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A Systematic Review of Dynamometry and its Role in Hand Trauma Assessment

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Abstract: The dynamometer was developed by American neurologists and came into general use in the late 19th century. It is still used in various ways as a diagnostic and prognostic tool in clinical settings. In this systematic review we assessed in detail the different uses of dynamometry, its reliability, different dynamometers used and the influence of rater experience by bringing together and evaluating all published literature in this field. It was found that dynamometry is applied in a wide range of medical conditions. Furthermore, the great majority of studies reported acceptable to high reliability of dynamometry. Jamar mechanical dynamometer was used most often in the studies reviewed. There were mixed results concerning the effect of rater experience. The factors influencing the results of dynamometry were identified as age, gender, body weight, grip strength, BMI, non/dominant hand, assessing upper/lower limbs, rater and patient's strength and the distance from the joint where the dynamometer is placed. This review provides an understanding of the relevance and significance of dynamometry which should serve as a starting point to guide its use in hand trauma assessment. On the basis of our findings, we suggest that hand dynamometry has a great potential, and could be used more often in clinical practice.

Keywords: Dynamometer, Jamar mechanical dynamometer, grip strength, hand trauma, systematic review.

INTRODUCTION

The dynamometer ranks among the instruments developed by American neurologist which came into use in late 19th century [1-3]. William Alexander Hammond (1828-1900) described several dynamometers and the dynamograph for the purpose of assessing muscle power and graphically recording these data respectively [4]. In 1868 Mathieu, a French instrument maker from Paris, constructed Hammond's first dynamometer and by the end of 19th century it was the most popular instrument of its kind [4]. Despite being part of the small group of diagnostic tools used in 19th century, there were several limitations associated with dynamometers [1, 4]. However, dynamometry is still used, and commonly applied to determine muscle strength [5].

Currently, various examinations and investigations can be used by clinicians in order to predict the patients' diagnosis and prognosis. With the help of these predictions, the individuals that are at higher risk of unwanted future events can be identified, and adequate measures can be taken to reduce risks of further injuries. Assessing the muscle strength aids to spot the areas of muscle weakness and injury [6]. Accurate and quantifiable musculoskeletal testing decreases the chances of a misdiagnosis, and an appropriate rehabilitation protocol can be prescribed. Despite all these advantages, muscle strength examination is not commonly used to predict clinical outcomes, since there is a high controversy concerning its efficiency and dissimilar research outcomes retains researchers. Furthermore, there is not adequate information regarding the reliability of this instrument, thus it may be at times difficult for clinician to know how reliable different dynamometers are or what type of dynamometer to use in the first place.

Evidence has shown us that dynamometry has been used in various ways as a diagnostic and prognostic tool in clinical settings. Nevertheless, there are no articles bringing together and summarizing the various uses of dynamometry. The studies referencing the applications were searched predominantly using Medline, CINAHL (EBSCO), ZETOC, PubMed, EMBASE and AMED. The purpose of this study is to assess in detail the different uses of dynamometry, its reliability, different dynamometers used and the influence of rater experience by bringing together and evaluating all published literature in this field. This review provides an understanding of the relevance and significance of dynamometry which should serve as a starting point to guide its use in hand trauma assessment.

MATERIALS AND METHOD

The studies referencing applications of dynamometry were searched predominantly using the electronic databases Medline, CINAHL (EBSCO), ZETOC, PubMed, EMBASE, AMED, PREMEDLINE In-Process & Non-Indexed

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Citations (OvidSP), ASSIA (CSA Illumina), Conference Proceedings Citation Index: Science (ISI) on Web of Knowledge, PsycINFO (OvidSP), Science Citation Index (ISI) on Web of Knowledge, Social Sciences Citation Index (ISI) on Web of Knowledge and Cochrane Library (Wiley). The following keywords were used to cite relevant articles: Dynamometry, hand-held dynamometry, Dynamometer, hand trauma, Reliability of dynamometry, rater experience, mortality, survival, disability, hospital or surgery. The inclusion criteria were based on 1) using dynamometry to assess clinical outcome 2) any study evaluating the reliability of dynamometry 3) any study comparing dynamometry with either manual muscle testing or another device or both 4) any study commenting on the influence of rater experience in using dynamometry and validity of the results. Studies were excluded which 1) were any language other than English 2) did not use dynamometry to report on a clinical outcome 3) were not available for free viewing. A total of 169 articles were reviewed. 102 articles were identified as relevant according to the inclusion criteria above. All studies meeting the inclusion criteria were summarized and the relevant information was recorded in Tables **1-5** and Figs. (**1**, **2**) depending on whether the studies assessed the reliability, different uses, different methods or devices, or rater experience related to dynamometry. Specifically in each table the authorship, sample, method and/or device and the relevant findings of the study were recorded.

RESULTS

Out of the 169 articles reviewed, 90 were found to be relevant according to the inclusion criteria. These studies were reviewed carefully and summarized in different tables according to whether they included information about the use, reliability, different types or rater experience related to dynamometry.

Onder *et al.,* [7] studying 884 disabled women commented on the limitations of dynamometry and concluded that grip strength failed to significantly predict the onset of progressive disability of activities of daily living. Figueiredo *et al.,* [8] reported that handgrip strength was "not associated (t-test) with total hospital length of stay, development of infection, blood use, acute cellular rejection or global resource utilization"[8]. O'Shea *et al.,* [9] reported that hand held dynamometry is suitable for testing hypotheses and monitoring changes in muscle strength in COPD patients but is unlikely to detect changes in muscle strength. Watters *et al.,* [10] found that handgrip dynamometry cannot replace other nutritional assessment test despite being a quick, easy and reproducible test. However Guo *et al.,* [11] found that hand grip strength is a reliable measure of the patient's nutritional status. Similarly, Klidjian *et al.,* [12] reported that dynamometry is a useful screening test for malnutrition that can predispose patients to major complications following surgery and Wang *et al.,* [13] identified handgrip strength together with serum albumin to be a measure for nutritional assessment. Stokes *et al.,* [14] used dynamometry to develop a model to categorize patients into low-effort or sincere group. Selles *et al.,* [15] described Rotterdam Intrinsic Hand Myometer as being able to assess muscle loss more directly than grip and pinch dynamometers.

