

RELIABILITY AND VALIDITY OF A MODIFIED ISOMETRIC DYNAMOMETER IN THE ASSESSMENT OF MUSCULAR PERFORMANCE IN INDIVIDUALS WITH ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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ABSTRACT

Objectives: The aim of this study was to evaluate the reliability and validity of a modified isometric dynamometer (MID) in performance deficits of the knee extensor and flexor muscles in normal individuals and in those with ACL reconstructions. **Methods:** Sixty male subjects were invited to participate of the study, being divided into three groups with 20 subjects each: control group (GC), group of individuals with ACL reconstruction with patellar tendon graft (GTP, and group of individuals with ACL reconstruction with hamstrings graft (GTF). All individuals performed isometric tests in the MID, muscular strength deficits collected were subsequently compared to the tests performed on the Biodex System 3 operating in the isometric and isokinetic mode at speeds of 60°/s and 180°/s. Intraclass ICC correlation calculations were done in order to assess MID reliability,

specificity, sensitivity and Kappa's consistency coefficient calculations, respectively, for assessing the MID's validity in detecting muscular deficits and intra- and intergroup comparisons when performing the four strength tests using the ANOVA method. **Results:** The modified isometric dynamometer (MID) showed excellent reliability and good validity in the assessment of the performance of the knee extensor and flexor muscles groups. In the comparison between groups, the GTP showed significantly greater deficits as compared to the GTF and GC groups. **Conclusion:** Isometric dynamometers connected to mechanotherapy equipments could be an alternative option to collect data concerning performance deficits of the extensor and flexor muscles groups of the knee in subjects with ACL reconstruction.

Keywords - Knee, Anterior cruciate ligament; Protocols; Retrospective studies

INTRODUCTION

Researchers who study the knee joint use torque, work, and power as units of measurement for comparisons between groups of individuals or different interventions. Studies examining the influence of using different types of grafts⁽¹⁾, graft fixation techniques⁽²⁾, rehabilitation protocols⁽³⁾, and differences between

the sexes⁽⁴⁾ in muscle and functional performance in patients undergoing surgery provide reliable data that support the development of rehabilitation protocols by clinicians of the field.

Experts in the field have much interest in assessing the performance of the extensor and flexor muscles of

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the knee because the literature provides benchmarks for the progression of the phases of postoperative rehabilitation for ACL reconstruction surgery, allowing patients to start running, agility training, and to return to competitive sports based on the deficits found in the injured knee compared to the contralateral knee⁽⁵⁾.

The assessment of muscle deficits in athletes in the pre-season favors preventive interventions through the correction of deficits of the knee extensors and flexors or the restoration of the agonist-antagonist balance⁽⁶⁾. Among the tests and equipment developed for the evaluation of muscle performance in the knee extensors and flexors, computerized isokinetic dynamometers are considered the gold standard⁽⁷⁾.

However, isokinetic dynamometers are inaccessible to most physiotherapists in Brazil due to its high cost, the fact there are no domestic manufacturers, and because they require considerable space for installation.

These factors make it difficult for clinicians and laboratory researchers to have access to the muscle performance of knee extensors and flexors in any kind of disease. An alternative to this problem would be to use isometric tests that could reproduce the deficits found in tests performed on computerized isokinetic dynamometers. Various authors have used a handheld isometric dynamometer model⁽⁸⁻¹⁰⁾.

This device is a digital dynamometer that can be used to measure isometric torque at various joints performing manual strength tests. It has shown good intraobserver reliability for evaluation of the shoulder rotators in normal subjects⁽¹¹⁾, good correlation with isokinetic dynamometers in the assessment of the muscle strength of shoulder rotators in patients with neurological sequelae⁽¹²⁾, and good agreement in the evaluation of the knee extensors in geriatric patients⁽¹³⁾. However, to evaluate the lower limb muscle performance of physically active individuals, the digital dynamometer has many disadvantages, because the patient is not stabilized and a strong examiner is needed to maintain the joint angle to be tested during the examination. These two factors have led to reports of poor reliability in the evaluation of powerful muscle groups like the quadriceps⁽¹⁴⁾ and poor correlation has been observed between the manual digital dynamometer and computerized isokinetic dynamometers in the assessment of patients with a postoperative knee status⁽¹⁵⁾. These findings may be related

to the type of methodology used to assess and collect data related to muscle performance. However, there is a need to develop equipment that can use a system for patient stabilization, joint angle settings to collect data on significant muscle deficits, allowing for targeted intervention that could be easily reproduced in different clinical and research centers. This requires evaluating the validity and reliability criteria between deficits in isometric and isokinetic muscle performance collected using different types of dynamometers.

The objectives of this study were to evaluate the intraobserver reliability of a modified isometric dynamometry (MID) device and its validity for classifying performance deficits of the extensor and flexor muscle groups of the knee in normal subjects and patients who underwent ACL reconstruction using examination with the Biodex System 3 dynamometer as a reference.

