of forces of extensors and flexors in the knee joint measured in isometric conditions at the level of 0.56–0.68; all correlations were statistically significant (below $p < 0.001$). On the basis of the results, the authors came to the conclusion that hand grip strength may be used as an alternative to the muscle strength of lower limbs. Also, Bohannon et al. [41] obtained high coefficients of the linear correlation between hand grip strength and the moments of forces of knee joint extensors, in the range of 0.772 to 0.805 ($p < 0.001$), in the group of healthy adults. However, despite such a high correlation, they found that the differences in the activities requiring hand grip strength and knee extension exclude widespread support to use them interchangeably.

Yeung et al. [25] performed tests in six different places, and thanks to that, several large study groups were created, i.e., two groups of young individuals and five groups of elderly people. On the basis of the conducted analyses, it was ascertained that in the study group of young individuals linear correlation coefficients between hand grip strength and the moments of forces of knee joint extensors fell into the range from 0.36 to 0.45 ($p < 0.05$), whereas in the study group of the elderly, from 0.35 to 0.67 ($p < 0.05$). The researchers observed that the dependence between hand grip strength and the force of the knee extension differed at an individual level. Due to this fact, the application of the measurement of only one group of muscles as an indicator of general strength seems to be unjustified.

Buendía-Romero et al. [8] performed tests on a small group of 13 elderly individuals with an average age of 87 years. Value r of the Pearson correlation between hand grip strength (dominant and non-dominant) and the moments of forces of knee extensors fell into the range of 0.47–0.68 (statistically significant). The main conclusion reached by Buendía-Romero et al. [8] was that the force of the knee extension constitutes a repeatable and appropriate evaluation method in the screening tests of lower limbs. However, they did not address the dependence between hand grip strength and the force of the knee extensors. Neither did they define whether the hand grip strength itself was sufficient for the assessment of general strength. Yeung et al. [42] developed models based on the analysis of linear regression in order to investigate the relationship between hand grip strength and the moments of muscle forces in the knee joint, taking into considerations aspects such as age and gender, as well as physical and psychological features. The researchers came to the conclusion that health features are more related to the knee extension force than hand grip strength.

Chan et al. [43] conducted studies in a large group of 764 individuals (243 men, 521 women), each participant was above 75 years of age. In the first phase of the analyses, the results were normalized using square root transformation followed by standardization

into Z scores, whereas the dependence itself was determined by means of linear regression. The researchers obtained the value 0.44 (95% CI) in the case of hand grip strength and the force of the knee extensor (dominant sides), and 0.87 (95% CI) in the case of hand grip strength and the knee extensor strength (non-dominant sides). The next model was adapted to age and gender, and thanks to that fact, a value of 0.42 was obtained for the dominant side and 0.87 for the non-dominant side. The researchers found that in the elderly population, the strength of the quadriceps and hand grip strength were related only to a moderate degree, and were independently connected with several health effects. The researchers also determined that the combination of the measurements of muscle strength in lower limbs and hand grip strength may be useful in the diagnostics of health conditions; however, they did not define whether the measurement of sole hand grip strength was going to be sufficient.

Samuel et al. [44] searched for a linear dependence between hand grip strength and the moments of forces of knee joint extensors in a group of younger and elderly individuals, taking into account their gender. Only the group of young women showed statistically significant Pearson's correlations ($r = 0.83$, $p = 0.01$). The correlation coefficient for the whole group amounted to 0.73 ($p = 0.000$). Samuel et al. [44] additionally determined the ratio of hand grip strength to quadriceps strength. It amounted to 0.75 in young adults, which means that the strength of knee extensors surpassed hand grip strength by approximately 25%. A higher value was reached in the case of elderly people, equaling 1.1. A decrease in the muscle strength was expected with increasing age; however, a higher ratio of hand grip strength to quadriceps strength indicated a bigger loss of quadriceps strength in comparison to hand grip strength with increasing age.