Table 1. General Uses of Dynamometry

Cerebral palsy [16]
MB leprosy [17]
Huntington's Disease [18]
Charcot-Marie-Tooth (CMT) disease [15, 19, 20]
ICU-acquired paresis [21]
Duchenne Muscular Dystrophy (DMD) [22]
cystic fibrosis [23]
COPD [9]
Ulnar and median nerve injuries [24]
Capsuliti [2]
Stroke [26-28]
Coronary artery disease [29]
Tetraplegia [30]
Osteoarthritis [31]
Hemiparesis [28]
Malnutrition [10]
Patients with disability [7, 32]
Pneumonia [33, 34]
Acute rehabilitation [35]
Oral and maxillofacial cancer [11]
Gastrointestinal cancer [36]
Coronary artery bypass grafting [37]
Liver transplant [38]
Rheumatoid arthritis [39] [40-44]
ESRD (end stage renal disease) [45]
chronic PD patients [13]
Cirrhosis [46]
Hip fracture [47, 48]
Spinal cord injury [49]
Haematological cancer [50]
Spina bifida [51]
spinal muscular atrophy (SMA) [52]

Intrinsic Hand Myometer was reported to better assess muscle loss directly than grip and pinch dynamometers [15]. Bohannon [6] states that grip dynamometer is suitable for upper limb assessment but not lower limb in which case strength knee extension dynamometer can be applied. Newman *et al.,* [55] determined grip strength as having a higher potential to be incorporated in clinical practice compared to isokinetic dynamometry as it is easier to measure. This shows that the not all dynamometers can be suitable for similar assessments. A further issue is that the specific dynamometer employed was not always stated.

Of the 90 studies, 22 assessed the reliability of dynamometers used. Most of these reported an acceptable to

Table 2. Different Types of Dynamometers Used

Number	Dynamometer	Number of Studies Using Device	References
1	Jamar mechanical dynamometer	11	
2	Sphygmomanometer	5	[17, 39, 40, 44, 58]
3	Smeldy hand dynamometer	4	[13, 32, 59, 60]
4	Kin-Com dynamometer	3	[55, 61, 62]
5	Harpenden hand-grip dynamometer	3	[47, 63, 64]
6	Martin Vigorimeter	3	[65-67]
7	"single spring" dynamometer	3	[36, 38, 68]
8	Rotterdam Intrinsic Hand Myometer (RIHM)	2	[15, 24]
9	BIODEX dynamometer	2	[25, 69]
10	Fugl-Meyer motor scale	1	[70]
11	Nicholas Hand-Held Dynamometer (NHHD)	1	[71]
12	Baseline and Grip dynamometers	1	[72]
13	Penny and Giles myometer	1	[61]
14	Hand-held electric dynamometer	1	[73]
15	Spring-loaded device	1	[73]
16	Chatillon Series D hand-held spring-scale dynamometer	1	[74]
17	Preston Dynamometer	1	[75]
18	RKK grip dynamometer	1	[76]
19	Therapeutics Instruments dynamometer	1	[77]
20	MyGripper dynamometer	1	[78]
21	Duffield dynamometer	1	[79]
22	Kratos ZM dynamometer	1	[46]
23	Clinifeed/Roussel dynamometer	1	[48]

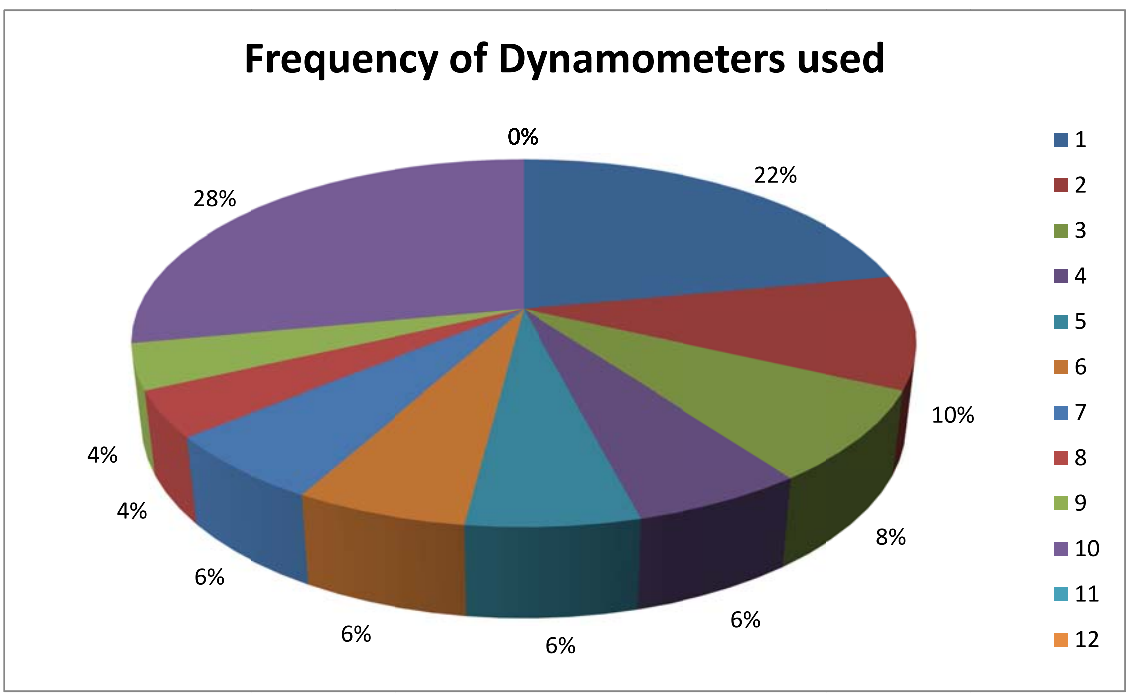

Fig. (1). Frequency of dynamometers used in the studies reviewed.

