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RESEARCH STUDY

Assessment of Quadriceps Muscle Performance by Hand-Held, Isometric, and Isokinetic Dynamometry in Patients With Knee Dysfunction

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One component of patient evaluation is muscle performance assessment. The purpose of this study was: 1) to determine the difference and correlation between hand-held, isometric, and isokinetic dynamometry test results in patients with knee dysfunction and 2) to determine the effect of pain during such testing. Bilateral quadriceps strength in 23 subjects with unilateral knee dysfunction was tested using concentric and eccentric isokinetic dynamometry at 60°/sec, isometric dynamometry, and hand-held dynamometry, both at 60° of knee flexion. Pain ratings were obtained before, during, and after each test. Statistical analysis revealed a significant difference between involved and uninvolved limbs for eccentric isokinetic dynamometry ($p = 0.002$) and hand-held dynamometry ($p = 0.005$); no difference was found between limbs for the concentric isokinetic and isometric dynamometry ($p > 0.05$). Mean percent deficits in quadriceps strength ranged from 11 to 18%, with no significant difference found between testing modes. Pearson product moment correlations ranged from 0.34 to 0.76 when comparing testing modes. No significant difference existed in pain scores before, during, and after each mode of testing. It was concluded that large variation existed between different testing modes, which results in different conclusions regarding the strength of the quadriceps in patients with knee dysfunction.

Key Words: *muscle strength, knee, methods*

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Assessment of muscle performance is one component of evaluation in patients with orthopaedic and neurologic dysfunction (18). A need exists for quantitative, objective measures of muscle performance that provide documentation of progress and intervention efficacy. Manual muscle testing is a widely used method for evaluating muscle performance. However, research has shown that manual muscle testing is subjective, especially at the higher muscle test grades, and may not detect muscle performance deficits (5,6,24). Other commonly used clinical methods of instrumented muscle testing include hand-held, isokinetic, and isometric dynamometry. All three methods are reported to be reliable measures of muscle performance (3–5,9,10,19,20).

Clinically, hand-held dynamometry is easy to use, low cost, and requires minimal training. Conversely, computerized isokinetic and isometric dynamometry is costly, requires extensive training, and occupies large clinical space. Several studies have indicated that isometric and isokinetic measurements may be evaluating similar characteristics of muscle function (1,10,11,14). The coefficients of determination (r^2) describing the relationship between isometric and isokinetic dynamometry for knee extension range from 0.46 to 0.86 in previous studies (1,7,8,10,12). The relationship between hand-held dynamometry and both isokinetic

Diagnosis	N	%
Anterior knee pain syndrome	8	35
ACL reconstruction	7	30
Patella realignment (tibial tubercle)	5	22
Arthroscopic meniscectomy	2	9
Patella tendinitis	1	4

ACL = Anterior cruciate ligament.

TABLE 1. *Subjects' diagnoses.*

0	No pain
1	Dull vague ache
2	Slight persistent pain
3	More than slight pain
4	Painful
5	Very painful
6	Unbearably painful

TABLE 2. *Talag pain scale used to assess pain. (Adapted from Talag (21), reproduced with permission from the American Alliance for Health, Physical Education, Recreation and Dance, Reston, VA 22091).*

and isometric dynamometry has also been reported to be correlated with coefficients of determination ranging from 0.32 to 0.72 (5,15). No studies were located that compared hand-held, isokinetic, and isometric dynamometry for a patient population. If these testing modes are highly correlated and reveal similar findings regarding muscle function, then clinicians may choose the less expensive and time-consuming devices for evaluating muscle performance.

Another issue that has been raised regarding muscle performance is the possible confounding influence of pain during testing. Lysholm (13) has reported that knee pain reduces quadriceps isokinetic torque values. Deones et al (5) compared isokinetic dynamometry and hand-held dynamometry and concluded "we believe that pain didn't influence our results," but quantification of pain during testing was not reported.

