Feasibility of Three-Speed Isokinetic Knee Testing Protocol

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ABSTRACT

Objectives: Develop a protocol to assess isokinetic concentric knee flexion and extension testing at three different velocities.

Methods: Ten subjects were each assessed on two test days by two clinicians. Clinicians followed a protocol developed to ensure consistency in subject set-up on the isokinetic dynamometer. Knee flexion and extension were assessed at three different velocities. Average peak torque, angle of peak torque, and total work for both the quadriceps and hamstrings muscles were assessed for reliability, via intra-class correlation coefficients (ICC), between testers and between days. Limb symmetry indices (LSIs) were also calculated and compared between testers and between days.

Results: Intra-rater reliability varied; peak torque, for both muscles, had moderate reliability for both clinicians [ICC(3,1) ≥ 0.669 (95% CI: 0.546-0.773)], total work was good to excellent for both clinicians and had the highest reliability values for all variables of interest [ICC(3,1) = 0.813 (95% CI: 0.731-0.877)]. Inter-rater reliability ranged from poor to moderate depending on the variable; total work had the highest reliability for both the quadriceps and the hamstrings, whereas the angle of peak torque had the lowest inter-rater reliability for both muscle groups. Limb symmetry indices for peak torque and total work were not significantly different between clinicians (p=0.72 and p=0.94, respectively).

Conclusion: The findings of this study demonstrated that testers who are trained and familiar with isokinetic dynamometer testing set-up and protocols prior to performing assessments on patients may help to minimize the effect set-up may have on output measurements.

Key terms: lower extremity, dynamometer, flexors, extensors

INTRODUCTION

Isokinetic dynamometry is considered the gold standard for clinical assessment of muscle strength and is used to monitor rehabilitation progress.[1] In particular, clinicians frequently use isokinetic dynamometry testing to assist in return-to-sport after anterior cruciate ligament (ACL) injury decision making.[2–4] Absolute limb strength of both the involved and uninvolved limbs are typically assessed, and is used to determine bilateral deficits. A bilateral strength deficit of 10-15%, or 85-90% limb-symmetry, is one of several requisite criterions a clinician uses to determine if a patient can safely return to sport.[5–7] However, some patients may require several dates of isokinetic testing throughout their rehabilitation to reach a 90% strength limb-symmetry. With such a small observable difference in muscle strength necessary for return-to-sport clearance, isokinetic dynamometry tests must be consistent between testing sessions. Therefore, it is critical to establish a repeatable and reliable isokinetic testing protocol to ensure that differences observed between limbs and between test dates are reflective of a patient's true rehabilitation progress, not due to error (tester, machine, joint alignment, measurement, etc.).

Although the importance of isokinetic strength assessment has been noted in return-to-sport readiness after ACLR, a standardized and reliable protocol has yet to be established.[4] To the authors' knowledge, no previous study has investigated three clinically relevant isokinetic velocities, between testers, between sessions, and between sites as part of a single study. Therefore, the purpose of this feasibility study was to develop a reliable protocol to assess isokinetic concentric knee flexion and extension testing at three different velocities for future methods to be utilized with larger clinical studies. It was hypothesized that the protocol would yield excellent reliability for all variables of interest (e.g., peak torque, total work, and angle of peak torque) and no difference in limb symmetry indices between clinicians.

METHODS

The study was approved by the Mayo Clinic Institutional Review Board (IRB 17-001833, Rochester, MN, USA). Informed consents were obtained from each participant. Ten subjects were recruited from a sample of convenience. Subjects were included if they were recreationally active a minimum three times per week for sixty minutes. Subjects were excluded (1) if they had a history of lower extremity musculoskeletal injury within two years, (2) if they were taking any medication or supplements known to affect performance, or (3) if they had a reported medical condition that could affect strength (e.g., acute infection, neurological, or cardiovascular disease). Anthropometric data were measured for each subject (height, weight) prior to testing. Subjects were asked their preferred leg to kick a soccer ball to determine the dominant leg.

