Title: Predictors of a Second Anterior Cruciate Ligament Injury Compliments the Decision-Making Process of Return to Sport Following Anterior Cruciate Ligament Reconstruction – A Multifactorial Approach

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Predictors of a Second Anterior Cruciate Ligament Injury Compliments the Decision-Making Process of Return to Sport Following Anterior Cruciate Ligament Reconstruction – A Multifactorial Approach

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Background: Criteria for return to sport (RTS) following anterior cruciate ligament (ACL) reconstruction are frequently used without reference to valid cut-off values. Nine predictors of second ACL injury have been identified consisting of both physiologic and patient-reported components, which facilitates the development of a multifactorial RTS test battery.

Purpose: The purpose of the present study was to present a multifactorial test battery consisting of predictors of a second ACL injury to provide a framework for understanding the complex decision-making process of RTS after ACL reconstruction.

Study Design: Cross sectional study.

Methods: Twenty-nine ACL reconstructed patients (16 males and 13 females) participated in the study. The multifactorial test battery consisted of patient-reported outcome measures (Knee Injury and Osteoarthritis Outcome Score - Quality of Life (KOOS-QoL) and the shortened version of the Tampa Scale of Kinesiophobia (TSK-11)) and experimental tasks (quadriceps strength limb symmetry index (LSI), hamstring/quadriceps (H/Q) ratio and triple hop for distance LSI). Spearman Rank correlation analysis, the cut-off values of the predictors and the incidence rate of second ACL injury was used to emphasize the understanding of the multifactorial approach in the evaluation of risk of a second ACL injury.

Results: Three significant moderate correlations were found between KOOS-QoL and both TSK-11, triple hop for distance LSI and H/Q ratio ($P<0.05$). No participants passed all cut-off values across the predictors. On the basis of both the incidence rate and the cut-off values, divergence in identifying participants at risk of a second ACL injury were found between the predictors.

Conclusion: The findings shows complementarity between the predictors in identifying participants at risk of a second ACL injury. This support applying a multifactorial approach in the decision-making process of RTS after ACL reconstruction.

Clinical Relevance: The findings contribute to the development of targeted rehabilitation interventions with the purpose of obtaining the lowest reinjury risk upon RTS.

Key words: ACLR, Second ACL injury, Multifactorial test battery, Injury risk

Introduction

One of the most common sport-related injuries in football, handball and soccer is anterior cruciate ligament (ACL) injuries.[1,2] These injuries typically occur in noncontact situations involving pivoting, landing and cutting maneuvers.[3] ACL injuries result in functional disabling conditions and often require surgical reconstruction for individuals who wish to continue in sports.[4,5] Despite undergoing ACL reconstruction, only 55% of patients return to competitive levels of sports participation.[6] Of those patients returning, 6-37% sustains a reinjury inclusive of both contralateral ACL rupture and ipsilateral graft rupture.[7-9] These reinjury rates underline the challenge of deciding when to return to sport (RTS) to minimize the risk of sustaining a second ACL injury.[10] Different criteria are used to determine the optimal time point of RTS.[11] In fact, 134 different criteria are presented in a systematic review, which purpose was to describe criteria used for clearance of RTS following ACL reconstruction.[11]