METHODS

Three groups, involving a total of 60 male volunteers aged between 18 and 40 years, were recruited through verbal invitation by telephone. The first, called the control group (CG) consisted of 20 volunteers with no history of knee injury who participate in amateur sports. The second, called the patellar tendon group (PTG) was formed by 20 volunteers who underwent ACL reconstruction with a patellar tendon autograft. The third group consisted of 20 volunteers who underwent ACL reconstruction with flexor tendons (semitendinosus and gracilis) autografts; this group was called the flexor tendons group (FTG). All of the volunteers from the PTG and the FTG underwent surgery performed by the orthopedic surgeons of the Knee Surgery Group at the Hospital Municipal Celso Pierro, Pontificia Universidade Católica de Campinas. The general characteristics of the three groups of participants and the details of the postoperative status of the PTG and the FTG are described in Table 1.

The inclusion criteria for the CG were the absence of a previous history of knee injury of any nature, absence of neuromuscular disorders, differences in ligament laxity between knees < 3 mm assessed by the KT 1000. The inclusion criteria for the FTG and the PTG were six postoperative months completed, absence of inflammatory signs, normal gait, absence of neuromuscular disorders, and no complaints of instability in the activities of daily living. Exclusion

Table 1 – General characteristics of the volunteers distributed into the three groups analyzed: CG, PTG, and FTG.

Variables	CG	PTG	FTG
Sample (N)	20	20	20
Age (years)	24.95 (± 5.18)	32.6 (± 7.76)	27.55 (± 6.88)
Height (cm)	175.1 (± 7.35)	176.2 (± 8.48)	179.5 (± 8.99)
Weight (kg)	75.8 (± 8.7)	85.5 (± 14.3)	79.9 (± 8.7)
Girth*	0.8 (± 0.6)	1.42 (± 1.1)	1.35 (± 1.3)
Tegner scale	5.5	6.2	6.7
PO time (months)	*****	8.5 (± 5.45)	8.5 (± 4.00)
Supervised rehabilitation	*****	10/20	15/20
Home rehabilitation	*****	10/20	5/20

Legend: CG = control group; PTG = patellar tendon group; FTG = flexor tendons group.
*Girth demonstrating differences between the thighs in values collected 15 cm from the superior end of the patella.
Source: FMRP-USP

criteria for all groups were: history of bilateral ligament injuries, prior knee ligament reconstruction surgery of any kind, fractures of any kind in the lower limbs, combined ligament ruptures, advanced osteoarthritis in the tibiofemoral or patellofemoral joints with evident deviation of the joint axis.

All volunteers received detailed written instructions describing how the test would be conducted and signed an informed consent form agreeing to participate. The project was approved by the Ethics Committee of the Hospital das Clínicas, School of Medicine, Ribeirão Preto – Universidade de São Paulo, record number 2977/2007.

The subjective Lysholm⁽¹⁶⁾ evaluation was used to functionally characterize the sample. This scale is widely used and has been validated for the Portuguese language⁽¹⁷⁾. The Tegner scale⁽¹⁸⁾ was used to assess the sports level of volunteers in the three groups.

The KT 1000 arthrometer (MEDmetric, San Diego, CA) was used to assess all groups. In the CG, the equipment assessed the inclusion and exclusion criteria of the study participants. In the PTG and the FTG, the KT 1000 was used to determine the clinical stability of the operated knee.

Initially, all participants underwent a clinical evaluation. In the clinical evaluation, in addition to the collection of anthropometric data, the volunteer underwent some parts of the physical examination, which included assessment of the passive range of motion (ROM), thigh girth, and completing the Lysholm and Tegner questionnaire.

After clinical evaluation, volunteers underwent arthrometric KT 1000 examination, through the manual maximum test (MMT). Three MMTs were performed and the highest value was recorded on the clinical evaluation form. In the PTG and the FTG, the uninjured knee was always tested first, and in the control group, the non-dominant knee.

After the completion of the MMT, all volunteers performed a five minute warm-up on a stationary bicycle, followed by three 30-second series of traditional stretches for the quadriceps and hamstrings.

To collect data on the functional performance of the participants, we developed a modified isometric dynamometry (MID) device. This device is designed to collect the torque of the knee extensor and flexor through isometric contractions.

To make quantification of the deficits in muscle performance of the participants involved possible, we used two Kratos[®] Model LDC (Kratos Industrial Equipment Ltda.) analog traction dynamometers (Figure 1a). The traction dynamometers are made of cast aluminum housing, have a capacity to 100kgf, offering 2% accuracy of the read point, and are supplied with a calibration certificate tracked by the Brazilian Calibration Network (RBC, Rede Brasileira de Calibração). The traction dynamometers were installed in the back of the mechanotherapy unit, where the weights were originally allocated (Figure 1b).

