Roxburgh et al. (2021) *Int J Res Ex Phys*. 16(2):81-91.

IJREP

International Journal of Research in Exercise Physiology

Original Research Article

The Absolute and Relative Reliability of Hand-held Dynamometry in Patients with Severe Lower-limb Osteoarthritis Scheduled for Total Joint Replacement Surgery

Brendon H. Roxburgh[1,2], Holly A. Campbell[1], James D. Cotter[2], Ulla Reymann[1], Michael J.A. Williams[3], David Gwynne-Jones[1,4], Kate N. Thomas[1]

[1]Department of Surgical Sciences, Dunedin School of Medicine, University of Otago, Dunedin, New Zealand
[2]School of Physical Education, Sport and Exercise Sciences, University of Otago, Dunedin, New Zealand
[3]Department of Medicine, Dunedin School of Medicine, University of Otago, Dunedin, New Zealand
[4]Department of Orthopaedic Surgery, Dunedin Hospital, Southern District Health Board, Dunedin, New Zealand

ABSTRACT

Introduction: Hand-held isometric dynamometry is a convenient alternative to gold standard isokinetic dynamometry for the assessment of skeletal muscle strength. The purpose of this study was to quantify the absolute and relative reliability of hand-held dynamometry, for the measurement of lower-limb isometric strength in patients with severe hip and knee osteoarthritis, scheduled for total hip or knee replacement surgery. **Methods:** Forty participants with severe osteoarthritis scheduled for hip (n = 20) and knee (n = 20) replacement were included in this retrospective cross-sectional analysis. Isometric muscle strength was assessed using a Microfet2 hand-held dynamometer for knee extension and flexion and hip abduction and extension. Absolute reliability was calculated using standard error of measurement and minimal detectable change and relative reliability was determined by intraclass correlation coefficient. **Results:** Standard error of measurement values ranged from 4.4-6.9 N for hip abduction and extension in the hip osteoarthritis group, and 4.1-11.4 N for knee extension and flexion in the knee osteoarthritis group. The minimal detectable change values ranged from 15.4-24.3% of maximal voluntary contraction for hip abduction and extension in the hip osteoarthritis group, and 12.1-22.8% of maximal voluntary contraction for knee extension and flexion in the knee osteoarthritis group. The relative reliability was excellent for all four muscle groups, ranging from 0.96-0.97 on the affected and 0.96-0.98 on the non-affected sides the hip osteoarthritis group, and 0.92-0.99 and 0.96-0.98 in the knee osteoarthritis group. **Conclusion:** The absolute reliability of the hand-held dynamometer tended to be greatest for measurements of the affected joint, and relative reliability was excellent at all four testing sites, for both groups. The results of this study support the use of hand-held dynamometry for knee extension and knee flexion assessment in patients scheduled for knee replacement surgery and hip abduction and hip extension in patients scheduled for hip replacement surgery.

KEYWORDS: Assessment; Muscle fitness; Muscular strength.

Introduction

Skeletal muscle strength is a fundamental component of physical function. Skeletal muscle weakness and / or dysfunction is strongly correlated with mortality in older adults [1, 2]. Muscle strength is also an important physical parameter for those with or at-risk of developing osteoarthritis. For example, several studies have independently shown that weaker quadriceps and hip abductor muscle strength is associated with the development of knee osteoarthritis [3-5]. As the quadriceps play an important role in slowing the rate of leg descent and dissipating potentially harmful loads during heel-strike, articular cartilage damage may be accelerated by quadricep weakness [4, 6]. Meanwhile, hip abductor weakness is hypothesised to alter knee joint loading, accelerating osteoarthritis progression [5].

The gold standard assessment tool for muscle strength assessment is isokinetic dynamometry [7]. Whilst isokinetic dynamometry is useful in the research setting due to its highly reliable and valid strength measurements, the apparatus is large and expensive, limiting its portability and practicality in clinical practice or field testing. Moreover, it can take some time to set up the system for each test and to fit the participant to the device (i.e., align to joint and fasten stabilisation belts). Hand-held dynamometry (HHD) is an alternative assessment modality and is performed similarly to manual muscle testing [8]. However, unlike manual muscle testing, HHD quantifies the generated force. Furthermore, the HHD device is significantly cheaper (US$1,000 vs. US$40,000), quicker and easier to perform and extremely portable (pocket-sized), compared to isokinetic dynamometry.