4. Discussion

The aim of the systematic review of the literature was to verify whether hand grip strength can be used as an indicator of overall strength and functional performance. This task required ordering the existing knowledge and results obtained in scientific research on the dependences between hand grip strength and muscle strength/moments of forces in the joint muscles.

Selected articles were subjected to the impact of methodological quality assessment (risk of bias). The score for all articles was above 75%, with an average score for all articles of 85.61%, $SD = 6.73$. This shows a correct selection of articles of high scientific quality.

Based on the systematic review of the literature, only half of the studies analyzed showed a relationship between hand grip strength and muscle force moments in the trunk, upper and lower limbs. No definitive conclusions can be drawn about the existence of these relationships in different age groups or for specific parts of the body.

On the basis of the conducted literature review, it was observed that in the search of dependences between the moments of muscle forces and hand grip strength, the majority of authors decided to seek correlations by limiting the study group to the group consisting only of elderly individuals: 12 articles [8,11,24,26,34,35,37–40,42,43]. Only four articles were found where the dependences were looked for in the group of young subjects [23,29,33,36], and one paper described the dependences in the group of adults at an average age of 52 years [30]. Five research papers attempted to determine such dependences both in the group of young and elderly individuals [25,31,32,41,44].

The analyzed articles encompassed the total number of 2965 elderly individuals and additionally 112 elderly individuals with coexisting conditions [40], 752 healthy adults, 30 physically active subjects and 120 ill patients after stroke [30], or spinal cord injury [33]. In two publications [31,41], the results were analyzed jointly in the group of young and elderly individuals. Despite the clinical heterogeneity of the study groups, the focus of

the study was to determine the relationship between hand grip strength and muscle force moments. The correlation coefficients analyzed, rather than the experimental results from the different groups, determined whether hand grip strength could be used as an indicator of overall strength and functional performance.

In the analyzed articles, the measurement of hand grip strength was performed most frequently according to the recommendations of the American Society of Hand Therapy, i.e., in a sitting position, with the elbow flexed at an angle of 90° . Also, measurements carried out in other positions could be found, such as with the limb extended (straight limb) [31], in a standing position [25,29,32,42,43], e.g., with the limb hanging by the body side [29,32,42]. The most popular device used for the measurement of hand grip strength is a dynamometer manufactured by Jamar company (Sammons Preston, Illinois, USA) [23–26,30,31,34,35,37,38,40–43]; however, other types are also applied: Lafayette [29], E-Link [11], Vetek [32], TTK 5101 Grip-D [8], TSD121C Biopac System [39], Saehan Corporation [33], Citec type CT3001 [36], Good Strength dynamometer [25] and Biometrics Data Link software [44]. The Biodex system is most often used for the measurements of the moments of muscle forces [11,23,24,26,30,32–34,37–39]. The studies analyzed were characterized by methodological heterogeneity due to different measurement equipment. The measurement results were presented in the same unit of measurement (Tables 3–5). However, the relationship analyzed was demonstrated by the value of the correlation coefficients.

Researchers performed measurements of the moments of muscle forces in isokinetic or isometric conditions in various angular positions. The following muscles were tested: flexors and extensors of the hip joint, abductors and adductors of the hip joint, flexors and extensors of the knee joint, dorsal and plantar flexors of the tarsal joint, extensors and flexors of the trunk, external and internal rotators of the shoulder, and abductors and adductors of the shoulder blade. The greatest interest is aroused by the search for the dependence between hand grip strength and the moments of forces of extensors and flexors of the knee joint [8,24,25,37–44] (Figure 3). The methodological differences in testing, including different measuring equipment and different measuring positions of participants, can affect the correlation results analyzed.

