

1-1-2011

# Intra-tester and inter-tester reliability of the MicroFET 3 hand-held dynamometer.

M N. Clarke

*Royal College of Surgeons in Ireland*

D A. Ni Mhaircheartaigh

*Royal College of Surgeons in Ireland*

G M. Walsh

*Royal College of Surgeons in Ireland*

J M. Walsh

*Royal College of Surgeons in Ireland*

Dara Meldrum

*Royal College of Surgeons in Ireland*

---

## Citation

Clarke MN, Ni Mhaircheartaigh DA, Walsh GM, Walsh JM, Meldrum D. Intra-tester and inter-tester reliability of the MicroFET 3 hand-held dynamometer. *Physiotherapy Practice and Research*. 2011;31(1)13-18.

This Article is brought to you for free and open access by the School of Physiotherapy at e-publications@RCSI. It has been accepted for inclusion in School of Physiotherapy Articles by an authorized administrator of e-publications@RCSI. For more information, please contact [epubs@rcsi.ie](mailto:epubs@rcsi.ie).

---

— Use Licence —



This work is licensed under a [Creative Commons Attribution-Noncommercial-Share Alike 4.0 License](https://creativecommons.org/licenses/by-nc-sa/4.0/).

---

# Intra-tester and inter-tester reliability of the MicroFET 3 hand-held dynamometer

Clarke MN,<sup>1</sup> Ni Mhuirheartaigh DA,<sup>1</sup> Walsh GM,<sup>1</sup> Walsh JM,<sup>1,2</sup> Meldrum D<sup>1</sup>

<sup>1</sup> School of Physiotherapy, The Royal College of Surgeons in Ireland, Dublin, Ireland.

<sup>2</sup> Department of Physiotherapy, Trinity Centre for Health Science, St. James's Hospital, Dublin, Ireland.

## ABSTRACT

**Background:** The reliability of the MicroFET 3 has not previously been reported in the literature. The aim of this study was to evaluate intra-tester and inter-tester reliability of the MicroFET3 hand-held dynamometer (HHD) in three lower limb muscle groups.

**Methods:** Maximum voluntary isometric contraction (MVIC) of hip extension, knee extension and ankle plantar flexion were measured in 38 healthy participants (males=18, females=20) by two testers on separate days using the MicroFET3 HHD. The reliability analysis was carried out using intra-class correlation coefficients (ICCs) to measure association and Bland and Altman plots to demonstrate agreement.

**Results:** The results showed that intra-tester reliability was moderate to excellent; with associations ranging from ICC 0.56 - 0.92 and higher agreement for knee and ankle than hip measurements was shown. Inter-tester reliability was lower, with hip and knee associations ranging from ICC 0.60 - 0.66. Ankle measurements inter-tester associations were particularly low (ICC 0.23 and 0.15). These values would not be considered acceptable for clinical use. Bland and Altman plots used to demonstrate agreement between testers displayed a considerable lack of agreement with discrepancies of up to 150N noted in measurements.

**Conclusion:** The results suggest that the MicroFET3 HHD displayed moderate to excellent intra-tester reliability and poor to moderate inter-tester reliability and agreement with discrepancies noted between muscle groups. While use of this instrument can be recommended when consistently used by a single tester, further reliability analysis should be carried out before this instrument could be recommended for use by different testers in the clinical setting.

**Keywords:** Muscle Strength; Muscle Strength dynamometer; Reliability of Results

**Corresponding author:** J. M. Walsh, E-mail: julie.broderick@tcd.ie

## INTRODUCTION

Strength testing is one of the cornerstones of physical examination and an increase in strength is the aim of many rehabilitation programs.<sup>1</sup> Manual muscle testing (MMT) is the most commonly used method of strength testing in the clinical setting and is a subjective measurement technique whereby the tester applies resistance to a maximum voluntary muscle contraction.<sup>2</sup> Among its advantages it is a quick and simple procedure providing information that can be useful in differential diagnosis, prognosis and treatment of neuromuscular and musculoskeletal deficits. Various factors must be taken into account when testing muscles including test standardization, appropriate positioning, observation of how the patient performs the test and avoidance of pain or discomfort which may inhibit the participant from performing a maximal contraction.<sup>3</sup> There has been much controversy over the reliability of MMT grades<sup>4-7</sup> as good visual and palpation skills are necessary to identify changes in muscle grades, a skill that depends on the experience of the examiner<sup>2, 8</sup>.