With any form of measurement, the measure must be reliable and consistent. Two types of reliability are referred to in the literature; absolute and relative reliability. Absolute reliability quantifies the degree to which repeated measures vary *within* individuals. The standard error of measurement (SEM) is a measure of absolute reliability, assessing how random measurement error influences results by quantifying the typical deviation between observed scores and the true score [9]. Whilst the SEM quantifies the associated error for testing performed at one time (e.g., pre-intervention), the minimal detectable change (MDC, based on the SEM) is another measure of absolute reliability, quantifying the associated error with multiple comparisons of the same measure (e.g., baseline vs. follow-up). Naturally, any real change in muscle strength needs to be greater than any random measurement error associated with the testing; therefore, the MDC is relevant for clinicians or researchers wishing to evaluate progress in individuals over time. A common statistic used for measuring relative reliability is the intraclass correlation coefficient (ICC) [9]; the ICC assesses how well individuals maintain their rank order within a cohort when repeated measurements are performed.

HHD is a reliable and valid tool in a range of patient populations, compared to isokinetic dynamometry [8]; this includes women with knee osteoarthritis and patients post-total hip (THR) / knee replacement surgery (TKR) [10, 11]. However, limited data are available on the reliability of the device in patients with severe osteoarthritis, scheduled for THR or TKR. A small number of studies in patients with hip and knee osteoarthritis have used a modified form of HHD and / or attached stabilisation belts around the participant / limb [11-13]; however, this is not always feasible in the clinical / field setting and may actually *increase* measurement error [13]. Another source of high measurement error in previous research in patients with hip osteoarthritis is a lack of technique standardisation [14].

There is a need for studies utilising rigorous technique standardisation and no additional equipment / apparatus (e.g., stabilisation belts, chairs) to investigate a feasible and reliable form of HHD, in those with severe lower-limb osteoarthritis. Therefore, the primary aim of this study was to assess the absolute and relative reliability of HHD, for the measurement of lower-limb isometric strength in patients with severe hip and knee osteoarthritis, scheduled for THR / TKR. Specifically, this study aimed to quantify the SEM, MDC and ICC of the device in this cohort.

Methods

Study design

This study was a retrospective, cross-sectional analysis of 40 adults (14 men and 26 women) with severe lower-limb osteoarthritis recruited for a prehabilitation study. Ethical approval for the study was obtained from the Health and Disability Ethics Committee of New Zealand (Ref: 18/NTA/148) and registered with the Australia New Zealand Clinical Trial Registry (ACTRN12620000153910). Written, informed consent was obtained, and all procedures conformed to the standards set by the Declaration of Helsinki.

Patients with end-stage hip or knee osteoarthritis waitlisted for THR or TKR at the regional public hospital were recruited for this study between September 2019 and January 2020; all patients recruited during this period were included in this analysis.

Following consenting, participants were required to attend two assessment sessions at the laboratory. The first session involved obtaining informed and written consent, a brief medical history, collecting anthropometric and resting cardiovascular measures. The second assessment session involved body composition analysis, health-related quality of life and osteoarthritis impact questionnaires and physical function, including HHD assessment.

Experimental procedures

Hand-held muscle dynamometry

Muscle strength was assessed using a manufacturer-calibrated HHD (MicroFet2, Hoggan Scientific, Salt Lake City, USA). All measurements were taken by a single researcher (BR), a registered clinical exercise physiologist with >10 years' experience in exercise assessment in clinical populations, including of skeletal muscle strength. The HHD was zeroed and then placed in standardised anatomical locations for each muscle group, per manufacturer guidelines (see below). Immediately prior to testing each muscle group, participants were provided standardised instructions and asked to maintain maximal effort against the HHD for approximately 5 s. The researcher provided a countdown from three, and on "go!" participants initiated their maximal voluntary contraction (MVC). Verbal encouragement was provided during each MVC, with the peak value being recorded for later analysis. Each muscle group was tested three times, alternating between sides, with at least 30 s of rest between each trial; for all muscle groups the first measure on each side was considered a familiarisation trial and not included in the analysis. The order for testing the most osteoarthritis affected / non-osteoarthritis affected sides was randomised for each participant.

