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Associations of isokinetic and isotonic knee strength with knee function and activity level after anterior cruciate ligament reconstruction: a prospective cohort study

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ABSTRACT

Background: Although isokinetic dynamometry often serves as a reference to assess the concurrent validity of weight-machine isotonic strength testing, it is unknown whether isokinetic knee strength is associated with knee function and activity level more strongly than isotonic knee strength in patients with an anterior cruciate ligament reconstruction (ACLR). This study aimed to compare the associations of isokinetic and isotonic knee strength with knee function and work-and-sports activity levels in patients with ACLR.

Methods: One-hundred and six patients with a unilateral ACLR participated. At three months post-ACLR, isokinetic quadriceps and hamstrings strength was measured using an isokinetic dynamometer whilst isotonic strength was measured using weight machines. At six months post-ACLR, patients performed the single-leg hop-for-distance test. Self reported knee function and work-and-sports activity levels were assessed by the Lysholm Knee Score and Tegner Activity Score, respectively.

Results: In multivariable analyses, isotonic and isokinetic quadriceps strength limb symmetry indices (LSIs) were significantly associated with all outcomes ($P \leq 0.03$) and had comparable predictive performance. Isotonic and isokinetic hamstrings strength LSIs were significantly associated with Lysholm scores ($P \leq 0.03$) and isotonic hamstrings strength was additionally significantly associated with hop-for-distance LSI ($P = 0.01$).

Conclusions: Weight machine-derived isotonic quadriceps strength was independently and consistently associated with knee function and work-and-sport activity level post-ACLR. Isokinetic knee strength was not more strongly associated than isotonic knee strength with the various outcomes. These findings have logistic and economic implications because the isokinetic dynamometer system is relatively expensive and its operation requires more logistic effort and technical skills.

1. Introduction

In patients with an anterior cruciate ligament reconstruction (ACLR), weakness of the knee muscles is a risk factor for reduced knee function and sports activity level [1]. Although isokinetic dynamometry is considered the gold standard for muscle strength assessment in ACLR [1], the isokinetic dynamometer system is relatively expensive and its operation requires time and technical skills. Indeed, the impracticality of isokinetic testing in many clinical settings has been acknowledged and has even motivated research into self-report screening tools for isokinetic quadriceps weakness [2]. Among the alternatives to isokinetic dynamometry, isotonic

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knee strength measured using conventional weight machines has been shown to be reliable and closely correlated with isokinetic strength in people with [3] and without [4,5] ACLR. Although isokinetic dynamometry often serves as a reference to assess the concurrent validity of weight-machine isotonic testing, it is unknown whether isokinetic knee strength was associated with future knee function and activity level more strongly than isotonic knee strength in patients with ACLR. And given the increasing need to remove healthcare resources from less cost-effective technologies [6,7], a head-to-head comparison of the two assessment methods takes on even greater relevance.

Thus, our study aimed to compare, in patients with ACLR, the prospective associations of isokinetic and isotonic knee strength with knee function and work-and-sports activity level.

2. Methods

2.1. Patients

Our study cohort comprised patients from an ongoing longitudinal study that aimed to identify risk factors for knee disability after an ACLR. Between October 2014 and March 2016, we identified 265 patients who were at least moderately active before anterior cruciate ligament (ACL) rupture (Tegner activity level [8] 5 and above) and who underwent a primary ACLR and postoperative outpatient physiotherapy at a major metropolitan hospital. All patients were scheduled for evaluation within a month preoperatively and approximately three and six months postoperatively, and we selected a cohort of 106 patients who had no missing month-3 knee strength (isokinetic or isotonic strength) and month-6 outcome measures (hop distance or self-report measures). Included patients were similar to those who were excluded because of missing data (data not shown). The institutional review board approved the study.

