Clinical Decision Algorithm Associated With Return to Sport After Anterior Cruciate Ligament Reconstruction

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Context: Understanding the factors that predict return to sport (RTS) after anterior cruciate ligament reconstruction facilitates clinical decision making.

Objective: To develop a clinical decision algorithm that could predict RTS and non-RTS based on the differences in the variables after anterior cruciate ligament reconstruction.

Design: Cross-sectional study.

Setting: University laboratory.

Patients or Other Participants: A total of 150 athletes in any sport involving deceleration, jumping, cutting, or turning enrolled in the study. All participants answered the International Knee Documentation Committee and Anterior Cruciate Ligament Return to Sport After Injury (ACL-RSI) questionnaires and performed balance and isokinetic tests.

Main Outcome Measure(s): The classification and regression tree (CART) was used to determine the clinical decision algorithm associated with RTS at any level and RTS at the preinjury level. The diagnostic accuracy of the CART was verified.

Results: Of the 150 participants, 57.3% (n = 86) returned to sport at any level and 12% (n = 18) returned to sport at the preinjury level. The interactions among the peak torque extension at 300°/s >93.55 Nm, ACL-RSI score >27.05 (P = .06), and postoperative time >7.50 months were associated with RTS at any level identified by CART and were factors associated with RTS. An ACL-RSI score >72.85% was the main variable associated with RTS at the preinjury level. The interaction among an ACL-RSI score of 50.40% to 72.85%, agonist : antagonist ratio at 300°/s ≤63.6%, and anteroposterior stability index ≤2.4 in these participants was the second factor associated with RTS at the preinjury level.

Conclusions: Athletes who had more quadriceps strength tended to RTS at any level more quickly, even with less-than-expected psychological readiness. Regarding a return at the preinjury level, psychological readiness was the most important factor in not returning, followed by a better agonist : antagonist ratio and better balance.

Key Words: classification and regression tree, muscle strength, postural balance, prediction rules

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Key Points

- The combination of quadriceps strength, Anterior Cruciate Ligament Return to Sport After Injury (ACL-RSI) score, and postoperative time was associated with return to sport (RTS) at any level.
- The ACL-RSI score alone and the combination of ACL-RSI score, agonist : antagonist ratio, and anteroposterior stability index were related to RTS at the preinjury level.
- The clinical decision algorithm can guide the treatment of athletes by focusing on factors necessary for RTS, especially at the preinjury level.

Anterior cruciate ligament (ACL) injury can affect an athlete's ability to decelerate, jump, cut, and turn.[1] Thus, anterior cruciate ligament reconstruction (ACLR) aims to restore joint stability[2] and enable a safe return to sport (RTS) at the preinjury level,[3] especially high-level activities.[4] Postoperative rehabilitation aims to reduce symptoms, restore function, reduce the risk of reinjury, and enable the athlete to RTS at the preinjury level.[3]

However, not all athletes can RTS at the preinjury level. The rates of return vary from 33% to 65%.[2,5] Despite the lack of consensus on the criteria for determining the ideal time to RTS after ACLR,[4] certain factors have been associated with RTS and the risk of reinjury, such as sex, age,[5] quadriceps strength deficit, limitation of knee range of motion,[6] negative psychological responses (eg, fear of reinjury and loss of motivation or interest in the RTS),[7] and neuromuscular dysfunction.[8] Even if these factors are relevant in isolation, difficulties exist in establishing their relationship with—and, thus, their influence on—RTS when viewed together. Functional single-hop tasks are usually included in the RTS criteria and have been shown to predict future injury risk.[9] The other criteria are not often considered.

Greater confidence in sport performance and less fear of reinjury in months 4,[10] 6, and 12 postinjury discriminate between who does and who does not RTS.[11] Good knee function seems to be related to RTS[10] and to quadriceps strength.[12] Isokinetic tests commonly assess the asymmetry between limbs without appropriate regard for quadriceps

strength or even the quadriceps : hamstrings strength ratio.[4] Postural stability is altered in individuals after ACLR,[13] although whether it is associated with RTS at the preinjury level remains unclear.[14]

Investigators have evaluated isolated factors associated with RTS after ACLR, yet research on classification algorithms that examine the differences between groups that returned to the sport and those that did not remains limited. Thus, our aim was to develop a clinical decision algorithm that could predict RTS and non-RTS based on the differences in certain variables (postoperative time, Anterior Cruciate Ligament-Return to Sport After Injury [ACL-RSI] score, International Knee Documentation Committee [IKDC] score, balance and isokinetic testing) after ACLR.