The need for greater objectivity in clinical examination has led to the development of devices such as the hand-held dynamometer (HHD) and isokinetic machines. The isokinetic machine is considered the gold standard in muscle testing with validity<sup>9-10</sup> and reliability<sup>11</sup> well documented. However, this equipment is time consuming to use, expensive and not readily accessible to most practitioners.<sup>12</sup>

Dynamometers offer an alternative to the isokinetic machine as they are a portable, time-efficient and relatively inexpensive method of measuring isometric contractions<sup>13</sup> and have also been shown to be valid and reliable when compared to the isokinetic machine.<sup>12</sup> Also, with the publication of normative data, HHDs offer a simple alternative in clinical practice and provide a more quantitative objective measure than MMT.<sup>14</sup>

The reliability of HHDs has been previously reported in the literature.<sup>14-17</sup> Studies have used a variety of different dynamometers and none of these have compared reliability among the different models. Further to this, reliability of the MicroFET3 has not been established. Before the MicroFET3 can be used clinically or as part of future research, the reliability of this instrument must be determined.<sup>18</sup>

The main limitation of HHD studies to date is the influence of tester strength, which inherently affects the ability of the tester to stabilize the dynamometer appropriately.<sup>2, 12, 17, 19-20</sup>

Measurements obtained may therefore vary according to the tester's strength. There are also inconsistencies in describing different muscle groups when using HHDs<sup>2</sup> which is especially evident in larger muscle groups.<sup>17</sup> A number of studies have highlighted difficulties in testing lower-limb muscle strength accurately,<sup>2, 21-22</sup> which may be due to increased force generated by lower-limb muscle groups.<sup>21</sup> Brinkman<sup>23</sup> concluded that HHDs were not reliable when testing large muscle groups exerting forces greater than 15kg. Agre et al<sup>22</sup>

carried out a study examining both intra- and inter-tester reliability of muscle strength in upper and lower extremities using a HHD. These authors concluded the instrument was reliable for measuring upper extremities in clinical practice. However, results obtained from lower extremity measurements were less reliable and it was concluded that the HHD was unacceptable for clinical assessment of the lower-limb.<sup>22</sup> Consequently the biggest challenge to these devices to date has been accurate measurement of lower limb strength.

A new dynamometer the MicroFET 3 was patented in 2005 (Hoggan Health Industries, West Jordan, UT). No literature has reported reliability measures of this instrument. The reliability of an instrument must be determined in order to eliminate it as a source of error.<sup>24,25</sup> The aim of this study therefore was to investigate intra- and inter-tester reliability as well as agreement between testers of the MicroFET3 HHD in three of the lower limb muscle groups.

**METHODOLOGY**

**Participants**

A convenience sample of 38 healthy participants (20 females and 18 males) from a university population volunteered to participate in this study. To be included in the study, participants had to be healthy and between the ages of 18 and 30 years. Participants were excluded if had a history of lower extremity injury in the three months prior to testing or if they had a history of any medical condition that would preclude exercise participation. Subjects were instructed to refrain from strenuous activity or alcohol for 24 hours prior to testing, and to refrain from eating for at least 3 hours before the test for standardisation.<sup>26</sup> Ethical approval was obtained from the Royal College of Surgeons of Ireland (RCSI) research ethics committee and subjects gave written, informed consent prior to participation.

**Study procedure**

The testers involved in this study were three final year female physiotherapy students. Two of these testers were randomly selected for the final analysis. The testers were trained and

instructed in the use of the MicroFET3 HHD prior to commencing testing by an experienced physiotherapist familiar with this equipment. Testers undertook a period of training and familiarization in the use of the HHD, to ensure competency and efficiency. In addition, a pilot study was carried out on eight participants prior to commencement of testing. Throughout the testing period, each tester was blinded to the values obtained by the other tester.