Hand grip strength dependences were most often correlated with the measured maximum moments of muscle forces. However, Mandalidis et al. [29] conducted research where they searched for the dependence between mean maximum moments and obtained lower values in comparison to other authors [23,29,30]. On the other hand, Felicio et al. [24] compared correlation values obtained for hand grip strength expressed in kgf and the moments of muscle forces expressed in Nm, or when they were normalized to body weight. Mandalidis et al. [29] and Felicio et al. [24] reported lower correlation values between hand grip strength and muscle moments when related to body weight compared to unnormalized results.

On the basis of the literature review (performed on 22 scientific articles), it was found that 11 articles showed a statistically significant, strong, positive correlation between the value of hand grip strength and the values of moments of muscle forces in the trunk, as well as upper and lower limbs [11,23,29,30,34,36–38,40–42]; five articles [24,32,33,35,39] determined that such a dependence was small and advised adopting a cautious approach to it; four articles [25,26,31,39] ascertained that there was no dependence, whereas two articles [8,43] did not interpret the meaning of the result.

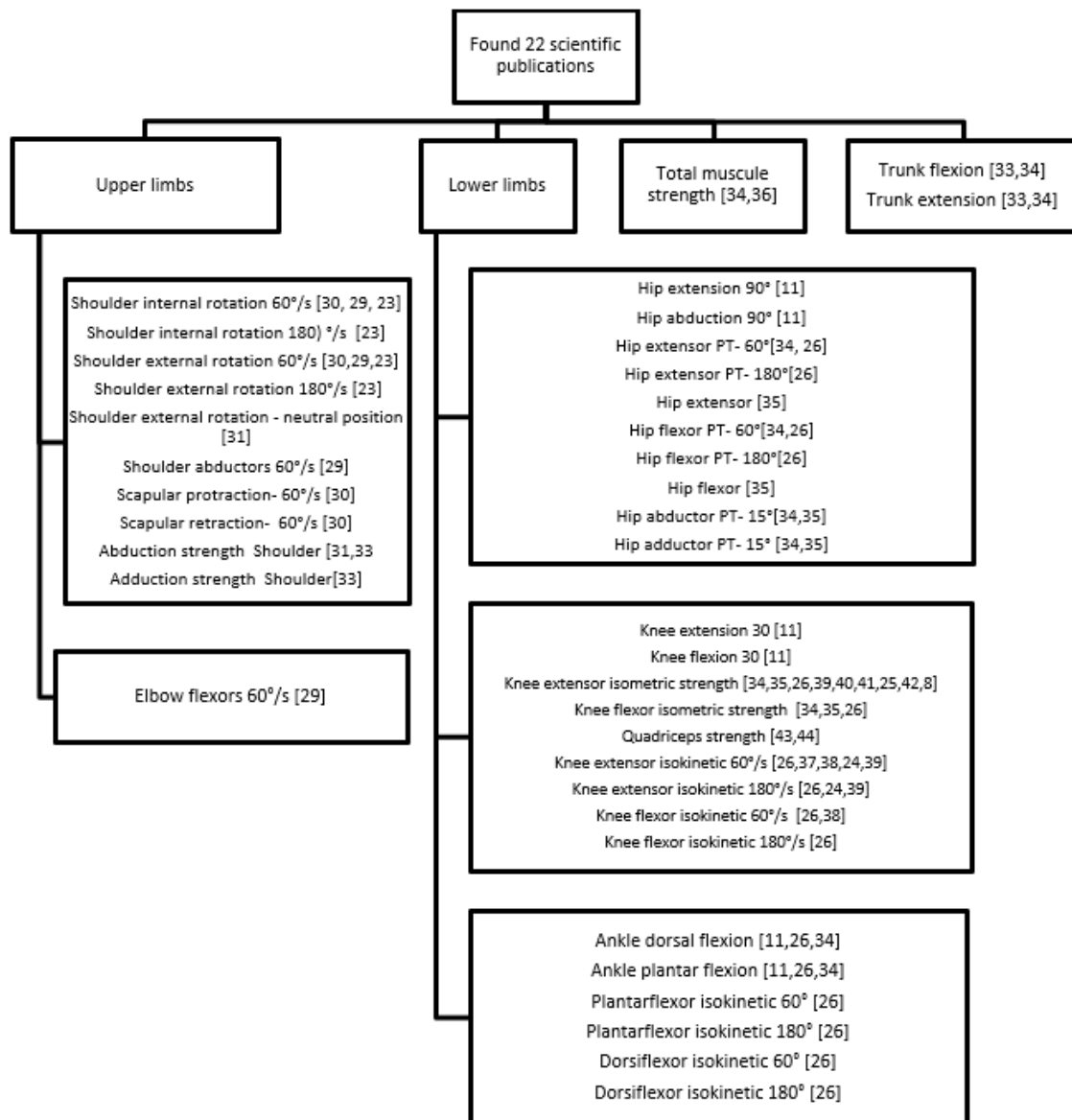


Figure 3. Classification of the analyzed publications according to the type of movement of the body part.

Dependences between the value of hand grip strength and the values of moments of muscle forces in the trunk, as well as upper and lower limbs may be analyzed in age groups. Taking into consideration the conclusions described in the articles where the study group consisted of elderly individuals, i.e., 12 articles [8,11,24,26,34,35,37–40,42,43], only 6 research teams ascertained that [11,34,37,38,40,42] hand grip strength could be used as a prognostic coefficient; 2 articles informed on a weak dependence [24,35]; whereas successive 2 articles reported the lack of dependence [26,39]. In the group of young individuals, i.e., in the case of 4 articles [23,29,33,36], a positive correlation was revealed in 3 groups [23,29,36], whereas, in the case of one group, caution was advised as per the prognosis of muscle strength on the basis of hand grip strength [33].