Two testers (NDS, CMK) were trained on how to properly execute the protocol prior to the first test date. All tests were performed on two HumacNORM isokinetic dynamometers (CSMi, Stoughton, MA, USA) at two sports medicine clinics.[8] On the two days of testing, one clinician completed the entire protocol with each subject at Mayo Clinic Sports Medicine Center (Rochester, MN). The subject returned in the afternoon and the second clinician repeated the protocol with each subject. Subjects returned to the testing center seven days later and both clinicians re-tested each subject a second time. A subset of subjects (n=5) completed a third day of testing at Mayo Clinic Square Sports Medicine Center (Minneapolis, MN, USA) by one clinician (NDS). The dynamometer was calibrated prior to the start of each test day according to the manufacturer's recommendations.

Subjects were instructed to warm up on a bicycle for five minutes. The first leg tested was randomized for each subject. Subjects were seated in the HumacNORM chair with the posterior of the subject's knee joint two finger widths from the edge of the seat and the chair position set to manufacturer's recommendations. The chair seatback was brought forward to meet the subject's lumbar region. To limit extraneous movement, restraining straps were secured across the subject's trunk, hips, and thigh (**Figure 1A**). The dynamometer height was raised to align with the lateral femoral epicondyle. A custom wooden block, the size of an iPhone 6, was used to ensure constant distance between the knee and dynamometer head for all subjects (**Figure 1B**). The force pad was secured two inches proximal to the medial malleolus, with the ankle aligned in neutral position (**Figure 1C**). Once all components were fastened, the chair and dynamometer rotation were unlocked, and the subject was asked to slowly extend their leg. With leg in full extension, the chair and dynamometer rotations were locked.

Range of motion during testing was set using voluntary maximal full extension (0°) to 100° of knee flexion. Before testing began, the subjects' limb was locked by the machine in a position of minimal knee flexion and subjects were asked to fully relax their leg to determine the passive effects of gravity on the limb. A fixed test sequence was established. Concentric strength of the knee flexors and extensors was tested at three velocities, first 60° per second, then 180° per second, and finally 300° per second. For familiarization with the test protocol, subjects completed four repetitions at each isokinetic velocity prior to the actual test. They were instructed to increase their perceived effort with each repetition (25%, 50%, 75%, 100% effort). The practice set was followed by a ten second rest period before the isokinetic test began. Subjects completed five continuous knee flexion and extension repetitions with maximum effort at 60° per second. Next, subjects completed ten continuous knee flexion and extension repetitions at 180° per second. The final test consisted of fifteen continuous knee flexion and extension repetitions at 300° per second. During all tests, the clinician verbally encouraged the subject to give their maximal effort and subjects were permitted to see the computer monitor for feedback during the test. The setup and testing protocol was repeated on the contralateral leg.