2.2. Knee strength

At three months after ACLR, all patients underwent isokinetic dynamometry testing and isotonic strength testing on two occasions, separated by two to five days. Concentric isokinetic strength of the quadriceps and hamstrings was measured using a Biodex System 4 isokinetic dynamometer (Shirley, NY, USA). With the patients seated, the gravity compensation procedure was performed by measuring the patient's passive limb weight at 30° of knee flexion. Following three submaximal warm-up repetitions, all patients performed seven consecutive maximal-effort extension and flexion repetitions. Among these repetitions, isokinetic quadriceps and hamstrings strength represented the highest torque achieved by the respective muscle groups. Strong verbal encouragement was given during testing. To allow patients to gain confidence with the testing protocol, we tested the contralateral knee before the operated knee. Our isokinetic protocol used an angular velocity of 60°/s [1] and the range-of-motion was set from 90° to 40° of knee flexion. Of note, this testing range-of-motion was chosen because terminal knee extension was reportedly associated with substantial shear forces transmitted to the ACL graft [9,10]. Although we did not have reliability data for our isokinetic protocol, one previous study [11] has reported good test–retest reliability for the isokinetic quadriceps strength (intraclass correlation coefficient, 0.80; coefficient of variation, 18%) and isokinetic hamstrings strength (intraclass correlation coefficient, 0.74; coefficient of variation, 17%) measures.

Concentric isotonic strength of the quadriceps and hamstrings was measured using a Cybex (Medway, USA) seated knee extension machine and a Cybex prone leg curl machine, respectively. Isotonic knee strength was determined using the one repetition maximum test, which is the maximum load (measured in pounds) the patient could lift once in good form [5]. Submaximal warm-up trials were given and they comprised three repetitions of bilateral knee extensions at <30 lb. Consistent with the isokinetic protocol, the contralateral knee was tested before the operated knee. Identification of the one repetition maximum strength of the involved knee began with a load at ~75% of the contralateral knee strength. For the isotonic quadriceps strength test, the range-of-motion was set from 90° to 40° of knee flexion; and from 0° to 90° for the isotonic hamstrings strength test. Thirty-second rest periods were given between trials, and most patients reached their one repetition maximum load between the fourth and fifth trials. Although we did not have reliability data for our isotonic protocol, previous studies have reported good test–retest reliability for the isotonic quadriceps strength [12] (intraclass correlation coefficient, 0.97; coefficient of variation, 17%) and isotonic hamstrings strength [13] (intraclass correlation coefficient >0.95) measures.

2.3. Outcomes

Trained technicians and physical therapists, who were unaware of the strength test results, assessed patients' hop performance and self-report knee function and work-and-sports activity level at six months after ACLR. Hop performance was assessed by the single-leg hop for distance test [14]. Patients stood on one leg and hopped maximally for distance. All tests were performed on the non-operated side followed by the operated side. Each patient performed two submaximal practice trials followed by three test trials, and the highest measurement was analyzed. Self-report knee function and work-and-sports activity level were assessed by the Lysholm Knee Scoring Scale [15] and Tegner Activity Score [8], respectively.

We used means with standard deviations (SDs) and medians with interquartile ranges (IQRs) for continuous variables and frequencies with percentages for categorical variables. A limb symmetry index (LSI) was calculated for the knee strength (isokinetic and isotonic) and hop-for-distance tests based on maximum load, peak torque, or hop distance ([involved limb / uninvolved limb] $\times$ 100%). Correlations between the various strength measurements were estimated using Spearman's rank correlation.

2.4. Statistical analysis

We used separate multivariable proportional odds regression [16] models to evaluate the associations of the various strength LSI measures with hop distance LSI, Lysholm scores, and Tegner scores, adjusting for age, sex, body mass index, pre-ACLR Lysholm scores, and pre-injury Tegner scores. Of note, we used proportional odds regression because no suitable transformation achieved normality of residuals required for ordinary least-squares regression [16]. To facilitate the interpretation and comparison of the regression results, we computed the adjusted odds ratios (ORs) comparing the 75th (3rd quartile) and 25th percentile (1st quartile) strength LSI values. These IQR-ORs represented a more clinically meaningful distinction than the conventional single-unit (one percent point) change in LSI values [16]. To avoid assuming linearity, all continuous predictors were modeled as restricted cubic splines [16,17] unless there was insufficient evidence against the linearity (null) assumption ($P > 0.20$). We assessed the appropriateness of all models using residual plots. In addition, we checked for interactions between sex and strength measures and found no statistically significant effect modification. $P < 0.05$ was considered statistically significant, and all analyses were performed using *R* software, version 3.3.2 (http://www.r-project.org).