METHODS

Study Design

This cross-sectional study was conducted in the Laboratory of Analysis of Human Movement of the Department of Physical Therapy at the Federal University of Ceará from November 2014 to January 2018. It was approved by the Ethics Committee at the university (protocol #1.000.404), and all participants signed a written consent form.

Sample

A total of 161 participants were recruited through information disseminated in the university hospital, outpatient clinics, and orthopaedic, trauma, and sports clinics. The participants were recreational athletes, aged at least 16 years, and active in any sport that involved deceleration, jumping, cutting, or turning, such as basketball, soccer, or volleyball. The participants' ACL injuries had to (1) be complete as proven by magnetic resonance imaging and by the Lachman and anterior drawer tests and (2) have been surgically treated at least 6 months earlier (as established in the literature on RTS[3,15]) with a complete or nearly complete rehabilitation process associated with some level of sport participation. Those who were in the final phase of rehabilitation could participate in the study if they (1) were more than 6 months postoperative, (2) had sufficient knee confidence to perform the tests, and (3) had no edema, complete range of motion, and the ability to perform the tests safely.[16] The rehabilitation was neither controlled nor accompanied. Hamstrings or patellar tendon grafts were permitted. Volunteers with concomitant injuries such as meniscal lesions, cartilage degeneration, and adjacent ligament injuries already treated were accepted as long as these conditions did not prohibit test or sport performance.

Recruits were excluded if any of the following were present: knee pain at the time of evaluation (pain > 3/10 if it prevented or impaired test performance); incomplete extension, flexion <110°, or both; lower limb fracture, edema, or surgery performed <6 months earlier. In case of bilateral ACLR, the most recent surgical procedure was considered. To approximate the findings to clinical practice, we decided not to exclude participants with bilateral lesions to determine if this would affect the RTS.

To assess the difference between those returning to the sport (at any level or the preinjury level) and those who did not return, we divided the participants between RTS at any level (RTS group) and no RTS at any level (N-RTS group).

Then, the same sample was divided between RTS at the preinjury level (RTS-PI) and no RTS at the preinjury level (N-RTS-PI). All participants answered 2 dichotomous (*yes* or *no*) questions: (1) "Have you returned to the sport?" Based on their answers, the participants were divided into the RTS and N-RTS groups. (2) "Did you return to the same level as before the injury?" Depending on their answers, the participants were again divided into the RTS-PI and N-RTS-PI groups.[17] After the allocations, we analyzed the results of the questionnaires and tests.

Data Collection

Initially, participants were asked to complete an evaluation form consisting of clinical and anthropometric characteristics. All were asked if they had returned to sport after surgery and rehabilitation. All participants answered the IKDC and ACL-RSI questionnaires and performed the isokinetic and balance tests. To avoid bias, the participants answered the evaluation form and both questionnaires without interference from the examiner. For this same reason, the isokinetic testing was performed last, to prevent the fatigue that might interfere with performance during the balance test.

Questionnaires. The 10 items of the IKDC are scored on a scale of 0 to 100, with 100 representing optimal function of the knee. The ACL-RSI has 12 items to examine the 3 psychological constructs identified as being associated with RTS: emotions, confidence in sport performance, and reinjury risk assessment. The score ranges from 0 to 100; the higher the score, the better the participant's psychological response.[18] Both questionnaires have been culturally adapted and validated for the Brazilian Portuguese population.[19,20]

Balance. To evaluate postural stability, we used the Balance System SD dynamometer (Biodex Medical Systems, Inc, Shirley, NY). Five stability levels were tested in 3 sets of 20 seconds separated by 10 seconds of rest. During the rest period, the participant was instructed not to move the assessed limb from its position and to keep the opposite limb on the side of the equipment. The uninjured limb was evaluated first. For each repetition, the test began at level 6, which is more stable, and ended at level 2, which is more unstable. The participant performed the test barefoot on the platform, following the foot-positioning guidelines by adhering to the equipment instructions and with the knee of the evaluated limb flexed to 10°, arms at the sides of the body, and eyes facing the screen. During the test, the participant was encouraged to keep the platform in the neutral position and to avoid touching the sidebars or the surface of the device with the foot of the unassessed limb (Figure 1A). The test was repeated if the participant used this support more than 3 times. The overall stability index, mediolateral stability index, and anteroposterior stability index (APSI) were analyzed.[21]