high reliability of dynamometry, regardless of what aspect of reliability they were looking at. Nevertheless, some studies reported contradicting results. O'Shea *et al.,* [9] argued that hand held dynamometry is not likely to detect changes in muscle strength for a subject with chronic obstructive pulmonary disease. McMahon *et al.,* [80] showed that placing the hand-held dynamometer farther away from the joint centres increases the reliability of the measurements. Verschuren *et al.,* [81] argued that inter-tester reliability of hand held dynamometry is questionable in measuring lower extremity muscle strength. Wadsworth *et al.,* [74] found that the reliability of muscle testing using a hand held dynamometer could be affected by the rater's gender, body weight and grip strength as these parameters affect the rater's ability to stabilize the dynamometer. Rice *et al.,* [82] showed that for predicting hand function while opening a select group of containers, pinch and grip dynamometry are not the most reliable tools to be used. Arnold *et al.,* [83] assessing the inter-rater and intra-rater reliability of hand held dynamometry in 18 men and women aged 65 to 92 concluded that it is not a reliable measure for ankle strength. However, they reported that hand held dynamometry showed good reliability for isometric hip and knee strength. Another situation dependent application of hand held dynamometer was explained by Mahony *et al.,* [51] involving a cohort of 20 children with spina bifida. They found that hand held dynamometry has acceptable inter-rater reliability unless, the child cannot move limb against gravity, where manual muscle testing should be used [51]. Interestingly Kelln *et al.,* [84] when assessing intra-tester, inter-tester and within session reliability of hand held dynamometer found that it can be a reliable tool unless the subject can overpower the tester.

Most studies assessed the test re-test reliability followed by the combined assessment of inter- and intra-rater reliability. Results are summarized below in Tables **3** and **4**.

Table 3. Assessment of Reliability

Reliability	Number of Studies Assessing Reliability	References
Test re-test	7	[9, 20, 31, 61, 90, 92, 93]
inter-rater	4	[51, 81, 85, 94]
intra-rater	2	[74, 87]
within session	1	[18]
inter-instrument	1	[95]

Studies commenting on the rater's experience and its effect on the results were also included. Larson *et al.,* [49] claimed that the experience of rater did not affect the level of measurement reliability. Burns *et al.,* [30] found that hand held dynamometry make and break techniques showed high reliability in weak elbow extensor and flexor when performed by novice examiner. Similarly, Lindstrom-Hazel *et al.,* [85] showed that occupational therapy students can be reliable in testing after being trained and tested for competency. On the contrary, Goonetilleke *et al.,* [73] reported that greater rater experience increased the overall accuracy but not the reproducibility or variability.

DISCUSSION

In this systematic review we looked at 90 papers which included the different uses of dynamometry, its reliability, different dynamometers used and the influence of rater experience in the results produced. The data was collected from a wide range of sources and the dynamometers involved were used to measure a variety of outcomes. This

Reliable	Unreliable
[49]	(83)
[83]	(51)
[85]	(81)
[50]	(84)
[51]	(9)
[86]	
[18]	
[87]	
[84]	
[23]	
[88]	
[89]	
[20]	
[30]	
[90]	
[52]	
[91]	
[61]	
[62]	
[31]	

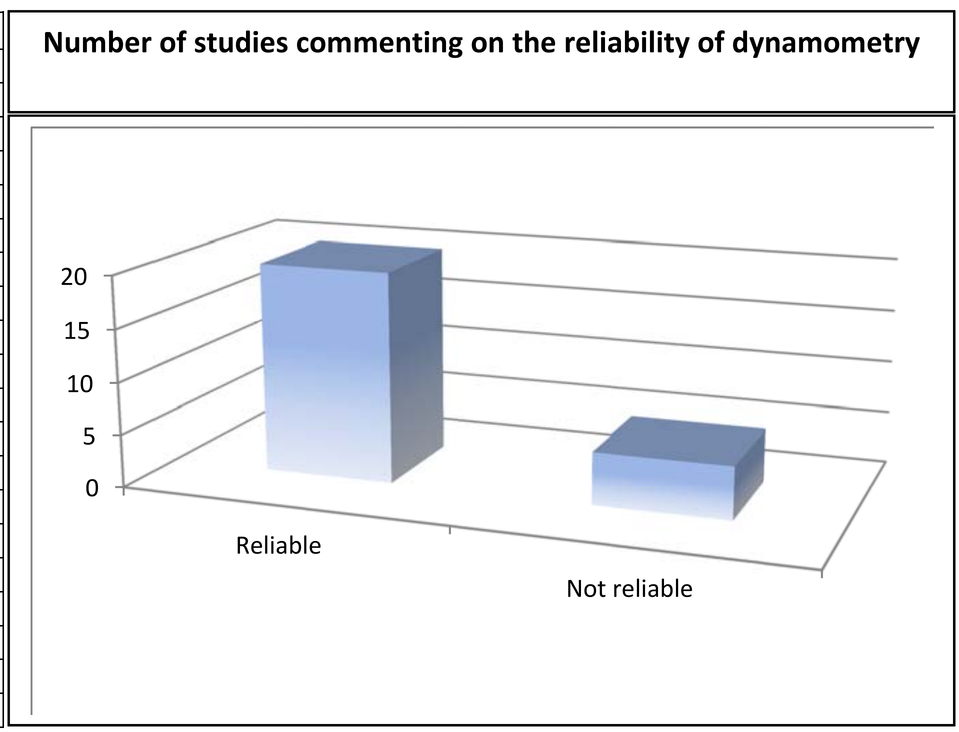

Fig. (2). The reported reliability of dynamometry in the reviewed studies.

