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Single-legged hop tests as predictors of self-reported knee function in non-operatively treated individuals with ACL injury

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Abstract

Background—Previous studies have found significant predictors for functional outcome after ACL reconstruction, however, studies examining predictors for functional outcome in non-operatively treated individuals are lacking.

Hypothesis—Single-legged hop tests predict self-reported knee function (IKDC2000) in non-operatively treated ACL-injured individuals 1 year after baseline testing.

Study Design—Cohort study (prognosis); Level of evidence, 2.

Methods—Ninety-one non-operatively treated subjects with an ACL injury were tested using 4 one-legged hop tests on average 74 ± 30 days after injury in a prospective cohort study. Eighty-one subjects (89 %) completed the IKDC2000 1 year later. Subjects with an IKDC2000 score equal to or higher than the age- and gender-specific 15th percentile score from previously published data on an uninjured population were classified as having self-reported function within normal ranges. Logistic regression analyses were performed to identify predictors of self-reported knee function. The Area Under the Curve (AUC) from Receiver Operating Characteristic curves was used as a measure of discriminative accuracy. Optimal limb symmetry index (LSI) cutoff for the best single-legged hop test was defined as the LSI with the highest product of sensitivity and specificity.

Results—Single hop for distance symmetry indexes predicted self-reported knee function at the 1-year follow-up (p=0.036). Combinations of any 2 hop tests (AUC=0.64–0.71) did not give a higher discriminative accuracy than the single hop alone (AUC=0.71). A cutoff of 88 % (LSI) for the single hop revealed a sensitivity of 71.4 % and a specificity of 71.7 %.

Conclusion—The single hop for distance (LSI) significantly predicted self-reported knee function after 1 year in non-operatively treated ACL-injured subjects. Combinations of 2 single-legged hop tests did not lead to higher discriminative accuracy than the single hop alone.

Keywords

Anterior cruciate ligament; prognosis; single-legged hop test; knee function

INTRODUCTION

Anterior cruciate ligament (ACL) injuries entail serious consequences, including loss of dynamic stability, increased risk of subsequent knee injuries, and early onset of knee osteoarthritis.[35] Whereas reconstructive surgery seems widely accepted as the preferred treatment for highly active individuals,[5] the role of non-operative treatment of ACL injuries has lately been a topic of interest.[4,29] In a recently published randomized trial comparing structured rehabilitation and early surgery with structured rehabilitation and optional delayed surgery, Frobell et al.[17] reported no significant differences between the two groups in patients' self-reported knee function 2 years after inclusion. Previous studies have also shown that non-operative treatment may be an alternative in selected patients groups.[7,25,30] Therefore, a paramount clinical challenge is to identify patients who will not regain satisfactory knee function following non-operative treatment with structured rehabilitation. To our knowledge, no study has examined if functional tests can predict 1-year outcome following non-operative treatment.[32]

Single-legged hop tests are functional tests that have been used to identify individuals who can regain dynamic knee stability after an ACL injury.[16] Fitzgerald et al.[15] showed that the 6-meter timed hop in conjunction with other measures could predict successful short-term return to sport following specific non-operative management. However, this classification algorithm has later been shown to have poor ability to predict return to sport at a 1-year follow-up.[31] Additionally, returning to the pre-injury level of activity does not give an objective measurement of knee function, as a substantial group of non-operatively managed individuals mitigate their activity levels for various reasons when they decide not to undergo reconstructive surgery.[11,31,32] This underlines the need for an alternative functional outcome measure in this patient group. The International Knee Documentation Committee Subjective Knee Form (IKDC2000)[20] has previously shown to be a valid outcome measure for knee function in the ACL-injured population.[19,20] Furthermore, normative data from a population without knee injuries is available for comparison[3], making it possible to identify patients with self-reported knee function within or below normal ranges.