The equipment was calibrated prior to each evaluation of extensor and flexor muscle isometric torque performance. Calibration was done using a 5kg weight, placed first on a Filizola[®] digital scale for confirmation of the weight and then connected to two Kratos[®] dynamometers to confirm the load. The torso, hip, and thigh of the subjects were stabilized with

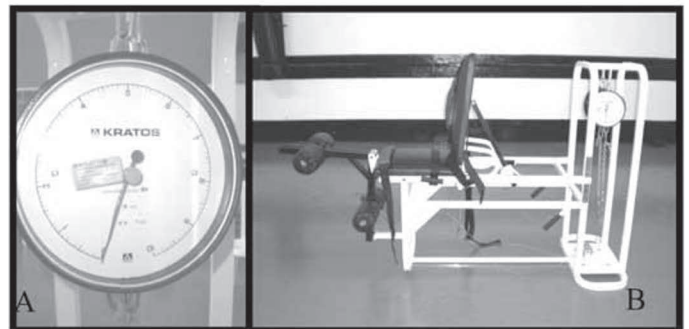


Figure 1 – (A) Kratos[®] analog traction dynamometer. (B) Mechanotherapy equipment adapted to accommodate the Kratos[®] analog dynamometer in the rear portion of the device.

Velcro straps (Figure 2a). The distal resistance support or tibial support was placed two fingers above the lateral malleolus. The volunteers were instructed to cross their arms over their chest to isolate the knee extensor moment. After correctly positioning the volunteer in the MID device the knee was positioned at 60° of flexion. For the evaluation of the isometric flexor torque, the patient was positioned prone and Velcro belts were placed to stabilize the pelvis to avoid compensation. After correctly positioning the volunteer, the knee was positioned at 30° of flexion. The patient was instructed to slowly flex the knee from a resting position of approximately 0° until it created tension in the steel cable blocking the continuation of the movement. When the blocking was detected, the evaluator at the patient's side used the goniometer to measure the knee angle (Figure 2b). After the correct positioning of volunteers, they were familiarized with the procedure. First, the patient was told that after the verbal command «prepare,» he was to slowly extend (to assess the extension torque) or flex (to assess the flexion torque) the knee to once again create tension in the steel cable; after verifying that the extension movement was blocked, the volunteer was asked to exert maximum knee extension force for five seconds under the constant verbal command of the examiner. Familiarization was repeated, in which the participant exerted 100% of his voluntary force, followed by three maximal voluntary isometric contractions (MVIC) lasting five seconds, and 90-second

intervals between repetitions. The examination was started with the non-dominant leg in the CG and the contralateral leg in the PTG and the FTG. All kgf values were recorded, ignoring only the value for the familiarization trial.

To validate the MID in the evaluation of muscular performance, the same volunteers underwent the second stage of testing the knee extensor and flexor torque after a one-week interval using the computerized isokinetic dynamometer (Biodex Multi-Joint System 3 Pro) belonging to the Orthopedics and Traumatology Assessment and Intervention Laboratory (LAIOT, Laboratório de Avaliação e Intervenção em Ortopedia e Traumatologia) of the Post-Graduate Course in Physical Therapy, Universidade Federal de São Carlos (UFScar), previously configured using software to operate specifically in the isometric and isokinetic modes.

Before starting the tests, isometric and isokinetic tests were randomized by lottery.

After calibrating the equipment, the volunteers performed a warm-up on an ergometric bicycle for five minutes and quadriceps and hamstring stretches. After warming up, the patients were positioned in the seat of the isokinetic dynamometer and stabilized in the torso, pelvis, and hip by restraining straps in order to avoid compensation during the examination (Figure 2c).

For the assessment of the isometric extension torque, the knee was positioned at 60° of flexion. After



Figure 2 – (A) Positioning of the volunteers in the modified isometric dynamometer (MID) to collect isometric extension torque data. (B) Positioning of volunteers in the MID to collect isometric flexion torque data. (C) Positioning of volunteers in the Biodex System 3 to collect the flexor and extensor isometric and isokinetic torque data.

positioning the knee, the patient was instructed to perform MVIC of knee extension for five seconds with intervals of 90 seconds between contractions. The first attempt was performed to familiarize the volunteer, followed by three MVIC. For the evaluation of the flexor torque, the knee was positioned at 30° of flexion. After positioning the knee, the volunteers performed MVIC of knee flexion for five seconds with intervals of 90 seconds between contractions, following the same protocol used for obtaining the isometric extension torque. To evaluate the isokinetic torque, a protocol was developed with two speeds, 60°/s and 180°/s. At 60°/s, the volunteers performed two sets of five movements of knee extension and flexion, and at 180°/s, two sets of five and 15 repetitions. At both speeds, the volunteers performed movements between the angles of 0 and 90 degrees as quickly and as strongly as possible, with intervals of 90 seconds between sets. The first series was used to familiarize the patient with the isokinetic test.

For all tests, the examination was initiated with the non-dominant leg in the CG and the contralateral leg in the PTG and the FTG.

STATISTICAL ANALYSIS

Intraobserver reliability assessment

The MID intraobserver reliability was performed before beginning the isometric and isokinetic tests.