3. Results

Table 1 shows the patients' characteristics. The sample comprised patients (mean (SD) age, 27 (eight) years) who were predominantly male (n = 83, 78%) and 75 patients (71%) participated in competitive sports (Tegner activity level 7 and above) before ACL rupture. Mean knee pain rating was low during isokinetic and isotonic knee testing (≤0.3 points and ≤1.2 points, respectively). Absolute knee strength measurements showed high pairwise correlations: the Spearman correlation coefficient between isokinetic and isotonic quadriceps strength was 0.91; between isokinetic and isotonic hamstrings strength, 0.80. Knee strength LSI measurements showed moderate pairwise correlations: the Spearman correlation coefficient between isokinetic and isotonic quadriceps strength LSI was 0.63; between isokinetic and isotonic hamstrings strength LSI was 0.58.

At six months post-ACLR, Lysholm scores increased significantly from preoperative levels (66 ± 18 preoperatively versus 89 ± 11 postoperatively, $P < 0.001$) and Tegner activity level scores decreased significantly from pre-injury levels (7.0 ± 1.3 at pre-injury versus 4.5 ± 1.4 postoperatively, $P < 0.001$). As shown in Table 2 and Figures 1–3, after adjusting for age, sex, body mass index, pre-ACLR Lysholm scores, and pre-injury Tegner scores, both isotonic and isokinetic quadriceps strength LSIs were consistently associated with hop distance LSI ($P \leq 0.01$), Lysholm scores ($P \leq 0.03$), and Tegner scores ($P \leq 0.02$). The odds ratios for isotonic quadriceps strength LSI (ORs, 1.96–3.02) were comparable or higher than those for isokinetic quadriceps strength LSI (ORs, 1.57–2.10). Both

Table 1
Demographic and clinical characteristics of patients.

Characteristics	All patients (n = 106)
Demographics	
Age (years)	20 **24** 31 (26 ± 8)
Men	78% (83)
BMI (kg/m^2)	21.8 **23.8** 26.2 (24.2 ± 3.4)
Concomitant meniscal injury	50% (53)
Bone–patellar–bone ACL graft	7% (7)
Preoperative Lysholm score	57 **68** 79 (66 ± 18)
Pre-injury Tegner score	6.0 **7.0** 7.0 (7.0 ± 1.3)
Postoperative (month-3) measures	
Isokinetic quadriceps strength (Nm)	133 **159** 199 (162 ± 49)
Isokinetic quadriceps strength LSI (%)	73 **77** 85 (78 ± 12)
Isokinetic quads-test pain	0 **0** 0 (0.31 ± 1.09)
Isotonic quadriceps strength (lb)	80 **100** 125 (102 ± 35)
Isotonic quadriceps strength (kg)	36 **45** 57 (46 ± 16)
Isotonic quadriceps strength LSI (%)	69 **75** 85 (76 ± 13)
Isotonic quads-test pain	0 **0** 1.00 (0.83 ± 1.49)
Isokinetic hamstrings strength (Nm)	69 **84** 100 (85 ± 22)
Isokinetic hamstrings strength LSI (%)	78 **85** 92 (86 ± 11)
Isokinetic hams-test pain	0 **0** 0 (0.11 ± 0.61)
Isotonic hamstrings strength (lb)	40 **50** 60 (53 ± 19)
Isotonic hamstrings strength (kg)	18 **23** 27 (24 ± 8.6)
Isotonic hamstrings strength LSI (%)	70 **80** 92 (80 ± 17)
Isotonic hams-test pain	0 **0** 2 (1.2 ± 1.8)
Postoperative (month-6) measures	
Hop distance (cm)	96 **116** 152 (111 ± 55)
Hop distance LSI (%)	66 **77** 93 (72 ± 31)
Lysholm score	84 **91** 99 (89 ± 11)
Tegner score	3.0 **4.0** 5.5 (4.5 ± 1.4)

Continuous variables are summarized as 25th **50th** 75th percentiles (mean ± SD). Categorical variables are summarized as percentages and frequencies (n). Scores on the Tegner range from 0 to 10, with higher scores indicating greater work-and-sports activity level. Scores on the Lysholm range from 0 to 100, with higher scores indicating greater knee function. ACL, anterior cruciate ligament; BMI, body mass index; LSI, limb symmetry index.