The main purpose of this study was therefore to determine if single-legged hop tests in the early phase after ACL injury were predictive of self-reported knee function assessed with the IKDC2000 in non-operatively treated individuals 1 year after baseline testing. Additionally, we wanted to assess if a combination of 2 single-legged hop tests would lead to higher discriminative accuracy than 1 hop test alone.

MATERIAL AND METHODS

Subjects

We prospectively recruited 205 subjects referred to our institution, Hjelp24 Norwegian Sports Medicine Clinic (Hjelp24 NIMI), between August 2003 and May 2009 with a unilateral ACL rupture (less than 6 months since injury). The ACL rupture was confirmed by magnetic resonance imaging and ≥ 3 mm side-to-side difference[9] with a KT-1000 arthrometer (MedMetrics, San Diego, CA). Subjects were eligible for participation if they were between the ages of 13 and 60 years and had a preinjury activity level of I or II (> 50 hours/year) according to Hefti et al.[19] Level I activities include jumping, cutting and pivoting sports (e.g. soccer, team handball, basketball and floorball), and level II activities contain lateral movements, but less pivoting than level I (e.g. racquet sports, alpine skiing and snowboarding). Activities with no jumping or pivoting (e.g. running, cycling, cross-country skiing and weightlifting) are classified as level III. Subjects were excluded from participation in the study if the MRI showed concomitant ligamentous injury (grade III–IV),

fracture, or full-thickness articular cartilage damage, or if they had current or previous injury to the contralateral leg. Subjects were included if the MRI showed a meniscus tear, but they had no symptoms during plyometric activities.

At our institution, all patients undergo a previously published 5 week progressive rehabilitation program after injury, either as preoperative training or the start of non-operative management.[13] During this 5 week period, the patients receive information about operative and non-operative treatment. In collaboration with the patient, the responsible orthopaedic surgeon and physical therapist then make the decision on whether the patient should continue with non-operative treatment or undergo reconstructive surgery. The orthopaedic surgeon makes the final decision on whether or not a patient is offered surgery. The main reason for choosing continued non-operative treatment is that the patient does not aim at returning to level I pivoting sports and experiences acceptable or no functional limitations. Of the initial 205 patients, 91 (44.4 %) subjects were non-operatively treated at the 1-year follow-up (Fig. 1), and thus comprise the target population in this study. The proportion of operatively and non-operatively treated subjects in this study is comparable to our previously published clinical cohort of ACL-injured subjects.[30]

All subjects underwent initial rehabilitation until they had no knee effusion, no limitations in knee range of motion, and were able to hop on the involved limb without subsequent effusion or pain. Once these criteria were met, the baseline single-legged hop tests were conducted. After the tests, patients were enrolled in a progressive rehabilitation program. The aim of the rehabilitation program was first to restore muscle strength and neuromuscular control, and finally to prepare the patients for return to their desired activity level through agility drills and plyometric training. The rehabilitation program followed principles previously described by our research group.[13,30] The specific choice of exercises, training loads, progression and length of the rehabilitation period were individualized to each patient's functional level. All patients were encouraged to consult their physical therapist at least once a week for progression of the program the first 1–2 months after the baseline tests, and monitored no less than once a month until they were discharged. Non-operatively treated patients at our institution undergo up to 4 months of supervised rehabilitation. All patients are encouraged to do their rehabilitation program at least 2–3 times a week and to continue knee specific training after they are discharged.

All subjects signed a written informed consent form at the time of inclusion. The study was approved by the Regional Ethics Committee for South-Eastern Norway.

Data collection

The single-legged hop tests used in this study were the single hop for distance, the crossover hop for distance, the triple hop for distance and the 6-meter timed hop (Fig. 2).[34] The hop tests were conducted in the described order for all subjects. All subjects performed 1 practice trial for each leg, followed by 2 measured and recorded trials. No restrictions were given for arm movement, and no subjects wore a knee brace. The injury risk when performing single-legged hop tests in accordance with the criteria we used in this study is minimal. In the last 8 years, 1 (0.3 %) out of 369 patients has had a give-away episode that resulted in mild effusion the next day. Subsequent arthroscopy showed no injury to the menisci or cartilage, and no other injuries have been reported.