Nine volunteers without knee injuries were verbally invited to participate in the study. The nine volunteers underwent the full protocol to assess the isometric flexion and extension torque of the knee previously described in this paper. The test protocol was repeated within 24 hours after the end of the first test sequence. The difference from the normal test is that an independent examiner was responsible for kgf data collection; the main examiner was unable to see the results in the first and second test sequence. The interday ICC was calculated between the highest value obtained in the flexor and extension torque between the first and second sequences of tests. To study the intraobserver test-retest reliability of the MID, we used the ICC intraclass correlation coefficient for the interday variation of the measures.

The MID device does not have an interface with a computer and, consequently, with specific software for the calculation of deficits. Therefore, the

isometric torque data were recorded in the volunteers evaluation forms and then calculated using the following equation:

$$\text{Deficit} = \frac{\text{non-dominant side}}{\text{dominant side}} (\times 100) (- 100)$$

GC

$$\text{Deficit} = \frac{\text{injured knee}}{\text{contralateral knee}} (\times 100) (- 100)$$

PTG and FTG

Validity of the MID in the evaluation of muscle performance of the knee extensors and flexors

Analysis of variance (ANOVA) for repeated measures was used to compare the measurements within each group, that is, to compare the same individual within each group performing the isometric test in the MID, the isometric test in the Biodex System 3, the isokinetic test at 60°/s and 180°/s in the Biodex System 3 for the group of the knee extensors and flexors, in order to analyze whether there are differences among the four types of tests.

The second method for analyzing the validity was the calculation of the sensitivity and specificity of the MID to detect significant deficits or deficits within normal parameters. Significant deficits were defined as differences > 15% between the knees and normal deficits were those with values ≤ 15%⁽¹⁹⁾. The sensitivity criterion demonstrates how sensitive a positive test is to detecting disease or, in the present study, significant muscular deficit defined as a > 15% difference between knees⁽²⁰⁾. The specificity criterion shows how specific a negative test is to detecting any disease or, in the present study, deficits in the normal range ≤ 15%⁽²⁰⁾. The MID was compared with the three tests performed in the Biodex System 3 in the isometric and isokinetic mode at the speeds of 60°/s and 180°/s, considering such tests as the gold standard.

Kappa agreement was also calculated between the MID and the three types of strength tests on the Biodex System 3 performed by the three groups of volunteers. The classification of the degree of agreement between the tests was based on the value of Kappa, being: (excellent agreement: > 0.75), (moderate-strong corre-

lation: $r = 0.40$ to 0.75), (poor agreement: < 0.40)⁽²¹⁾. For the analysis of Kappa agreement, the three groups were condensed into just one group of 60 subjects and the MID compared with the isometric Biodex, MID x isokinetic Biodex at 60°/s and MID x isokinetic Biodex at 180°/s. The analysis was performed for both muscle groups (extensors and flexors).

Intergroup comparison of the isometric torque of knee extensors and flexors

Analysis of variance (ANOVA) with the Bonferoni post hoc test with the value of $p < 0.05$ was used for an intergroup comparison for CG, PTG, and FTG for the isometric and isokinetic tests, arthrometry, and the Lysholm questionnaire.

RESULTS

Table 1 shows the characteristics of the three groups in the related items of age, weight, height, flexion and extension ROM, thigh girth, level of sports participation through the Tegner scale⁽¹⁸⁾, time after surgery, and type of rehabilitation used after surgery in the PTG and the FTG. The absence of significant differences in flexion and extension ROM and postoperative ligament laxity can also be observed in Tables 1 and 2, reflecting proper surgical technique in both groups.

In Table 2 we can see the difference between CG, PTG and FTG in relation to ligament laxity and the Lysholm questionnaire. In the evaluation of ligament laxity using the KT 1000, a significantly lower difference in the amount of anterior tibial translation between the knees was observed in the CG compared with PTG and FTG ($p < 0.05$), but in the three groups the average ligament laxity was within normal limits, under 3 mm. There was no significant difference between the PTG and the FTG. In the Lysholm questionnaire used to characterize the sample, both groups showed lower values than the control group, however, the PTG showed significantly lower score compared to the FTG ($p < 0.05$).

Intraobserver test-retest reliability in the MID

The MID has demonstrated excellent intraobserver test-retest reliability in a 24-hour interval, reaching an ICC value of 0.95, 95% CI (0.87 to 0.98) for the extension torque and ICC values of 0.95, 95% (0.87 to 0.98) for the flexor torque (Table 3). A Student's t-test

was also performed to analyze the interday difference of the average of the knee extensor and flexor torque. The results showed no significant interday differences for knee flexor and extensor torque (Table 3).

Table 2 – Intergroup comparison of ligament laxity values between the knees using the KT 1000 and the Lysholm questionnaire using analysis of variance ANOVA with Bonferoni post hoc test ($p < 0.05$).