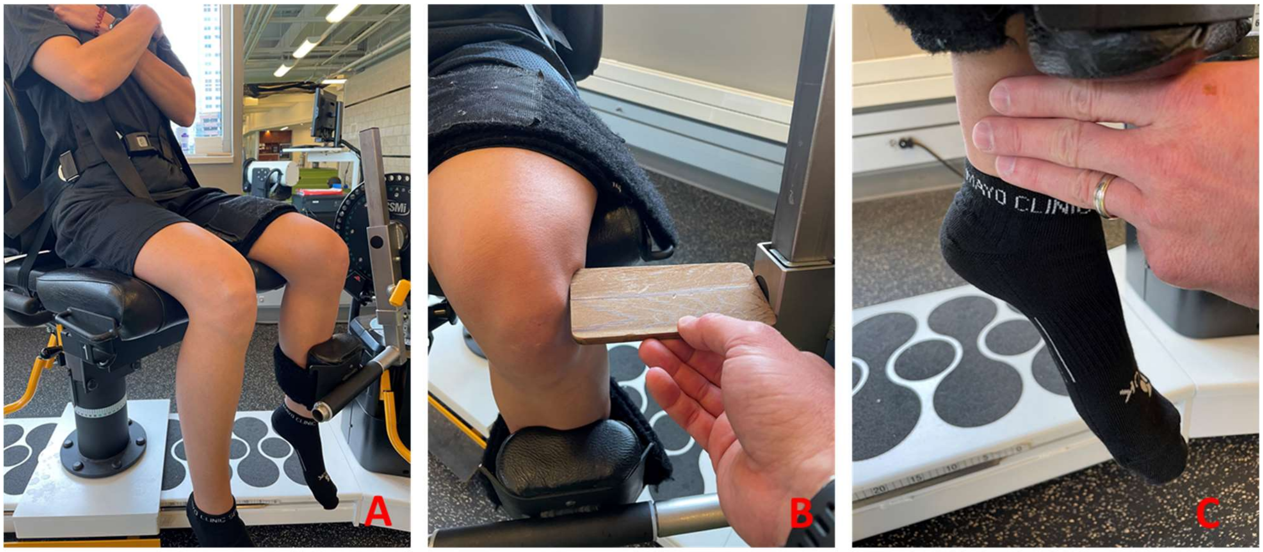

Figure 1: Subject alignment seated on the dynamometer. A) Restraining straps secured across subject's truck, hips, and thigh, B) distance measured between knee joint center and dynamometer head, and C) force pad secured two inches superior to medial malleolus.

Data were processed with a custom LabVIEW graphical user interface to extract variables of interest from the raw data (National Instruments, Austin, TX, USA). Variables of interest included average peak torque, angle of peak torque, and total work for both the quadriceps and hamstrings muscles. Limb symmetry indices were calculated for each peak torque and total work (Dominant / Non-dominant x 100). Statistical analyses were performed in BlueSky Statistics (BlueSky Statistics LLC, Chicago, IL, USA) and JMP 14 Pro (SAS Institute, Cary, NC, USA). Intra-rater, inter-rater (k=2), and inter-site reliability were determined using interclass correlation coefficients (ICC). Intra-rater [ICC(3,1)] and inter-rater [ICC(3,k)] correlations were examined separately for each of the independent variables (peak torque, angle of peak torque, and total work) for each of three velocities.[9–12] Intra-rater reliability was calculated from all repetitions for each velocity for each subject. There were no significant differences between limbs or velocities, therefore, they were combined in each ICC assessment. The average of all repetitions for each subject was used to calculate inter-rater reliability. Values less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 are indicative of poor, moderate, good, and excellent reliability, respectively.[13] Limb symmetry indices were compared using paired t-tests ($p<0.05$).

RESULTS

Ten participants (5M/5F) were recruited for the study (average age 27.4 ± 2.0 years, average height 173.9 ± 11.6 cm, and average weight 73.0 ± 14.5 kg). One subject (F) did not return for the second day of testing, resulting in nine subjects included in analysis for inter-rater and intra-rater reliability.

Intra-rater

Intra-rater reliability varied from poor to moderate and poor to excellent for Clinician 1 and

2, respectively (**Table 1**). Peak torque, for both the quadriceps and the hamstrings, had moderate reliability for both clinicians. Total work for both muscle groups was good to excellent for both clinicians and had the highest reliability values for all variables of interest. Angle of peak torque had poor reliability for both muscle groups and both clinicians, with the exception of moderate reliability for quadriceps as set-up by Clinician 1.

Inter-rater

Inter-rater reliability ranged from poor to moderate for both the quadriceps and hamstrings muscle groups (**Table 2**). Total work had the highest reliability for both the quadriceps [ICC(3,k) = 0.881 (95% CI: 0.836-0.914)] and the hamstrings [ICC(3,k) = 0.872 (95% CI: 0.823-0.907)], whereas the angle of peak torque had the lowest inter-rater reliability for both muscle groups [ICC(3,k) < 0.447 (95% CI: 0.237-0.600)].

Inter-site

For the subset of subjects who completed testing at both sites, reliability for all three variables of interest ranged from moderate to excellent (**Table 3**). Similar to intra-rater and inter-rater reliability, total work had the highest reliability of all three variables and was considered excellent for both the quadriceps and the hamstrings [ICC(3,k) ≥ 0.980 (95% CI: 0.971-0.986)]. Peak torque for both muscle groups was good [ICC(3,k) ≥ 0.852 (95% CI: 0.788-0.897)] and angle of peak torque only had moderate reliability between test sites [ICC(3,k) ≤ 0.713 (95% CI: 0.588-0.800)].