These criteria are constituted of both objective measures and patient-reported outcome measures.[11] The excessive number of criteria underlines the lack of consensus among clinicians when evaluating patients readiness for RTS. This has led to an increase in the development of test batteries consisting of RTS criteria.[12] However, these criteria are frequently used without reference to valid cut-off values.[12] Literature on whether patients meeting the criteria avoids sustaining a secondary ACL injury is scarce.[12,13] However, in a previous phase of the current study (unpublished data, 2019)[13], we synthesized six studies identifying nine predictors of second ACL injury. Two of the predictors were patient-reported outcome measures: (i) Greater fear evaluated with the shortened version of the Tampa Scale of Kinesiophobia (TSK-11)[8], and (ii) low self-reported knee function evaluated with the Knee Injury and Osteoarthritis Outcome Score - Quality of Life (KOOS-QoL)[14]. The remaining seven predictors were identified through experimental tasks: (iii) Low hamstring/quadriceps (H/Q) ratio[15], (iv) deficit in quadriceps strength limb symmetry index (LSI)[16], (v) categorization of patients being in high-risk based on their performance in triple hop for distance, inclusive of both distance hopped normalized to height and LSI[17], (vi) net hip internal rotator moment impulse[18], (vii) increased frontal plane knee joint range of motion[18], (viii) greater asymmetry in sagittal plane knee moments[18] and (ix) deficits in postural stability[18]. These predictors represent different factors related to knee function and secondary ACL injury risk[13].

The findings indicate that both experimental tasks and patient-reported outcome measures are relevant in the decision-making process of RTS following ACL reconstruction. Recent literature proposes a multifactorial RTS approach consisting of both physiologic and patient-reported components[4,19-21]. In agreement with this multifactorial approach, the predictors presented in our previous work (unpublished data, 2019)[13] facilitates the development of a RTS test battery, with reference to cut-off values shown to predict second ACL injury.

Thereby, the purpose of the present study was to present a multifactorial test battery consisting of predictors of a second ACL injury to provide a framework for understanding the complex decision-making process of RTS after ACL reconstruction. It was hypothesized that the multifactorial test battery combining the predictors would provide a complimentary evaluation of the risk of a second ACL injury.

Methods

Subjects

This study used a cross-sectional design in which data from patient-reported outcome measures and experimental tasks were collected during a single test session lasting approximately 30 minutes. In the present study 106 ACL reconstructed patients were invited (App 1), of which thirty-one patients were willing to participate and thereby recruited. To be eligible for participation, patients had to meet the inclusion criterion of no previous or current injury to the contralateral limb, which could restrict the measurements at the time of testing. All patients underwent ACL reconstruction at Aalborg University Hospital, Denmark, between April 2017 and March 2018. The included participants were between 17-49 years old and were recruited regardless of graft type, concomitant injuries, pre-injury- and current activity level.

Procedure

All participants were informed about the procedure and signed a written informed consent (App. 2). Demographic information consisting of height, weight, age and activity level[22] was collected. In addition, information concerning the reconstruction procedure and injury was likewise collected. Of the nine predictors identified in the previous phase of the current study (unpublished data, 2019)[13], the following were chosen based on clinical applicability and formed the multifactorial test battery: KOOS-QoL, TSK-11, triple hop for distance LSI, quadriceps strength LSI and H/Q ratio. Before testing, a 7 min warm up protocol consisting of stretching and bodyweight exercises was performed (App. 3). The order of testing was (i) completion of KOOS-QoL, (ii) TSK-11, (iii) triple hop for distance and (iv) isokinetic muscle strength.

Patient-reported Outcome Measures

KOOS-QoL

The KOOS-QoL provides an evaluation of self-reported knee function in terms of awareness and lifestyle changes.[23] The KOOS-QoL is a 4-item questionnaire, where each question is scored from 0 to 4 using five Likert boxes, which provides a possible total score ranging from 0-16 (App 4). The total score is transformed to a normalized score ranging from 0-100, where zero represent seriously knee problems and 100 represents no knee problems.[24] The KOOS-QoL has demonstrated good test-retest reliability (ICC = 0.86).[24] The KOOS-QoL was found as predictor of second ipsilateral ACL injury, with a cut-off value of <44 increasing the risk by 3.7.[14]