Hand-held dynamometry – Knee extension & flexion

Participants were seated on the edge of a bed, with their arms folded across the chest and legs hanging freely (hips and knees at approximately 90° flexion). The HHD was placed on the anterior aspect of the tibia, just proximal to the malleoli. (Figure 1-A). To measure knee flexion the HHD was placed on the Achilles tendon, just distal to the malleoli (Figure 1-B Participants were instructed to "keep your arms folded, whilst trying to straighten (extension) / bend (flexion) your leg and pushing (extension) / pulling (flexion) against the device as hard as possible".

Hand-held dynamometry – Hip extension

Participants lay supine on the bed with their arms folded across the chest. The HHD was placed on an 8 cm high box, positioned under the Achilles tendon, just proximal to the malleoli (Figure 1-C). Participants were instructed to "keep both legs fully straight, glutes on the bed and arms folded across the chest, throughout the test and push down on the device with the heel as hard as possible".

Hand-held dynamometry – Hip abduction

The participant lay supine on the bed with their arms folded across the chest, ensuring the non-testing side was hard against a fixed wall. The HHD was placed just proximal to the lateral epicondyle of the femur (Figure 1-D). Participants were instructed to "keep both legs fully straight, glutes on the bed and arms folded across the chest, throughout the test and move the leg towards the tester as hard as possible".

Other measures

Height was measured in metres using a stadiometer (Wedderburn WS-HRP, Auckland, New Zealand) and body mass in kilograms using scales (SECA 760, Hamburg, Germany). Body mass index (BMI) was calculated using the following formula: BMI = mass (kg) / height $(m)^2$. Bioimpedance analysis was also performed (InBody 230, Seoul, South Korea).

To characterise the degree to which participants were impacted by OA, participants completed Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) [15] and Oxford hip score (OHS) / Oxford knee score (OKS) questionnaires [16]. Higher scores on the WOMAC indicate worse pain, stiffness and functional limitations (0-96); a score of ≥30 is recommended for surgical referral [17]. Lower scores on the OHS / OKS (0-48) indicate greater osteoarthritic pain; specifically, a score of 0-19 may indicate severe osteoarthritis, 20-29 moderate-severe osteoarthritis, 30-39 mild to moderate hip arthritis and 40-48 satisfactory joint function.

Standardisation

To ensure test repeatability, participants abstained from moderate or high-intensity exercise / physical activity for at least 24 h prior to assessment sessions. Testing was conducted in a climate-controlled room.

Statistical Analyses

SPSS (version 25.0, IBM, USA) was used for all statistical analysis. Descriptive data are expressed as mean ± standard deviation (SD) or n (% of the whole). The SEM was calculated ($SEM = SD * \sqrt{1 - ICC}$) as a measure of absolute reliability, where SD is the standard deviation of all trials for each muscle group [9]. MDC values were calculated ($MDC = SEM * 1.96 * \sqrt{2}$) as additional measures of absolute reliability. Intra-rater relative reliability was assessed using interclass correlation coefficients ($ICC_{2,\ k}$), calculated using a two-way mixed model for absolute agreement. ICC statistics were classified based on criteria published by Vincent [18] (i.e., questionable: (< 0.8); moderate: (0.8-0.89), or high reliability (>0.9)). To test for differences between trials for each muscle group, paired sample t-tests were performed. To test for differences between operative and non-operative sides, a mean of the two trials for operative and non-operative sides were calculated and the difference between means compared using paired sample t-tests. Statistical inferences were made using an α of 0.05.

Results

Patients

Forty participants scheduled for THR / TKR were included in the analysis. The twenty participants with severe hip osteoarthritis were 67 ± 9 y, predominantly female (n=13, 65%), class 1 obese (BMI 30.5 ± 5.5 $kg \cdot m^{-2}$) and had severe osteoarthritis (OHS score 14.2 ± 8.6). The twenty participants with severe knee osteoarthritis were 69 ± 8 y, predominantly female (n=13, 65%), class 1 obese (BMI 34.4 ± 9.1 $kg \cdot m^{-2}$) and had severe osteoarthritis (OKS score 16.2 ± 8.1). All tests were completed without incident. Further details on participant characteristics are presented in Table 1.