In the case of research which analyzed the results of correlation jointly for the group of adults and elderly individuals [25,30–32,41,44], information on the occurrence of dependences was found in two publications in the scientific literature [30,41]; two articles came to the conclusion that one should be cautious in such an assessment [32,44], whereas two articles revealed no such dependences [25,31].

Dependences between the values of hand grip strength were also searched for with reference to the results of moments of muscle forces for particular parts of the body, i.e., the trunk, upper and lower limbs. Six articles assessed the dependence between hand grip strength and the moments of muscle forces in upper limbs [23,29–33], including three articles [23,29,30] indicating a positive linear dependence; two articles informed about a weak correlation [32] or advised a cautious approach to the result [33]; one article indicated the lack of dependence [31].

In five analyzed articles [11,26,34–36], the dependence was sought between hand grip strength and muscle strength of the lower limbs, including three articles indicating a positive linear dependence [11,34,36], 1 showing the lack of dependence [26] and 1 revealing a weak dependence [35]. Among other researchers, Porto et al. [34] reached the conclusion that the very measurement of hand grip strength was sufficient to assess the strength abilities of a particular muscle group; however, it could not be used if there were contraindications against using an isokinetic dynamometer, e.g., recent injuries.

However, the greatest interest among researchers was aroused by the search for dependence between hand grip strength and strength abilities of the muscles in the knee joint. Such a relationship was sought after in 16 articles in total [8,11,24–26,32,34,35,37–44].

Seven independent studies found a positive correlation [11,34,37,38,40–42]; four articles [24,32,35,44] advised a cautious approach to hand grip strength as a muscle strength predictor or recommended further investigations; three articles informed about the lack of dependences [25,26,39]; finally, two articles did not clearly state if it was a proper predictor [8,43]. At the same time, one of the articles, which defined the dependence as weak, informed that the best approximate predictor is the values of moments of extension and flexion forces in the knee joint [32]. It is important to note the correlation values that have been obtained in previous studies. Some authors have conducted studies on a large group of people and obtained low statistically significant correlation coefficients [25,36,38], so caution should be exercised in drawing firm conclusions.