TSK-11

The TSK-11 is an 11-item questionnaire, which obtains information regarding fear of movement/reinjury (App 5).[8] Participants rate each item on a 4-point Likert scale with scoring categories ranging from 'strongly disagree' to 'strongly agree'. The total score of the questionnaire is calculated by summing the responses. The possible total score ranges from 11 to 44, with greater fear of movement/reinjury indicated by higher scores. The TSK-11 demonstrates concurrent validity assessed in relation to the original Tampa Scale for Kinesiophobia and excellent test-retest reliability (ICC = 0.81).[25] Fear has previously been evaluated using TSK-11 in ACL reconstructed patients.[8,26] The TSK-11 was identified as predictor of a second ipsilateral ACL injury, with a cut-off value of ≥19 leading to a 13 times increased risk.[8]

Experimental Tasks

Triple Hop for Distance

Triple hop for distance provides a collective measure of functional power, postural stability and muscle strength.[27,28] The participants performed three consecutive maximal effort jumps on the same limb in a straight line. They initiated by swinging the arms forward while jumping as far as possible on the same limb, immediately followed by two jumps. The landing of the third jump had to be stabilized and held for one second to be recorded as successful. The distance was measured from the toe take-off point to the toe of the final landing point. One familiarization trial for each limb was performed after which two trials for each limb in alternating order were recorded. The uninvolved limb was tested first and the mean distance for each limb was calculated. The mean distance for each limb was used for calculating the triple hop for distance LSI, by dividing the mean distance of the involved limb by that of the uninvolved limb and multiplying by 100. The triple hop for distance expresses a valid performance-based outcome measure and excellent reliability, with intraclass correlation coefficients of 0.88 for patients undergoing rehabilitation following ACL reconstruction.[29] Categorization of patients being in high-risk based on their performance in triple hop for distance LSI (<98.5%), was identified as predictor of a second ACL injury with an increased risk of 5.14.[17]

Isokinetic Muscle Strength

Muscle strength of the quadriceps and hamstring muscles was tested using an isokinetic dynamometer (HUMAC NORM, CSMI, Stoughton, USA). The sampling frequency of the torque was 500 Hz. Participants were seated in the isokinetic dynamometer with the hip flexed at 90°. Straps were secured around the torso, thigh and tibia to ensure strength measurement of the hamstring and quadriceps muscles. For each participant the dynamometer was individually adjusted to ensure that the axis of the dynamometer arm was in line with the transverse axis of the knee. Before initiating the strength measurements, the participants range of motion of knee flexion and extension was measured. Furthermore, the lower limb was weighed to perform correction of gravity. The isokinetic measurements consisted of five alternating maximal concentric contractions of the quadriceps and hamstring muscles. The measurements were initiated with a concentric contraction of the quadriceps muscles and were performed at an angular velocity of 60°/s.[15,16] Before completing the protocol, four submaximal trials were performed at approximately 20, 40, 60 and 80% of maximal effort for familiarization[16], followed by a one-minute rest interval. The participants were instructed to “kick out and pull back as hard and fast as possible”. Furthermore, the participants held the handles by the seat and kept their head and shoulders against the seat rest. Verbal encouragement was provided. Peak quadriceps and hamstring torque among the five trials was collected and used for further analysis. The peak torque values were used for calculation of quadriceps strength LSI and H/Q ratio for the involved limb. The isokinetic dynamometer demonstrates high relative reliability (ICC >0.9) and moderate absolute reliability when using the peak torques from quadriceps and hamstring muscles.[30] Deficit in quadriceps strength LSI (<84.4%)[16] and low H/Q ratio (<58%)[15] were found to predict a knee reinjury. For every 1% increase in quadriceps strength LSI the reinjury rate was reduced with 3%.[16] Furthermore, a 10% difference in H/Q ratio for the involved limb led to a 10.6 times greater likelihood of sustaining an ACL graft rupture.[15]

Statistical analysis

Spearman Rank correlation analysis was performed to determine possible relationships between the predictors of the multifactorial test battery. The Spearman Rank correlation analysis was applied due to its robustness to significant outliers.[31] The data from H/Q ratio showed a significant outlier, which was defined by lying at least 1.5 times the interquartile range from the boxplot.[32] Relationships was interpreted as: trivial (r < 0.10), low (r = 0.10-0.29), moderate (r = 0.30-0.49), high (r = 0.50-

0.69), very high (r = 0.70-0.89), or nearly perfect to perfect (0.90-1.00).[1] The statistical analysis was conducted using IBM SPSS Statistics (25.0). The significance level was set at P<0.05.