Lower limb strength was measured using the MicroFET3 HHD – The MicroFET3 is a battery operated hand-held device which measures peak force. It is a load-cell based strain gauge type of dynamometer whereby a force distorts a strain gauge and converts it to an electrical signal which can be downloaded to accompanying software to support data analysis. The MicroFET3 measures forces in Newtons (N), up to a value of 890N.

Testing was carried out in the RCSI Movement Laboratory on two occasions, one week apart. During the first visit, the study was explained to the participants. Participants warmed up on a stationary bike for five minutes and then performed stretches to the major muscle groups of the lower extremity, holding each stretch for 10 seconds. Following this, the MicroFET3 was used to measure knee extension, hip flexion and ankle plantar-flexion strength on one leg. The leg to be tested was randomly selected by tossing a coin. Testing positions<sup>27-29</sup> and stabilizations were standardized and strictly adhered to (Table 1). Verbal instructions for each test were standardized as follows: “Push as hard as you can, as hard as you can, as hard as you can”, in a loud voice. Isometric strength was measured using a make test as this test has been shown to be more reliable than the break test.<sup>15</sup> The make test is carried out by the examiner holding the dynamometer stationary while the subject exerts a maximal force against it.<sup>30</sup> Participants were instructed to perform three consecutive maximal efforts, lasting five seconds each. In order to avoid fatigue, a rest period of 30 seconds separated each contraction. This procedure was repeated by each tester, giving a total of 18 measurements for each participant. The testing sequence was consistently carried out in the following order; knee extension followed by

**Table 1** Positions for Testing

<b>Movement</b>	<b>Position</b>	<b>Strap Position</b>	<b>Dynamometer Position</b>	<b>Instruction</b>	<b>Reference</b>
<b>Knee Extension</b>	Sitting in quadriceps bench Hips & knees in 90° flexion Hands on thigh, palmar surface upwards	Lower 1/3 of thigh proximal to knee	Anterior leg proximal to ankle	Straighten out your knee	Wang et al. (2002) <sup>27</sup>
<b>Hip Extension</b>	Prone lying on plinth Knee extended Hands by their side palmar surface upwards	Across pelvis	Posterior thigh proximal to knee	Lift your leg off the bed keeping your knee straight	Taylor et al. (2004) <sup>28</sup>
<b>Ankle Plantar flexion</b>	Prone lying on plinth Ankle in neutral Hands by their side palmar surface upwards	Lower leg proximal to ankle	Plantar surface of metatarsal heads	Point your toes towards me	Nollet & Beelen (1999) <sup>29</sup>

hip extension and ankle plantar-flexion and the order in which the testers performed the procedure was randomised by tossing a coin. There was a rest period of three minutes between testers. Measurement 1 recorded by each tester was regarded as the familiarisation measurement. The maximum recording from measurements 2 and 3 was documented as the baseline data against which subsequent data was evaluated against.<sup>31</sup> These results were placed in an envelope, sealed, and were not consulted until after the second visit. The second visit involved retesting the participants using the same protocol and order of testing as during the first visit.

**Data analysis**

Reliability was evaluated by computing Intra-class Correlation Coefficients (ICC) which analyse the consistency between two or more quantitative measures<sup>25</sup> and Bland and Altman Plots<sup>32</sup> which measured agreement. Intra-class correlation coefficients were calculated from a single measure chosen as the maximum value obtained during testing and ICC (3,1), one way random, was used to evaluate intra-tester reliability while ICC (2,1), two-way random was used to evaluate inter-tester reliability.<sup>33</sup> Correlation or association is greater as the ICC value gets closer to 1.<sup>34</sup> It has been reported in the literature that ‘moderate’ association can be judged by ICC values between 0.50 - 0.75

