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ORIGINAL RESEARCH

MEASURES OF HIP MUSCLE STRENGTH AND RATE OF FORCE DEVELOPMENT USING A FIXATED HANDHELD DYNAMOMETER: INTRA-TESTER INTRA-DAY RELIABILITY OF A CLINICAL SET-UP

Lasse Ishøi, PT, MSc[1]
Per Hölmich, MD, DMSc[1]
Kristian Thorborg, PT, MSportsPT, PhD[1,2]

ABSTRACT

Background: Evaluation of hip muscle function is considered an important part of the examination and treatment of physically active subjects with hip and groin pain. However, methods to reliably measure explosive hip muscle strength are lacking.

Hypothesis/purpose: The purpose was to investigate the reliability of a clinically available set-up using a fixated handheld dynamometer to test isometric peak force and rate of force development of the hip abductors, adductors, flexors, and extensors.

Methods: Seventeen subjects (males: 9, females: 8, mean aged 25.4 (+/- 4.2) y, with mean body mass of 73.9 (+/- 15.2) kg, and mean height 174.2 (+/- 12.4) cm) were included. One experienced tester performed all measures in a randomized order. Three trials of isometric peak force and early- (0-100 ms) and late-phase (0-200 ms) rate of force development for the hip abductors, adductors, flexors, and extensors were obtained using a fixated handheld dynamometer. The trial with the highest value for each measure was used for analysis. Test-retest sessions were separated by 30 minutes of rest.

Results: No systematic between-session bias were observed for any of the measures. The relative intra-tester reliability ($ICC_{2,1}$) for peak force, 0-100 ms rate of force development, and 0-200 ms rate of force development ranged from 0.93-0.96, 0.82-0.93, and 0.85-0.92, respectively, corresponding to good reliability for all force measures.

Conclusion: The present study shows that assessment of isometric hip muscle peak force, including early- (0-100 ms) and late-phase (0-200 ms) rate of force development using a fixated handheld dynamometer have good intra-tester reliability for testing of the hip adductors, abductors, flexors and extensors. Thus, in clinical research settings where an isokinetic dynamometer may not always be readily accessible, the present test procedure can be used as a feasible alternative to reliably provide objective of hip muscle function relevant for rehabilitation of patients with hip and groin pain.

Level of evidence: Level 3, Reliability study

Key words: groin, handheld dynamometer, neuromuscular function, reproducibility, movement system

[1] Sports Orthopaedic Research Center – Copenhagen (SORC-C), Department of Orthopaedic Surgery, Copenhagen University Hospital, Amager-Hvidovre, Denmark
[2] Physical Medicine & Rehabilitation Research – Copenhagen (PMR-C), Department of Orthopaedic Surgery and Physical Therapy, Copenhagen University Hospital, Amager-Hvidovre, Denmark

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CORRESPONDING AUTHOR
Lasse Ishøi
Sports Orthopedic Research Center – Copenhagen (SORC-C), Department of Orthopaedic Surgery, Copenhagen University Hospital, Amager-Hvidovre, Kettegård Allé 30, 2650 Hvidovre, Denmark.
E-mail: lasse.ishoei@regionh.dk
Phone: +45 20438110

INTRODUCTION

The assessment of muscular function is considered an integrated part of the physical examination of patients presenting with musculoskeletal pain. Specifically, in physically active subjects with hip and/or groin pain, assessment and monitoring of hip muscle strength is considered paramount to identify muscular deficits around the hip joint and to tailor treatment.[1] Reliable and clinically applicable procedures to measure maximal hip muscle strength have been developed using handheld dynamometry with and without external fixation.[2-4] Thus, in subjects with longstanding hip and/or groin pain, assessment of maximal hip muscle strength has been widely adopted clinically to quantify strength profiles,[5-8] to monitor progression and efficacy of treatment,[9,10] and as part of prevention strategies [11] and risk stratification.[12,13] Furthermore, assessment of maximal hip muscle strength has been applied to evaluate the efficacy of various hip strengthening protocols.[2,3]