METHODS

Subjects

Twenty-three subjects (17 males, six females) who were seen at St. Francis Outpatient Physical Therapy, Indianapolis, IN, participated in this study. Subjects had unilateral knee pathology, including both surgical and nonsurgical cases (Table 1) with a prescription for rehabilitation and knee extensor muscle performance testing. Subjects ranged in age from 15 to 54 years ($\bar{X} = 27.17 \pm 12.41$ years). All subjects were advised of the purpose and risks of the study, and then each subject completed an informed consent form approved by the St. Francis Hospital and Health Centers Research Committee. Subjects were excluded from the study if any of the following criteria were met: *1)* neurological or neuromuscular pathology, *2)* increased knee pain with manual muscle testing, or *3)* anterior cruciate ligament reconstruction less than 5 months postsurgery.

Testing Procedures

Testing was performed during a scheduled physical therapy appointment. All testing was completed on the same day, with the order of testing device randomly determined. The uninvolved limb was tested first, followed by testing of the involved limb for all three modes. Subjects were asked to rate their pain using a 0–6 scale (Table 2) (21) immediately before, during, and immediately following each test. For the warm-up, subjects rode a stationary bicycle for 5 minutes prior to the first test. A timed 5-minute rest was given between testing modes. Subjects were informed that they could end a testing session at any time because of knee pain or fatigue.

Hand-Held Dynamometer Test

The hand-held dynamometer (Microfet, Draper, UT) was one instrument used to test bilateral knee extensor muscle performance. All subjects were tested by the same tester, and the uninvolved limb was tested first. Subjects were seated at the edge of a treatment table and positioned in 60° of knee flexion using a standard goniometer. The hand-held dynamometer was positioned two finger widths above the lateral malleolus on the anterior tibia. Subjects were asked to stabilize their pelvis by holding onto the edge of the treatment table. A make test was used, in which the tester matches the muscle force generated by the subject, as contrasted with a break test, in which the tester attempts to exceed the force generated by the subject (23).

Four warm-up contractions were performed, with subjects instructed to gradually increase their knee extension force over 3 seconds. Subjects were instructed to give approximately 50% effort in the first three warm-ups and a maximal contraction on the fourth warm-up. Four maximal trials were then performed, with the peak force of the fourth contraction recorded.

Isometric Dynamometer Test

Isometric knee extension peak force was measured using the Kin-Com 500H (Chattanooga Corp., Chattanooga, TN). Bilateral testing was performed with the uninvolved limb tested first. Subjects were tested at 60° of knee flexion as measured using the dynamometer goniometer. Testing was then performed with the subjects seated, using stabilization straps at the pelvis and over the anterior thigh. The dynamometer axis was aligned with the axis of the knee, identified as a point on the lateral femoral condyle 2.5 cm superior to the fibular head. Gravity correction was not used.

Four warm-up contractions were performed, with subjects instructed to gradually increase their knee extension force over each 3-second isometric bout. Subjects were instructed to give approximately 50% effort in the first three warm-ups and a maximal contraction on the fourth warm-up. Three maximal trials were then performed, with the maximal peak force recorded.

Isokinetic Dynamometer Test

Concentric and eccentric knee extension peak force was measured using the Kin-Com. Bilateral testing was performed with the uninvolved limb tested first. Subjects were tested at 60°/sec isokinetic speed through 70° of knee motion (10–80° of knee flexion) as measured using the dynamometer axis. Testing was performed with the subjects seated, using stabilization straps at the pelvis and over the anterior thigh. The dynamometer axis was aligned with the axis of the knee, identified as a point on the lateral femoral condyle 2.5 cm superior to the fibular head. Gravity correction was not used.

Four concentric and eccentric warm-up contractions were performed, with subjects instructed to give approximately 50% effort in the first three warm-ups and a maximal contraction on the fourth warm-up. Maximal concentric and eccentric trials were then performed until three reproducible force curves were obtained. Maximal concentric and eccentric peak forces were recorded. No visual feedback was provided to the subject during the test. Standardized verbal instructions were given using the word "push" to begin the concentric contraction and the word "resist" to begin the eccentric contraction.

Testing Reliability

Reliability for hand-held dynamometry was performed using 10 normal subjects prior to initiation of the study. Testing procedure was as described in the hand-held dynamometry testing section. Each subject was tested twice within 2 hours with the tester blinded to test results. Isokinetic and isometric dynamometry reliability on the Kin-Com was determined using 10 normal subjects in two sessions 1 week apart. Testing procedure was as described in the isometric and isokinetic dynamometry testing sections.