and ‘good’ to ‘excellent’ association over 0.75.<sup>32</sup> However, in order to consider an instrument suitable for clinical use, the ICC value must be over 0.90.<sup>32</sup> The ICC does not give an indication of magnitude of disparity between measurements.<sup>32</sup> Therefore, Bland and Altman Plots and standard error of measurement (SEM) were used to compliment the inter-rater analysis. Bland and Altman plots provide a visual representation of the degree of agreement between measurements.<sup>32</sup> The SEM is an estimate of measurement error and the smaller the SEM the greater the agreement. SEM was calculated using the following formula;  $S \times (\sqrt{1-ICC})$  where S corresponds to the pooled standard deviation and ICC is the reliability coefficient.<sup>35</sup> All analysis was performed using SPSS Version 15 for Windows (SPSS Inc, Chicago, IL) statistics software.

**RESULTS**

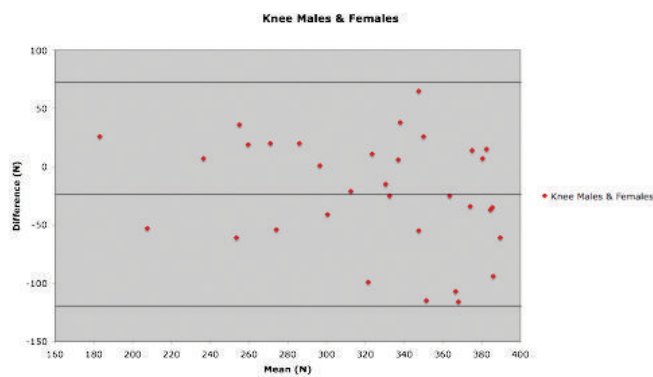
Thirty-eight healthy participants were recruited to participate in this study (18 males and 20 females). The mean age was  $21.8 \pm 2.4$  years. Five male participants were excluded from the knee extension testing protocol. In these instances testers were unable to match the forces exerted by the participants and were therefore unable to maintain an isometric contraction. As a result, the measurements obtained were deemed unreliable.

**Table 2** Intra-tester reliability and agreement

<b>Intra-tester reliability</b>				
<b>Muscle Group</b>	<b>ICC (95% CI)</b>		<b>SEM (N)</b>	
<b>Tester</b>	1	2	1	2
Knee (n=33)	0.86 (0.74, 0.93)	0.88 (0.78, 0.94)	19.38	21.51
Hip (n=38)	0.57 (0.3, 0.75)	0.92 (0.85, 0.96)	33.64	16.86
Ankle (n=38)	0.56 (0.29, 0.74)	0.88 (0.78, 0.94)	21.89	18.91
<b>Intra-tester agreement</b>				
<b>Movement</b>	<b>d (N)</b>	<b>SD diff</b>	<b>95% Limits of agreement (N)</b>	
<b>Tester 1</b>				
Knee	-9.7	27.4	-64.5 - 45.1	
Hip	-21.4	35.4	-92.7 - 49.3	
Ankle	10.3	31.0	-51.7 - 72.4	
<b>Tester 2</b>				
Knee	-13.4	30.0	-73.5 - 46.7	
Hip	-28.2	23.8	-75.8 - 19.3	
Ankle	-8.2	26.7	-61.7 - 45.3	

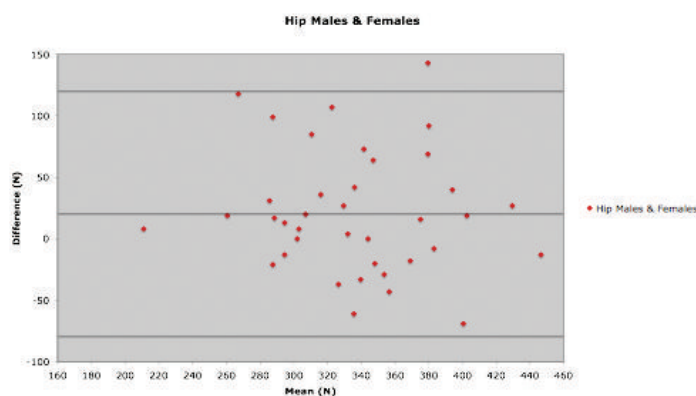
ICC= Intraclass correlation co-efficients, 95% CI = 95% confidence interval, SEM = standard error of measurement, D=difference, N=Newtons, SD diff= Standard deviation of difference