Table 2
Associations of isokinetic and isotonic knee strength with knee function and work-and-sports activity level.[a]

	Percentile		Hop distance LSI		Lysholm score		Tegner level	
	25th	75th	OR (95% CI)[b]	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Quadriceps								
Isotonic strength LSI	68.9	85.0	3.02 (1.59–5.74)	<0.01	1.69 (1.06–2.72)	0.03	1.96 (1.18–3.25)	<0.01
Isokinetic strength LSI	72.5	84.6	2.10 (1.18–3.73)	0.01	1.57 (1.07–2.29)	0.02	1.68 (1.10–2.56)	0.02
Hamstrings								
Isotonic strength LSI	69.8	92.1	2.08 (1.18–3.64)	0.01	1.77 (1.06–2.94)	0.03	1.41 (0.86–2.32)	0.17
Isokinetic strength LSI	78.2	92.4	1.71 (0.95–3.11)	0.08	1.94 (1.14–3.31)	0.03	1.12 (0.67–1.87)	0.66

[a] Results shown are from proportional odds regression models predicting week-24 hop distance limb symmetry index (LSI), Lysholm knee scores, and Tegner activity levels. All analyses were adjusted for age, sex, body mass index, pre-anterior cruciate ligament reconstruction Lysholm scores, and pre-injury Tegner activity levels.
[b] Odds ratios (ORs) estimate the odds of better functional knee outcomes at the 75th vs. the 25th percentile values of each strength measure. For example, other variables being equal, patients with an isotonic quadriceps LSI of 85% (75th percentile) had, on average, 3.0 times (95% CI, 1.6–5.7 times) the odds of having greater hop distance LSI relative to patients with a quadriceps LSI of 69% (25th percentile). CI, confidence interval.