The presented cut-off values were used to evaluate the number of participants passing each predictor in the test battery. The studies identifying the predictors regarding quadriceps strength LSI and H/Q ratio reported no specific cut-off values.[15,16] Thereby, the mean values of the groups not sustaining a reinjury were used for the evaluation.[15,16]

The incidence rate of second ACL injury in a population comparable to the cohort of the present study was 15%.[2] This corresponds to approximately five participants sustaining a second ACL injury in the present study. Based on this, the five lowest scoring participants were identified for each predictor to investigate agreement between predictors in identifying the same participants at risk of second ACL injury.

Results

Population Characteristics

Thirty-one participants were involved in the present study. Two participants were unable to complete all experimental tasks and were excluded, leaving 29 with complete data sets. Table 1 presents anthropometric measures, surgical information and distribution of pre-injury- and current activity level. In addition, table 1 shows the mean, standard deviation and range for all patient-reported outcome measures and experimental tasks. The participants individual scores from the experimental tasks and patient-reported outcome measures are presented in App. 6.

Table 1. Characteristics of the participants (n=29)

Sex [M/F]	16/13
Age [years]	27.8 ± 8.5
Height [cm]	176.1 ± 9.1
Body mass [kg]	76.6 ± 15.5
Months from reconstruction to testing [mean ± SD]	19.0 ± 3.6
Activity level, pre-injury/current [n]	
Level I	23/9
Level II	5/4
Level III	1/14
Level VI	0/2
Graft Type [n]	
ST	26
BPTB	3
Concomitant injuries [n]	
Meniscus	8
Cartilage	2
Meniscus + cartilage	1
Patient-reported outcome measures and experimental tasks [mean ± SD] (Range)	
KOOS-QoL [0-100]	54.4 ± 20.7 (19-94)
TSK-11 [11-44]	23.4 ± 5.1 (12-34)
THD LSI [%]	94.8 ± 6.5 (79.6-105.4)
Quadriceps LSI [%]	92.4 ± 11.9 (71-121.3)
H/Q ratio [%]	52.1 ± 8.2 (38-76)

Anthropometric measurements are presented as mean ± standard deviation. Surgical information is presented as absolute values. Patient-reported Outcome Measures and Experimental Tasks are presented as mean values ± standard deviation and ranges. M = Male, F = Female, n = Number of participants, ST = Semitendinosus, BPTB = Bone-patellar tendon-bone, KOOS-QoL = Quality of Life subscale of the Knee Injury and Osteoarthritis Outcome Score, TSK-11 = Shortened version of the Tampa Scale of Kinesiophobia, THD = Triple hop for distance, LSI = Limb symmetry index, H/Q = Hamstring/quadriceps ratio.

Correlations

The relationships between the predictors is presented in table 2. The Spearman Rank correlation analysis showed a negative significant correlation between KOOS-QoL and TSK-11 (P<0.05). Furthermore, the analysis identified positive significant correlations between KOOS-QoL and both triple hop for distance LSI (P<0.05) and H/Q ratio (P<0.05). All significant correlations were interpreted as moderate. No significant relationships were found between the remaining predictors.

Table 2. Spearman's rank correlation coefficients between the predictors.