Test	Control group N = 20	(SD)	PTG N = 20	(SD)	FTG N = 20	(SD)
Lysholm questionnaire	100*	.0	87.4**	12.9	93.8	6.14
KT 1000 (mm)	0.7†	.49	2.94	2.26	2.89	1.98

Legend: CG = control group, PTG = patellar tendon group, FTG = flexor tendons group
 * CG with significantly higher scores than those of the PTG and the FTG ($p < 0.001$)
 ** PTG with significantly lower scores than those of the FTG ($p < 0.001$)
 † CG with values of the difference in anterior tibial translation between knees significantly lower than those of the PTG and the FTG ($p < 0.001$)
 Source: FMRP-USP

Table 3 – Intraobserver reliability test, test-retest ICC for evaluation of interday knee extensor and flexor deficit collected in nine normal subjects (18 knees) with a 24-hour interval in the modified isometric dynamometer (MID).

N	Muscle group	1 st test mean	2 nd test mean	Interday ICC ^{2,1}	95% CI
9 individuals (18 knees)	Extensor	49.7 ± 10.7	49.8 ± 11.6	0.95	(0.87–0.98)
9 individuals (18 knees)	Flexor	18.9 ± 5.41	19.06 ± 5.12	0.95	(0.87–0.98)

Source: FMRP-USP

Intragroup and intergroup comparisons of the extension torque deficit

When the intragroup comparison is made, there were no significant differences in mean extension torque deficits in the four test methods in the CG and the FTG (Table 4). The mean values of the extension torque deficits in the PTG were significantly higher in the isometric test performed in the MID and the isokinetic test at 60°/s in the Biodex System 3, compared with isometric test and isokinetic test at 180°/s, both performed in the Biodex System 3 ($p < 0.001$) (Table 4).

When the intergroup comparison is made, the values of the deficit in extension torque were significantly lower in the CG in the four types of tests compared with the PTG and the FTG ($p < 0.001$) (Table 4).

The FTG showed significantly lower extension torque deficits compared with the PTG in the isometric

test performed in the MID and in the isokinetic test at 60°/s using the Biodex System 3 ($p < 0.001$), with no differences observed between the PTG and the FTG in the isometric test and isokinetic test at 180°/s, both performed in the Biodex System 3 (Table 4).

Table 4 – Intergroup comparison of extensor and flexor torque deficits collected in the modified isometric dynamometer (MID), isometric Biodex, isokinetic at 60°/s and 180°/s. ANOVA with Bonferroni post hoc test.

Test	CG N = 20	(SD)	PTG N = 20	(SD)	FTG N = 20	(SD)
MID (extensors)	6.81*	(4.59)	32.11	(15.24)	18.69**	(18.90)
Isometric Biodex (extensors)	8.15*	(4.63)	25.45	(11.65)	18.23	(15.42)
Isokinetic 60°/s (extensors)	7.71*	(4.21)	32.30	(14.30)	18.70**	(17.79)
Isokinetic 180°/s (extensores)	5.85*	(3.89)	22.63	(10.51)	15.83	(13.26)
MID (flexors)	8.27	(7.27)	-1.42***	(13.96)	8.38	(16.34)
Isometric Biodex (flexors)	6.28	(5.44)	4.64	(9.84)	8.90	(7.25)
Isokinetic 60°/s (flexors)	5.05	(5.13)	4.00	(12.22)	8.99	(10.01)
Isokinetic 180°/s (flexors)	6.09	(3.85)	2.51	(13.49)	7.20	(9.85)

Legend: CG = control group, PTG = patellar tendon group, FTG group = flexor tendons group
* Control group with a significantly lower extensor torque deficit than the PTG and the FTG ($p < 0.001$)

** FTG with a significantly lower extensor torque deficit than the PTG ($p < 0.001$)

*** PTG with a significantly lower flexor torque deficit than the CG and the FTG ($p < 0.001$)

Source: FMRP-USP

Intragroup and intergroup comparisons of the flexion torque deficit

In the intragroup analysis, only the PTG showed significantly lower deficit values in the isometric testing performed in the MID compared with the other test modalities, the Biodex isometric test, the Biodex isokinetic test at 60°/s, and the Biodex isokinetic test at 180°/s ($p < 0.001$) (Table 5). In the intergroup analysis, the PTG demonstrated a significantly lower deficit than that of the CG and the FTG only in the isometric testing performed in the MID, showing negative values, indicating that the average flexor torque developed by the injured limb was higher or overlapped the values of the contralateral healthy limb ($p < 0.001$) (Table 4).

MID sensitivity and specificity in the evaluation of extension torque deficits

In the CG, sensitivity values from 0% to 50% and specificity values between 94.7% and 100% were observed in comparisons of the tests conducted in the MID, using isometric and isokinetic testing at 60°/s and 180°/s performed in the Biodex System 3 as the gold standard (Table 5). In the PTG, sensitivity values of 86.7% to 89.5% and specificity values of 20% to 100% were observed (Table 5). In the FTG, values between 66.7% and 88.9% sensitivity and 54.6% to 72.7% specificity were detected (Table 5).