Isokinetic Dynamometer. Before the evaluation of quadriceps and hamstrings strength on the isokinetic dynamometer, each participant completed a 5-minute stationary bicycle warm-up.[22] Positioning in the isokinetic dynamometer was as follows: with the participant sitting in the chair, (1) the popliteal fossa was positioned 2 cm from the end of the seat, (2) the hip was positioned at 85° of flexion, (3) the device's axis of movement was aligned with

Figure 1. Biodex System 4 Pro (Biodex Medical Systems Inc, Shirley, NY). A, Postural-stability test. B, Isokinetic test for knee extension and flexion.

the intercondylar line of the knee, and (4) the lever arm was held 2 cm above the lateral malleolus. Belts were used to stabilize the trunk, abdomen, and thigh of the assessed limb (Figure 1B). Maximum extension and flexion were established, followed by testing for an adequate initial knee position at 90° of flexion and weighing of the test limb. The participant's information (eg, dominance and injured limb) were registered in the device's system. The protocol consisted of 5 repetitions with a maximum speed of 60°/s and 15 repetitions with a maximum speed of 300°/s and a range of 110°. Continuous oral encouragement was provided.[22] The isokinetic dynamometer expresses values of peak torque (PT) and torque normalized by weight and calculates the limb symmetry index (LSI). The agonist:antagonist ratio (A:AN ratio) and the LSI were calculated according to the following formulas, respectively:

$$A : AN \ Ratio = \frac{(Hamstring \ Peak \ Torque)}{(Quadriceps \ Peak \ Torque)} \times 100$$

$$LSI = 100 - [(Injured \ Limb/Uninjured \ Limb) \times 100].$$

Statistical Analysis

We determined the data distribution using the Kolmogorov-Smirnov test. Descriptive statistics, independent *t* tests, and χ^2 tests were used to characterize the sample. Data analysis was performed using SPSS (version 22.0; IBM Corp, Armonk, NY).

The classification and regression tree (CART) was used to develop the clinical decision algorithm associated with RTS at any level and RTS at the preinjury level. The CART is a nonparametric, binary recursive statistical resource for multivariate data that uses dichotomous divisions to create the classification algorithm. The most important variables tend to appear in the top nodes and have the greatest effect.

The values of the lower nodes remain related to the classification algorithm analysis. In addition, CART can deal with missing values.[23] A 10-fold cross-validation was used to develop the clinical decision rules. The variables inserted into the model were postoperative time (time between ACLR and assessment); PT for extension and flexion at 60°/s and 300°/s; torque normalized by weight for extension and flexion at 60°/s and 300°/s; A:AN ratio of the injured limb at 60°/s and 300°/s; LSI for extension and flexion at 60°/s and 300°/s; the overall stability index, medial-lateral stability index, and APSI; and the IKDC and ACL-RSI questionnaire scores. At the top of the classification algorithm is the parent node, which contains the set of information to be analyzed. The parent node was divided into child nodes, which are as pure as possible for the dependent variables.[23] The cutoff values for the parent node of 10% and the child node of 5% of the sample values were considered.

The diagnostic accuracy of the CART model for identifying those who returned to the sport at any level and those who returned to the sport at the preinjury level was verified by calculating the sensitivity (SN), specificity (SP), positive likelihood ratio (+LR), negative likelihood ratio (−LR), and odds ratio (OR).

According to the tests of those who reported not having returned at the preinjury level, *SP* was defined as the percentage of people who did not return to sport or did not return at the preinjury level because it had few false-positives. According to the tests of those who reported having returned at the preinjury level, *SN* was defined as the percentage of people who returned to sport or returned at the preinjury level because it had few false-negatives. A +*LR* is the ratio of the true-positive to false-positive patients, and a −*LR* is the ratio of the true-negative to false-negative patients. When we analyzed the values independently, the tests with high SN and low −LR were useful to exclude RTS or RTS-PI, and the tests with high SP and high +LR were useful to confirm RTS or RTS-PI.