Limb Symmetry Indices

Limb symmetry indices for peak torque and total work were not significantly different between clinicians (p=0.72 and p=0.94, respectively). Moreover, peak torque LSIs both favored the dominant leg (104% and 105% for Clinician 1 and Clinician 2, respectively). Similarly, total work LSIs also both favored the dominant leg (102% for both clinicians).

Table 1. *Intraclass Correlation Coefficients and 95% Confidence Intervals for Each Variable of Interest for Clinician 1 and Clinician 2.*

		Intra-rater ICC(3,1) Clinician 1	Interpretation	F	*P*	Intra-rater ICC(3,1) Clinician 2	Interpretation	F	*P*
Quads	Peak Torque	0.669 (0.546, 0.773)	Moderate	7.064	<0.001	0.717 (0.606, 0.808)	Moderate	8.605	<0.001
	Total Work	0.833 (0.757, 0.890)	Good	15.916	<0.001	0.919 (0.879, 0.948)	Excellent	35.102	<0.001
	Angle of Peak Torque	0.580 (0.439, 0.705)	Moderate	5.136	<0.001	0.392 (0.232, 0.549)	Poor	2.930	<0.001
Hams	Peak Torque	0.725 (0.616, 0.814)	Moderate	8.922	<0.001	0.659 (0.533, 0.765)	Moderate	6.785	<0.001
	Total Work	0.813 (0.731, 0.877)	Good	14.072	<0.001	0.886 (0.831, 0.926)	Good	24.245	<0.001
	Angle of Peak Torque	0.342 (0.181, 0.505)	Poor	2.556	<0.001	0.470 (0.316, 0.616)	Poor	3.660	<0.001

Table 2. *Intraclass Correlation Coefficients and 95% Confidence Intervals for Each Variable of Interest between raters.*

	Inter-rater ICC (3,k)	Interpretation	F	*P*
Peak Torque	0.737 (0.637, 0.810)	Moderate	3.805	<0.001
Total Work	0.881 (0.836, 0.914)	Good	8.425	<0.001
Angle of Peak Torque	0.447 (0.237, 0.600)	Poor	1.809	<0.001
Peak Torque	0.774 (0.688, 0.836)	Good	4.425	<0.001
Total Work	0.872 (0.823, 0.907)	Moderate	7.783	<0.001
Angle of Peak Torque	0.221 (-0.076, 0.435)	Poor	1.283	0.065

Table 3. *Intraclass Correlation Coefficients and 95% Confidence Intervals for Each Variable of Interest for inter-site testing.*

		Inter-Site ICC (3,k)	Interpretation	F	*P*
Quads	Peak Torque	0.852 (0.788, 0.897)	Good	6.776	<0.001
	Total Work	0.983 (0.976, 0.988)	Excellent	60.714	<0.001
	Angle of Peak Torque	0.713 (0.588, 0.800)	Moderate	3.484	<0.001
Hams	Peak Torque	0.857 (0.795, 0.901)	Good	7.005	<0.001
	Total Work	0.980 (0.971, 0.986)	Excellent	49.543	<0.001
	Angle of Peak Torque	0.648 (0.495, 0.755)	Moderate	2.840	<0.001

DISCUSSION

The purpose of this feasibility study was to determine the reliability of an isokinetic knee flexion and extension testing battery in healthy participants. The results of the study partially support the hypothesis. Total work, for both quadriceps and hamstrings muscle groups, had overall the best reliability (intra-rater, inter-rater, and inter-site) of all variables, ranging from moderate to excellent. In addition, LSI values for both peak torque and total work were not significantly different between clinicians. The results of this study suggest that total work is a more reliable measurement of isokinetic dynamometry performance than peak torque and angle of peak torque when a standardized patient set-up and testing battery is used.