MID sensitivity and specificity in the evaluation of flexion torque deficits

In the CG, values of 0% sensitivity and 84.2% to 85% specificity were observed when comparing the test conducted in the MID, using the isometric test

Table 5 – The sensitivity and specificity of the modified isometric dynamometer (MID) in detecting subjects in the control group (CG), patellar tendon group (PTG), and flexor tendons group (FTG) with significant deficits > 15% or without < 15% of the knee flexor and extensor torque using the isometric test and isokinetic test performed in Biodex System 3 as the gold standard.

Test	Sensitivity	95% CI	Specificity	95% CI
MID x BIET (CG)	50%	(1.3-98.7%)	100%	(81.5-98.7%)
MID x B60ET (CG)	0%	(0.0-97.5%)	95%	(74-97.5%)
MID x B180ET (CG)	0%	(0.0-97.5%)	94.7%	(74-99.9%)
MID x BIET (PTG)	88.9%	(65.3-98.6%)	50%	(1.3-98.7%)
MID x B60ET (PTG)	89.5%	(66.9-98.7%)	100%	(2.5-100%)
MID x B180ET (PTG)	86.7%	(59.6-98.3%)	20%	(1.0-71.7%)
MID x BIET (FTG)	88.9%	(51.7-99.7%)	72.7%	(39.1-94%)
MID x B60ET (FTG)	77.8%	(40-97.2%)	63.6%	(30.8-89.1%)
MID x B180ET (FTG)	66.7%	(29.9-92.5%)	54.6%	(23.4-83.3%)
MID x BIFLEXT (CG)	0%	(0.0-97.5%)	84.2%	(60.4-96.6%)
MID x B60FLEXT (CG)	0%	(0.0-97.5%)	84.2%	(60.4-96.6%)
MID x B180FLEXT (CG)	0%	(0.0-97.5%)	85%	(60.4-96.6%)
MID x BIFLEXT (PTG)	33%	(1.90.6%)	100%	(80.5-100%)
MID x B60FLEXT (PTG)	50%	(1.3-98.7%)	100%	(81.5-100%)
MID x B180FLEXT (PTG)	50%	(1.3-98.7%)	100%	(81.5-100%)
MID x BIFLEXT (FTG)	66.7%	(9.4-99.2%)	58.8%	(33-81.6%)
MID x B60FLEXT (FTG)	60%	(14.7-94.7%)	60%	(32.2-83.7%)
MID x B180FLEXT (FTG)	83.3%	(35.9-99.6%)	71.4%	(41.9-91.6%)

Legend: MID = modified isometric dynamometer test, BIET = Biodex isometric extensor torque, B60ET = Biodex isokinetic 60°/s extensor torque, B180ET = Biodex isokinetic 180°/s extensor torque, BIFLEXT = Biodex isometric flexor torque, B60FLEXT = Biodex isokinetic 60°/s flexor torque, B180FLEXT = Biodex isokinetic 180°/s flexor torque

Source: FMRP-USP

and isokinetic test at 60°/s and 180°/s performed in the Biodex System 3 as the gold standard (Table 5). Values of 33% to 50% sensitivity and 100% specificity were observed in the PTG group (Table 5). Values between 60% and 83.3% sensitivity and 58.8% to 71.4% specificity were detected in the FTG (Table 5).

Analysis of intertest agreement using the Kappa method for all groups (N = 60).

In the analysis of agreement of the extension torque comparing the MID with the three tests in the Biodex System 3, the Kappa values remained between 0.46 and 0.73, showing moderate to strong agreement (Table 6). When the comparison was made only between the three tests in the Biodex System 3, the Kappa values remained between 0.55 and 0.63, achieving the same classification (Table 6).

In the analysis of agreement between the flexor torque tests, Kappa values remained between 0.17 and 0.48, showing significant agreement in the comparison between isometric MID testing and the isokinetic test at 180°/s (k = 0.48, p < 0.001) (Table 6). When the comparison was made only between the three Biodex System 3 tests, the Kappa values remained between 0.42 and 0.56, showing moderate to strong agreement (Table 6).

Table 6 – Analysis of intertest agreement using the Kappa method for the flexor and extensor torque deficits of all groups (N = 60).

Test	Kappa	p	95% CI
MID x Biodex iso (extensors)	0.73	< 0.001	(0.48-0.98)
MID x Biodex 60°/s (extensors)	0.70	< 0.001	(0.44-0.95)
MID x Biodex 180°/s (extensors)	0.46	< 0.001	(0.21-0.71)
<i>Biodex iso x Biodex 60°/s (extensors)</i>	0.63	< 0.001	(0.38-0.88)
<i>Biodex iso x Biodex 180°/s (extensors)</i>	0.56	< 0.001	(0.31- 0.81)
<i>Biodex 60°/s x Biodex 180°/s (extensors)</i>	0.55	< 0.001	(0.30-0.81)
MID x Biodex iso (flexors)	0.25	0.037	(0.01-0.50)
MID x Biodex iso (flexors)	0.25	0.037	(0.01-0.50)
MID x Biodex 60°/s (flexors)	0.17	< 0.148	(-0.06-0.41)
MID x Biodex 180°/s (flexors)	0.48	< 0.001	(0.24-0.72)
<i>Biodex iso x Biodex 60°/s (flexors)</i>	0.46	< 0.001	(0.21-0.71)
<i>Biodex iso x Biodex 180°/s (flexors)</i>	0.56	< 0.001	(0.31-0.82)
<i>Biodex 60°/s x Biodex 180°/s (flexors)</i>	0.42	= 0.001	(0.17-0.67)