In addition to the assessment of maximal muscle strength, assessment of rate of force development, defined as the change in force over time (Newtons per second) may also have important clinical implications for patients and athletes.[14] Additionally, assessment of rate of force development may be more sensitive to detect deficits in neuromuscular function[14-16] and may be more associated with certain explosive sport-specific activities[14,17] compared to measuring maximal muscle strength alone. As most physically active subjects with longstanding hip and groin pain often aim to return to vigorous sport activities[1,18] assessment of hip muscle rate of force development could be a relevant parameter to monitor during treatment. However, in subjects with longstanding hip and groin pain, assessment of hip muscle rate of force development data has only been conducted sparsely.[19] A reason for this may be the lack of easy and clinically available procedures to measure rate of force development, which traditionally have been performed using isokinetic dynamometry.[15,16,19] The use of a handheld dynamometer with the ability to track force over time may, however, provide an easy, inexpensive, reliable, and valid way to quantify rate of force development in hip muscles.[20] Such devices have been available for clinicians for many years, but have so far not been investigated widely in relation to their use for obtaining valid and reliable rate of force development measures of the hip muscles in a clinical setting. Thus, only a single study by Mentiplay et al.[20] have investigated this, showing high intra-tester reliability and concurrent validity, compared to isokinetic dynamometry, of hip muscle peak rate of force development obtained during a 200 ms time window. However, as the muscle force generated in a certain time epoch (e.g. 0-100 ms vs. 0-200 ms) is associated specifically to intrinsic contractile properties and/or peak muscle strength, respectively,[21] evaluation of different time epochs for hip muscle rate of force development is needed to get a detailed quantification of muscular function.[14] Furthermore, as the hip testing positions in Mentiplay et al.[20] was performed without external fixation of the handheld dynamometer, this may easily affect reliability and validity if testing is performed in strong and explosive individuals, such as athletes, where the muscle strength of the athlete may exceed the tester's strength.[22] However, such bias can be effectively eliminated by external fixation of the dynamometer.[2]

The purpose was to investigate the reliability of a clinically available set-up using an external-fixated hand-held dynamometer to test isometric peak force and rate of force development of the hip abductors, adductors, flexors, and extensors.

METHODS

Study design

The present study investigated intra-tester intra-day reliability of peak force, 0-100 ms rate of force development (RFD_{100}), and 0-200 ms rate of force development (RFD_{200}) for assessment of the hip abductors, adductors, flexors, and extensors, using an external-fixated handheld dynamometer. All tests were conducted by a single experienced tester (LI) who has been part of the development of the testing protocol. Subjects were included by a convenience sampling based on advertisement at the Physiotherapy Department at Metropolitan University College, Denmark. The reporting follows the Proposed Guidelines for Reporting Reliability and Agreement Studies (GRRAS).[23] Approval was obtained by the Ethics Committee of the Capital Region, Denmark (16041360) and the Data Protection Agency (AHH-2017-091). All subjects gave their informed consent in accordance with the Declaration of Helsinki.

Subjects

Seventeen subjects (males: 9, females: 8, mean age 25.4 (+/- 4.2) y, mean body mass 73.9 (+/- 15.2) kg, mean height 174.2 (+/- 12.4) cm) were included from the Metropolitan University College, Denmark. Subjects between 18-40 years old were eligible for inclusion. Exclusion criteria were: any current pain in the hip and groin region, knee, or low back that were considered by the subject to influence their ability to perform a maximal muscle contraction of the hip abductors, adductors, flexors, or extensors.

Data collection

All tests were conducted in a clinical examination room at Metropolitan University College, Denmark by a single experienced tester (LI). Peak isometric force, RFD_{100} and RFD_{200} of the hip abductors, adductors, flexors, and extensors were recoded using a handheld dynamometer with a sampling frequency of 100 Hz (Hoggan MicroFET2, Scientific L.L.C., Salt Lake City, USA), which was calibrated prior to testing of each subject. Peak force was measured as Newton (N) [2] whereas RFD_{100} and RFD_{200} were measured as Newton/second (N/s).[14] The testing protocol in the present study was inspired by a previously published standardized procedure which used an external-belt fixation of the dynamometer and has shown high inter-tester reliability for peak isometric hip abduction (ICC: 0.85, SEM %: 7.9), adduction (ICC: 0.94, SEM %: 6.2), flexion (ICC: 0.76, SEM %: 10.4), and extension force (ICC: 0.95, SEM %: 5) in healthy athletes.[2]

For hip abduction/adduction the person being tested was in supine position, with the test-leg placed at the end of the examination table, and the opposite leg slightly flexed. The dynamometer was placed 5 cm proximal to the proximal edge of the lateral malleolus or 5 cm proximal to the proximal edge of the medial malleolus for hip abduction and adduction, respectively.[2,3] The dynamometer was externally fixated by the tester's hand/arm placed between the wall and the dynamometer (Figure 1A,B).