**Figure 1. Bland and Altman distribution of knee measurements Day 1, between Tester 1 & 2.**

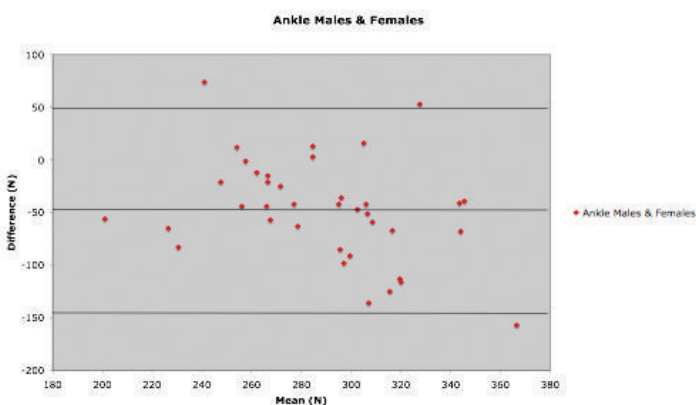


Figures 1-3, the differences are plotted against the mean measurements (N=Newtons) for males and females combined. Horizontal lines are drawn at the mean difference, and at the mean difference plus and minus 1.96 times the standard deviation of the differences. Each dot shows an individual data point for each subject.

**Figure 2. Bland and Altman distribution of hip measurements Day 1, between Testers 1 & 2.**



**Figure 3. Bland and Altman distribution of ankle measurements Day 1, between Testers 1 & 2.**



**Table 3** Inter-rater reliability on days one and two calculated using the Intra class correlation co-efficient (ICC 2,1) for all subjects.

Muscle Group	ICC (95 % CI)	ICC (95 % CI)
Day	Day One	Day Two
Knee (n=33)	0.61 (0.42, 0.76)	0.66 (0.48, 0.80)
Hip (n=38)	0.60 (0.42, 0.75)	0.66 (0.49, 0.79)
Ankle (n=38)	0.23 (0.03, 0.45)	0.15 (0.04, 0.37)

Confidence intervals (CI) corresponding to the ICC are shown in brackets

**Intra-tester reliability and agreement**

Intra-tester reliability results for participants are presented in Tables 2. ICC values for the knee testing protocol were good to excellent (0.86 and 0.88). ICC values obtained by tester 1 for the hip and ankle demonstrated moderate association (0.56 and 0.57). However results obtained by tester 2 were good to excellent (0.88 and 0.92). The standard error of measurements (SEM) was higher in tester 1 than tester 2 except in the knee testing protocol (Table 2). The mean differences for both knee and ankle measurements were closer to zero indicating better agreement. Hip measurements displayed a wider range of values indicating weaker agreement (Table 2).

**Intra-tester reliability and agreement**

ICCs for inter-tester reliability for both days are shown in Table 3. When all subjects were analyzed together moderate association was demonstrated for the hip and knee (ICCs ranged from .60 - .66). Ankle measurement ICCs showed poor association on both days (ICCs .23 and 0.15). A selection of Bland and Altman plots to demonstrate agreement between testers are shown in Figs. 1, 2, and 3 displaying a considerable lack of agreement with discrepancies of up to 150N noted in measurements.

**DISCUSSION**

The aim of this paper was to investigate the intra-tester and inter-tester reliability of the MicroFET3 HHD. Our results indicated moderate to excellent intra-tester reliability and lower inter-tester reliability based on maximal isometric contractions.

It has been reported that ‘moderate’ association can be judged by ICC values between 0.50 to 0.75 and ‘good’ to ‘excellent’ association over 0.75.<sup>32</sup> However in order to consider an instrument suitable for clinical use, the ICC value must be over 0.90.<sup>32</sup> Values calculated in this study reflect those reported by other authors who examined the same muscle groups.<sup>20, 27, 29, 36</sup>

The high force levels produced by the male participants may have posed difficulty for the female testers in maintaining the resistance for the five-second duration. However, this should not have affected association and agreement when analysed. In addition, there was very little evidence of a difference in reliability when the sexes were analysed separately.