Legend: MID = modified isometric dynamometer – Biodex iso = isometric testing performed on the Biodex System 3 dynamometer – Biodex 60°/s = isokinetic test performed at 60°/s in the Biodex System 3 dynamometer – Biodex 180°/s = isokinetic test performed at 180°/s in the Biodex System 3 dynamometer

Source: FMRP-USP

DISCUSSION

The first objective of this study was to analyze the intraobserver test-retest reliability of the MID. The results showed excellent intraobserver reliability in the assessment of knee extension and flexion torque in healthy subjects with an ICC of 0.95 for the knee extensors and flexors.

These intraclass correlation coefficient values are very similar to those of studies using different dynamometers to assess muscle performance in different joints and individuals⁽⁸⁻¹⁰⁾.

Another objective was to directly examine whether the deficit data collected in the MID equipment would be similar to the deficits found in the Biodex System 3 operating in the isometric and isokinetic mode. To do so, sensitivity and specificity tests were used and agreement between measures was calculated using the Kappa coefficient. These methods were used due to their frequent use in epidemiology, mainly for testing methods and diagnostic techniques^(20,21). With the main objective of using isometric and isokinetic dynamometers to quantify and define imbalances and abnormalities of the musculoskeletal system, it would be ideal to investigate the agreement between two devices to provide similar data.

The results showed that the MID demonstrated good to high specificity in the evaluation of the knee extensors and flexors in the CG compared with the isometric test and isokinetic test in the Biodex System 3, with high specificity in the evaluation of the knee extensors and flexors compared with the isokinetic test at 60°/s. In the PTG, the MID showed moderate specificity values in the evaluation of the knee extensors and flexors, however, it showed good sensitivity in the evaluation of the knee extensor in the PTG. In the FTG, good sensitivity was observed in the evaluation of extensors compared with isometric testing with the Biodex System 3; there was moderate sensitivity in comparison with the other tests, with values between 66.7% and 77.8%. In the assessment of the knee flexor in the FTG, the MID demonstrated good sensitivity when compared with isokinetic testing at 180°/s. In comparison with the other tests, the sensitivity values were moderate, between 60% and 67%. Studies that compared the two methods of measuring muscle deficits using the sensitivity and specificity criteria were not found in the literature.

In evaluating the Kappa agreement coefficient,

moderate to strong agreement values were demonstrated ($k = 0.43$ to 0.73 , $p < 0.001$) between the MID and the isometric and isokinetic tests performed in the Biodex System 3 to evaluate extension torque.

These agreement values are similar to those found by Martin et al. ($k = 0.69$, $p < 0.001$), who used the Kappa coefficient to compare manual digital dynamometer and the Biodex System 3 using only isometric contractions in elderly subjects⁽¹³⁾.

In the evaluation of the flexor torque, the Kappa index of agreement showed moderate to strong values only in the comparison of the MID with isokinetic testing at $180^\circ/s$ and poor agreement when the MID was compared with the Biodex System 3 isometric and isokinetic tests.

Some authors believe that the Kappa coefficient does not always show a fair result, because it presents low values even if there is high correlation between trials^(21,22).

Björklund et al. studied the agreement in the performance assessment of knee injuries in athletes between two physical therapists. In one of the tests, the Kappa coefficient showed moderate-strong consistency of agreement ($k = 0.54$), although the agreement between the two therapists was 85%⁽²²⁾. In this study, we observed the same behavior in the evaluation of flexor torque in the FTG, comparing the MID with isometric test and isokinetic test at $60^\circ/s$ in the Biodex; Kappa values were low (0.17 to 0.25), but the two devices equally rated the presence or absence of deficits in 76% and 78% of 60 individuals, respectively.

In the intergroup analysis, greater extension torque deficits were found in the PTG compared to the FTG on all four tests; however, the p-value was statistically significant in only two tests: the isometric MID (32.11 ± 15.24) and the isokinetic at $60^\circ/s$ (32.30 ± 14.30). These results are similar to those of studies that demonstrated greater extension torque deficits in patients with a patellar tendon graft^(23,24). The mean values of the deficits found in the PTG and the FTG are similar to those found in studies that analyzed the extension torque deficits six to seven months after surgery, with mean deficit values between 24.6% and 37% for patellar tendon graft techniques and between 21.6% and 26% for flexor tendons graft techniques^(25,26).

It can be observed in the analysis of intergroup flexor torque that, in general, the FTG showed mean deficits greater than that of the PTG in all four tests; however, the p value was statistically significant only

in the test performed in the MID (8.38 ± 16.34 vs. -1.42 ± 13.96 , respectively). The mean values of deficits found in the PTG and the FTG are similar to those of studies that examined the flexor torque deficits in the postoperative period, with an average deficit between -1 and 6% for patellar tendon graft techniques and between 3% and 10% for flexor tendons graft techniques⁽²⁶⁻²⁸⁾. There were no differences between the CG and the FTG on all tests.