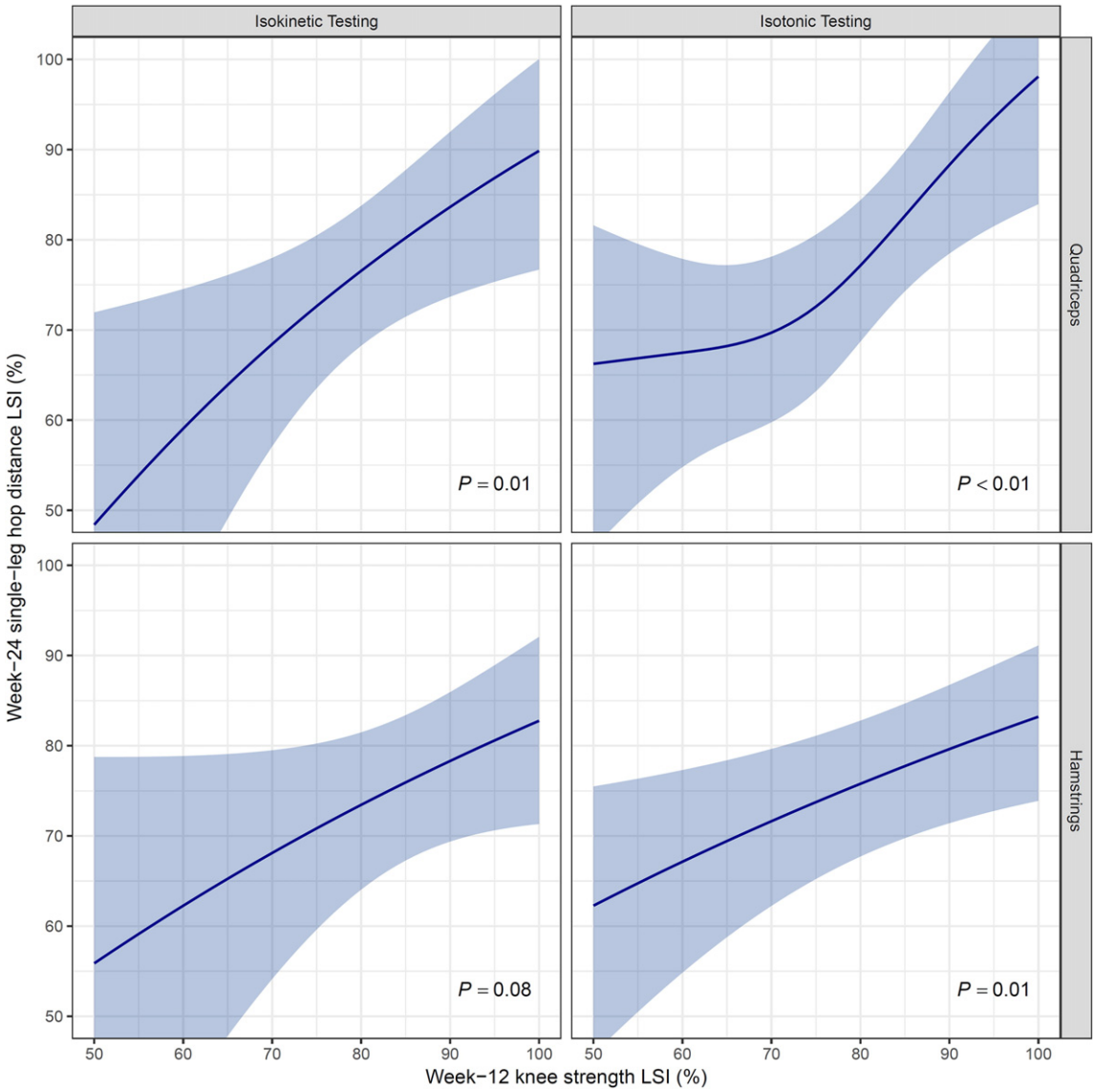

Figure 1. Associations of week-12 isotonic and isokinetic knee strength limb symmetry index (LSI) with week-24 single-leg hop distance LSI, after adjusting for covariates. Shaded regions represent 95% CI for the regression estimates.