Table 1: Descriptive statistics of participants. Data are mean (SD) or as an absolute number with the percentage (%) of the whole.

Variable	Hip osteoarthritis mean (SD) / n (%) n = 20	Knee osteoarthritis mean (SD) / n (%) n = 20
Age (y)	66.5 (8.7)	69.1 (7.5)
Male/female	7 (35%) / 13 (65%)	7 (35%) / 13 (65%)
Body mass (kg)	85.7 (17.6)	96.3 (27.7)
BMI ($kg \cdot m^{-2}$)	30.5 (5.5)	34.4 (9.1)
Muscle mass (kg)	29.8 (9.8)	30.3 (9.2)
Body fat mass (kg)	34.0 (16.9)	41.9 (17.4)
Fat free mass (kg)	51.8 (13.1)	54.5 (15.2)
Percent body fat (%)	38.4 (16.8)	42.3 (10.2)
WOMAC	59.9 (18.8)	58.6 (16.4)
OHS / OKS	14.2 (8.6)	16.2 (8.1)

BMI = body mass index; WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index; OHS = Oxford Hip Score; OKS = Oxford Knee Score.

Hip osteoarthritis

Mean isometric muscle strength scores were not statistically different between trial 1 and trial 2 for all muscle groups in the hip osteoarthritis group (i.e., $p \geq 0.15$; Table 2). The MVC and SEM values were lowest for hip abduction on the affected side, and highest for hip extension on the affected side (Table 3). The MDC values represent 19.7% and 19.1% of the highest mean MVC for hip abduction and 24.3% and 15.4% for hip extension, respectively. Values for knee extension and flexion are included in Table 2. The $ICC_{2, k}$ showed high relative reliability (0.96-0.98) for hip abduction and extension on both the affected and non-affected sides (Table 2)[18].

Mean isometric muscle strength was ~21% lower on the affected, compared to non-affected side for hip abductor (-20.0 N; -29.3 to -10.7, p < 0.001), and extensor strength (-18.5 N; -29.3 to -7.7, p = 0.002) and knee extensor (-27.5 N; -44.4 to -10.5, p = 0.003) and flexor strength (-18.6 N; -33.2 to -4.0, p = 0.015).

Knee osteoarthritis

Mean isometric muscle strength scores were not statistically different between trial 1 and trial 2 for each muscle group in the knee osteoarthritis group (i.e., $p \geq 0.13$; Table 3), except for hip abduction on the non-affected side, which showed a 10% increase across the two trials (p = 0.007). For knee extension and flexion, the SEM and MDC values were lower on the affected side, compared to non-affected side. The MDC values represented 22.3% and 22.8% of the highest mean MVC for knee extension and 12.1% and 18.3% for knee flexion, respectively. Values for hip abduction and extension are included in Table 3. The $ICC_{2, k}$ showed high relative reliability (0.98-0.99) for knee extension and flexion on both sides [18].

Mean isometric muscle strength was ~14% lower on the affected side, compared to non-affected side for knee extensor (-17.7 N; -31.4 to -3.9, p = 0.015), and hip extensor strength (-12.0 N; -22.2 to -1.9, p = 0.023). There was no difference in knee flexor (-11.4 N; -18.1 to 3.3, p = 0.119) and hip abductor (-4.7 N; -18.1 to 8.7, p = 0.119) strength, between the affected and non-affected sides.

Table 2. Absolute and relative reliability of isometric muscle strength assessed by hand-held dynamometry in participants with severe hip osteoarthritis scheduled for total hip arthroplasty (n = 20).