The OR was calculated to verify the possibility of the same event occurring in both the exposed and unexposed groups.[24] We considered the participants whose cut scores identified the probability of returning to the sport or returning at the preinjury level as the exposed group and those whose cut scores indicated the probability of not returning to the sport or not returning at the preinjury level as the unexposed group.

RESULTS

Eleven participants were excluded: 6 because of exacerbated knee pain (>3/10) during the tests, 4 because of a recent fracture of the lower limb, and 1 because of flexion deficit >110°. Characteristics of the 150 participants are presented in Table 1. No significant or surgically treated chondral lesion was present in the sample. Moreover, the number of concomitant or bilateral lesions did not differ between groups. The test values and questionnaires scores by group are shown in Table 2.

Among the demographic variables, only the time between surgery and follow-up (postoperative time) was different between the RTS and N-RTS groups and between the RTS-PI and N-RTS-PI groups and thus, we included it in the CART analysis (Table 1). Postoperative time was a mean of

Table 1. Clinical and Anthropometric Characteristics of the Study Population (N = 150)

Variable	Returned to Sport (n = 86)	No Return to Sport (n = 64)	Returned to Sport at the Preinjury Level (n = 18)	No Return to Sport at the Preinjury Level (n = 132)
		Group		
Age, y	28.7 ± 7.1	27.4 ± 7.2	30.4 ± 9.8	27.8 ± 6.7
Male sex, %	91.9[a]	79.7[a]	83.3	87.1
Height, cm	173 ± 7.8	173.4 ± 7.3	173.6 ± 7.3	173.1 ± 7.6
Weight, kg	81.7 ±14.4	81.7 ± 15.3	79.9 ± 15.6	82 ± 14.7
Body mass index, kg/m^2	27.8 ± 7.4	27.1 ± 4.1	29.2 ± 14.5[c]	27.3 ± 4[c]
Right-leg dominance, %	89.5	79.7	83.3	85.6
Time between injury and surgery, mo	14.2 ± 31.6[a]	17.4 ± 37.9[a]	13.9 ± 37.7	15.8 ± 33.9
Time between surgery and follow-up, mo	32 ± 29.9[b]	17 ± 18.7[b]	45.3 ± 39.1[c]	23 ± 22.7[c]
Tendon graft, %				
Hamstrings	82.3	91.4	93.8	85.1
Patellar	17.7	8.6	6.3	14.9
Injured limb, %				
Right	55.8	46.1	61.1	59.1
Left	37.2	34.4	38.9	35.6
Bilateral	7	1.6	0	5.3
Concomitant injuries				
Meniscus	51.2	56.3	44.4	54.5
PCL	0	3.1	0	1.5
MCL	1.2	1.6	0	1.5
LCL	1.2	0	0	0.8
Meniscus + PCL	2.3	0	0	1.5
Meniscus + MCL	3.5	0	5.6	1.5
Meniscus + LCL	4.7	0	0	3
Meniscus + PCL + LCL	1.2	0	0	0.8
Meniscus + MCL + LCL	1.2	0	0	0.8
Meniscus + PCL + MCL + LCL	1.2	0	0	0.8
None	32.6	39.1	50	33.3
Soccer athletes, %	57	61.7	38.9[c]	61.8[c]

Abbreviations: LCL, lateral collateral ligament; MCL, medial collateral ligament; PCL, posterior cruciate ligament.

[a] The mean of those who returned to sport was different from that of those who did not return ($P < .05$).

[b] The mean of those who returned to sport was different from that of those who did not return ($P < .001$).

[c] The mean of those who returned to sport at the preinjury level was different from that of those who did not return at the preinjury level ($P < .001$).

32 ± 29.9 months in the RTS group, 17 ± 18.7 months in the N-RTS group, 45.3 ± 39.1 months in the RTS-PI group, and 23 ± 22.7 months in the N-RTS-PI group. Among the 150 participants, 3 were unable to complete the balance test because they had to use the lateral bars for support to maintain balance, thereby invalidating the test for those difficulty levels. In addition, 1 patient chose not to perform the isokinetic test on the injured limb for fear of reinjury. We processed the missing data using CART.