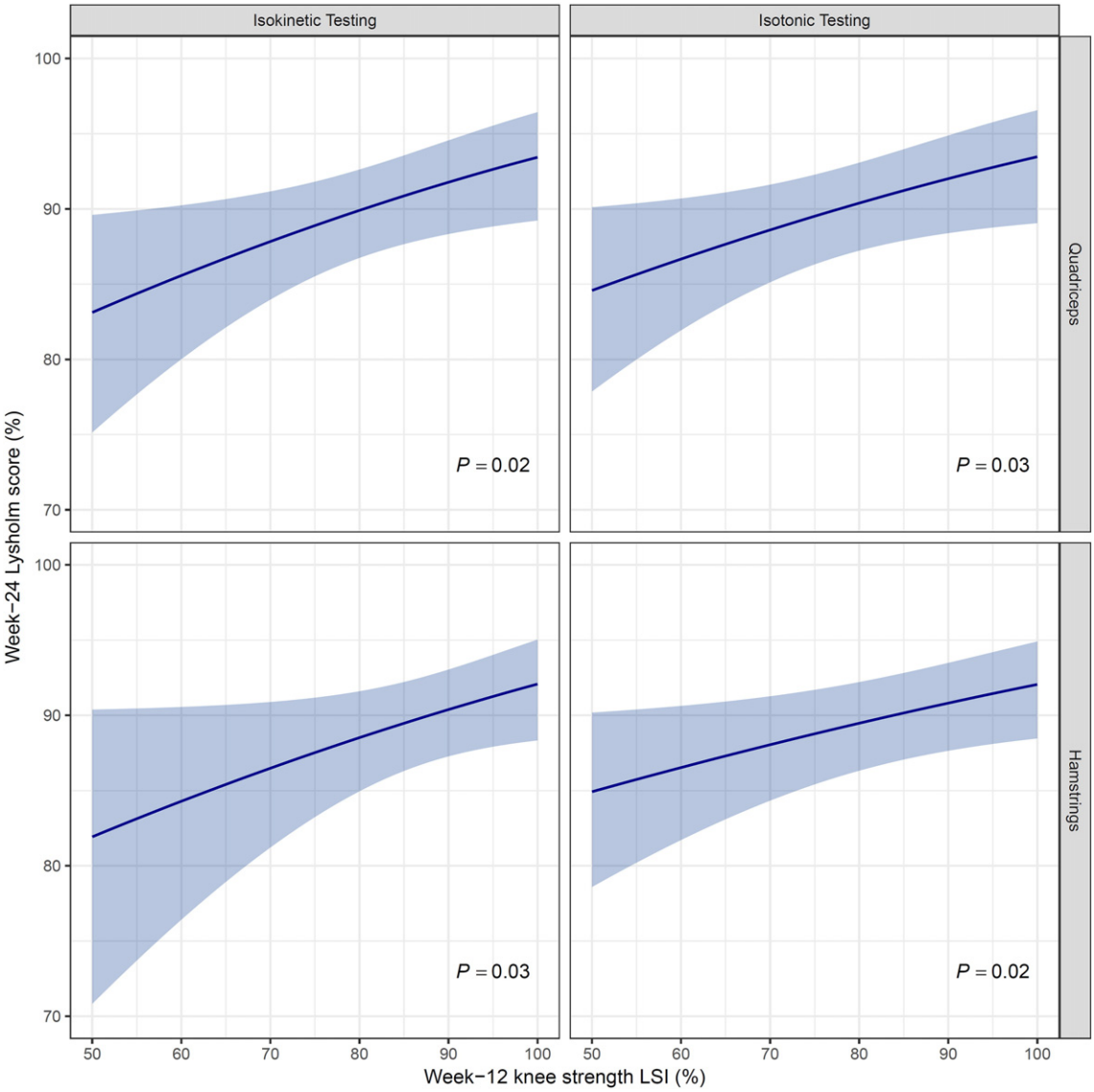

Figure 2. Associations of week-12 isotonic and isokinetic knee strength limb symmetry index (LSI) with week-24 Lysholm score, after adjusting for covariates. Shaded regions represent 95% CI for the regression estimates.

isotonic and isokinetic hamstrings strength LSIs were significantly associated with Lysholm scores ($P \leq 0.03$) and only isotonic hamstrings strength was significantly associated with hop distance LSI ($P = 0.01$).

4. Discussion

In this prospective study of 106 patients with ACLR, we found that independent of covariates, quadriceps strength LSI was generally more strongly associated than hamstrings strength LSI with future knee function and activity levels. Additionally, isokinetic knee strength did not seem to be more strongly associated than isotonic knee strength with the various outcomes.

Few previous studies [3–5] have examined the concurrent validity between absolute isokinetic and isotonic quadriceps strength measures, and our results build on prior work by showing that the two measures were closely correlated in patients with ACLR (Spearman's $\rho = 0.91$). Contrary to views about weight-machine-derived isotonic quadriceps strength as being just a proxy measure to isokinetic quadriceps strength, we found that isotonic quadriceps strength LSI had comparable, if not better, predictive performance compared with isokinetic quadriceps strength LSI. To our knowledge, the present study is the first to directly compare the prospective associations of isokinetic and isotonic quadriceps strength with knee function and activity levels in patients with ACLR. The mechanisms responsible for our findings are unclear but previous experimental studies have shown that quadriceps activation was higher during isotonic knee extension than during isokinetic movements [18,19]. Given also that persistent

