Original Article

Correlation of Hand-held Dynamometer and Isokinetic Dynamometer for Determining Quadriceps Index in Post-operative Anterior Cruciate Ligament Reconstruction

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Background: Quadriceps strength is a key factor in determining rehabilitation progression and the return to sports for patients with anterior cruciate ligament (ACL) reconstruction. Muscle strength can be measured with isokinetic dynamometers (ISOs) or hand-held dynamometers (HHDs).

Objective: To ascertain the correlation between the quadriceps index (QI) derived from ISO and HHD measurements of post-operative ACL reconstruction patients, and to compare the sitting and prone positions for quadriceps strength assessments using HHDs.

Materials and Methods: Patients who underwent ACL reconstruction over 3 months beforehand were included. Quadriceps strengths were ascertained with an ISO by 1 examiner with patients seated, and with an HHD by 2 examiners with patients seated and prone. QI is the quadriceps strength value of the involved leg expressed as a percentage of that of the uninvolved leg. The correlations between the QI values of each ISO and HHD setting were established.

Results: Sixty patients, averaging 29.6 years of age, were evaluated. The intraclass correlation coefficient (ICC) of the inter-examiner reliability between the ISOs and HHDs by two examiners were 0.59 and 0.43 (sitting position), and 0.40 and 0.24 (prone position). The ICC of the inter-examiner reliability between the HHD results of two examiners was 0.60 for sitting position and 0.43 for prone position.

Conclusion: The QIs obtained using HHDs with patients in sitting position had a poor-to-moderate correlation with those from ISOs. Moreover, the QIs procured using HHDs had a higher correlation with those from ISOs when patients were seated compared to when they were prone.

Keywords: Anterior cruciate ligament reconstruction, Hand-held dynamometer, Quadriceps index, Quadriceps muscle strength

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The anterior cruciate ligament (ACL) in the knee is commonly injured, and it is often treated with ACL reconstruction. Nevertheless, many individuals continue to exhibit impaired functional performance due to a reduced range of motion and quadriceps muscle strength deficit[1]. Quadriceps muscle strength level is a crucial clinical indicator of progression in accelerated rehabilitation programs during the post-operative ACL reconstruction follow-up period. The strength also determines the time to return to sports activities[2,3].

Quadriceps muscle strength is commonly reported as the value of a side-to-side comparison. The quadriceps index (QI) is defined as the relative quadriceps strength of the involved leg compared to that of the uninvolved leg, expressed as a percentage. Based on published rehabilitation protocols after ACL reconstruction surgery, quadriceps muscle strength symmetry is used to make clinical decisions on when to recommence sports activities. Recent publications have recommended that the quadriceps strength must be over 80%, and in some articles over 90%, compared with the contralateral side in order to undertake sports again[4,5]. The present study focused on the QI parameter because, being a percentage, it allows for ready comparison of results from one study to another, regardless of different strength metric used for the QI calculations.

The isokinetic dynamometer (ISO) is considered the gold standard of strength testing[6] but its cost and lack of portability impede its use by clinicians. In 2011, a systematic review by Stark et al[7] demonstrated that a hand-held dynamometer (HHD) was a reliable tool for assessing muscle strength. However, that study reviewed 17 articles that examined different muscle groups, with only 8 of the 17 publications focusing on the quadriceps muscle strength associated with various knee pathologies. Two common limitations found in the use of HHDs are lack of testing position consensus and inconsistent results due to the effect of the examiner's strength[8].

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The objectives of the present study were to establish the correlation between HHDs and ISOs in determining QIs of post-operative ACL reconstruction patients, and to compare the results of the sitting and prone positions when using HHDs to assess quadriceps muscle strength. Our primary hypothesis was that HHD-based calculations of the QIs in post-operative ACL reconstruction patients would correlate well with ISO-based determinations. The secondary hypothesis was that using HHDs on prone patients to obtain their QIs would have a higher correlation with ISO-derived QIs than HHD-based assessments performed with the patients seated.