Return to Sport at Any Level

Among the 150 participants, 57.3% (86) returned to sport at any level. Peak torque extension at 300°/s, ACL-RSI score, and postoperative time were identified by the classification algorithm as factors associated with RTS. The interactions among the peak torque extension at 300°/s >93.55 Nm ($P = .07$), ACL-RSI score >27.05 ($P = .06$), and postoperative time >7.50 months ($P = .04$) and the interaction between extension PT at 300°/s ≤ 93.55 Nm and postoperative time >35.5 months ($P = .04$) were factors associated with RTS (Figure 2).

The model was able to correctly associate 67 (77.9%) of the 86 participants who returned to sport and 54 (84.3%) of

the 64 participants who did not RTS. The diagnostic accuracy and OR of the model are shown in Table 3.

Return to Sport at the Preinjury Level

Among the 150 participants, only 12% (n = 18) returned to sport at the preinjury level. The ACL-RSI score, A:AN ratio at 300°/s, and APSI stability index were determined by the classification algorithm to be factors associated with RTS-PI. An ACL-RSI score >72.85% was the main factor associated with RTS-PI ($P = .06$). The interaction among an ACL-RSI score of 50.40% to 72.85%, A:AN ratio at 300°/s ≤ 63.6% ($P = .02$), and APSI ≤ 2.4 ($P = .02$) in these participants was the second factor associated with RTS-PI. The main factors associated with N-RTS-PI were the interaction between scores <50.40% on the ACL-RSI ($P = .01$) and an APSI >1.25 ($P = .001$). The interactions between an ACL-RSI score of 50.40% to 72.85% and an A:AN ratio >63.6% or those between an A:AN ratio ≤63.6% and APSI >2.4 were predictors for N-RTS-PI (Figure 3).

The model was able to correctly associate 17 (94.4%) of the 18 participants who returned to sport at the preinjury level and 121 (91.6%) of the 132 participants who did not

**Table 2. Isokinetic, Balance, and Questionnaire Results (N = 150)**

Variable	Returned to Sport (n = 86)	No Return to Sport (n = 64)	Returned to Sport at the Preinjury Level (n = 18)	No Return to Sport at the Preinjury Level (n = 132)
Peak torque, injured limb, Nm				
Extension, 60°/s	180.9 ± 56.3[b]	147.1 ± 57.9[b]	198.4 ± 52.9[c]	162.3 ± 58.8[c]
Flexion, 60°/s	97.8 ± 26.1[b]	81.9 ± 28.1[b]	104.1 ± 30.3[c]	89.3 ± 27.3[c]
Extension, 300°/s	108.4 ± 29.7[b]	88 ± 34.6[b]	113.9 ± 29.5	97.8 ± 33.4
Flexion, 300°/s	65.6 ± 15.6[b]	57.2 ± 15.3[b]	69.4 ± 18.4[c]	61 ± 15.4[c]
Peak torque/body weight, injured limb, %				
Extension, 60°/s	223.6 ± 69.2[b]	181.2 ± 70.1[b]	241.6 ± 63.2[c]	200.7 ± 72.4[c]
Flexion, 60°/s	119.8 ± 29[b]	102.1 ± 35.8[b]	125.8 ± 30.7	110.5 ± 33.1
Extension, 300°/s	132.8 ± 33.3[b]	111.9 ± 30.3[b]	138 ± 31.8	122 ± 33.4
Flexion, 300°/s	80.6 ± 18.5	74.9 ± 32.2	84.5 ± 21.5	77.3 ± 25.7
Agonist : antagonist ratio, injured limb, %				
60°/s	57.6 ± 18.6	59.5 ± 21.7	53 ± 10.6	59.2 ± 20.8
300°/s	62.4 ± 13.5	64.7 ± 13.6	61.4 ± 7.4	63.7 ± 14.2
Limb symmetry index, %				
Extension, 60°/s	19.8 ± 20.3[b]	32.5 ± 21.5[b]	12.4 ± 11.3[c]	27 ± 22.2[c]
Flexion, 60°/s	8.9 ± 14.6[b]	19.3 ± 20[b]	7.9 ± 11.8	14.1 ± 18.4
Extension, 300°/s	16.3 ± 14.5[a]	21.3 ± 15.3[a]	10.8 ± 6.9[c]	19.4 ± 15.5[c]
Flexion, 300°/s	5.5 ± 16.3	9.9 ± 20.5	1.3 ± 16.2	8.2 ± 18.4
Stability index, °				
Overall	5.5 ± 2.5	6 ± 3	4.8 ± 1.8	5.8 ± 2.8
Anterior-posterior	3.3 ± 1.7	3.3 ± 1.9	2.6 ± 1.1	3.4 ± 1.9
Medial-lateral	3.8 ± 2	4.3 ± 2.5	3.7 ± 1.6	4.1 ± 2.3
International Knee Documentation Committee score, %	75.5 ± 14.9[b]	66.6 ± 16.2[b]	87.2 ± 9.5[d]	69.5 ± 15.6[d]
Anterior Cruciate Ligament Return to Sport After Injury score, %	52.4 ± 17.6[b]	40.3 ± 18.6[b]	70.6 ± 19.1[d]	44.1 ± 16.6[d]