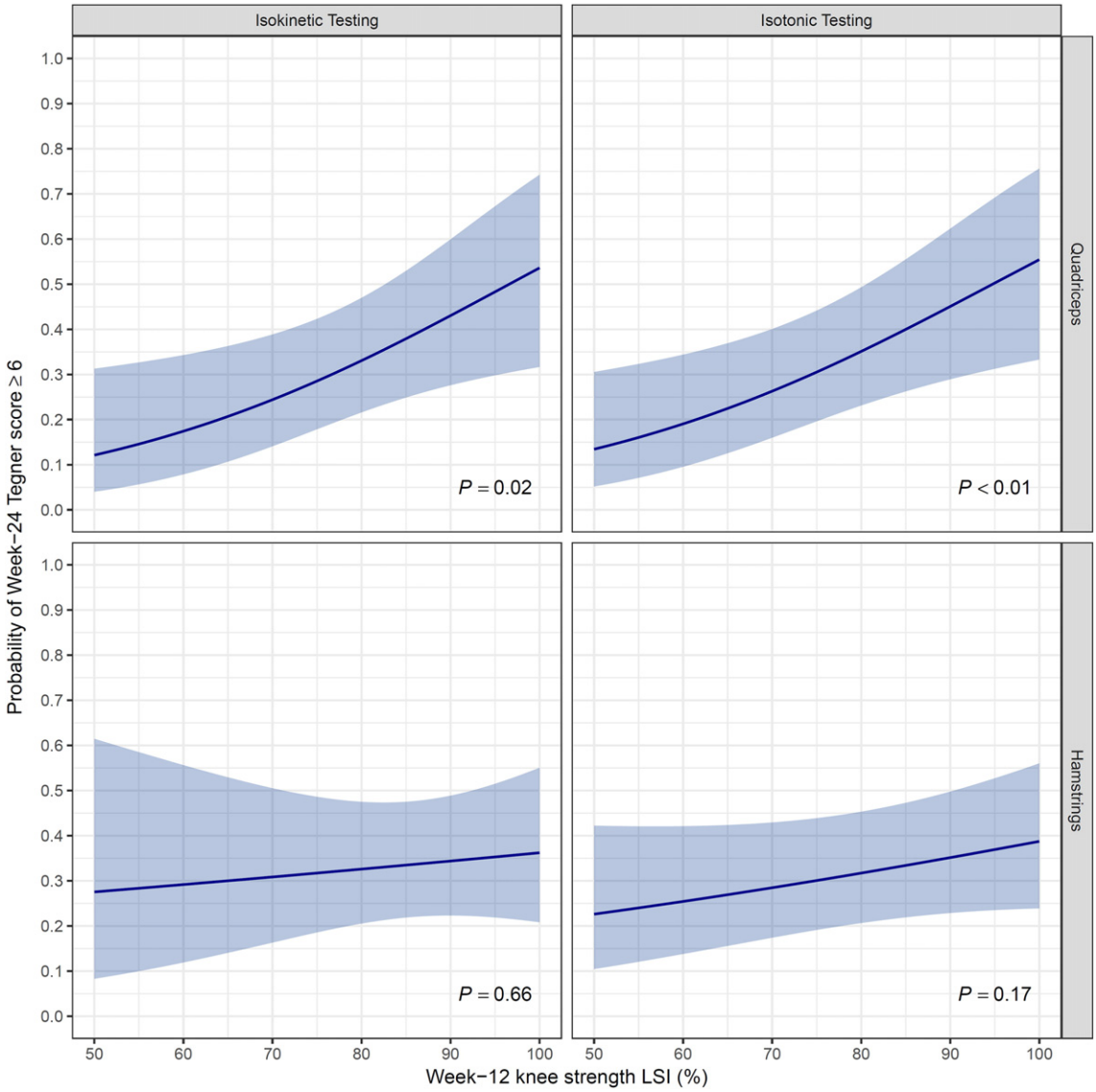

Figure 3. Associations of week-12 isotonic and isokinetic knee strength limb symmetry index (LSI) with week-24 Tegner scores, after adjusting for covariates. Shaded regions represent 95% CI for the regression estimates.

quadriceps weakness in ACLR has a complex etiology that involves quadriceps activation failure due to multiple factors [20], we speculate that the greater predictive validity of isotonic quadriceps strength may relate to its greater sensitivity in detecting quadriceps activation failure and weakness in patients with ACLR. Indirectly supporting this, we have observed that variability tended to be greater for isotonic than for isokinetic quadriceps strength LSI in our sample (IQR, 16 vs. 12 percentage points) and median isotonic strength LSI was lower than median isokinetic LSI (77% vs. 75%, $P = 0.02$ from a Wilcoxon signed rank test). Granted, these explanations are speculative and future studies should examine the contributions of neural excitability and voluntary activation to isokinetic and isotonic quadriceps strength. Nevertheless, our results do support a potential role of isotonic quadriceps testing in ACLR rehabilitation.