The observed relationships between hand grip strength and muscle torque may be influenced by anatomical factors, neuromuscular coordination (motor unit recruitment), lifestyle and diet. Hand grip strength is a function of muscle mass and cross-sectional area. Greater muscle mass throughout the body (e.g., in the upper limbs, arms or forearms) is directly related to a greater ability to generate force in the hand. In addition, the type of muscle fibers (fast-twitch or slow-twitch) affects both hand grip strength and the strength generated by other muscle groups.

Based on the review, we suggest that hand grip strength tests should be conducted in accordance with the recommendations of the American Society of Hand Therapy. However, in the case of muscle force moments, the test position depends on the joint being tested, so we recommend that it be in accordance with the recommendations of the manufacturer of the measuring device.

As results from the conducted systematic review of the literature, only half of the analyzed scientific articles showed correlation between hand grip strength and the moments of muscle forces in the trunk, upper and lower limbs. Methodological differences in testing, such as different measuring position of participants, elbow placement, age, gender, presence of disabilities, type of instruments used [45–47], and study size, can influence the analyzed correlation results. These factors may reduce comparability between studies, and lead to discrepancies in findings. Therefore, standardizing measurement protocols is crucial to ensure more reliable and consistent outcomes. No irrefutable conclusion about the existence of dependences can be reached in age groups and with reference to the results obtained for particular parts of the body.

Due to significant discrepancies in the research so far, hand grip strength should not be automatically applied as an indicator of overall strength and functional performance. The measurements of hand grip strength and the moments of muscle forces should complement each other.

4.1. Limitations and Directions of Further Research

The limitation of the performed literature review was the fact that out of 22 analyzed articles, only 1 focuses on testing both upper and lower limbs. It seems quite important to check whether correlations are mutual, i.e., whether simultaneous and similar-level correlations occur with reference to strength abilities of upper and lower limbs. It is also necessary to study the correlation of hand grip strength and the moments of muscle forces in the joints for movements performed in different planes in the same representative group of subjects.

A limitation of the study was that it was based only on cross-sectional articles with the omission of longitudinal studies. However, the investigated problem (correlation between hand tightness and muscle force moments) does not require the analysis of changes over time.

Another limitation was that in some articles, the size of the study group may be underrepresented.

Regular measurements of hand grip strength as a predictor of muscular system strength capacity could be used in physiotherapy. In the future, it is important to develop a simple method of measuring muscle strength in the lower limbs and other parts of the body undergoing physiotherapy, and provide reference values for each age group and gender. However, it should be noted that the use of hand grip strength as a substitute for knee extensor muscle strength does not show the effect of knee extensor strength training and may also affect the motivation of the subject.

4.2. Clinical Suggestions and Practical Applications

Based on the results of this systematic review, the following clinical suggestions are suggested:

- The hand grip strength test can be used as a screening test to identify any strength deficits or muscle imbalances, especially because it is carried out using reliable measuring equipment. The test is simple, quick and not expensive. Abnormal screening results can be a suggestion to expand the diagnosis of the musculoskeletal system, for example, in office workers [48].
- Regular measurements of hand grip strength, which is a predictor of musculoskeletal strength capacity, could be used in physiotherapy to assess progress in the rehabilitation process.
- Regular measurements of hand grip strength could be useful in the diagnosis of sarcopenia [49,50].
- Studies have shown a positive correlation between hand grip strength and torque [23, 29], suggesting that measuring isometric hand grip strength can be a useful indicator of muscle strength in different muscle groups. In athletes, particularly those with limited access to more sophisticated measurement tools such as isokinetic dynamometers, regular monitoring of hand grip strength can help assess muscle strength and identify any imbalances or deficits in the strength of specific muscle groups.

5. Conclusions

The performed literature studies show that it is necessary to be cautious about the generalization that hand grip strength can be used as an indicator of overall strength and functional performance.

On the grounds of the current scientific knowledge, it cannot be stated that there is an irrefutable proof that there is dependence between hand grip strength and the moments of muscle forces, neither with reference to different age groups, nor particular parts of the body.

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