	KOOS-QoL	TSK-11	THD LSI	Quadriceps LSI	H/Q ratio
KOOS-QoL	-	-0.430*	0.374*	0.082	0.388*
TSK-11	-	-	-0.019	0.271	-0.129
THD LSI	-	-	-	0.116	0.136
Quadriceps LSI	-	-	-	-	-0.172
H/Q ratio	-	-	-	-	-

* indicates significant correlation at the 0.05 level. KOOS-QoL = Quality of Life subscale of the Knee Injury and Osteoarthritis Outcome Score, TSK-11 = Shortened version of the Tampa Scale of Kinesiophobia, THD = Triple hop for distance LSI = Limb symmetry index, H/Q = Hamstring/ quadriceps ratio.

Risk Assessment

Figure 1 illustrates the normalized score of each participant to the best scoring participant in each patient-reported outcome measure and experimental task. Each color represents a separate patient-reported outcome measure or experimental task. The rank of the participants is indicated by the numbers. Failing the predictors cut-off values was indicated by hatched colors.

Regarding the patient-reported outcome measures, 21 and three participants passed the KOOS-QoL and TSK-11 cut-off values, respectively. Eight participants passed the cut-off value for H/Q ratio. Concerning quadriceps strength LSI, 22 participants achieved the cut-off value. Ten participants passed the cut-off value of triple hop for distance LSI. No participants managed to pass all cut-off values and two participants (P11 and P22) passed none. Conflicts between one predictor and the remaining predictors in the evaluation of risk of a second ACL injury were present. The KOOS-QoL and H/Q ratio diverged from all other predictors in one case. In four cases, the TSK-11 contradicted all other predictors. The quadriceps strength LSI contradicted the remaining predictors in five cases. In no cases, triple hop for distance LSI differed from the evaluation of all other predictors.

Table 3 presents the occurrence of the five lowest scoring participants across the patient-reported outcome measures and experimental tasks.