Table 4. Combined Assessment of Reliability

Reliability	Number of Studies Assessing Reliability	References
Inter- and intra- rater	5	[30, 49, 50, 83, 89]
inter- session, intra-session and test re-test	2	[52, 91]
within session test re-test	1	[86]
intra-session test re-test	1	[62]
inter- and intra-session	1	[88]
inter-rater, intra-rater and within session	1	[84]
Within-session inter- and intra-tester reliability and between session intra-rater reliability	1	[80]

Table 5. Summary of Studies Involving Rater Experience

Study/Sample	Use	Device/Method	Relevant Finding
Larson *et al.,* [49]/Individuals with spinal cord injury	Rater experience	Hand held dynamometry	measurement reliability not affected by the rater experience
Lindstrom-Hazel *et al.,* [85]/73 healthy university students, faculty, and staff members	Inter-rater reliability of student assessors	Hand and pinch strength/Hand held dynamometry	occupational therapy students can be reliable in testing after training and testing for competency
Mahony *et al.,* [51]/20 children with spina bifida (10 males, 10 females; mean age 9 years 10 months; range: 5 to 15 years)	Student assessment	Hand held dynamometry and Manual muscle testing	When the child is incapable of moving limb against gravity, MMT should be used. otherwise, HHD.
Burns *et al.,* [30]/19 patients with upper limb weakness secondary to tetraplegia	Rater experience	Hand held dynamometry	Showed high reliability in weak elbow extensor and flexor when performed by novice examiner.
Goonetilleke *et al.,* [73]/Nine muscle groups in 19 patients with motor neuron disease	Reproducibility, variability and accuracy according to rater experience	Hand-held electric dynamometer + Spring-loaded device	Greater rater experience increased the overall accuracy but not the reproducibility or variability

was not limited to hand trauma assessment. We found that dynamometry has been applied in a variety of clinical setting ranging from Charcot-Marie-Tooth (CMT) disease [15, 19, 20] to Cerebral palsy [16] and Huntington's Disease [18]. All in all, 32 different medical applications were found in the 43 studies reviewed for the general uses of dynamometry. There are, however, very few studies looking at each individual condition.

We then identified the various types of dynamometers currently used in clinical practice. Among the 50 studies reviewed for different dynamometry devices, Jamar dynamometer proved to be the most used [8, 26, 32-34, 53-57] followed by modified sphygmomenometers [17, 39, 40, 44, 58] Smedly hand dynamometer [13, 32, 59, 60] Kin-Kom dynamometer [55, 61, 62] Harpenden handgrip dynamometer [6, 47, 63]. Martin Vigorimeter [65-67] and "single-spring" dynamometer [36, 38, 68]. However, it was found that not all dynamometers can be suitable for similar assessment. A further issue is that the specific dynamometer employed was not always stated. This could affect our results, in that we simply have more data concerning Jamar dynamometer than, say, Duffield dynamometer.

A further aim of this systematic review was to assess the reliability of dynamometry. Most of the 22 studies assessing the reliability reported an acceptable to high reliability of dynamometry, regardless of what aspect of reliability they were looking at. Nevertheless, some studies discussed situations where dynamometry is reliable, as well as when it is unreliable. Overall, we can conclude that the reliability of dynamometry depends on the type of dynamometer used and the clinical situation where it is applied. Therefore, a dynamometer having a high reliability in measuring muscle strength in one part of the body may prove to produce unreliable results when used in a different part of the body. Also, according to O'Shea *et al.,* [9] we can assume that the reliability may vary when used in different clinical conditions. Furthermore, the reliability of dynamometry is questionable if the subject is too weak to move limb against gravity [51] or strong enough to overpower the tester [84]. According to McMahon *et al.,* [80] the reliability is increased if the dynamometer is placed farther away from the joint centres. Other factors affecting the reliability of hand held dynamometry were listed by Wadsworth *et al.,* [74], which include the rater's gender, body weight and grip strength, since they influence the rater's ability to stabilize the dynamometer. One limitation of this part of the review was that not all the studies measured the same aspect of reliability. Most studies assessed the test re-test reliability [9, 20, 31, 61, 90, 92] followed by the combined assessment of inter- and intra-rater reliability [30, 49, 50, 83, 89] as summarized in Tables **3** and **4**.

There were few studies which analyzed the influence of rater experience on the results. Larson *et al.,* [49] assessing

Individuals with spinal cord injury and Burns *et al.,* [30] examining 19 patients with upper limb weakness secondary to tetraplegia provide a straightforward conclusion that reliable results can be produced by novice examiner. Lindstrom-Hazel *et al.,* [85] showed that occupational therapy students can be reliable in testing after being trained and tested for competency. On the contrary, Goonetilleke *et al.,* [73] in a study involving 19 patients with motor neuron disease argues that the overall accuracy, but not reproducibility and variability, was increased with greater rater experience.

Despite the numerous positive findings in this systematic review, we should take into account the various factors which have been reported to influence the results obtained. Pincus *et al.,* [39] distinguished between the results obtained for men compared with women and concluded that the survival rate according to mean grip strength was statistically significant in women but not men. On the contrary, Stenvinkel *et al.,* [45] reported that low hand grip strength was a good predictor of outcome in men but not in women. In another study Pincus *et al.,* [44] also found that the mean grip strength was not different between the patients who died and the ones who did not. Davies *et al.,* [48] showed that handgrip strength was predictive of complications for patients over 80 but not for those under 80. Luna-Heredia *et al.,* [72] noted that grip strength is dependent on age, gender, BMI and dominant/non-dominant hand. Wadsworth *et al.,* [74] found that the reliability of muscle testing using a hand held dynamometer could be affected by the rater's gender, body weight and grip strength as these parameters affect the rater's ability to stabilize the dynamometer. Other factors include measuring upper or lower extremity strength [81], the distance where dynamometer is placed from the joint centres [80], subject not being able to move limb against gravity [51] and subject overpowering the rater [84].