	Trial 1 (N)	Trial 2 (N)	$ICC_{2,k}$ (95% CI)	SEM (N)	MDC (N)	MDC as a % of MVC
Affected side						
Knee extension	125.4 ± 57.0	126.4 ± 62.3	0.964 (0.910-0.986)	11.2	31.0	24.5
Knee flexion	81.8 ± 38.1	82.0 ± 49.2	0.953 (0.878-0.982)	9.4	26.1	31.8
Hip abduction	61.8 ± 25.2	61.1 ± 23.8	0.967 (0.918-0.987)	4.4	12.2	19.7
Hip extension	78.5 ± 36.3	74.1 ± 33.5	0.960 (0.900-0.984)	6.9	19.1	24.3
Non-affected side						
Knee extension	156.8 ± 57.5	155.2 ± 65.4	0.959 (0.895-0.984)	12.3	34.1	21.8
Knee flexion	97.7 ± 60.2	97.3 ± 56.8	0.979 (0.948-0.992)	8.4	23.2	23.7
Hip abduction	82.6 ± 32.3	85.3 ± 34.2	0.968 (0.921-0.987)	5.9	16.3	19.1
Hip extension	93.2 ± 31.6	94.6 ± 30.9	0.971 (0.927-0.988)	5.3	14.6	15.4

ICC = intraclass correlation coefficient; SEM = standard error of measurement; MDC = minimal detectable change; MVC = maximal voluntary contraction; N = Newtons.

Table 3: Absolute and relative reliability of isometric muscle strength assessed by hand-held dynamometry in participants with severe knee osteoarthritis scheduled for total knee arthroplasty (n = 20).

	Trial 1 (N)	Trial 2 (N)	$ICC_{2,k}$ (95% CI)	SEM (N)	MDC (N)	MDC as a % of MVC
Affected side						
Knee extension	119.2 ± 65.0	121.2 ± 68.4	0.978 (0.944-0.991)	9.8	27.1	22.3
Knee flexion	92.6 ± 44.8	94.6 ± 43.7	0.991 (0.977-0.996)	4.1	11.5	12.1
Hip abduction	69.7 ± 33.0	72.6 ± 33.2	0.968 (0.913-0.988)	5.8	16.2	22.3
Hip extension	81.5 ± 37.3	78.1 ± 33.9	0.917 (0.773-0.970)	10.1	28.1	34.4
Non-affected side						
Knee extension	137.6 ± 75.3	138.0 ± 73.4	0.976 (0.940-0.991)	11.4	31.5	22.8
Knee flexion	104.9 ± 48.5	106.8 ± 48.3	0.978 (0.944-0.991)	7.1	19.6	18.3
Hip abduction	73.7 ± 30.3	80.8 ± 27.1	0.956 (0.809-0.986)	6.0	16.6	20.5
Hip extension	90.4 ± 37.3	93.3 ± 42.5	0.958 (0.886-0.985)	8.1	23.4	24.0

ICC = intraclass correlation coefficient; SEM = standard error of measurement; MDC = minimal detectable change; MVC = maximal voluntary contraction; N = Newtons.

Discussion

The primary aim of this study was to establish the absolute and relative reliability of a HHD device, for knee extension and flexion and hip abduction and extension strength in patients with severe osteoarthritis, scheduled for THR and TKR. The results showed that absolute reliability (i.e., MDC values) for measures of knee extensor and flexor strength were 12-23% of MVC in the knee osteoarthritis group, however MDC values for hip abductor and extensors were slightly larger (21-34% of MVC). Similarly, in the hip osteoarthritis group, MDC values for hip abductor and extensor measures were 15-24% of MVC, whilst MDC values for knee extensor and flexor strength were slightly larger (22-32% of MVC). For both groups, in all four muscle groups of interest, relative reliability was excellent (i.e., $ICC_{2,k}$ >0.9). These results support the use of HHD as a reliable assessment tool, particularly for the assessment of isometric muscle strength of the affected joint, and can be used without additional equipment (i.e., stabilisation belts), making it a viable and portable option for clinical and field research use.

The MDC is the necessary magnitude of difference between multiple comparisons (at separate time points) of the same measure (i.e., baseline vs. follow-up) to be considered "real"; that is, any change seen in an individual's strength measure below or above the original score, greater than the MDC is considered clinically meaningful[9]. The highest MDC values were recorded for knee extension in both groups, as this movement also produced the largest mean MVC values. When MDC is indexed to MVC, Koblbauer et al. [13] showed large measurement error for knee extension (MDC = 19-31% of MVC) and flexion (30-58% of MVC) in patients scheduled for TKR; this means strength gains / losses of greater than 31% of MVC for extension and 58% of MVC for flexion would be required to detect a clinically meaningful change. In the current study, smaller MDC values for knee extension and flexion in patients scheduled for TKR on both the affected (22 & 12% of MVC) and non-affected sides (23 & 18% of MVC) were observed.