The subjects filled out the International Knee Documentation Committee Subjective Knee Form (IKDC2000)[20] directly after performing the baseline single-legged hop tests, and at the 1-year follow-up after functional testing. The IKDC2000 is a self-reported functional outcome measure that evaluates knee symptoms, function and what activities patients perceive they can perform.[20] The IKDC2000 is scored from 0 to 100 with higher scores

representing better knee function and less symptoms, and has shown to be a reliable,[20] valid[20] and responsive[21] knee-specific measure for the ACL-injured population. It has also shown to reflect patient satisfaction[24] and to contain items that are highly endorsed by ACL-injured patients.[18,24] To our knowledge, the IKDC2000 is currently the only knee-specific self-reported outcome measure with published age- and gender-specific normative data from an uninjured population.[3]

Data management and statistical analysis

Hop limb symmetry index (LSI) was expressed as the percentage of the longest involved limb hop distance divided by the longest uninvolved limb hop distance for each single-legged hop test except the 6-m timed hop, where LSI was expressed as the percentage of the fastest uninvolved limb time divided by the fastest involved limb time.

The IKDC2000 scores of the ACL-injured subjects were compared with previously published IKDC2000 scores from a population without prior or current knee problems.[3] Subjects were classified according to the 15th percentile score from the age- and gender-specific normative data. We defined self-reported knee function to be within normal ranges when the IKDC2000 score was equal to or above the 15th percentile. The subjects with self-reported knee function within normal ranges thus scored within the upper 85 % range of scores reported by uninjured people of the same gender and age. Subjects with IKDC2000 scores below the 15th percentile reported lower scores than the majority of uninjured people, and were classified as having self-reported knee function below normal ranges. Other studies have used the mean (approximately 30th percentile) IKDC2000 score from normative data of uninjured individuals[26] or the median (50th percentile) KOOS score from a general population,[44] but the 15th percentile from the normative data of uninjured people was chosen as a cutoff point to ensure that subjects with scores below the cutoff point had scores that differed from what could be considered a normal variation in IKDC2000 scores. To illustrate the effect of using different cutoff points, the results of additional analyses performed with the 30^{th} and the 50^{th} percentile are provided in an appendix.

Baseline comparisons between subjects with self-reported knee function within and below normal ranges after 1 year were conducted using a Chi-square test for nominal data and a Mann-Whitney U test for discrete data. Logistic regression was used to evaluate if LSI on each single-legged hop test predicted self-reported knee function. Receiver operating characteristic (ROC) curves were computed by calculating sensitivity and specificity values for each single-legged hop test across the range of possible scores. Sensitivity referred to the proportion of individuals with IKDC2000 scores below the 15th percentile correctly identified by the single-legged hop tests. Conversely, specificity referred to the proportion of individuals with IKDC2000 scores above the 15th percentile correctly identified. The area under each curve (AUC) was used as a measure of the tests' overall discriminative accuracy. To evaluate the discriminative accuracy of combinations of 2 single-legged hop tests, multiple logistic regression models were computed. Subsequently, the predicted probabilities from each regression model were used as the independent variable, and self-reported knee function within or below normal ranges was used as the dependent variable for the ROC curve analysis. Alpha level for all analyses was set to .05. Finally, the optimal cutoff score for the best test was determined by the LSI score with the highest product of sensitivity and specificity values, and the corresponding sensitivity, specificity, positive likelihood ratio and negative likelihood ratio were reported. All statistical analyses were performed using the SPSS v.17.0 for Windows (Chicago, IL)

RESULTS

The baseline single-legged hop tests were conducted 74.0 ± 30.7 (mean ± SD) days from injury. There were no significant correlations between days from injury to baseline testing and the symmetry indexes for any of the hop tests ($r = 0.05–0.18$, all $p > 0.15$). Eighty-one of the 91 non-operatively treated subjects (89 %) returned for follow-up tests 1 year after functional testing (mean ± SD days from baseline testing to follow-up: 396.9 ± 29.5). The final sample consisted of 40 women and 41 men, with a mean age of 29.2 ± 8.8 years at baseline. Forty-four (54.3 %) subjects were active at level I and 37 (45.7 %) subjects at level II prior to injury. The mean IKDC2000 score at baseline was 72.4 ± 11.1.