Ultimately, by looking at the results of this systematic review we can conclude that dynamometry is a reliable tool that is currently being used for a wide range of medical conditions. From the results of this study we can see that only a small number of studies involved the use of dynamometry in hand trauma assessment. By looking at the general reliability of dynamometry, we can say that there would be no harm in applying dynamometry in hand trauma assessment. In fact we found a number of advantages to using dynamometry. These being due to its cheap [61-63, 69, 95] reproducible [63], sensitive [12, 68] convenient [63], quick [91], objective [91], simple [61], viable [95], portable [69, 95] and objective [31] nature. Based on the results found we suggest that dynamometry is used more often in clinical practice. At the same time we should take into account the various factors which have been reported to influence the results.

CONCLUSION

In this systematic review of the literature we have collected the available evidence concerning the reliability, general use, different types and the influence of rater experience in dynamometry. The results have been presented in Tables **1-5** and Figs. (**1**, **2**) in the results section. It was found that dynamometry is applied in a wide range of medical conditions. Furthermore, the great majority of studies reported acceptable to high reliability of dynamometry, regardless of the different type of device or aspect of reliability they were looking at. In total, 23 different types of dynamometers were identified of which Jamar mechanical dynamometer was used most often in the studies reviewed. There were mixed results concerning the effect of rater experience. The factors influencing the results of dynamometry were identified as age, gender, body weight, grip strength, BMI, non/dominant hand, assessing upper/lower limbs, rater and patient's strength and the distance from the joint where the dynamometer is placed. Due to its numerous advantages found in this review, we suggest that hand dynamometry has a great potential, and could be used more often in clinical practice.

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CONFLICT OF INTEREST

None declared.

REFERENCES

[1] Lanska DJ. The role of technology in neurologic specialization in America. Neurology 1997 ; 48(6): 1722-7.

[2] Lanska DJ, Dietrichs E. History of the reflex hammer. Tidsskr Nor Laegeforen 1998; 118(30): 4666-8.

[3] Lanska DJ, Edmonson JM. The suspension therapy for tabes dorsalis. A case history of a therapeutic fad. Arch Neurol 1990; 47(6): 701-4.

[4] Lanska DJ. William Hammond, the dynamometer, the dynamograph. Arch Neurol 2000 ; 57(11): 1649-53.

[5] Su CY, Lin JH, Chien TH, Cheng KF, Sung YT. Grip strength in different positions of elbow and shoulder. Arch Phys Med Rehabil 1994; 75(7): 812-5.

[6] Bohannon RW. Dynamometer measurements of hand-grip strength predict multiple outcomes. Percept Mot Skills 2001; 93(2): 323-8.

[7] Onder G, Penninx BW, Ferrucci L, Fried LP, Guralnik JM, Pahor M. Measures of physical performance and risk for progressive and catastrophic disability: results from the Women's Health and Aging Study. J Gerontol A Biol Sci Med Sci 2005; 60(1): 74-9.

[8] Figueiredo F, Dickson ER, Pasha T, *et al*. Impact of nutritional status on outcomes after liver transplantation. Transplantation 2000; 70(9): 1347-52.

[9] O'Shea SD, Taylor NF, Paratz JD. Measuring muscle strength for people with chronic obstructive pulmonary disease: retest reliability of hand-held dynamometry. Arch Phys Med Rehabil 2007; 88(1): 32-6.

[10] Watters DA, Haffejee AA, Angorn IB, Duffy KJ. Nutritional assessment by hand grip dynamometry. S Afr Med J 1985; 68(8): 585-7.

[11] Guo CB, Zhang W, Ma DQ, Zhang KH, Huang JQ. Hand grip strength: an indicator of nutritional state and the mix of postoperative complications in patients with oral and maxillofacial cancers. Br J Oral Maxillofac Surg 1996; 34(4): 325-7.

[12] Klidjian AM, Foster KJ, Kammerling RM, Cooper A, Karran SJ. Relation of anthropometric and dynamometric variables to serious postoperative complications. Br Med J 1980 ; 281(6245): 899-901.

[13] Wang AY, Sea MM, Ho ZS, Lui SF, Li PK, Woo J. Evaluation of handgrip strength as a nutritional marker and prognostic indicator in peritoneal dialysis patients. Am J Clin Nutr 2005; 81(1): 79-86.

[14] Stokes HM, Landrieu KW, Domangue B, Kunen S. Identification of low-effort patients through dynamometry. J Hand Surg Am 1995; 20(6): 1047-56.

[15] Selles RW, van Ginneken BT, Schreuders TA, Janssen WG, Stam HJ. Dynamometry of intrinsic hand muscles in patients with Charcot-Marie-Tooth disease. Neurology 2006; 67(11): 2022-7.

[16] Scholtes VA, Becher JG, Comuth A, Dekkers H, Van DL, Dallmeijer AJ. Effectiveness of functional progressive resistance exercise strength training on muscle strength and mobility in children with cerebral palsy: a randomized controlled trial. Dev Med Child Neurol 2010; 52(6): e107-13.

[17] Suresh M, Nicholls PG, Das L, Van Brakel WH. Voluntary muscle testing and dynamometry in diagnosis of motor impairment in leprosy: a comparative study within the INFIR Cohort Study. Lepr Rev 2008; 79(3): 277-94.