For hip flexion the person being tested was sitting at the edge of the examination table, with the hips in 90 degrees of flexion. The dynamometer was fixated 5 cm proximal to the proximal edge of the patella using a rigid belt fastened to a glass suction cup on the ground (Figure 1C).[2] For hip extension the person being tested was in prone position, with the legs placed at the end of the examination table. The dynamometer was placed posteriorly at the ankle 5 cm proximal to the proximal edge of the lateral malleolus. The subject was instructed to perform a hip extension movement, rather than a knee flexion. The dynamometer was externally fixated using a rigid belt fastened to a glass suction cup on the ground (Figure 1D).[2] During all test procedures, subjects were instructed to stabilize themselves by holding on to the examination table with both hands. Only the dominant leg was tested.

Prior to each test of the hip abductors, adductors, flexors, and extensors, two warm-up trials at 50% and 100% of maximal voluntary isometric force (MVC) were performed, followed by three valid MVC trials at the rate of one trial every 60 s. To emphasize the "rate of force development" part of the MVC trials, subjects were instructed, prior to each MVC trial, to push as "*fast and hard against the dynamometer as possible, and to keep pushing until instructed to relax*" (approximately 3-4 s).[14] Standardized verbal encouragement was provided during each MVC trial by the tester, as: ''*3-2-1-go-push-push-push-and relax.*'' [2,3]

The force output (Newton) of the dynamometer was transmitted to a commercial software program (TBS, Hoggan, Scientific L.L.C., Salt Lake City, USA) via a Bluetooth connection, and subsequently extracted to a custom-made spreadsheet (Microsoft Excel, USA) for analyses of peak force and rate of force development (Supplementary file). Peak force, RFD_{100} and RFD_{200} were identified from the trial with the highest value, respectively.[2] Rate of force development was calculated as the mean change in force per second during the time intervals 0-100 ms (RFD_{100}) and 0-200 ms (RFD_{200}), with the onset of force ($t = 0$ ms) set at 6.67 N above baseline force.[14]

The measurements were performed in a randomized sequence, with an identical sequence used during the retest session. Subjects rested 30 minutes between the test-retest sessions.

Figure 1. *Testing set-up for testing of A) hip adductors, B) hip abductors, C) hip flexors, and D) hip extensors. Tests for hip adductors and abductors use an externally fixated dynamometer by the tester's hand/arm placed between the wall and the dynamometer. Tests for hip flexors and extensors use a belt for external fixation.*

Statistical methods

To assess for systematic bias between test sessions, the between-session difference in mean values were investigated using paired t-tests with a significance level set at $p < 0.05$. The relative reliability was assessed using ICC (2,1, *consistency definition*) with corresponding 95% confidence intervals (95% CI). The relative reliability was interpreted as poor ($ICC < 0.50$), moderate ($0.50 \leq ICC \leq 0.75$), or good ($ICC > 0.75$).[24] Absolute reliability was assessed as 1) the standard error of measurement (SEM) calculated as: $SD_{pooled} x \sqrt{1 - ICC}$[25], and 2) the SEM % calculated as: $\left(\frac{SEM}{mean_{pooled}}\right) x\, 100$.[26] Furthermore, SEM % was used to calculate the minimal detectable change % (MDC %) at an individual (MDC_{ind} %) and group (MDC_{group} %) level as $SEM\,\% * 1.96 * \sqrt{2}$ and $\frac{SEM\,\% * 1.96 * \sqrt{2}}{\sqrt{n}}$ where n is the sample, respectively.[25,27] All statistical analyses were performed in SPSS (v. 23, IBM Corporation, New York, USA).