The mean IKDC2000 score at follow-up was 89.0 ± 9.3. When classified according to gender- and age-specific normative data, sixty subjects (74.1 %) had IKDC2000 scores within normal ranges, meaning a score higher or equal to the 15th percentile from the normative data. Conversely, 21 subjects (25.9 %) had scores below normal ranges. The median 1-year IKDC2000 scores for the two groups were 94.3 and 78.2 respectively (Table 1). Significantly more females than males had IKDC2000 scores within normal ranges at the 1-year follow up (Table 1). No other statistically significant differences were found between subjects with IKDC2000 scores within and below normal ranges (Table 1). Subjects with IKDC2000 scores within normal ranges had significantly higher single hop symmetry indexes than subjects with IKDC2000 scores below normal ranges (Table 2). The single hop for distance was the only single-legged hop test that significantly predicted self-reported knee function (Table 3). Combinations of any 2 single-legged hop tests did not result in higher discriminative accuracy than the single hop test alone (Table 3–4). The cutoff point with the highest product of sensitivity and specificity for the single hop was 88 % limb symmetry (Table 5). The corresponding sensitivity, specificity, positive and negative likelihood ratios are presented in Table 5.

Additional analyses using the 30^{th} and the 50^{th} IKDC2000 normative percentiles revealed that the single hop for distance was the strongest predictor regardless of IKDC2000 cutoff (Appendix Table 3). In addition to the single hop, the crossover hop was also a significant predictor of an IKDC2000 score above the 30^{th} percentile. Furthermore, the single hop, crossover hop and triple hop all significantly predicted an IKDC2000 score above the 50^{th} percentile.

DISCUSSION

The principal finding of this study was that limb symmetry index for the single hop for distance test significantly predicted self-reported knee function assessed with the IKDC2000 1 year after baseline in non-operatively treated ACL-injured individuals. With a cutoff score of 88 % LSI, the single hop for distance test showed a sensitivity of 71.4 % and a specificity of 71.7 %. Additionally, combining 2 single-legged hop tests did not lead to higher discriminative accuracy than the single hop for distance test alone.

Single-legged hop tests are most commonly used to evaluate knee function at a set point in time.[11,13,34] The results from this study show that the single hop for distance can also be used to predict knee function 1 year after functional testing. Of the 81 subjects included in this study, 60 (74.1 %) had self-reported knee function within normal ranges at the 1-year follow-up. Given a baseline single hop LSI above 88 %, the estimated probability of having IKDC2000 scores within normal ranges was 89 % (95 % CI, 81–94 %). Conversely, the estimated probability of having IKDC2000 scores within normal ranges was 57 % (95 % CI, 45–68 %) for subjects with single hop LSI below 88 %. If used as described in this study, clinicians can thus make more accurate prognoses for 1-year outcome after non-operative

treatment by implementing the single hop for distance test in their practice. Most importantly, the single hop for distance can be used to identify patients with high probability of having self-reported knee function within normal ranges 1 year later. However, as our results showed that more than half of the patients with symmetry indexes below 88 % at baseline reported IKDC2000 scores within normal ranges at the 1-year follow-up, the single hop for distance could not be used to identify patients who are likely to have low IKDC2000 scores 1 year later.