[18] Busse ME, Hughes G, Wiles CM, Rosser AE. Use of hand-held dynamometry in the evaluation of lower limb muscle strength in people with Huntington's disease. J Neurol 2008; 255(10): 1534-40.

[19] Burns J, Bray P, Cross LA, North KN, Ryan MM, Ouvrier RA. Hand involvement in children with Charcot-Marie-Tooth disease type 1A. Neuromuscul Disord 2008; 18(12): 970-3.

[20] Burns J, Redmond A, Ouvrier R, Crosbie J. Quantification of muscle strength and imbalance in neurogenic pes cavus, compared to health controls, using hand-held dynamometry. Foot Ankle Int 2005; 26(7): 540-4.

[21] Ali NA, O'Brien JM Jr, Hoffmann SP, *et al*. Acquired weakness, handgrip strength, and mortality in critically ill patients. Am J Respir Crit Care Med 2008; 178(3): 261-8.

[22] Mattar FL, Sobreira C. Hand weakness in Duchenne muscular dystrophy and its relation to physical disability. Neuromuscul Disord 2008; 18(3): 193-8.

[23] Fuster CO, Fuster GO, Galindo AD, Galo AP, Verdugo JM, Lozano FM. Analysis of energy expenditure in adults with cystic fibrosis: comparison of indirect calorimetry and prediction equations. Arch Bronconeumol 2007; 43(7): 366-72.

[24] Schreuders TA, Selles RW, Roebroeck ME, Stam HJ. Strength measurements of the intrinsic hand muscles: a review of the development and evaluation of the Rotterdam intrinsic hand myometer. J Hand Ther 2006; 19(4): 393-401.

[25] van MJ, Roebroeck ME, Selles RW, Stam HJ. Responsiveness of isokinetic dynamometry parameters, pain and activity level scores to evaluate changes in patients with capsulitis of the shoulder. Clin Rehabil 2006; 20(6): 496-501.

[26] Harris JE, Eng JJ. Individuals with the dominant hand affected following stroke demonstrate less impairment than those with the nondominant hand affected. Neurorehabil Neural Repair 2006; 20(3): 380-9.

[27] Tomasevic S, Filipovic D, Hajdu L, Naumovic N. Importance of use of dynamometry during medical rehabilitation in patients after stroke. Med Pregl 2003; 56(11-12): 507-10.

[28] Bohannon RW, Larkin PA, Smith MB, Horton MG. Relationship between static muscle strength deficits and spasticity in stroke patients with hemiparesis. Phys Ther 1987 ; 67(7): 1068-71.

[29] Pierson LM, Miller LE, Pierson ME, Herbert WG, Cook JW. Validity of hand-held dynamometry for strength assessment in cardiac rehabilitation. J Cardiopulm Rehabil 2005 ; 25(5): 266-9.

[30] Burns SP, Breuninger A, Kaplan C, Marin H. Hand-held dynamometry in persons with tetraplegia: comparison of make- versus break-testing techniques. Am J Phys Med Rehabil 2005; 84(1): 22-9.

[31] Hayes KW, Falconer J. Reliability of hand-held dynamometry and its relationship with manual muscle testing in patients with osteoarthritis in the knee. J Orthop Sports Phys Ther 1992; 16(3): 145-9.

[32] Rantanen T, Volpato S, Ferrucci L, Heikkinen E, Fried LP, Guralnik JM. Handgrip strength and cause-specific and total mortality in older disabled women: exploring the mechanism. J Am Geriatr Soc 2003; 51(5): 636-41.

[33] Bohannon RW, Maljanian R, Ferullo J. Mortality and readmission of the elderly one year after hospitalization for pneumonia. Aging Clin Exp Res 2004; 16(1): 22-5.

[34] Vecchiarino P, Bohannon RW, Ferullo J, Maljanian R. Short-term outcomes and their predictors for patients hospitalized with community-acquired pneumonia. Heart Lung 2004; 33(5): 301-7.

[35] Bohannon RW. Measuring knee extensor muscle strength. Am J Phys Med Rehabil 2001; 80(1): 13-8.

[36] Kalfarentzos F, Spiliotis J, Velimezis G, Dougenis D, Androulakis J. Comparison of forearm muscle dynamometry with nutritional prognostic index, as a preoperative indicator in cancer patients. JPEN J Parenter Enteral Nutr 1989; 13(1): 34-6.

[37] Cook JW, Pierson LM, Herbert WG, *et al*. The influence of patient strength, aerobic capacity and body composition upon outcomes after coronary artery bypass grafting. Thorac Cardiovasc Surg 2001; 49(2): 89-93.

[38] Mahalakshmi VN, Ananthakrishnan N, Kate V, Sahai A, Trakroo M. Handgrip strength and endurance as a predictor of postoperative morbidity in surgical patients: can it serve as a simple bedside test? Int Surg 2004; 89(2):1 15-21.

[39] Pincus T, Brooks RH, Callahan LF. Prediction of long-term mortality in patients with rheumatoid arthritis according to simple questionnaire and joint count measures. Ann Intern Med 1994; 120(1): 26-34.

[40] Pincus T, Callahan LF, Vaughn WK. Questionnaire, walking time and button test measures of functional capacity as predictive markers for mortality in rheumatoid arthritis. J Rheumatol 1987; 14(2): 240-51.

[41] Callahan LF, Pincus T, Huston JW, III, Brooks RH, Nance EP Jr, Kaye JJ. Measures of activity and damage in rheumatoid arthritis: depiction of changes and prediction of mortality over five years. Arthritis Care Res 1997; 10(6): 381-94.

[42] Corbett M, Dalton S, Young A, Silman A, Shipley M. Factors predicting death, survival and functional outcome in a prospective study of early rheumatoid disease over fifteen years. Br J Rheumatol 1993; 32(8): 717-23.