Materials and Methods

Participants

The study protocol was approved by the Institutional Review Board. Patients who had undergone an ACL reconstruction more than 3 months beforehand were recruited and fully informed before signing a consent form at the hospital's sports clinic. The exclusion criteria were patients with multiple knee ligament injuries, knee pain, and limited range of knee motion. By assuming a correlation of 0.6 between the two measurements and a level of significance of 0.05, a sample size of 60 subjects was calculated[9].

Procedures

The HHD and ISO tests were performed on the same day during one of the regular post-operative follow-up sessions scheduled for each patient at the hospital's sports clinic. The ISO tests were performed by an experienced operator, while the HHD tests were completed by two athletic trainers. "Examiner A" was a sthenic-built male athletic trainer, while "Examiner B" was a hyposthenic-built female athletic trainer. Both examiners had undertaken HHD training and regularly used the devices in their routine practice. All study participants and all examiners were blinded to the results of the individual tests until each set of three tests for a particular position or leg had been completed.

Isokinetic dynamometer

Quadriceps strength was measured with an ISO (Con-Trex MJ; CMV AG, Dubendorf, Switzerland). Each participant was seated on a machine with 90 degrees of hip flexion and 90 degrees of knee flexion. The chest and pelvis were strapped to allow only knee movement, with the range of motion set at 0° to 90° of flexion. The ISO pad was strapped on the examined leg 3 centimetres above the lateral malleolus (Figure 1). Starting with a warm-up session, the participant extended and flexed the knee against the pad with only half of the maximum force for a total of three repetitions. The same motions were subsequently performed three more times, but at maximum force. Ten minutes of rest was allowed before the identical procedure was carried out on the opposite leg[10,11].

Hand-held dynamometer

Ten minutes after finished ISO testing, a digital HHD (MicroFET 2; Hoggan Health Industries Inc., Draper, UT, USA) was used to test the quadriceps strength of the uninvolved leg compared to the involved leg. The HHD tests were performed by the two examiners, with the patients in a sitting and then a prone position.

In the case of the sitting position, each participant was positioned on the edge of a table to permit 90 degrees of knee flexion. The HHD device was placed on the examined leg on the anterior aspect of the tibia at 3 centimetres above the lateral malleolus (Figure 2). For the warm-up session, the participant was asked to carry out an isometric voluntary contraction of the quadriceps muscle against the HHD device with only half of the maximum force and then to hold the position for 5 seconds. The action was performed 3 times in total. The leg action was then performed three more times, but at maximum force, with the same holding period of 5 seconds between each contraction. Ten minutes of rest was allowed before doing the test on the other leg[12-15].

The participant then lay down on the table in a prone position, but with 90 degrees of knee flexion. The HHD was placed on the anterior aspect of distal tibia at 3 centimetres above the lateral malleolus (Figure 3). The test was carried out using the same warm-up, testing, and resting protocols as described for the sitting position.

After the first examiner finished, the second examiner repeated all six HHD tests (three each in the sitting and prone positions).

Statistical analysis

All statistical analyses were carried out using SPSS Statistics for Windows, version 18.0 (SPSS Inc., Chicago, IL, USA). Data were assessed for normality using a Shapiro–Wilk test, with the data conforming to normal distribution. Descriptive statistics (mean and standard deviations) were used to describe the participants' demographic data. Assessments of the intra- and inter-examiner reliabilities were conducted using the intraclass correlation coefficient (ICC) with 95% confidence intervals. The associations and

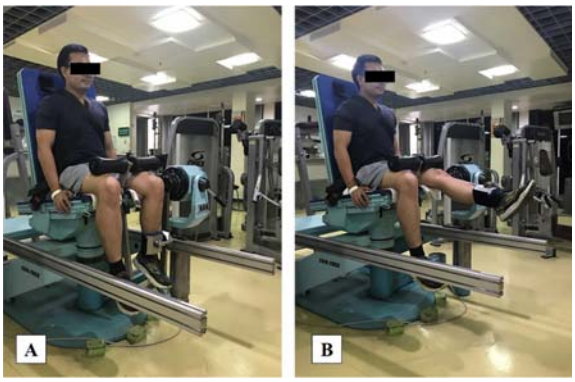

Figure 1. Isokinetic dynamometer set up. A) Start-position of the test, B) End-position of the test.