RESULTS

Participants

Seventeen subjects were included in the analyses of hip abduction and flexion peak force and rate of force development, whereas 16 and 15 subjects were included in the analyses of hip adduction and extension peak force and rate of force development, respectively, due to technical errors related to the dynamometer.

Reliability

No systematic bias in peak force, RFD_{100} or RFD_{200} were observed between the two test sessions for all hip positions (p≥0.117; Table 1). The relative intra-tester reliability (ICC 2,1) for peak force, RFD_{100}, and RFD_{200} ranged from 0.93-0.96, 0.82-0.93, and 0.85-0.92, respectively, corresponding to good reliability for all force measures (Table 1). The absolute intra-tester reliability (SEM %) for peak force, RFD_{100}, and RFD_{200} ranged from 5.9-7.6%, 10.6-15.5%, and 7.4-14.0%, respectively (Table 1). MDC_{ind} % for peak force, RFD_{100}, and RFD_{200} ranged from 16.4-21.0%, 29.3-43.1%, and 20.5-38.9%, respectively, whereas MDC_{group} % for peak force, RFD_{100}, and RFD_{200} ranged from 4.0-5.3%, 7.1-11.1%, and 5.0-9.7%, respectively (Table 1).

DISCUSSION

The main findings the present study were that standardized measures of hip muscle peak force and rate of force development (0-100 ms and 0-200 ms) for abduction, adduction, flexion, and extension were found to have good (ICC > 0.75) [24] intra-tester intra-day reliability. To increase the application of these findings, a spreadsheet (Microsoft Excel, USA) for calculation of rate of force development and peak force based on the extracted CSV-file from the

Table 1. *Intra-tester intra-day reliability of peak hip strength and hip rate of force development using an external-fixated handheld dynamometer in healthy subjects (n = 17).*

Isometric hip actions	Session 1 Mean (SD)	Session 2 Mean (SD)	Difference session 1-session 2 Mean (SD)	Paired t-test p-value	ICC (2.1) * [CI 95%]	SEM	SEM (%)	MDC_{ind} (%)	MDC_{group} (%)
Peak Force (N)									
HABD	171.9 (48.8)	169.1 (46.8)	2.9 (17.5)	0.508	0.93 [0.83;0.98]	12.2	7.1	19.8	4.8
HADD	183.5 (67.4)	181.4 (66.6)	2.1 (20.0)	0.686	0.96 [0.88;0.98]	13.8	7.6	21.0	5.3
HF	321.9 (87.4)	315.3 (90.5)	6.6 (26.9)	0.328	0.95 [0.88;0.98]	18.8	5.9	16.4	4.0
HE	271.1 (76.7)	262.1 (74.6)	9.0 (27.9)	0.232	0.93 [0.81;0.98]	19.4	7.3	20.2	5.2
RFD 0-100 ms (N/s)									
HABD	1055.5 (566.0)	967.9 (569.3)	87.7 (218.1)	0.117	0.93 [0.81;0.97]	152.5	15.1	41.8	10.1
HADD	990.6 (400.2)	1000.0 (422.2)	-9.5 (187.5)	0.686	0.90 [0.73;0.96]	130.5	13.1	36.3	9.1
HF	2534.7 (700.4)	2410.4 (749.4)	124.3 (373.8)	0.189	0.87 [0.67;0.95]	261.5	10.6	29.3	7.1
HE	1500.5 (587.1)	1430.0 (509.9)	70.6 (326.9)	0.417	0.82 [0.55;0.94]	227.8	15.5	43.1	11.1
RFD 0-200 ms (N/s)									
HABD	561.7 (199.6)	598.4 (288.7)	-36.9 (144.9)	0.204	0.86 [0.65;0.95]	80.0	13.8	38.2	9.3
HADD	598.8 (211.5)	583.1 (238.0)	15.7 (119.1)	0.606	0.87 [0.66;0.95]	82.8	14.0	38.9	9.7
HF	1391.2 (345.3)	1412.6 (401.2)	-21.3 (149.2)	0.564	0.92 [0.80;0.97]	103.6	7.4	20.5	5.0
HE	1040.3 (343.3)	1003.2 (324.1)	37.1 (180.1)	0.439	0.85 [0.62;0.95]	125.6	12.3	34.1	8.8