[43] Mitchell DM, Spitz PW, Young DY, Bloch DA, McShane DJ, Fries JF. Survival, prognosis, and causes of death in rheumatoid arthritis. Arthritis Rheum 1986; 29(6): 706-14.

[44] Pincus T, Callahan LF, Sale WG, Brooks AL, Payne LE, Vaughn WK. Severe functional declines, work disability, and increased mortality in seventy-five rheumatoid arthritis patients studied over nine years. Arthritis Rheum 1984; 27(8): 864-72.

[45] Stenvinkel P, Barany P, Chung SH, Lindholm B, Heimburger O. A comparative analysis of nutritional parameters as predictors of outcome in male and female ESRD patients. Nephrol Dial Transplant 2002; 17(7): 1266-74.

[46] Alvares-da-Silva MR, Reverbel da ST. Comparison between handgrip strength, subjective global assessment, and prognostic nutritional index in assessing malnutrition and predicting clinical outcome in cirrhotic outpatients. Nutrition 2005; 21(2): 113-7.

[47] Meyer HE, Tverdal A, Falch JA, Pedersen JI. Factors associated with mortality after hip fracture. Osteoporos Int 2000; 11(3): 228-32.

[48] Davies CW, Jones DM, Shearer JR. Hand grip--a simple test for morbidity after fracture of the neck of femur. J R Soc Med 1984; 77(10): 833-6.

[49] Larson CA, Tezak WD, Malley MS, Thornton W. Assessment of postural muscle strength in sitting: reliability of measures obtained with hand-held dynamometry in individuals with spinal cord injury. J Neurol Phys Ther 2010; 34(1): 24-31.

[50] Knols RH, Aufdemkampe G, de Bruin ED, Uebelhart D, Aaronson NK. Hand-held dynamometry in patients with haematological malignancies: measurement error in the clinical assessment of knee extension strength. BMC Musculoskelet Disord 2009; 10: 31.

[51] Mahony K, Hunt A, Daley D, Sims S, Adams R. Inter-tester reliability and precision of manual muscle testing and hand-held dynamometry in lower limb muscles of children with spina bifida. Phys Occup Ther Pediatr 2009; 29(1): 44-59.

[52] Merlini L, Mazzone ES, Solari A, Morandi L. Reliability of hand-held dynamometry in spinal muscular atrophy. Muscle Nerve 2002; 26(1): 64-70.

[53] Schlussel MM, dos Anjos LA, de Vasconcellos MT, Kac G. Reference values of handgrip dynamometry of healthy adults: a population-based study. Clin Nutr 2008; 27(4): 601-7.

[54] Aronin PA, Kerrick R. Value of dynamometry in assessing upper extremity function in children with myelomeningocele. Pediatr Neurosurg 1995; 23(1): 7-12.

[55] Newman AB, Kupelian V, Visser M, *et al*. Strength, but not muscle mass, is associated with mortality in the health, aging and body composition study cohort. J Gerontol A Biol Sci Med Sci 2006; 61(1): 72-7.

[56] Al SS, Markides KS, Ray L, Ostir GV, Goodwin JS. Handgrip strength and mortality in older Mexican Americans. J Am Geriatr Soc 2002; 50(7): 1250-6.

[57] Kerr A, Syddall HE, Cooper C, Turner GF, Briggs RS, Sayer AA. Does admission grip strength predict length of stay in hospitalised older patients? Age Ageing 2006; 35(1): 82-4.

[58] Milne JS, Maule MM. A longitudinal study of handgrip and dementia in older people. Age Ageing 1984; 13(1): 42-8.

[59] Metter EJ, Talbot LA, Schrager M, Conwit R. Skeletal muscle strength as a predictor of all-cause mortality in healthy men. J Gerontol A Biol Sci Med Sci 2002; 57(10): B359-65.

[60] Rantanen T, Guralnik JM, Foley D, *et al*. Midlife hand grip strength as a predictor of old age disability. JAMA 1999; 281(6): 558-60.

[61] Boiteau M, Malouin F, Richards CL. Use of a hand-held dynamometer and a Kin-Com dynamometer for evaluating spastic hypertonia in children: a reliability study. Phys Ther 1995; 75(9): 796-802.

[62] Stratford PW, Balsor BE. A comparison of make and break tests using a hand-held dynamometer and the Kin-Com. J Orthop Sports Phys Ther 1994; 19(1): 28-32.

[63] Harries AD. A comparison of hand-grip dynamometry and arm muscle size amongst Africans in North-East Nigeria. Hum Nutr Clin Nutr 1985; 39(4): 309-13.

[64] Phillips P. Grip strength, mental performance and nutritional status as indicators of mortality risk among female geriatric patients. Age Ageing 1986; 15(1): 53-6.

[65] Rolland Y, Lauwers-Cances V, Cesari M, Vellas B, Pahor M, Grandjean H. Physical performance measures as predictors of mortality in a cohort of community-dwelling older French women. Eur J Epidemiol 2006; 21(2): 113-22.

[66] Giampaoli S, Ferrucci L, Cecchi F, *et al*. Hand-grip strength predicts incident disability in non-disabled older men. Age Ageing 1999; 28(3): 283-8.

[67] Albrand G, Munoz F, Sornay-Rendu E, DuBoeuf F, Delmas PD. Independent predictors of all osteoporosis-related fractures in healthy postmenopausal women: the OFELY study. Bone 2003; 32(1): 78-85.

[68] Hunt DR, Rowlands BJ, Johnston D. Hand grip strength--a simple prognostic indicator in surgical patients. JPEN J Parenter Enteral Nutr 1985; 9(6): 701-4.

[69] Martin HJ, Yule V, Syddall HE, Dennison EM, Cooper C, Aihie SA. Is hand-held dynamometry useful for the measurement of quadriceps strength in older people? A comparison with the gold standard Bodex dynamometry. Gerontology 2006; 52(3): 154-9.