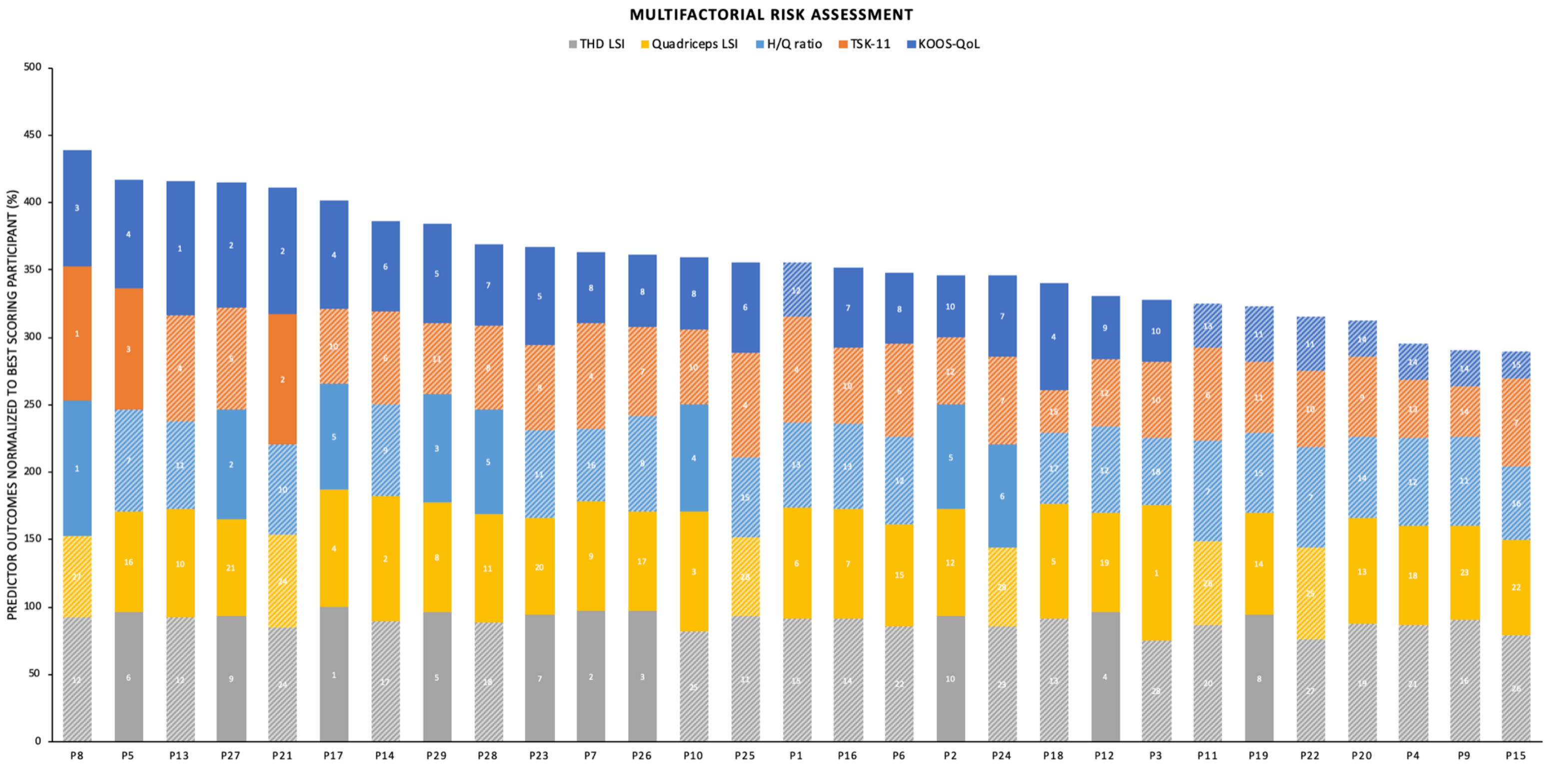

Figure 1. Participants outcomes from the different predictors normalized to the best scoring participant. Each color represents a predictor. The number indicates the ranking of the participant. The hatched colors indicate failure to pass the cut-off values. KOOS-QoL = Quality of Life subscale of the Knee Injury and Osteoarthritis Outcome Score, TSK-11 = Shortened version of the Tampa Scale of Kinesiophobia, THD = Triple hop for distance, LSI = Limb symmetry index, H/Q = Hamstring/quadriceps ratio, P = Participant.

Table 3. Occurrence of patients among the five lowest scoring patients in the predictors.

KOOS-QoL	$P15_3$	$P9_2$	$P4_2$	P20	$P11_2$
TSK-11	$P18_2$	$P9_2$	$P4_2$	P12	$P22_3$
THD LSI	$P3_2$	$P22_3$	$P15_3$	P10	P2
Quadriceps LSI	P24	P25	P8	$P11_2$	$P22_3$
H/Q ratio	$P3_2$	$P18_2$	$P15_3$	P7	P19

1-3 indicates the number of occurrences among the five lowest scoring patients. KOOS-QoL = Quality of Life subscale of the Knee Injury and Osteoarthritis Outcome Score, TSK-11 = Shortened version of the Tampa Scale of Kinesiophobia, THD = Triple hop for distance LSI = Limb symmetry index, H/Q = Hamstring/quadriceps ratio, P = Participant.

Two participants were identified as scoring among the five lowest in three separate predictors. In addition, five participants were identified in two predictors. Nine participants were found to score among the five lowest once. A total of 16 different participants were identified across all patient-reported outcome measures and experimental tasks. All participants represented in table 3 failed to pass the cut-off values of the predictors, in which they are represented.

Discussion

The present study observed significant moderate correlations between KOOS-QoL and both TSK-11, triple hop for distance LSI and H/Q ratio. No participants passed all cut-off values, and two participants achieved none of the cut-off values. Divergence in identifying participants at risk of a second ACL injury were found between the predictors. This supports the hypothesis of complementarity among predictors in the multifactorial test battery when evaluating risk of a second ACL injury.