[a] The mean of those who returned to sport was different from that of those who did not ($P < .05$).

[b] The mean of those who returned to sport was different from that of those who did not ($P < .001$).

[c] The mean of those who returned to sport at the preinjury level was different from that of those who did not return at the preinjury level ($P < .05$).

[d] The mean of those who returned to sport at the preinjury level was different from that of those who did not return at the preinjury level ($P < .001$).
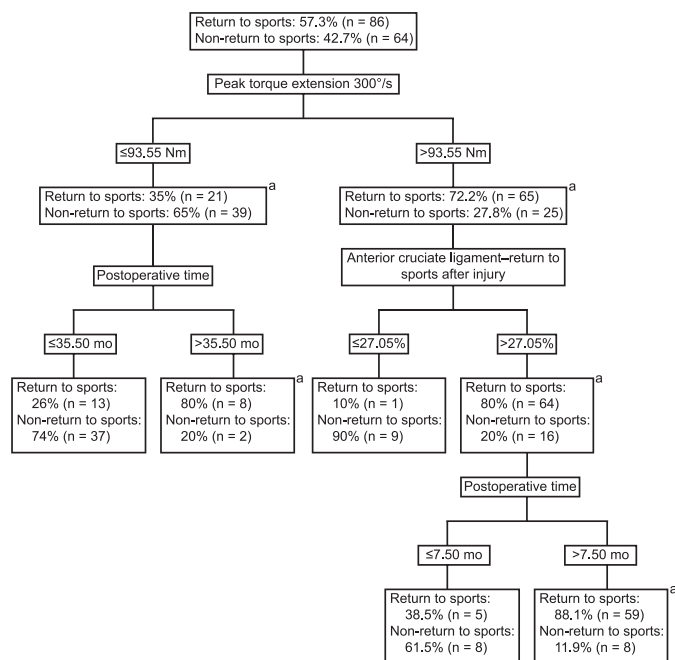
Figure 2. Classification and regression tree (CART) of return to sport at any level. [a] Return-to-sport interaction.

RTS at the preinjury level. The diagnostic accuracy and OR of the model are provided in Table 3.

DISCUSSION

Our findings support the hypothesis that the interaction of factors related to RTS after ACLR can identify the differences between participants eligible for RTS at any level and those eligible for RTS at the preinjury level. Whereas the classification algorithm for the RTS at any level was better at identifying those who could return at any level with good sensitivity, the algorithm for RTS at the preinjury level best identified those who did not return at the preinjury level with good specificity. The variables

Table 3. Diagnostic Accuracy of the Classification and Regression Tree (CART) Models, Value (95% Confidence Interval)