This study does not provide evidence as to why the single hop for distance was a significant predictor of self-reported knee function after 1 year, while the other 3 single-legged hop tests were not. It could be hypothesized that patients might be more apprehensive to perform consecutive hops or hopping as fast as possible, compared to performing only 1 hop. This could introduce a higher degree of measurement error for the crossover hop, the triple hop and the 6-meter timed hop test. Still, previous reports on the test-retest reliability of hop tests[6,33,36,38,40] do not support this hypothesis fully, as only 2 studies have reported that the single hop for distance is the most reliable test of the 4.[6,36] Furthermore, as we did not randomize the order of the single-legged hop tests, it could also be that the first single-legged hop test performed could be the best hop test for predicting self-reported knee function in non-operatively treated subjects. We also examined if different cutoffs for the IKDC2000 (30th or 50th percentile) would disclose a different result. These analyses showed that the crossover hop and both the crossover hop and the triple hop were significant predictors for an IKDC2000 score above the 30th and 50th percentile, respectively. However, the single hop for distance was the strongest predictor and had the highest discriminative accuracy, regardless of IKDC2000 cutoff.

Our results showed that the single hop for distance test alone had a discriminative accuracy (AUC) of 0.71 (Table 2). The intent of this study was solely to evaluate the predictive ability of single-legged hop tests. Therefore, it only covers one aspect of what likely is a complex interaction between baseline knee function and future knee function. With a prediction model consisting of patient characteristics and intra-operative variables, Kowalchuk et al.[26] reported an AUC of 0.63 in ACL reconstructed patients. Other prediction models in patients with lower back pain or shoulder disabilities have also reported similar or lower discriminative accuracy (AUC 0.59–0.77).[22,23,27,28] The results from our study suggest that the single hop for distance test should be included as one of several potential predictors in future studies. Existing evidence also suggests a poorer outcome in patients with a high activity level,[8,14] concomitant cartilage injury,[10] and in patients that undergo meniscectomy.[10,42] In the current study, patients with symptomatic concomitant injuries were excluded, and non-operative treatment was not recommended if patients aimed at returning to level I pivoting sports. Our results also revealed a higher proportion of women in the group with IKDC2000 scores within normal ranges. In 2 previous studies, gender was not found to be related to outcome after non-operative treatment of ACL injuries.[8,39] One previous study reported that although an equal number of males and females was assigned to non-operative treatment, 81 % of patients who maintained non-operative treatment were female.[43] However, the statistical significance of the finding was not reported, and the sample size was limited. Our finding of a possible gender difference in treatment outcome warrants further investigation.

There is currently no consensus on what constitutes a satisfactory outcome after treatment of ACL injuries. In this study, the subjects' self-reported knee function was compared with a reference range obtained from uninjured individuals.[3] The 15th percentile from the normative data was set a priori to define age- and gender-specific normal ranges of IKDC2000 scores. Whereas the 50th or 30th percentile might be useful for identifying subjects who very likely have comparable IKDC2000 scores to uninjured individuals, the

15th percentile ensures a certainty that subjects with scores below the normal range have IKDC2000 scores that differ from a normal variation. One of the limitations of using normative values for classification is that the variation of scores in patients with knee problems is not known.[2] For that reason, we cannot exclude the possibility that subjects with IKDC2000 scores above the 15th percentile might be dissatisfied with their knee function. Furthermore, the study sample consisted of subjects who participated in pivoting sports prior to injury. Although the non-operatively treated patients at our institution are counseled to refrain from level I pivoting sports, they might have higher demands to their knee function than the normative population. Still, the group classified as having IKDC2000 scores within normal ranges had a median IKDC2000 score of 94.3 (Table 1), indicating minimal functional limitations at the 1-year follow-up.