The associations identified in the present study are similar to previous literature.[23,33] Tichonova et al.[23] identified a moderate correlation (r_s =0.31) between KOOS-QoL and TSK-11 scores in a sample of patients who had undergone ACL reconstruction or meniscectomy and rehabilitation.[23] The present study identified the strongest correlation between KOOS-QoL and TSK-11. The correlation was found to be negative, which was the result of the inverted scoring in the patient-reported outcome measures. A high score in KOOS-QoL equals good knee-related quality of life, whereas a low score in TSK-11 equals a low pain-related fear of movement/reinjury. Psychological responses as the result of injury occurs in most athletes, which causes negative emotions and lack of self-confidence with the injured knee.[34] The patient-reported outcome measures both questions lifestyle changes and confidence in the knee, which might be expressed in the significant negative correlation. Reinke et al.[33] found significant moderate correlation between triple hop for distance LSI and KOOS-QoL (r_s=0.3) in ACL reconstructed patients. The correlation coefficient between KOOS-QoL and triple hop for distance LSI in the present study were equally interpreted as moderate. The triple hop for distance task highlights the lower limbs strength, postural stability and confidence.[28,35] One of four questions in the KOOS-QoL relates to the confidence in the knee, which possibly explains the moderate correlation found in the present study. Muscle strength is displayed in quadriceps strength LSI and to some degree in triple hop for distance LSI.[28] However, no correlation between the predictors were identified, which could possibly be explained by divergence in functional requirements of the tasks.[28] The isokinetic dynamometer is often criticized for the lack of functional relevance to sporting situations, whereas triple hop for distance are designed to replicate the demands of sports.[28,36] Despite the present study showed significant correlations between KOOS-QoL and both TSK-11, triple hop for distance LSI and H/Q ratio, the moderate associations must be interpreted with caution. The lack of strong associations between all experimental tasks and patient-reported outcome measures underline that neither can serve as proxy for the others, when evaluating risk of second ACL injury.

The multifactorial test battery in the present study consists of experimental tasks and patient-reported outcome measures, which have been identified as predictors of a second ACL injury. Thereby, the participants at lower risk of sustaining a second ACL injury might be indicated by passing most cut-off values between the predictors in the test battery. No participants were identified in low risk of a second ACL injury, indicated by none passing all cut-off values. This finding is comparable to a previous study[4], which investigated deficits in ACL reconstructed patients using a multifactorial test battery. The multifactorial test battery consisted of both physiologic and patient-reported components similar to the present study. However, the criteria used for passing the test battery in Gokeler et al.[4], was used without reference to specific cut-off values. Only two out of 28 patients passed the test battery, which gives evidence to an increased difficulty to pass.[4] Despite this increased difficulty implementation of a multifactorial test battery consisting of multiple discharge criteria might be necessary to reduce the incidence rate. This is supported by Kyritsis et al.[15], which found that the athletes not meeting a set of discharge criteria were four times more likely to sustain an ACL graft rupture compared to the athletes meeting the discharge criteria. The set of objective discharge criteria applied did not fulfill the requirements of specific cut-off values and the multifactorial approach due to the lack of patient-reported outcome measures.[15]

Figure 1 shows 11 cases where one predictor conflicts the remaining predictors in the evaluation of risk for secondary ACL injury. Triple hop for distance LSI was the only predictor, which did not oppose against any of the other predictors. Thereby, it was not decisive in classifying risk of a second ACL injury for any of the participants. This finding could indicate omission of the triple hop for distance from the multifactorial test battery. However, triple hop for distance comprises functional relevance to sporting situations in contrast to the remaining predictors.[28] Additionally, the findings from table 3 supports the understanding that each predictor represents different complementary factors related to knee function and secondary ACL injury risk, by identifying 16 different participants among the five lowest scoring participants of each predictor.