Dependent Variable	ICC	$\bar{X}$ (N)	SEM (N)	p
Hand-held dynamometer	.92	290.0	4.3	.71
Isometric	.81	396.0	76.71	.01
Isokinetic concentric	.83	397.5	7.42	.76
Isokinetic eccentric	.76	446.5	53.72	.18

ICC (2,1) = Intraclass correlation coefficient.
SEM = SD $\sqrt{1 - ICC}$.

TABLE 3. *Reliability data (N = 10).*

Statistical Analyses

Intraclass correlation coefficients (ICC 2,1) (17) and standard error of measurement (SEM) (2) were used to determine reliability for all testing modes prior to initiation of this study. Dependent t tests were used to compare involved with uninvolved limbs for each testing mode. Bonferroni correction (.05/4 = .0125) was performed to adjust for multiple t tests. Percent deficits (involved − uninvolved/uninvolved × 100) were calculated for all subjects and were then compared across all testing modes using a repeated measures analysis of variance. Pearson product moment correlations were used to determine the relationship between deficits for each testing mode. In addition, coefficient of variation was determined (SD/$\bar{X}$ × 100%). Pain data (before, during, and after testing) were analyzed using a repeated measures analysis of variance.

RESULTS

Reliability Study

Intraclass correlation coefficients ranged from 0.76 to 0.92, and standard errors of measurement ranged from 4.3 to 76.71 N for all testing modes (Table 3). A significant difference existed between testing trials for isometric testing (p = 0.01).

Comparative Study

All subjects completed the study; no subjects met any of the exclusionary criteria. Dependent t tests revealed a significant difference between the involved and uninvolved limbs for eccentric isokinetic dynamometry (df = 45, t = 18.88, $p < .05$) and hand-held dynamometry (df = 45, t = 14.96, $p < .05$). No significant difference existed between the involved and uninvolved limbs for concentric isokinetic dynamometry and isometric dynamometry ($p >$ 0.05). Average percent deficit between the involved and uninvolved limbs ranged from 11 to 18% for the testing modes (Table 4). No significant difference existed between percent deficits obtained from the different testing modes ($p > .05$). Testing modes showed a large range of values for patients, as indicated by the large coefficient of variation values (Table 4). Comparing the percent deficit across all four testing conditions for each patient, great variation existed in the difference between limbs, de-

Dependent Variable	$\bar{X}$ (%)	SD (%)	Range (%)	CV
Hand-held dynamometer	−11	18	−11 to +16	−165
Isometric	−11	25	−7 to +41	−219
Isokinetic concentric	−12	3	−75 to +43	−260
Isokinetic eccentric	−18	28	−73 to +46	−155

CV = Coefficient of variation (SD/Mean × 100).

TABLE 4. *Percent deficit as determined by each testing device ($p > 0.05$).*

pending on the mode of testing. In only seven of the 23 patients was there agreement in which extremity was weaker or stronger. The sign (−) indicates that the injured quadriceps produced a lower force, while the sign (+) indicates that the injured quadriceps produced a greater force (Table 5). As presented in Table 6, the Pearson product correlations ranged from 0.34 (hand-held to isometric dynamometry) to 0.76 (isometric to concentric isokinetic dynamometry).

Analysis of the pain data showed no significant difference between the involved and uninvolved limbs before, during, and after each test (Table 7). Also, no significant difference was detected between pain ratings for each mode of testing.