Previous studies have investigated the reliability of isokinetic concentric knee flexion and extension at a range of velocities, from 60° per second to 300° per second.[14–16] Despite the same gross motor task, different isokinetic testing velocities elicit different neural recruitment and co-coordination of musculature.[17] Thus, multiple velocities have been used to assess muscle strength in variable testing conditions. Previously reported reliability has ranged from acceptable to excellent, depending on variables reported and study designs.

Similar to the current study, high relative reliability of peak torque and average work was observed for knee flexors and extensors for all velocities when assessed by one tester between three sessions.[15] Intra-machine reliability of the knee flexors and extensors peak torque has been reported from good to excellent.[14] Faster velocity (180°/second vs. 60°/second) was shown to have poorer within-day and between-day reproducibility.[16] In addition, significant bias was observed for peak torque between testing sessions for knee flexors at 180° per second.[16]

The specific testing battery of isokinetic speeds and repetitions utilized in the current study aligns with previously described methodologies. For example, in a study that utilized knee flexion and extension isokinetic dynamometry to assess the likelihood of anterior cruciate ligament (ACL) graft rupture, 60°, 180°, and 300° per second testing velocities were used when testing 150 athletes after ACL reconstruction.[5] In addition, the protocol developed and utilized in the current study aligned with previous investigations that assessed concentric knee flexion and extension at 60° per second in a restricted range of motion from 0° to 100° with a gravity correction applied.[4]

In addition, we have developed a clinician-friendly protocol that reduced set-up time by using standardized distances for alignment (e.g., distance of posterior knee from chair, knee joint center to dynamometer, and force pad from ankle joint center) rather than requiring documentation of chair and dynamometer position settings to replicate for future testing. Exact chair and dynamometer settings and position numbers may not actually be the most important for repeatable and reliable testing, as this study found knee joint alignment resulted in reliable total work measurements. It is important to note that each step in the protocol presented here may be critical; it is unknown how skipping or altering a step would affect the overall set up and subsequent reliability of total work performed during the testing battery. The protocol presented in the current study presents a clinician-friendly strategy to assess knee flexion and extension capabilities at three different velocities to reliably assess total work performed during the test. Utilization of this protocol in future studies of pathological conditions or longitudinal rehabilitation subjects would help to ensure confidence that observed changes may be associated with clinical changes rather than noise associated with altered set-up or position in the dynamometer itself during isokinetic testing.

It is interesting to note that we anecdotally noticed both testers become more efficient in their subject alignment as testing progressed, which indicates there was a learning effect of the protocol even though they were both trained clinicians who had previously used the HumacNORM. This suggests that for future testing, testers should practice subject set-up prior to data collection to gain confidence and experience in properly setting up a patient to collect the most accurate data. This is particularly interesting since both testers were clinicians who were previously familiar with HumacNORM testing. It is unknown how new users of the HumacNORM would affect reliability of the total work measurement.

As a feasibility study to assess the developed protocol, no *a priori* power analysis was performed. Therefore, analysis and interpretation of the ICC values presented herein is limited due to the small sample size that was used to explore if a larger reliability study is warranted with a larger, properly powered sample size. Finally, the sample in this feasibility study consisted of healthy participants, whereas the target population of isokinetic measurement is typically a clinical population. Therefore, determining reliability in larger future studies that include symptomatic or clinical subjects is warranted to further understand the reliability of the testing protocol.

CONCLUSION

In conclusion, we recommend that testers are trained and familiar with isokinetic dynamometer testing set-up and protocols prior to performing assessments on patients and athletes to minimize the effect the set-up may have on output measurements. We have demonstrated a reliable knee flexion and extension isokinetic testing protocol that warrants larger studies and that may one day be used in return-to-sport isokinetic testing, which is a particularly important component of the multifactorial assessment of function and recovery after ACLR for return to sport decision making. In addition, this protocol could be used to help monitor progress throughout rehabilitation at time points of interest (e.g. 6-month post-ACLR, 9-month, 12-month).

LIMITATIONS

A small sample of convenience was used (n=9 for analysis) and said analysis should be viewed with caution if applied for a clinical purpose. Furthermore, it is possible that highly-trained athletes or injured athletes in recovery may have more advanced strategies and repeatable muscle power output, and thus could result in additional variables having improved reliability.