The data in the current study also compare similarly with those published for the gold standard, isokinetic dynamometry. Chopp-Hurley et al. [11] reported relative reliability of ICC 0.96 (0.91-0.98) and 0.93 (0.85-0.97) in 28 older women with knee osteoarthritis, during knee extension and flexion using isokinetic dynamometry. With respect to absolute reliability, the authors reported MDC values of 18 & 20% of mean MVC for knee extension and flexion on the osteoarthritic side. The superior reliability values in the current study were achieved without the use of stabilisation belts or additional equipment, supporting previous work in healthy participants and those with knee osteoarthritis, that strict standardisation of technique is sufficient to achieve high absolute and relative reliability with HHD [8, 13].

With respect to hip osteoarthritis, Pua and colleagues [12] reported high relative reliability using HHD for hip extensor strength ($ICC_{2,2}$ = 0.96) and moderate reliability for hip abductor strength ($ICC_{2,2}$ = 0.84) on the affected side; the ICC values in the current study were identical for hip extension ($ICC_{2,k}$ = 0.96) and higher for hip abduction ($ICC_{2,k}$ = 0.97) on the affected side. Absolute reliability was also higher, with lower SEM and MDC values in the current study (SEM = 4.4 N and 6.9 N; MDC = 12.2 N and 19.1 N) for hip abduction and extension respectively, compared to Pua et al.'s work [12] (SEM = 12.1 N and 13.3 N; MDC = 28.0 N and 30.8 N); again, this superior reliability was achieved without any additional equipment, which was used in the previous study [12].

Previous studies have shown that the muscle strength of the tester affects the reliability of strength measurements [19]. The hip extension test was the only measurement where the tester was not holding the device, therefore it was plausible that reliability would be increased. Whilst absolute and relative reliability values for hip extension were acceptable, reliability values tended to be lower than other muscle groups, especially for the knee osteoarthritis group. As mentioned earlier, Koblbauer and colleagues [13] examined the reliability in patients scheduled for TKR. The authors modified their HHD by fixing it to certain structures and found high measurement error; it may be that reliability is highest when the device is used as it is designed, as hand-held. Furthermore, the hip extension movement is less intuitive than the other three measurements and it is possible that there was a learning effect.

An interesting observation, but not related to the primary aims of the study, was that the hip osteoarthritis group had deficits in knee extensor and flexor strength on the affected side, compared to the non-affected side. Conversely, TKR patients had no differences in hip strength between the affected and non-affected sides. Beyond the scope of this study, it is not possible to know whether these strength deficits preceded the development of hip osteoarthritis, potentially contributing to the disease; or rather are a compensatory change following osteoarthritis development, due to favouring the non-affected side.

Limitations

The results of this study should be interpreted with consideration of the limitations. Firstly, we did not assess inter-rater reliability and measurements were collected in a single session. This limits the interpretation of our findings and future studies should investigate these. All MVCs were performed in the single session and although every effort was made to allow for adequate recovery between reps and muscle groups, residual muscle fatigue and / or joint pain may have influenced the results.

Conclusion

The absolute reliability of the hand-held dynamometer tended to be greatest for measurements of the affected joint, whilst relative reliability was excellent at all testing sites, in both groups. The results of this study support the use of hand-held dynamometry for knee extension and knee flexion assessment in patients with severe knee osteoarthritis scheduled for knee replacement surgery, and hip abduction and hip extension in patients with severe hip osteoarthritis scheduled for hip replacement surgery. Due to the large minimal detectable change values required to detect true physiological change, caution should be exercised for hand-held dynamometry measurement of the hip abductors and extensors in patients with knee osteoarthritis, or knee extensors and flexors in patients with hip osteoarthritis.

Address for Correspondence

Kate Thomas PhD. Department of Surgical Sciences, Dunedin School of Medicine, University of Otago, Dunedin, New Zealand.
Email: kate.thomas@otago.ac.nz

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