In our study, hamstrings strength LSI was generally less strongly associated than quadriceps strength LSI with month-6 knee outcomes. As with the quadriceps strength results, isokinetic hamstrings strength did not seem to be more strongly associated than isotonic hamstrings strength with the various outcomes: both isokinetic and isotonic hamstrings strength LSIs were significantly associated with Lysholm scores; however, isotonic – but not isokinetic – hamstrings strength LSI was additionally significantly associated with future hop distance (Table 2). It is difficult to compare the results for the two modes of hamstrings strength with those for the quadriceps because the present study gave greater parity to both modes of quadriceps testing, which were performed with the patients in a seated position and with the same testing range-of-motion. In contrast, we assessed isokinetic hamstrings strength in a seated position whereas isotonic strength was assessed using a prone leg curl machine — a widely used training machine in clinical rehabilitation. Potentially, differences associated with prone versus seated knee flexion movements – for example, levels of medial and

lateral hamstrings activation [21] – could have, at least partially, accounted for our findings. Interestingly, it has also been recently reported in 42 patients with ACLR that isokinetic hamstrings strength deficits were greater when tested in the prone position than in the seated position [22]. Thus, although our study did not show a superiority of isokinetic hamstrings strength over isotonic hamstrings strength, further studies that standardize testing positions are clearly needed to pursue a deeper understanding of the results.

One potential implication of our findings is that since measurements of knee strength preceded and were associated with the various knee outcomes, isotonic strength testing using weight machines in patients with ACLR is suitable for identifying those at risk for future knee disability. Thus, in a busy or resource-depleted clinical setting, the more sophisticated measurements of isokinetic knee strength are unlikely to be required. This implication is compelling because isokinetic testing in many clinical settings may be impractical as the isokinetic dynamometer system is relatively expensive and its operation requires more logistic effort and technical skills. Nevertheless, we acknowledge that replication of our findings in other cohort studies is required and that the definitive cost–benefit analysis would require a randomized, comparative effectiveness trial evaluating the use of strength data derived from the isokinetic dynamometer and weight machines in making clinical decisions.

4.1. Limitations

Our study has limitations. First, our sample comprised predominantly men which limited the generalizability of our results to women. Second, although we calculated knee strength LSI to allow for valid comparisons between the different test modes and muscle groups, it is possible for contralateral knee strength weakness post-ACLR to spuriously inflate the LSI values [23]. Third, concentric (isokinetic or isotonic) knee strength represents just one aspect of muscle performance and our study did not consider other aspects of performance such as eccentric knee strength or knee rate-of-torque development [24,25]. This limitation, however, does not diminish the importance of our findings or of weight-machine muscle testing because (i) concentric knee strength is the best studied and most widely used measure in the research and clinical settings and because (ii) it is possible, through modifications [25,26], to obtain alternative measures of muscle performance during weight-machine muscle testing. Fourth, although we examined associations prospectively, we obtained knee strength measurements at only one time point and could not assess the influence of longitudinal changes in strength measurements on functional knee outcomes. Future studies are needed to establish time trends and determine longitudinal associations.

5. Conclusion

In summary, weight-machine-derived isotonic quadriceps strength LSI was independently and consistently associated with knee function and work-and-sport activity level post-ACLR, and isokinetic knee strength was not more strongly associated than isotonic knee strength with the various outcomes. Future work should focus on refining or developing muscle assessment techniques that are more cost-effective, require less preparation, and better identify patients who are at risk of knee weakness and future knee disability.

Conflict of interest

The authors declare that they have no conflicts of interest.

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