Concerning quadriceps strength LSI and H/Q ratio, both measures describes a proportion of muscle strength between either the hamstring and quadriceps muscles or quadriceps muscles between the involved and uninvolved limb.[15,16] This results in the possibility of displaying great strength relationships without accounting for the actual muscle strength. Two patients (P9 and P2) demonstrated this tendency in relation to quadriceps strength LSI by showing high LSI but low actual muscle strength and vice versa (App. 7). This underlines an issue when evaluating muscle strength with LSI, and the use of normative strength data would be advantageous.[37] Normative data would allow comparison of individual values to peers and thereby provide a better understanding of objective muscle strength.[37] Larsen et al.[38] investigated the potential deficits in muscle strength in the reconstructed limb by comparing to either a control group or the uninvolved limb. The study identified a significant reduction of muscle strength in the uninvolved limb compared to the control group.[38] Furthermore, Wellsandt et al.[39] identified strength deficit of the uninvolved limb six months following reconstruction compared to prior reconstruction. This results in a biased comparison, when using the uninvolved limb as reference. Using a measure of the uninvolved limb prior to reconstruction or comparing to the muscle strength of control groups, results in a thorough description of the muscular strength properties around the knee joint.[38,39] Furthermore, the measure of LSI allows participants to score above 100%, indicating that the involved limb performs greater than the uninvolved limb. According to Grindem et al.[16], every percentage point increase in quadriceps strength symmetry reduce the reinjury rate by 3. With reference to this, the participant (P3) scoring 121% in quadriceps strength LSI in the present study had the lowest risk of sustaining a second knee reinjury. However, side-to-side asymmetries between limbs may increase risk of secondary ACL injury, resulting from over-reliance on the strongest limb, which might induce greater stress and torques on the knee.[27]

In summary, three moderate significant correlations were found in the present study, which were in line with previous literature. Furthermore, the predictors involved in the multifactorial test battery diverged in identifying patients at risk of a second ACL injury, based on the cut-off values of the predictors and the incidence rate. These findings support the understanding that each predictor quantifies different factors related to knee function and secondary ACL injury risk. This complementarity supports the multifactorial approach of combining both physiologic and psychological components in the evaluation of risk of a second ACL injury.

Limitations and strength of the study

The findings of the present study must be interpreted with caution. Firstly, the study design used in the present study eliminates the possibility to identify participants sustaining a second ACL injury. Prospective longitudinal studies are needed to further validate the predictors from the multifactorial test battery. Secondly, a small sample size of 29 participants was included. The study sample was not homogeneous in terms of sex, age, activity level and graft type, which causes differentiation from the high-risk population, which most frequently sustain a second ACL injury. While this increased the generalizability, the results might be affected. Thirdly, the inclusion criteria regarding time since surgery allowed a two-year difference between participants. Fourthly, the cut-off values for quadriceps strength LSI and H/Q ratio needs to be addressed. These were selected based on the mean values of the patients not sustaining a knee reinjury. Therefore, these cut-off values might not be ideal in evaluation of a safe RTS. Finally, movements biomechanics predictive of second ACL is not included in the multifactorial test battery in the present study. In our previous work (unpublished data, 2019)[13], we proposed the biomechanical predictors as the strongest for a second ACL injury. Involvement of these predictors would have challenged the clinical applicability of the test battery. An important strength of this study was the selection of the predictors, which were identified and reported in the previous phase of this work (unpublished data, 2019).[13]

Conclusion

In conclusion, KOOS-QoL showed significant moderate association with both TSK-11, triple hop for distance LSI and H/Q ratio. The predictors from the multifactorial test battery showed divergence in identifying participants at risk of second ACL injury. This evidence supports applying a multifactorial approach in the decision-making process of RTS after ACL reconstruction.

The proposal of this multifactorial test battery could provide relevant data during rehabilitation to identify deficits in factors known to predict second ACL injury. This contribute to the development of targeted rehabilitation interventions with the purpose of obtaining the lowest reinjury risk upon RTS.

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