Intra-tester reliability data obtained for Tester 1 and Tester 2 were consistent for knee measurements. However data for the hip and ankle varied considerably. Testers 1 and 2 demonstrated 'moderate to excellent' association for knee measurements (0.86 - 0.88), however there was less correlation between values calculated for the hip and ankle (0.57 - 0.92 and 0.56 - 0.88, respectively). It is also important to note that although the mean difference of the ankle measurements were less than that of the hip and knee for Tester 2, the degree of variation relative to the actual torque produced by the ankle is quite high, adding further to the poorer reliability measures at the ankle. Testers reported difficulty maintaining the position of the HHD on the metatarsal heads due to the shape of the transducer head and the high force levels exerted by the plantar-flexors. This is consistent with findings of Agre et al<sup>22</sup> and Colombo et al<sup>37</sup> who reported that "off centre" loading, i.e. force applied to the muscle at an angle other than 90°, resulted in inaccurate readings on the HHD, and therefore poorer results obtained for the lower limb muscle group.<sup>22</sup> Testers also reported difficulty aligning their arms in the direction of these high force levels due to inability to elevate the bed to an ergonomically advantageous position. A high level of localized tenderness was reported by participants where the dynamometer was placed during the testing protocol. Studies investigating the reliability of the HHD in measuring hip musculature, have reported that participants occasionally complained of discomfort due to positioning of the HHD, which may have limited the generation of a maximal contraction and may have influenced the validity of these measurements.<sup>21</sup> It is possible that these were contributing factors to the inconsistent figures.

Inter-tester reliability as estimated by the ICC (2, 1) and Bland and Altman plots was lower than that of intra-tester. Although hip and knee values ranged from 0.60 - 0.66 these would not be considered acceptable for use in the clinical setting. Ankle ICCs were very low on both days (0.23 and 0.15) indicating poor association between testers regardless of day tested. As the testers in this study were final year physiotherapy students, lack of experience in using the dynamometer clinically may have contributed to the low inter-tester reliability.

As reported elsewhere in the literature,<sup>2, 21</sup> it was also noted that intra-tester reliability tends to be greater than inter-tester reliability. This may be due to less inherent variability, tester strength<sup>17</sup> and subconscious participant inhibition with perceived weaker testers.<sup>38</sup> It is also possible that the tester, in anticipation of impending force levels exerted by the participants, may have applied a pressure to the limb evoking a myostatic stretch reflex which could result in greater force production.<sup>22</sup>

This study employed Bland and Altman plots to assess the agreement of inter-tester strength measurements. In addition to allowing for a more thorough analysis, they provide visualisation of differences in the measures and any outliers

present. The values for the mean difference for knee and ankle were close to zero indicating good agreement. The mean difference for the hip measurements ranged from -21.4N to -28.2N, indicating weaker agreement. The 95% limits of agreement for the mean difference included zero indicating minimal bias between the two measures. These results need to be interpreted with caution however, as the sample size in this study was less than 50. Research indicates that 95% limits of agreement will be wide if a sample size of at least 50 is not adhered to.<sup>34</sup>

## CONCLUSION

The results of this study suggest that the MicroFET3 HHD has moderate to excellent intra-tester reliability and poor to moderate inter-tester reliability based on maximal isometric contractions of the hip extensors, knee extensors and ankle plantar-flexors. Further research is required to investigate whether tester strength influences reliability of the MicroFET3 HHD and whether improved intra and inter tester reliability can be obtained with modification of the testing procedure.

Finally, notwithstanding these limitations, our results show that the MicroFET3 HHD can be considered a reliable instrument for testing muscle strength of knee extensors, hip extensors and ankle plantar-flexors, provided the measurements are consistently carried out by the same tester. This preliminary study may therefore guide other research in the area in the possible future use of the MicroFET3 HHD for clinical and research purposes.