	HHD	ISO	CON	ECC
1.	−27.9	+5.7	+3.5	+7.6
2.	−13.4	+10.8	+7.1	−1.5
3.	+6.2	−11.2	−8.6	−16.8
4.	−18.4	+10.6	−3.2	−11.1
5.	−49.0	−69.9	−74.6	−73.5
6.	+9.8	−22.7	−28.6	−11.9
7.	−27.2	−23.0	+18.4	−18.2
8.	−4.6	−2.5	−10.0	+3.8
9.	−6.1	−7.4	−2.4	+12.3
10.	−25.8	−49.4	−54.4	−70.3
11.	−46.1	−57.1	−73.8	−55.5
12.	−1.2	−20.9	−5.0	−33.0
13.	−8.6	−22.8	−19.8	+46.5
14.	−42.6	+10.1	−18.0	−36.1
15.	+15.5	+5.8	+13.8	−25.5
16.	−8.0	−17.9	−18.7	−22.5
17.	+10.7	−15.6	+42.8	+13.0
18.	+6.6	−6.1	−31.2	−41.1
19.	−7.5	+18.8	+18.6	−7.8
20.	+7.3	−4.3	−2.6	−.9
21.	−3.2	−17.6	−47.4	−38.2
22.	−3.8	−14.6	−8.2	−23.1
23.	−17.9	+40.8	+34.0	−7.9

HHD = Hand-held dynamometer.
ISO = Isometric.
CON = Isokinetic concentric.
ECC = Isokinetic eccentric.

TABLE 5. *Percent deficit (injured − noninjured/noninjured × 100) as determined by each testing mode. Negative sign indicates that the injured extremity's quadriceps force was less than the noninjured extremity's quadriceps force. Positive sign indicates that the injured extremity's quadriceps force was greater than the noninjured extremity's quadriceps force.*

	ISO	CON	ECC
HHD	.34	.45	.43
ISO		.76	.53
CON			.66

HHD = Hand-held dynamometer.
ISO = Isometric.
CON = Isokinetic concentric.
ECC = Isokinetic eccentric.

TABLE 6. *Pearson correlation coefficients matrix for percent deficit as determined by each testing mode.*

DISCUSSION

Regarding the reliability study, intraclass correlation coefficients were generally acceptable with the exception of eccentric isokinetic, which was .76. Tredinnick and Duncan (22) examined the reliability of concentric and eccentric testing on the Kin-Com and reported an ICC of .89 for concentric torque and .47 for eccentric torque. Deones et al (5) reported an ICC of .93 and a standard error of measurement of 15.6 N for knee extensor testing using the hand-held dynamometer at the 60° position. In this study, the standard errors of measurement relative to the mean values of the testing mode ranged from 1.30 to 19.40%, which, in our opinion, indicates relatively small measurement error (Table 3). For isometric dynamometry, a significant increase ($p = 0.01$) existed between the first and second test, indicating a learning effect occurred. Therefore, during isometric and eccentric isokinetic testing, more practice trials may be needed to decrease the measurement error and improve the intraclass correlation coefficients.

The purpose of this study was to determine the differences between various modes of muscle performance assessment in a group of subjects with knee dysfunction. All subjects were physician-referred to physical therapy for rehabilitation and muscle performance testing. Test results showed that eccentric isokinetic dynamometry and hand-held dynamometry revealed a significant difference between the involved and uninvolved quadriceps peak force. In contrast, involved and uninvolved concentric isokinetic force values and isometric force values were not significantly different for quadriceps peak force. All of the testing modes showed relatively similar average percent deficits between limbs for the group of patients tested, but a large amount of individual variation existed in percent deficit between testing modes, as demonstrated in Table 5. This illustrates the limited value of the mean without information concerning the standard deviation, coefficient of variation, and range.

Physical therapists are asked by referring physicians to evaluate a patient's readiness to return to work, sports, or activities of daily living. Historically, measures of muscle performance have been a major part of that determination. Depending on equipment and time available, different measures of muscle performance are employed. An underlying assump-

Testing Mode	Extremity/Condition					
	NI/B	I/B	NI/D	I/D	NI/A	I/A
Hand-held dynamometer	0	1	0	2	0	1
Isometric	0	1	1	2	0	1
Isokinetic concentric	0	0	0	1	0	1
Isokinetic eccentric	0	1	1	2	2	1

NI/B = Noninjured/before testing.
I/B = Injured/before testing.
NI/D = Noninjured/during testing.
I/D = Injured/during testing.
NI/A = Noninjured/after testing.
I/A = Injured/after testing.