Measure	Returned to Sport	Returned to Sport at the Preinjury Level
Sensitivity	87.0% (77.4%, 93.5%)	60.7% (40.5%, 78.5%)
Specificity	73.9% (62.3%, 83.5%)	99.1% (95.5%, 99.9%)
Positive likelihood ratio	3.3 (2.2, 4.9)	74.0 (10.2, 533.5)
Negative likelihood ratio	0.1 (0.1, 0.3)	0.4 (0.2, 0.6)
Odds ratio	19.0 (8.1, 44.3)	187 (22.7, 1541.1)
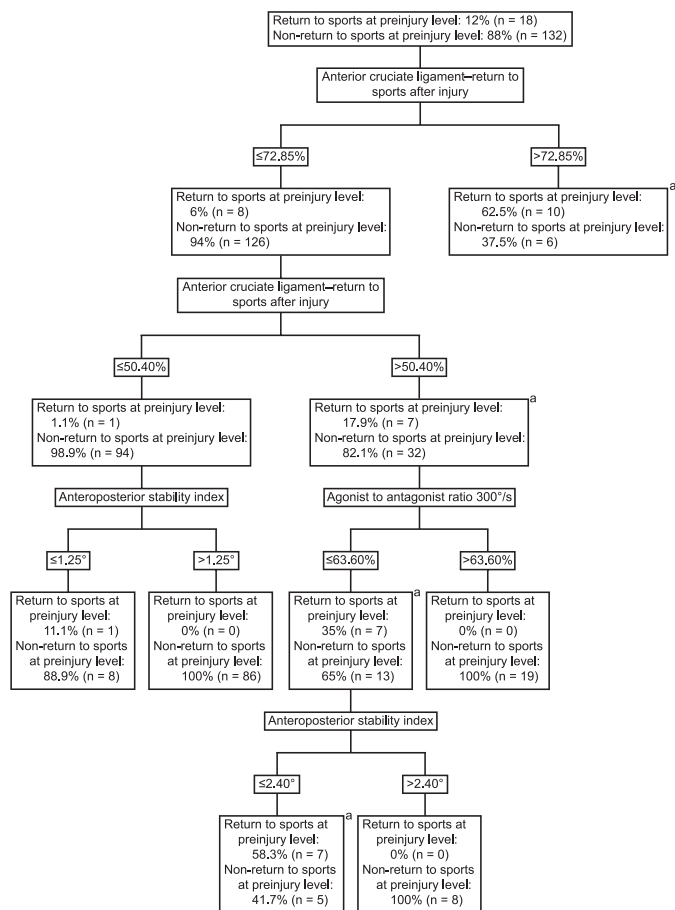
Figure 3. Classification and regression tree (CART) of return to sport at the preinjury level. [a] Return-to-sport interaction at the preinjury level.

selected by CART addressed the main factors described that could interfere in the RTS: muscular strength,[25] functional capacity,[4,25] psychological readiness,[7] balance,[8] and postoperative time.[9]

Decision making for RTS after ACLR is complex and involves several factors. The linear approach of using isolated variables to predict RTS is reductionist and possibly inadequate for clinical decision making. At times, this thinking does not directly relate to an isolated variable and the release for sport practice. The evaluation of readiness to RTS should be based on the complexity of the interaction of the evaluated variables and on finding the main determining factors associated with RTS.[26] Thus, our results show clinical relevance in quantifying the moment when each variable affects the RTS in an analysis in which all are integrated and in facilitating the identification of the correct moments for clinical decision making.

Quadriceps peak torque at 300°/s and its combination with ACL-RSI score and postoperative time were important factors associated with RTS at any level. The combination of ACL-RSI score, A : AN ratio at 300°/s, and anteroposterior stability was an important factor associated with RTS at the preinjury level.

Return to Sport at Any Level

At the top of the classification algorithm is quadriceps peak torque at 300°/s. Greater quadriceps symmetry at RTS

reduces the rate of reinjury.[9] In addition, a quadriceps strength deficit is 1 of the modifiable factors associated with a low return rate at the preinjury level.[4] However, a cohort of 58 athletes tested 6 months after ACLR demonstrated no differences in quadriceps strength deficits of 10% and 20% between participants who returned at the preinjury level and those who did not.[14] Only the quadriceps peak torque of the uninvolved limb seemed to be different between the groups: the group that returned to the sport exhibited an average of 223.3 Nm, and the group that did not RTS had an average of 251.7 Nm ($P = .05$).

We also analyzed the interaction with psychological readiness. According to the authors of the ACL-RSI,[18] the mean score of participants who gave up the sport was 39.1%. However, the results of Webster et al[18] were not consistent with ours: a score of 39.1% signified a withdrawal from the sport and a score of 27.05% signified an RTS at any level. This finding may reflect our looking at different factors than those of Webster et al.[18] A good ACL-RSI score would not be relevant to return at any level because our participants had excellent strength levels. In addition, the RTS group had a longer postoperative time than the N-RTS group, which could have made psychological readiness less important in the interaction with other variables.