## Declaration of interest

The authors report no conflict of interest.

## REFERENCES

1. Falrey AS, Courneya KS, Field CJ, et al: Physical Exercise and immune system function in Cancer survivors. *Cancer*. 2002;94(2):539-551.
2. Scott D, Bond E, Sisto SA: The Intra- and Inter-Rater Reliability of Hip Muscle Strength Assessments Using a Hand-Held Versus a Portable Dynamometer Anchoring Station. *Arch Phys Med Rehab*. 2004;85(4):598-603.
3. Cuthbert SC, Goodheart GJ: On the Reliability and Validity of Manual Muscle Testing: A Literature Review. *Chiropr Osteopat*. 2007;15(4):1-23.
4. Florence JM, Pandya S, King WM, et al: Intrarater Reliability of Manual Muscle Test (Medical Research Council Scale) Grades in Duchenne Muscular Dystrophy. *Phys Ther*. 1992;72(2):115-126.
5. Beasley WC: Quantitative Muscle Testing Principles and Applications to Research and Clinical Services. *Arch Phys Med Rehab*. 1961;42:398-425.
6. Frese E, Brown M, Norton BJ: Clinical Reliability of Manual Muscle Testing: Middle Trapezius and Gluteus Medius Muscles. *Phys Ther*. 1987;67:1072-1076.
7. Dvir Z: Grade 4 in Manual Muscle Testing: The Problem With Submaximal Strength Assessment. *Clin Rehabil*. 1997;11(1):36-41.
8. Hayes K, Walton JR, Szomor Z, et al: Reliability of Three Methods for Assessing Shoulder Strength. *Journal of Shoulder and Elbow Surgery*. 2002;11(1):33-39.
9. Patterson LA, Spivey WE: Validity and reliability of the LIDO active isokinetic system. *J Orthop Sports Phys Ther*. 1992;15:32-36.
10. Bembem MG, Grump KJ, Massey BH: Assessment of technical