The recent publication on the effect of non-operative treatment for ACL-injured subjects[17] as well as previous cohort studies[1,25,30] have shown that more knowledge is needed on non-operative treatment of ACL injuries, as a part of the ACL-injured population seems to cope well without surgery. However, the evidence for predictive factors of functional outcome after non-operative treatment is currently sparse. In future efforts to increase the knowledge on who will benefit from non-operative treatment, the timing of the treatment decision must also be addressed. In our study, the subjects were tested as soon as initial impairments were resolved and they were able to hop on one leg without subsequent effusion or pain. However, it is possible that the discriminative accuracy would improve if the single-legged hop tests were conducted later after injury. This line of thought is supported by a recent study by our group where conducting functional tests after 10 sessions of rehabilitation led to higher values for explaining who later went through surgery than performing a screening examination early after injury.[12] There are two specific advantages of delaying functional tests when they are to be used for predictive purposes. First, patients with high potential for improvement with rehabilitation are likely to improve their functional test results more rapidly than patients with less potential for improvement with rehabilitation. Secondly, single-legged hop tests might be more reliable after the patients have been introduced to plyometric exercises in rehabilitation.

We recognize that this study has some limitations. Only subjects with isolated ACL injuries or asymptomatic concomitant injuries were included, and the results cannot be generalized to subjects with symptomatic concomitant injuries. Furthermore, having an IKDC2000 score within the same range as uninjured people should not be mistaken as equivalent to having normal knee function, as abnormal movement patterns seem to persist in both operatively and non-operatively treated ACL-injured patients.[37,41] Identifying predictors for 1-year functional outcome is of significance because most ACL-injured individuals have finished rehabilitation and are back to their desired activity level at this point. Nevertheless, knee function might change over time. In the longer term, knee osteoarthritis and additional meniscus injury are important factors in evaluating whether or not a treatment outcome is truly satisfactory. Prospective studies with long-term follow-ups are therefore needed to increase the knowledge on predictive characteristics of ACL-injured patients that are able to succeed with non-operative treatment on a long-term basis.

CONCLUSION

Limb symmetry index for the single hop for distance significantly predicted self-reported knee function after 1 year in non-operatively treated ACL-injured individuals. Combinations of 2 single-legged hop tests did not result in higher discriminative accuracy than the single hop test alone. Clinicians can use the single hop test to give an indication of patients' potential for regaining self-reported knee function within normal ranges following non-operative treatment with structured rehabilitation. The results from this study suggest that

the single hop for distance should be included in future studies where multiple predictors for functional outcome after non-operative management of ACL injuries are evaluated.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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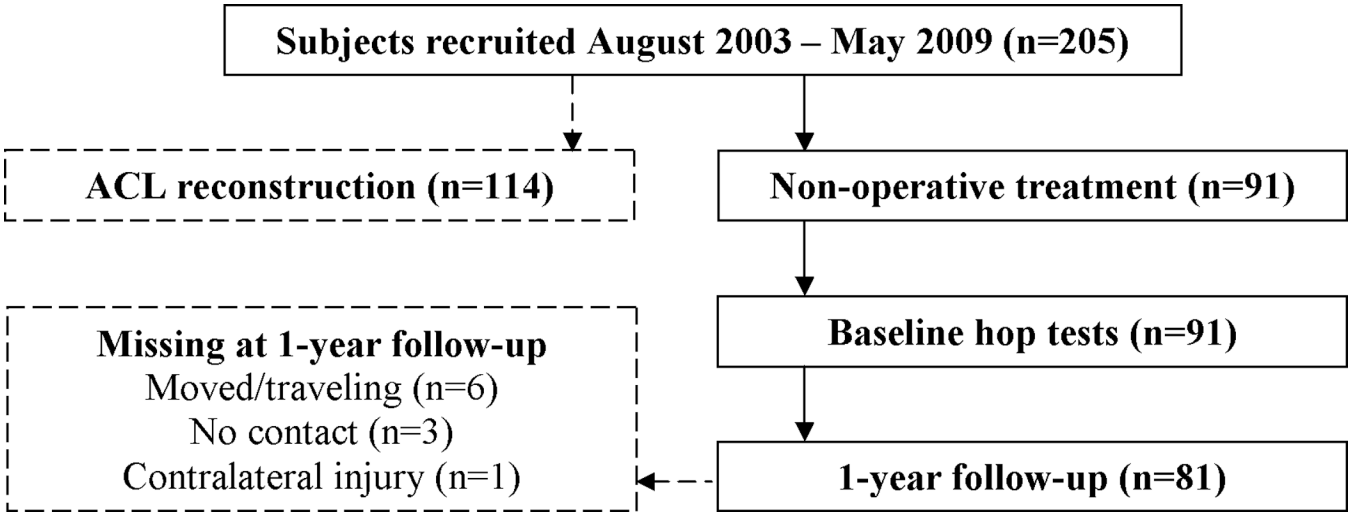

Figure 1.