RFD= rate of force development; N= Newton; N/s= Newton/second; ICC= Intraclass Correlation Coefficient; SEM= Standard Error of Measurement; MDC_{ind}= Minimal Detectable Change on an individual level; MDC_{group}= Minimal Detectable Change on a group level; SD= Standard Deviation; HABD= hip abduction; HADD= hip adduction; HF= hip flexion; HE= hip extension; RFD_{100}= 0-100 ms rate of force development; RFD_{200}=m0-200 ms rate of force development

* ICC used for consistency assessment between sessions.

MicroFET2 software (Hoggan MicroFET2, Scientific L.L.C., Salt Lake City, USA) is freely available as a supplementary file (www.spts.org). Thus, rate of force development and peak force can be calculated by copy-pasting the force-time values from the CSV-file into the supplementary spreadsheet. The fact that both peak force and rate of force development measures could be derived using the same test set-up adds to the applicability of this test procedure in clinical and research settings. Furthermore, the absolute reliability, SEM % <10 for peak force and SEM % ≤ 15.5 for rate of force development (0-100 ms and 0-200 ms) indicate that this simple and clinical available test set-up can be applied to measure hip muscle function with acceptable measurement error.[28]

In research settings, evaluation of differences or change is often of interest at a group level.[27] The MDC_{group} % in the present study suggests that group level changes exceeding 4.0-5.3% for peak force and 5.0-11.1% for rate of force development can be obtained with 95% confidence,[27] indicating that the set-up can be used to detect differences or changes in hip muscle function considered to be clinically relevant. In contrast, in the clinical setting, monitoring of peak force or rate of force development is often of interest at an individual level, with the MDC_{ind} % providing a 95% probability of an individual's true change score.[25] However, with MDC_{ind} % values ranging from 16.4-21.0% for peak force and 20.5-43.1% for rate of force development, clinically relevant changes or differences <10-15% may seem difficult to detect at an individual level. It should, however, be noted that subjects with hip pain often display large deficits in hip muscle peak force (approx. 10-25%),[19,29,30] thus improvements exceeding the MDC_{ind} % during rehabilitation is not unrealistic. Additionally, deficits in hip muscle rate of force development up to 51% have been observed in females with patellofemoral pain syndrome.[15] Nonetheless, the present study findings indicate the that test procedure is more suitable to be used in clinical research (or at a group level) settings compared to clinical settings, where subjects are often measured on an individual basis.

Rate of force development

The novelty of the present study is the introduction of a simple and inexpensive procedure to measure early- (0-100 ms) and late-phase (0-200 ms) hip muscle rate of force development using an external-fixated handheld dynamometer. Of note, the intra-tester reliability obtained in the present study is comparable to more expensive and time consuming test procedures using isokinetic dynamometry.[14,20] Thus, this novel procedure is feasible to be included in clinical practice where an isokinetic dynamometer may not be readily accessible, without compromising test-retest reliability. Furthermore, the use of an external-fixated handheld dynamometer in the present study makes the test procedure suitable to test even strong and powerful athletes, without introducing potential bias related to the tester's strength.[2,22]

The relative and absolute reliability of the rate of force development measures obtained in the present study are comparable to a previous report.[20] In Mentiplay et al.,[20] intra-tester reliability of muscle peak rate of force development (steepest interval on the ascending force curve) obtained during a 200 ms time window for hip abduction, adduction, flexion and extension showed ICC (2,1) values of 0.86-0.94 and SEM % values of 9.52-16.85. Noteworthy, Mentiplay et al.[20] did not use external fixation of the dynamometer indicating that hip muscle rate of force development may be obtained reliably without implementing external fixation. However, the findings from Mentiplay et al.[20] may not be readily implemented in clinical practice and research settings, as this procedure seems to be dependent on the tester's strength in relation to the person being tested.[22] In line with this, Thorborg et al.[22] observed inter-tester systematic bias in measurements of peak isometric hip muscle force performed with a handheld dynamometer between two testers with different upper-body strength, with the weakest tester recording the lowest force values. As peak isometric muscle force is associated with rate of force development,[21] such bias will also likely affect measures of rate of force development.[14] Furthermore, even small alterations of the joint angle in the beginning of the contraction, which is present if the tester is unable to entirely fixate the dynamometer by hand, may result in attenuation of force and compromise rate of force development values.[14] Although small movements are unavoidable seeking to minimize this should be prioritized when measuring rate of force development, highlighting the merit of an external-fixated dynamometer versus a procedure where the dynamometer is handheld.[14]

