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# Preoperative Predictors for Noncopers to Pass Return to Sports Criteria After ACL Reconstruction

**Erin H. Hartigan**[1,2], **Joseph Zeni Jr.**[1], **Stephanie Di Stasi**[1], **Michael J. Axe**[1,3], and **Lynn Snyder-Mackler**[1]

[1]University of Delaware [2]University of New England [3]First State Orthopaedics, Newark

## Abstract

Less than 50% of athletes pass criteria to return to sports (RTS) 6 months after ACL reconstruction (ACLR). Using data on 38 noncopers, we hypothesized that preoperative age, quadriceps strength index (QI), and knee flexion moments (KFM) during gait would predict the ability to pass/fail RTS criteria and that preoperative quadriceps strength gains would be predictive of passing RTS criteria. Gait analysis and strength data were collected before and after a preoperative intervention and 6 months after ACLR. Age, QI, and KFM each contributed to the predictability to pass or fail RTS criteria 6 months after ACLR. Collectively, the variables predict 69% who would pass and 82% who would fail RTS criteria 6 months after ACLR. Younger athletes who have symmetrical quadriceps strength and greater KFM were more likely to pass RTS criteria. Further, 63% of those who increased preoperative quadriceps strength passed RTS criteria, whereas 73% who did not failed. Increasing quadriceps strength in noncopers before ACLR seems warranted.

### Keywords

anterior cruciate ligament; noncopers; return to sports

After anterior cruciate ligament (ACL) rupture and reconstruction, many athletes desire to return to participation in their preinjury sports. Return to sports rates vary among investigations, though it is clear that not all athletes are able to return to their preinjury sports following ACL reconstruction (Lee et al., 2008; Nakayama et al., 2000; Smith et al., 2004). An overwhelming number of health care professionals recommend that an athlete can return to sports six months after ACL reconstruction (Alvarez et al., 2008; Aune et al., 2001; Barrett et al., 2002; Cascio et al., 2004; Ejerhed et al., 2003; Marcacci et al., 2003; Moller et al., 2001; Noyes et al., 2000; Peterson et al., 2001; Pinczewski et al., 2002; Scranton et al., 2002; Wagner et al., 2005; Webster et al., 2001). Despite the prevalence of this blanket recommendation, no prospective studies have validated the 6 month time frame for returning



Correspondence to: Erin H. Hartigan.

Erin H. Hartigan *(Corresponding Author)* is with the Physical Therapy Department and Biomechanics and Movement Sciences Program, University of Delaware, Newark, DE, and with the Physical Therapy Department, University of New England, Portland, ME. Joseph Zeni Jr. and Stephanie Di Stasi are with the Physical Therapy Department and Biomechanics and Movement Sciences Program, University of Delaware, Newark, DE. Michael J. Axe is with the Physical Therapy Department and Biomechanics and Movement Sciences Program, University of Delaware, Newark, DE, and with First State Orthopaedics, Newark, DE. Lynn Snyder-Mackler is with the Physical Therapy Department and Biomechanics and Movement Sciences Program, University of Delaware, Newark, DE.

to sports. In addition, there is a paucity of evidence that indicates which measurable variables help predict the likelihood of successfully returning our athletes to sports.

There is a differential response in athletes acutely after an ACL rupture (Eastlack et al., 1999) and patients can either be classified as a coper or noncoper based on functional performance. Copers are able to continue playing high-level sports without the need for ACL reconstruction, while noncopers have strength deficits and episodes of knee buckling (Fitzgerald et al., 2000a). Therefore, noncopers traditionally undergo ACL reconstruction before attempting to return to sports (Hurd et al., 2008b). Acutely after injury, non-copers present with quadriceps strength deficits on the involved limb (Eastlack et al., 1999; Rudolph et al., 2001), have altered movement patterns (Rudolph et al., 2001), and are older than those classified as potential copers (Hurd et al., 2008c). Even after ACL reconstruction, less than 50% of noncopers pass the return to sports criteria 6 months after ACL reconstruction (Hartigan et al., 2010). Preoperative and postoperative quadriceps strength influences functional outcomes after ACL reconstruction, with stronger patients having better outcomes after ACL reconstruction (Eitzen et al., 2009; Hurd et al., 2008a; Keays et al., 2003; Lewek et al., 2002; Noyes et al., 1991). Despite this, not all patients who regained postoperative quadriceps strength meet other return to sports criteria, indicating that quadriceps strength is not the only factor related to returning to sports (Hartigan et al., 2010).