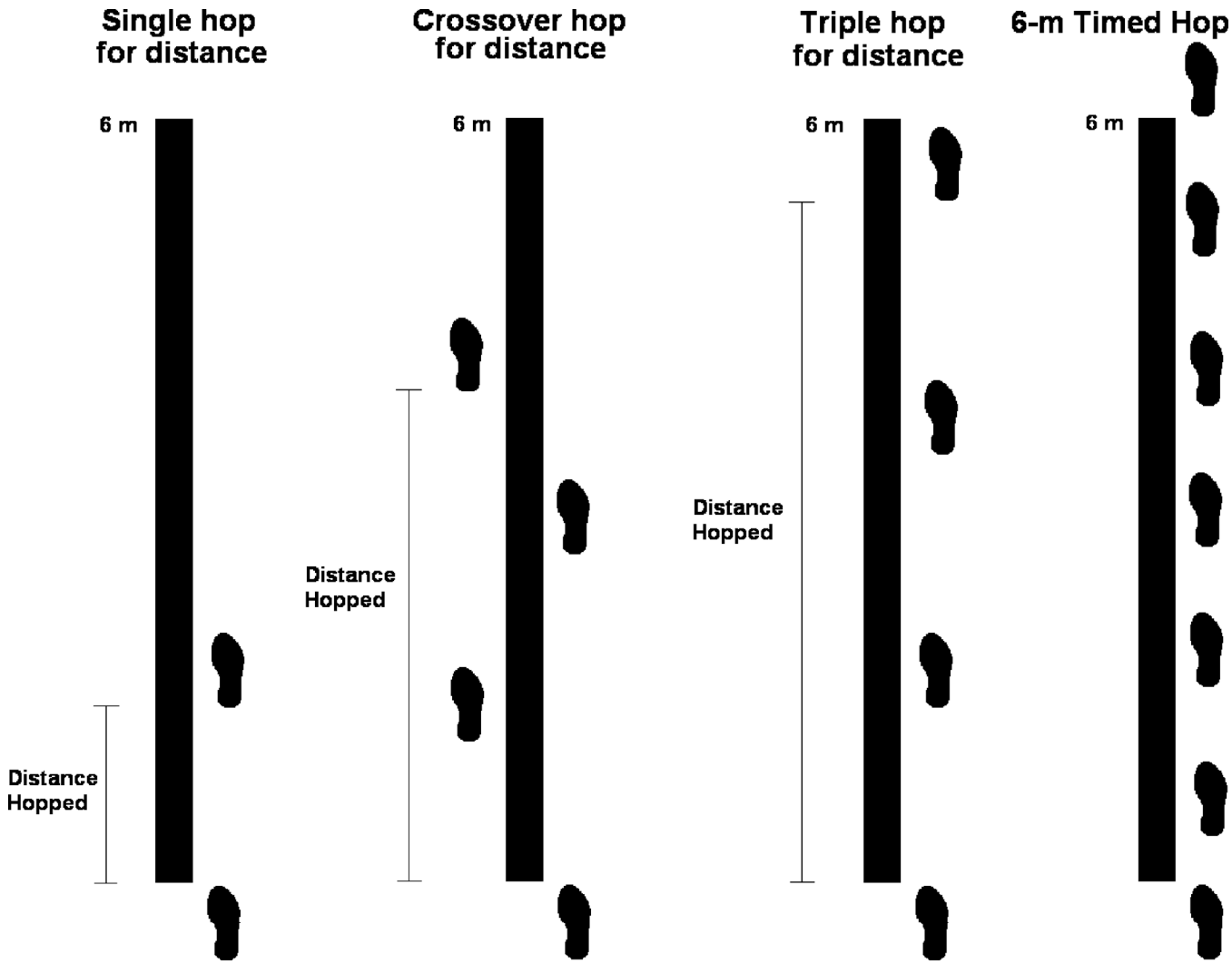

Figure 2.