When we look at the FTG in more detail, 45% (9/20) of the subjects in the FTG showed significant deficits ($> 15\%$) in the test conducted in the MID. When the test was performed on the Biodex System 3 dynamometer in the isometric mode and isokinetic mode at $60^\circ/s$ and $180^\circ/s$, the percentage of individuals with significant deficits is reduced to 15% (3/20), 20% (4/20), and 25% (5/20), respectively. These findings demonstrate that the analysis of the flexor torque in the prone position can more intensely challenge the individual and that deficits may be more evident.

The variations in the evaluation of flexor torque in the FTG found in the study can be related to the positioning of volunteers. As can be seen in Figure 2b, volunteers are placed in the prone position and stabilized at the level of the pelvic girdle to assess the knee flexor group in the MID.

In the isokinetic dynamometer, subjects are placed in a seated position with chest and pelvic stabilization. A correction for gravity is performed to measure the final torque values (Figure 2c). In the MID there is no correction for gravity for the data collected. To achieve maximal isometric contraction, the volunteers make the contraction against gravity and against the weight of the lever arm (Figure 2c). In the Biodex System 3, the direction of the isokinetic or isometric tension is in the same direction as gravity, so the values may vary between modalities and equipment even if the angle for the positioning of the knee at 30° for the isometric flexion torque test is standardized. Variations of the values collected are not restricted only to the MID; in the tests performed only in the Biodex System 3, especially the collection of the flexor torque data, the values of agreement provided by the Kappa coefficient are between 0.42 and 0.56, that is, moderate to strong agreement values (Table 1). The agreement between the deficits found between the two isokinetic speeds, $60^\circ/s$ and $180^\circ/s$, was moderate to strong ($k = 0.42$, $p < 0.001$), but less than the values of

agreement found between the MID and the isokinetic test at 180°/s ($k = 0.48$, $p < 0.001$). These results are consistent with studies that investigated the reliability of isokinetic dynamometers that observed excellent test-retest reliability for peak torque assessment performed on the same equipment⁽²⁹⁾, but with variability occurring even in comparisons between two isokinetic dynamometers from different manufacturers⁽³⁰⁾.

In the evaluation of ligament laxity between groups, the CG showed lower differences in laxity between knees compared with the FTG and the PTG; however the average values of both groups were within normal limits (3 mm)⁽³¹⁾. In the evaluation using the Lysholm scale, the mean scores of the PTG and the FTG were within a range of values similar to those found by other studies, ranging between 85 and 95 points for the patellar tendon graft and between 86 and 92 for the flexor tendons graft^(32,33).

As the present study aimed to assess the validity of the MID within the three groups of subjects, conclusions about the differences between the types of surgical techniques related to muscle performance are limited due to the retrospective format of the study.

The MID was designed because of the difficulty of accessing computerized isokinetic dynamometers. The adaptation of load cells or analog dynamometers in weight lifting equipment used in this study may be a low-cost alternative for assessing muscle deficits in the lower limbs, especially in the knee joint, as long as the evaluators follow strict protocols for data collection. All of the criteria related to techniques for the accurate assessment of muscle strength and power recommended by the American Society of Sports Physiology were followed in this study to analyze the reliability and validity of the MID, including standardization of warm-ups, familiarization, joint angle, duration of contractions, verbal commands, rest interval, number of repetitions, positioning, and stabilization of the volunteer⁽³⁴⁾.

This study demonstrated that despite the biomechanical differences between isometric and isokinetic tests, both can provide similar values of muscle strength deficits.

Sapega defines muscle strength as the ability to generate active muscle tension, independent of the specific condition in which this tension is being measured (slow or rapid contraction, contractions in a state of shortening or lengthening); he concludes that no special testing mode (isometric, isotonic, or isokinetic) is considered the best or most valid for measuring muscle strength⁽³⁵⁾.

Sapega's assertion reflects, in a sense, the abandonment of isometric tests in the 1970s due to the creation and consequently large-scale use of isokinetic dynamometers in the U.S.⁽³⁵⁾. Recently there has been a great increase in studies once again using isometric tests for the evaluation of the knee in different groups of patients, diseases, and interventions^(36,37). However, all these studies have used the isometric mode on the isokinetic equipment, which continues to make it an expensive and inaccessible option.

CONCLUSIONS

This study therefore demonstrated that adapting an analog isometric dynamometer by connecting it to a weight lifting equipment is easy to reproduce, with the possibility of obtaining data with high intraobserver test-retest reliability and considerable validity in the detection of muscle deficits in healthy subjects and individuals who underwent ACL reconstruction. The variability found between isometric tests was smaller than that found with isokinetic tests in the evaluation of the knee extension torque. The evaluation of isometric flexion torque in the prone position may reveal higher flexor torque deficits than the sitting position.

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