Figure 2. Hand-held dynamometry in a sitting position.

Figure 3. Hand-held dynamometry setup in a prone position.

correlations between the 2 examiners and the 2 testing devices were also measured using Pearson's correlation coefficient and a simple linear regression model (p-value <0.05).

Results

Sixty participants (53 males and 7 females; 36 left and 24 right side) with an average age of 29.6 years were evaluated. The average body mass index was 24.5 kg/m^2, and the average post-operative duration was 10.4 months (range: 3 to 70 months). No adverse events occurred during the testing procedures.

Average QI obtained from ISO was 71.13±21.32. Average QI calculated from HHD by Examiner A in sitting and prone position were 92.46±10.49 and 91.35±13.08, respectively. Average QI calculated from HHD by Examiner B in sitting and prone position were 96.10±9.68 (69.15 to 121.75) and 95.21±10.91 (72.40 to 123.48), respectively.

ICC values of 0.96 and 0.95 for the involved and uninvolved legs, respectively, were calculated for Examiner A for the intra-examiner reliability of the three quadriceps strength values obtained through HHD testing of the patient in a sitting position. The corresponding ICC values for Examiner B were 0.91 and 0.96. In the case of the prone position, the ICC values for the three HDD tests of the involved and uninvolved legs were 0.90 and 0.94 for Examiner A, and 0.90 and 0.95 for Examiner B, respectively.

In contrast, the correlation between the ISO and HHD measurements demonstrated lower reliability. The ICCs of the inter-examiner reliability of the QIs obtained from the ISO and the HHD results from examiners A and B were 0.59 and 0.43 for the sitting position, and 0.40 and 0.24 for the prone position, respectively. The inter-examiner reliabilities of the QIs obtained by examiners A and B using the HHD were 0.60 for the sitting position and 0.43 for the prone position.

The Pearson correlation coefficients for the QIs measured by the ISO and HHD are summarized in Table 1. The values of the QIs obtained by Examiner A using the ISO and HHD in a sitting position showed a statistically significant correlation (p<0.05) with the linear regression model of $QI_{ISO} = QI_{HHD} - 27$.

Discussion

The present study demonstrated that the QIs of post-operative ACL reconstruction patients determined by using HHDs in the sitting position had a poor-to-moderate correlation[16] with those obtained with ISOs, especially when performed by a sthenic-built examiner. QIs calculated using the HHD on patients in the sitting position had a higher correlation with the ISO results than those acquired by using the HHD on patients in the prone position.

Previous papers have compared the use of HHDs and ISOs to assess the strength of various muscle groups. Most of the studies primarily targeted on the peak force, for which HHDs showed a moderate-to-good reliability and validity, compared with ISOs[7]. Recently, Sinacore et al[17] reported the quadriceps strength for various knee pathologies using QIs derived from HHD and ISO measurements. They suggested that HHDs might be a suitable alternative for the

Table 1. Pearson correlation coefficients for quadriceps indices measured by isokinetic dynamometer and hand-held dynamometer

	ISO	Hand-held dynamometer			
		Sitting position		Prone position	
		A	B	A	B
ISO	1.00	0.52*	0.36	0.27	0.17
Sitting position					
A		1.00	0.44*	0.46*	0.13
B			1.00	0.15	0.20
Prone position					
A				1.00	0.28
B					1.00

* = $p<0.05$ was considered significant
A = Examiner A; B = Examiner B; ISO = Isokinetic dynamometer

measurement of knee extensor strength if ISO are unavailable. However, the authors warned of the risk of overestimating quadriceps strength because the QIs calculated from the HHD values were greater than those derived from the ISO values; their finding is consistent with the results of the present study.