Table 1

Characteristics of subjects with self-reported knee function within and below normal ranges at the 1-year follow-up

	Self-reported knee function below normal ranges (n = 21)	Self-reported knee function within normal ranges(n = 60)	P-value
Women/men (% women)	5/16 (23.8 %)	35/25 (58.3 %)	0.006
Preinjury activity level I/II (% AL I)	13/8 (61.9 %)	31/29 (51.7 %)	0.418
Age, median (IQR)	28 (23–31)	29 (24–35)	0.597
KT1000 side-to-side difference in mm, median (IQR)	5 (5–6)	6 (4–7)	0.778
IKDC2000 score at 1-year follow-up, median (IQR)	78.2 (72.4–83.9)	94.3 (89.7–97.7)	<0.001

AL = activity level

IQR = interquartile range

Table 2

Baseline single-legged hop test limb symmetry indexes in subjects with self-reported knee function within and below normal ranges and discriminative accuracy (AUC) at the 1-year follow-up

Baseline single-legged hop tests	Self-reported knee function below normal ranges (n = 21)	Self-reported knee function within normal ranges (n = 60)	AUC (95 % CI)	P-value
Single hop for distance LSI *	83.6 (81.1–91.0)	92.9 (85.1–98.3)	0.71 (0.59–0.84)	0.004
Crossover hop for distance LSI *	88.4 (85.2–93.6)	94.0 (83.7–99.0)	0.62 (0.49–0.74)	0.121
Triple hop for distance LSI *	88.4 (82.9–90.3)	90.8 (82.5–98.2)	0.63 (0.51–0.75)	0.074
6-m timed hop LSI *	91.5 (87.9–94.7)	95.2 (90.9–100.0)	0.64 (0.50–0.78)	0.065

LSI = Limb symmetry index

* Median (IQR)

IQR = Interquartile range

AUC = Area under the curve

Table 3

Results of univariate logistic regression analysis of predictors of self-reported knee function at the 1-year follow-up

Baseline single-legged hop tests	Odds Ratio (95 % CI)	P-value
Single hop for distance LSI	1.060 (1.004–1.119)	0.036
Crossover hop for distance LSI	1.025 (0.979–1.073)	0.289
Triple hop for distance LSI	1.027 (0.979–1.078)	0.269
6-m timed hop LSI	1.035 (0.986–1.087)	0.165

LSI = Limb symmetry index

Table 4

Area under the curve (AUC) for combinations of single-legged hop tests

Combinations of baseline single-legged hop tests	AUC (95 % CI)	P-value
Single hop, crossover hop	0.68 (0.55–0.82)	0.016
Single hop, triple hop	0.70 (0.58–0.83)	0.006
Single hop, 6-m timed hop	0.71 (0.58–0.85)	0.005
Crossover hop, triple hop	0.64 (0.52–0.76)	0.063
Crossover hop, 6-m timed hop	0.65 (0.51–0.79)	0.057
Triple hop, 6-m timed hop	0.65 (0.51–0.78)	0.059

AUC = Area under the curve

Table 5

Optimal cutoff, sensitivity, specificity, and likelihood ratios for the single hop for distance

	Optimal cutoff	Sensitivity (95 % CI)	Specificity (95 % CI)	Positive likelihood ratio (95 % CI)	Negative likelihood ratio (95 % CI)
Single hop for distance LSI	88 %	71.4 (50.0–86.2)	71.7 (59.2–81.5)	2.52 (1.55–4.09)	0.40 (0.20–0.80)

LSI = Limb symmetry index