- accuracy of the Cybex II isokinetic dynamometer and analog recording system. *J Orthop Sports Phys Ther.* 1988;10:12-17.
11. Timm KE, Gennrich P, Burns R, et al: The mechanical and physiological performance reliability of selected isokinetic dynamometers. *Isokin Exerc Sci.* 1992;2:192-190.
  12. Li RC, Jasiewicz JM, Middleton J, et al: The Development, Validity, and Reliability of a Manual Muscle Testing Device With Integrated Limb Position Sensors. *Arch Phys Med Rehab.* 2006;87:411-417.
  13. Van der Linden ML, Aitchison AM, Hazlewood ME, et al: Test-Retest Repeatability of Gluteus Maximus Strength Testing Using a Fixed Digital Dynamometer in Children with Cerebral Palsy. *Arch Phys Med Rehab.* 2004;85(12):2058-2063.
  14. Andrews AW, Thomas M, Bohannon RW: Normative Values for Isometric Muscle Force Measurements Obtained with Hand-Held Dynamometers. *Phys Ther.* 1996;76:248-259.
  15. Strafford 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;19:28-32.
  16. Wadsworth CT, Krishnan RK, Sear M, et al: Intrarater reliability of manual muscle testing and hand held dynamometric muscle testing. *Phys Ther.* 1987;67:1342-1347.
  17. Bohannon RW, Wikholm JB: Measurements of knee extension force obtained by two examiners of substantially different experience with hand held dynamometer. *Isokinetics and Exercise Science.* 1992;2:5-8.
  18. Bohannon RW: Intertester Reliability of Hand-Held Dynamometry: A Concise Summary of Published Research. *Perceptual and Motor Skills.* 1999;88:899-902.
  19. Vermeulan HM, Geertruida HB, Houwelingen HC, et al: A Comparison of Two Portable Dynamometers in the Assessment of Shoulder and Elbow Strength. *Physiotherapy Theory and Practice.* 2005;91:101-112.
  20. Ford-Smith CD, Wyman JF, Elswick RK, et al: Reliability of Stationary Dynamometer Muscle Strength Testing in Community-Dwelling Older Adults. *Arch Phys Med Rehab.* 2001; 82:1128-1132.
  21. Krause DA, Schlagel SJ, Stember BM, et al: Influence of Lever Arm and Stabilisation on Measures of Hip Abduction and Adduction Torque Obtained by Hand-Held Dynamometry. *Arch Phys Med Rehab.* 2007;88:37-41.
  22. Agre JC, Magness JL, Hull SZ, et al: Strength Testing with a Portable Dynamometer: Reliability for Upper and Lower Extremities. *Arch Phys Med Rehab.* 1987;68(7):454-458,
  23. Brinkmann JR: Comparison of a Hand-Held and Fixed Dynamometer in Measuring Strength of Patients with Neuromuscular Disease. *J Orthop Sports Phys Ther.* 1994;19(2):100-104.
  24. Bohannon RW: Intertester Reliability of Hand-Held Dynamometry: A Concise Summary of Published Research. *Percept Mot Skills.* 1999;88:899-902.
  25. Ortqvist M, Gutierrez-Farewik EM, Farewik M, et al: Reliability of a new instrument for measuring plantar-flexion strength *Arch Phys Med Rehab.* 2007;88(9):1164-1170.
  26. American College of Sports Medicine. *ACSM's guidelines for exercise testing and prescription* 6th ed. Philadelphia: Lippincott, Williams & Wilkins; 2000.
  27. Wang C, Olson S, Protas E: Test-Retest Strength Reliability: Hand-Held Dynamometry in Community-Dwelling Elderly Fallers. *Arch Phys Med Rehab.* 2002;83:811-815.
  28. Taylor NF, Dodd KJ, Graham HK: Test-Retest Reliability of Hand-Held Dynamometric Strength Testing in Young People With Cerebral Palsy. *Arch Phys Med Rehab.* 2004;85:77-80.
  29. Nollet F, Beelen A: Strength Assessment in Postpolio Syndrome: Validity of a Hand-Held Dynamometer in Detecting Change. *Arch Phys Med Rehab.* 1999;80:1316-1323.
  30. Bohannon RW: Test-retest Reliability of the MicroFET4 Hand-grip Dynamometer. *Physiotherapy Theory and Practice.* 2006;22(4):219-221.
  31. Meldrum D, Cahalane E, Keoghan F, et al: Maximum Voluntary Isometric Contraction: Investigation of Reliability and Learning Effect. *ALS and other motor neuron disorders.* 2003;4:36-44.
  32. Portney LG, Watkins MP, *Foundations of Clinical Research: Applications to Practice* 2nd ed. New Jersey: Prentice-Hall Inc; 2000.
  33. Shrout PE, Fleiss JL: Intraclass Correlations: Uses in Assessing Rater Reliability. *Psychological Bulletin.* 1979;86:420-428.
  34. Rankin G, Stokes M: Reliability of Assessment Tools in Rehabilitation: An Illustration of Appropriate Statistical Analyses. *Clin Rehab.* 1998;12:187-199.
  35. O' Sullivan C, Bentman S, Bennett K, et al: Rehabilitative Ultrasound Imaging of the Lower Trapezius Muscle: Technical Description and Reliability. *J Orthop Sports Phys. Ther.* 2007; 37:620-626.
  36. Nadler SF, DePrince ML, Hauesien N, et al: Portable Dynamometer Anchoring Station for Measuring Strength of the Hip Extensors and Abductors. *Arch Phys Med Rehab.* 2000;81:1072-1076.
  37. Colombo R, Mazzini L, Mora G, et al: Measurement of Isometric Muscle Strength: A Reproducibility Study of Maximal Voluntary Contraction in Normal Subjects and Amyotrophic Lateral Sclerosis Patients. *Med Eng and Phys.* 2000;22:167-174.
  38. Roebroeck ME, Harlaar J, Lankhorst GJ: Reliability Assessment of Isometric Knee Extension Measurements With a Computer-Assisted Hand-Held Dynamometer. *Arch Phys Med Rehab.* 1998;79:442-448.