[70] Castel-Lacanal E, Marque P, Tardy J, *et al*. Induction of cortical plastic changes in wrist muscles by paired associative stimulation in the recovery phase of stroke patients. Neurorehabil Neural Repair 2009; 23(4): 366-72.

[71] Ladeira CE, Hess LW, Galin BM, Fradera S, Harkness MA. Validation of an abdominal muscle strength test with dynamometry. J Strength Cond Res 2005; 19(4): 925-30.

[72] Luna-Heredia E, Martin-Pena G, Ruiz-Galiana J. Handgrip dynamometry in healthy adults. Clin Nutr 2005; 24(2): 250-8.

[73] Goonetilleke A, Modarres-Sadeghi H, Guiloff RJ. Accuracy, reproducibility, and variability of hand-held dynamometry in motor neuron disease. J Neurol Neurosurg Psychiatr 1994 ; 57(3): 326-32.

[74] Wadsworth C, Nielsen DH, Corcoran DS, Phillips CE, Sannes TL. Interrater reliability of hand-held dynamometry: effects of rater gender, body weight, and grip strength. J Orthop Sports Phys Ther 1992; 16(2): 74-81.

[75] Sarkisian CA, Liu H, Ensrud KE, Stone KL, Mangione CM. Correlates of attributing new disability to old age. Study of Osteoporotic Fractures Research Group. J Am Geriatr Soc 2001; 49(2): 134-41.

[76] Reeve J, Walton J, Russell LJ, *et al.* Determinants of the first decade of bone loss after menopause at spine, hip and radius. QJM 1999; 92(5): 261-73.

[77] Humphreys J, de la Maza P, Hirsch S, Barrera G, Gattas V, Bunout D. Muscle strength as a predictor of loss of functional status in hospitalized patients. Nutrition 2002; 18(7-8):616-20.

[78] Schroeder D, Hill GL. Predicting postoperative fatigue: importance of preoperative factors. World J Surg 1993; 17(2): 226-31.

[79] Webb AR, Newman LA, Taylor M, Keogh JB. Hand grip dynamometry as a predictor of postoperative complications reappraisal using age standardized grip strengths. JPEN J Parenter Enteral Nutr 1989; 13(1): 30-3.

[80] McMahon LM, Burdett R, Whitney SL. Effects of muscle group and placement site on reliability of hand-held dynamometry strength measurements. J Orthop Sports Phys Ther 1992; 15(5): 236-42.

[81] Verschuren O, Ketelaar M, Takken T, Van BM, Helders PJ, Gorter JW. Reliability of hand-held dynamometry and functional strength tests for the lower extremity in children with Cerebral Palsy. Disabil Rehabil 2008;30(18): 1358-66.

[82] Rice MS, Leonard C, Carter M. Grip strengths and required forces in accessing everyday containers in a normal population. Am J Occup Ther 1998; 52(8): 621-6.

[83] Arnold CM, Warkentin KD, Chilibeck PD, Magnus CR. The reliability and validity of handheld dynamometry for the measurement of lower-extremity muscle strength in older adults. J Strength Cond Res 2010; 24(3): 815-24.

[84] Kelln BM, McKeon PO, Gontkof LM, Hertel J. Hand-held dynamometry: reliability of lower extremity muscle testing in healthy, physically active, young adults. J Sport Rehabil 2008; 17(2): 160-70.

[85] Lindstrom-Hazel D, Kratt A, Bix L. Interrater reliability of students using hand and pinch dynamometers. Am J Occup Ther 2009; 63(2): 193-7.

[86] Morris SL, Dodd KJ, Morris ME. Reliability of dynamometry to quantify isometric strength following traumatic brain injury. Brain Inj 2008; 22(13-14): 1030-7.

[87] Katz-Leurer M, Rottem H, Meyer S. Hand-held dynamometry in children with traumatic brain injury: within-session reliability. Pediatr Phys Ther 2008; 20(3): 259-63.

[88] Crompton J, Galea MP, Phillips B. Hand-held dynamometry for muscle strength measurement in children with cerebral palsy. Dev Med Child Neurol 2007; 49(2): 106-11.

[89] Krause DA, Schlagel SJ, Stember BM, Zoetewey JE, Hollman JH. Influence of lever arm and stabilization on measures of hip abduction and adduction torque obtained by hand-held dynamometry. Arch Phys Med Rehabil 2007; 88(1): 37-42.

[90] Roy MA, Doherty TJ. Reliability of hand-held dynamometry in assessment of knee extensor strength after hip fracture. Am J Phys Med Rehabil 2004; 83(11): 813-8.

[91] Kilmer DD, McCrory MA, Wright NC, Rosko RA, Kim HR, Aitkens SG. Hand-held dynamometry reliability in persons with neuropathic weakness. Arch Phys Med Rehabil 1997; 78(12): 1364-8.

[92] Kolber MJ, Beekhuizen K, Cheng MS, Fiebert IM. The reliability of hand-held dynamometry in measuring isometric strength of the shoulder internal and external rotator musculature using a stabilization device. Physiother Theory Pract 2007; 23(2): 119-24.

[93] van den Beld WA, van der Sanden GA, Sengers RC, Verbeek AL, Gabreels FJ. Validity and reproducibility of hand-held dynamometry in children aged 4-11 years. J Rehabil Med 2006; 38(1): 57-64.

[94] Bohannon RW. Intertester reliability of hand-held dynamometry: a concise summary of published research. Percept Mot Skills 1999; 88(3 Pt 1): 899-902.

[95] Bohannon RW. Hand-held compared with isokinetic dynamometry for measurement of static knee extension torque (parallel reliability of dynamometers). Clin Phys Physiol Meas 1990; 11(3): 217-22.

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