Peak force

The relative and absolute reliability the hip muscle peak force measures are comparable to previous research using a test set-up with an external-fixated [2,31] or handheld dynamometer.[3,4,20] Similar to Mentiplay et al.,[20] the results of the present study suggest that peak hip muscle strength and rate of force development can be obtained during the same test set-up, without compromising reliability of peak force.[2-4,31] This has important clinical implications, as only a single test set-up and procedure is needed to quantify both peak hip force and rate of force development. This is interesting since the present study adopted a test instruction ("*push as fast and hard as possible*") focusing mainly on obtaining maximal rate of force development.[14] However, the peak force values obtained in the present study are comparable to previous reports focusing only on measuring hip muscle peak forces in healthy young subjects indicating that the peak force measures are valid.[2-4,31]

Clinical relevance of assessing hip muscle function

In athletes with longstanding hip and groin pain, restoring optimal muscular function around the hip joint is considered highly important.[1] Although, monitoring of peak isometric hip force is a cornerstone in the management of patients with hip and groin pain,[1] this may not reflect deficits in more demanding muscular actions, such as eccentric [5] or explosive muscle contractions.[16] Since rate of force development is largely determined by the neural drive,[14,32,33] assessment of this parameter may have increased sensitivity to detect important muscular deficits beside reduced peak force.[16] Furthermore, rate force development is associated with sport performance,[17,34] and therefore has important clinical implications in physically active subjects with hip and groin pain.[1,14] Of note, impaired early- (0-100 ms) and late-phase (0-200 ms) rate of force development for hip extension has been observed in subjects with femoroacetabular impingement syndrome scheduled for hip arthroscopy.[19] Such deficits may contribute to impaired sport performance often noted following hip arthroscopy for femoroacetabular impingement syndrome.[18] Thus, assessment of hip muscle rate of force development may be used to guide and tailor treatment and the return to sport process. In other patient groups, assessment of hip muscle rate of force development has also been conducted to provide detailed insights of muscular function, which can be used to guide management.[15,16] For example, in patients scheduled for total hip arthroplasty, reduced hip abductor rate of force development in the involved versus non-involved leg has been observed despite no between-leg difference in peak force.[16]

Limitations

A limitation of the present study is the inclusion of only 17 subjects, which is considered a small sample size for reliability studies,[35] thus may have affected error of measurements. Furthermore, no concurrent validity analyses compared to gold standard measures of peak force and rate of force development, that is isokinetic dynamometry, were performed.[14] However, concurrent validity of peak force and rate of force development has previously been established for handheld dynamometry with and without external fixation.[20,36] Thus, as this set-up applied an external-fixated handheld dynamometer, which allowed no-to-minimal movement of the dynamometer during testing, good concurrent validity of the present test procedures are expected.[14,20] Finally, the present study adopted an intra-tester design only, however inter-tester reliability is expected to be good due to the use of an external-fixated dynamometer.[2] However, technical issues such as dynamometer placement, joint angle position, and instruction and encouragement during testing may affect inter-tester reliability. Thus, focusing on these technical aspects are considered important when introducing different testers.

CONCLUSION

The results of the present study indicate that assessment of isometric hip muscle peak force, including early- (0-100 ms) and late-phase (0-200 ms) rate of force development using an external-fixated dynamometer have good intra-tester reliability when testing the hip adductors, abductors, flexors, and extensors. Furthermore, the test procedures showed an acceptable measurement error (SEM %: ≤15.5).

Thus, in clinical research settings where an isokinetic dynamometer may not always be readily accessible, the present test procedure can be used as a feasible alternative to reliably provide detailed insights of hip muscle function relevant for rehabilitation of patients with hip and groin pain.

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