TABLE 7. *Pain rating for each testing mode.*

tion of this practice has been that regardless of the mode of muscle assessment, similar differences between limbs will be found. In his review article on muscle performance assessment, Sapega (16) suggested that a muscle performance deficit of 20% or greater in a limb is "probably abnormal," and deficits ranging from 10 to 20% are "possibly abnormal." The results of this study demonstrate that for each individual subject, the percent deficit between the involved and uninvolved quadriceps peak force ranged from as much as −22 to +46.5%, depending on the testing device. As was reported, only seven of the 23 subjects had agreement in the sign of the percent deficit in all four tests. Certainly one would draw different conclusions regarding the status of the involved limb, depending on which testing device is used.

Kues et al (10) compared isometric peak torque, concentric peak torque, and eccentric peak torque in 20 healthy female subjects. They reported that the coefficient of determination (r^2) ranged from .73 to .94 between isometric, concentric, and eccentric peak torque. These measures were "moderately to highly correlated, suggesting that the measurements obtained during different maximal voluntary contractions may be assessing similar components of performance." Based on the small sample size in their study (N = 20) and subject variability, they identified a coefficient of determination of .70 or greater as a strong correlation, a coefficient of determination from .50 to .69 as a moderate correlation, and a coefficient of determination less than .5 as a weak correlation. Our coefficients of determination ranged from 0.12 to 0.58 between testing modes in subjects with knee dysfunction. Our coefficients of determination were lower, indicating a weaker correlation between testing modes in our study, which is supported by the variability in percent deficits between different testing modes (Table 5).

In a previous study using patients with knee dysfunction, Deones et al (5) found that hand-held dynamometry at 0 and 60° did not detect a difference between the involved and uninvolved quadriceps peak force, whereas concentric isokinetic dynamometry at 60°/sec did detect a significant difference. They raised the issue of the confounding influence of the strength of the tester as well as the lack of stabilization in hand-held dynamometry. In contrast, this study showed a significant difference between involved and uninvolved quadriceps peak force using hand-held and eccentric isokinetic dynamometry but no significant difference using concentric isokinetic dynamometry and isometric dynamometry. It was theorized that the strength of the tester may be a confounding variable in the use of hand-held dynamometry. A pilot study revealed a significant difference between testers of different strength. Consequently, the decision was made to use a single tester for the hand-held dynamometer testing.

No difference in pain ratings was found between testing modes.

Deones et al (5) also suggested that pain may be a confounding variable in a muscle performance deficit but stated that "no patients reported an increase in pain during or after the testing procedure." However, they failed to quantify pain ratings pre- and posttesting. As a secondary purpose of this study was to evaluate the confounding effect of pain on test results, pain ratings were assessed before, during, and after each testing mode. The results demonstrated that subjects' average pain ratings for all modes ranged from 0–2 on a 0–6 scale (Table 2). No difference in pain ratings was found between testing modes.

Limitations

Limitations in this study include the heterogeneous sample with respect to diagnostic groups and age. However, this represents a patient population and adds to the external validity of the study in our opinion. The small sample size (N = 23) is also acknowledged, and it is recognized that this may have impacted the large variability in the test results. Gravity correction was not used on the Kin-Com, as it was not possible to gravity correct the data obtained using hand-held dynamometry as well as gravity correction not commonly being used in clinical testing. In addition, reliability data revealed that a learning effect occurred between sessions for the isometric testing mode.

Future Research

A need exists for future research in the area of muscle performance assessment to clarify the differences between various modes of testing. Similar studies with larger clinical samples may decrease the effect of subject variability and clarify relationships between testing modes.

CONCLUSION

Differences between various modes of muscle performance assessment were examined in this study. Results of this study demonstrate that quadriceps testing by hand-held dynamometry and eccentric isokinetic dynamometry produced significant differences between the involved and uninvolved quadriceps peak force, whereas quadriceps testing by concentric isokinetic dynamometry and isometric dynamometry showed no difference. In addition, large variation existed between different modes of testing for individual subjects and resulted in different conclusions regarding quadriceps muscle performance. No significant difference existed in pain ratings before, during, or after testing, and no differences were found in pain ratings between testing modes. JOSPT

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