One factor that may influence the quadriceps strength values procured with HHDs is the testing position. For knee extensor strength measurements, many previous papers have used HHDs in the sitting position, with the knee flexed 90 degrees. Other researchers have used the prone position instead, with the knee flexed 90 degrees[18,19]. In addition, Martin et al[6] suggested that using HHDs in the supine position might offer feasible means of testing quadriceps strength in healthy older people. In the present study, we decided to compare HHD testing in both the sitting and the prone positions. The QIs derived from the use of HHDs on patients in the sitting position demonstrated a higher correlation between the two examiners than those on patients in the prone position. Comparing the QIs from ISO and HHD testing in the sitting position also showed a higher correlation than HHD testing in the prone position by both examiners. Therefore, the sitting position is more suitable than the prone position for the performance of HHD testing of post-operative ACL reconstruction patients.

Thorborg et al[20] reported that the strength of examiners in stabilizing a HHD device during a test is likely to be an important factor in the accuracy of the measurements. This is because sufficient strength levels are required to resist the movement of the tested leg. In the present study, the HHD tests performed in both the sitting and prone positions by Examiner B showed a lower correlation with the ISO tests than the HHD tests conducted by Examiner A. These results confirm that examiner strength plays an important role in assessing quadriceps strength when using HHDs.

In post-operative ACL reconstruction patients, asymmetrical quadriceps strength is a key factor in determining the progression in an accelerated rehabilitation program and the return to sports. However, the greater QIs obtained from HHDs than from ISOs could result in an overestimation of quadriceps strength, as evidenced in the present study by the figure of 27 obtained using a linear regression model for Examiner A in the sitting position (Table 1). Therefore, QIs derived with HHDs may not be appropriate to use as a threshold for returning to sports activities. Nevertheless, HHDs may be suitable alternative devices for use in evaluating improvements in quadriceps strength in the early phase of a rehabilitation program. During the early post-operative period, patients are advised to focus on improving the range of knee motions and strengthening quadriceps muscle with closed-chain exercises. Open-chain exercises should be used with caution in the first 3 months because they could produce excessive ACL graft tensioning[21,22]. This prevents the use of ISOs in this period. Furthermore, there are marked quadriceps strength deficits between the normal and operative legs in the early phase that can be demonstrated with HHD measurements. In contrast, late in a rehabilitation program, quadriceps strength deficits become smaller and may be difficult to detect with an HHD. Therefore, the strength measurements need to be more accurate in order to detect slight to moderate quadriceps strength deficits, as well as to use the QI as a threshold for return to play. It follows that during the late period of a rehabilitation program, ISOs and functional tests are better options for evaluating quadriceps function and determining the appropriate time to return to sports.

The limitations of the present study were that most participants were male, which is related to the gender distribution of the ACL-injured patients at our sports clinic.

Conclusion

The QIs of post-operative ACL reconstruction patients obtained using HHDs with patients in a sitting position had a poor-to-moderate correlation with those from ISOs. Moreover, the QIs procured using HHDs in a sitting position had a higher correlation with those from ISOs when patients were seated compared to when they were prone.

What is already known on this topic?

Previous studies compared the use of HHDs and ISOs to assess the strength of various muscle groups but primarily targeted on the peak force, for which HHDs showed a moderate-to-good reliability and validity compared with ISOs.

What this study adds?

The QIs of post-operative ACL reconstruction patients derived from HHD measurements taken with the patients seated had a poor-to-moderate correlation with the QIs that were based on ISO measurements. HHDs may be a suitable alternative device for evaluating improvements in quadriceps strength in the early phase of rehabilitation programs.

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Potential conflicts of interest

The authors declare no conflict of interest.

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