COMPETING INTERESTS

The authors declare they have no competing interests.

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REFERENCES

1. Stark T, Walker B, Phillips JK, Fejer R, Beck R. Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: A systematic review. *PM R*. 2011;3(5):472-479. doi:10.1016/j.pmrj.2010.10.025

2. Kyritsis P, Bahr R, Landreau P, Miladi R, Witvrouw E. Likelihood of ACL graft rupture: not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. *Br J Sports Med*. 2016;50(15):946-951. doi:10.1136/bjsports-2015-095908

3. Dingenen B, Gokeler A. Optimization of the Return-to-Sport Paradigm After Anterior Cruciate Ligament Reconstruction: A Critical Step Back to Move Forward. *Sport Med*. 2017:1-14. doi:10.1007/s40279-017-0674-6

4. Undheim MB, Cosgrave C, King E, et al. Isokinetic muscle strength and readiness to return to sport following anterior cruciate ligament reconstruction: Is there an association? A systematic review and a protocol recommendation. *Br J Sports Med*. 2015;49(20):1305-1310. doi:10.1136/bjsports-2014-093962

5. Kyritsis P, Bahr R, Landreau P, Miladi R, Witvrouw E. Likelihood of ACL graft rupture: not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. *Br J Sports Med*. 2016:bjsports-2015-095908. doi:10.1136/bjsports-2015-095908

6. Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study. *Br J Sports Med*. 2016;50(13):804-808. doi:10.1136/bjsports-2016-096031

7. Neeter C, Gustavsson A, Thomeé P, Augustsson J, Thomeé R, Karlsson J. Development of a strength test battery for evaluating leg muscle power after anterior cruciate ligament injury and reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2006;14(6):571-580. doi:10.1007/s00167-006-0040-y

8. de Araujo Ribeiro Alvares JB, Rodrigues R, de Azevedo Franke R, et al. Inter-machine reliability of the Biodex and Cybex isokinetic dynamometers for knee flexor/extensor isometric, concentric and eccentric tests. *Phys Ther Sport*. 2015;16(1):59-65. doi:10.1016/j.ptsp.2014.04.004

9. Landis JR, Koch GG. The Measurement of Observer Agreement for Categorical Data. *Biometrics*. 1977;33(1):159. doi:10.2307/2529310

10. Shrout PE, Fleiss JL. Intraclass correlations: Uses in assessing rater reliability. *Psychol Bull*. 1979;86(2):420-428. doi:10.1037/0033-2909.86.2.420

11. McGraw KO, Wong SP. Forming inferences about some intraclass correlation coefficients. *Psychol Methods*. 1996;1(1):30-46.

12. Fleiss JL. The Design and Analysis of Clinical Experiments. Vol 1. New York: Wiley; 1986. doi:10.1002/9781118032923

13. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J Chiropr Med*. 2016;15(2):155-163. doi:10.1016/j.jcm.2016.02.012

14. Habets B, Staal JB, Tijssen M, Van Cingel R. Intrarater reliability of the Humac NORM isokinetic dynamometer for strength measurements of the knee and shoulder muscles. *BMC Res Notes*. 2018;11(1):15. doi:10.1186/s13104-018-3128-9

15. Impellizzeri FM, Bizzini M, Rampinini E, Cereda F, Maffiuletti NA. Reliability of isokinetic strength imbalance ratios measured using the Cybex NORM dynamometer. *Clin Physiol Funct Imaging*. 2008;28(2):113-119. doi:10.1111/j.1475-097X.2007.00786.x

16. Blacker SD, Fallowfield JL, Bilzon JLJ, Willems MET. Within-day and between-days reproducibility of isokinetic parameters of knee, trunk and shoulder movements. *Isokinet Exerc Sci*. 2010;18(1):45-55. doi:10.3233/IES-2010-0367

17. Knapik J, Ramos M. Isokinetic and isometric torque relationships in the human body. *Arch Phys Med Rehabil*. 1980;61(2):64-67.