Regarding the postoperative period, the longer the recommended period for discharge is, the better the chances of tissue, psychological, and technical recovery when accounting for all the RTS factors at any level. Time also seemed to be directly relevant in reducing the risk of reinjury, with a 51% reduction for each month of delay until the ninth month.[9] The difference in the postoperative times before releasing patients may be due to our sample being mostly composed of recreational athletes. The possibility of a shorter rehabilitation time without a change in the risk of reinjury exists because of reduced sport demands.

Return to Sport at the Preinjury Level

Better sport performance and higher confidence levels are required to RTS at the preinjury level. Therefore, higher scores on the ACL-RSI indicate greater confidence and motivation, increasing the possibility of the athlete returning to the sport at the preinjury level.[5,11] Satisfaction with personal support, confidence in the rehabilitation, and attaining physical and clinical standards required for sport performance are essential for developing confidence regarding RTS.[11] The ACL-RSI mean score of the participants who returned at the competitive level was 76.3%.[18] The difference in the scores may be attributed to the fact that our sample was mostly composed of recreational athletes.

The A : AN ratio was also a predictor of RTS at the preinjury level. The quadriceps : hamstrings ratio was altered in athletes after ACLR compared with healthy athletes. This change was due to the dominance of the hamstrings over the quadriceps[27,28]: knee-extensor function may be impaired by the combination of quadriceps dysfunction and additional hamstrings coactivation.[28] The detraining period involving muscle atrophy, interruption of ACL proprioceptive information, pain, effusion, and a surgical procedure causes changes in neuromuscular

balance.[27] The greater hamstrings : quadriceps strength ratio seems to be more associated with the RTS at the preinjury level than with the isolated strength of these muscle groups.

The APSI was a factor associated with N-RTS at the preinjury level. According to Howells et al,[29] the athletes with ACLR had greater anteroposterior instability than the control group during a unilateral task. Culvenor et al[13] found that athletes who underwent ACLR had average mediolateral and anteroposterior stability increases of 23% and 14%, respectively, in comparison with healthy athletes. However, these findings do not appear to be clinically relevant. Researchers[14] who studied 58 athletes after primary ACLR noted no difference in postural stability (using the Biodex Balance System) between those who returned at the preinjury level after 6 months and those who did not return.

Athletes who have more quadriceps strength tend to RTS at any level more quickly, even with less than expected psychological readiness. Regarding RTS at the preinjury level, psychological readiness is the most important factor associated with not returning, followed by a better A : AN and better balance. The other studied variables, although relevant when viewed in isolation, did not seem to have the same effects when viewed in association with the IKDC score and concomitant and bilateral injuries. Moreover, concomitant injuries and the recovery of muscle symmetry did not appear to be related,[30] indicating that these factors may also lack relevance in the RTS. In clinical practice, the interactions between factors should be evaluated because variables that are important when viewed in isolation may not have the same relevance when viewed in conjunction with others.

This study has 4 limitations that should be considered. First, other factors may influence the RTS, such as performance on the hop tests, which were not included in the present study because of a logistical problem and because they are well-known criteria of RTS. We chose to verify the domains of knee function (IKDC score), psychological readiness (ACL-RSI score), postural stability (Biodex Balance System), and muscle function (isokinetic dynamometer). Future authors may consider evaluating the hop tests. Second, the participants' rehabilitation protocols were not controlled because we could not determine what worked for each one: for example, whether the muscular strengthening was adequate and whether rehabilitation included the RTS. Third, participants in the final phase of rehabilitation were included in the study because in-progress rehabilitation can influence the status of RTS sport at the preinjury level. Fourth, the cross-sectional design of the study prevented an assessment of cause and effect.

CONCLUSIONS

The combination of quadriceps strength at 300°/s, ACL-RSI score, and postoperative time was a factor associated with RTS at any level. The ACL-RSI score was the predictor of RTS at the preinjury level, followed by the A : AN ratio at 300°/s and APSI. The classification algorithm provided by CART, especially at the preinjury level, helps in clinical decision making about the appropriate treatment and the best time to release these athletes. The association of other factors, such as hop-test performance, with RTS should be verified in future studies.

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