Reduced external knee flexion moments are prevalent after ACL injury and persist after ACL reconstruction (Alkjaer et al., 2003; Bush-Joseph et al., 2001; DeVita et al., 1998; Hart et al., 2010; Rudolph et al., 1998, 2001; Rudolph & Snyder-Mackler, 2004; Timoney et al., 1993). The external knee flexion moment during stance is counteracted by activation of the quadriceps muscles. Noncopers typically demonstrate a reduced external knee moment, which may be a direct result of insufficient quadriceps strength (Rudolph et al., 2001), or in the presence of adequate quadriceps strength, may demonstrate a flawed neuromuscular strategy in these individuals. In addition, noncopers use excessive muscle activity in the hamstring and gastrocnemius muscles, which are antagonistic to the quadriceps muscles, hindering the ability of the quadriceps muscles to counteract the external flexion moment (Rudolph et al., 2001). The inability to use normal kinetic and neuromuscular control strategies may impact the ability to achieve higher level goals, including returning to sport, although this has not been empirically tested.

Age may also factor into recovery after ACL injury and surgery. The middle-aged population is more likely to be classified as noncopers (Hurd et al., 2008c), underscoring older age as a potential predictor of worse function after ACL rupture. Older individuals have delayed healing time and have difficulty overcoming muscle atrophy, which may strongly affect postoperative outcomes (Jarvinen & Kannus, 1987; Kannus et al., 1988; Sakuma & Yamaguchi, 2010).

The University of Delaware utilizes a strict set of criteria that must be achieved in order for athletes to return to sports after ACL reconstruction (Fitzgerald et al., 2000c). The athlete must demonstrate at least 90% symmetry between the injured and noninjured limb for quadriceps strength, timed hops, and hops for distance. In addition, the athletes must also have a score of 90% or greater on the Knee Outcome Survey—Activities of Daily Living Scale and the global rating scale of knee function. Noncopers have a poor prognosis of passing this strict return to sport criteria within six months of surgical reconstruction (Hartigan et al., 2010). Determining preoperative variables that predict the success of passing these return to sports criteria postoperatively may help improve the prognosis of athletes classified as noncopers.

Because preoperative status is related to outcomes after ACL reconstruction, our clinic has incorporated preoperative physical therapy to improve strength and neuromuscular control strategies for noncopers who are planning to undergo ACL reconstruction. A previous randomized control trial using a preoperative neuromuscular physical therapy intervention called *perturbation training* produced superior outcomes in a high-functioning subset of ACL injured patients. Perturbation training is a neuromuscular retraining program that teaches patients to use appropriate movement strategies in response to rapid, multidirectional perturbations at the foot/board interface. Patients who received perturbation training were 5 times more likely to successfully return to sports without further complaints of the knee giving way compared with those who did not receive perturbation training (Fitzgerald et al., 2000b). However, this same intervention did not have the equivalent effects in the noncoper cohort of ACL injured patients (Hartigan et al., 2010). This lack of effect in the noncoper group and the poor postoperative outcomes demonstrated by noncopers 6 months after ACL reconstruction prompted us to evaluate which specific variables contributed to return to sports success.

The purpose of this study was twofold. The first aim of the study was to determine which preoperative variables predict the ability of noncopers to return to sport six months after ACL reconstruction. We hypothesized that age, quadriceps strength and knee flexion moments would predict the ability to pass or fail return to sport criteria 6 months after ACL reconstruction. The second aim of the study was to determine if subjects who gained strength after the preoperative physical therapy intervention would have a better prognosis postoperatively. We hypothesized that preoperative quadriceps strength gains would be predictive of passing return to sports criteria after ACL reconstruction.

## Methods

Thirty-eight athletes diagnosed with an isolated ACL rupture were included in this analysis (Table 1). Athletes who participate in level 1 (e.g., basketball) or level 2 (e.g., soccer or heavy manual laborers) activities on a regular basis were recruited (Daniel et al., 1994; Hefti et al., 1993). Subjects were eligible for the study if they were classified as a noncoper during a screening by a physical therapist. An athlete is classified as a noncoper if he/she presents with any one of the following: (1) at least one episode of the knee giving way during daily activities; (2) a score of less than 80% on the Knee Outcome Survey—Activities of Daily Living Scale Questionnaire; (3) a score of less than 80% on the 6-m timed hop test; or (4) a score of less than 60% on the global rating of knee function questionnaire (Fitzgerald et al., 2000a). In addition, to be included in the study athletes must have been between 13 and 55 years old, had a complete ACL rupture confirmed by magnetic resonance imaging, demonstrated greater than a 3 mm difference in anterior translation between limbs using the KT 1000 arthrometer and were within 10 months of the ACL injury. Subjects were excluded if they presented with a full thickness chondral lesion greater than 1 $cm^2$, had a repairable meniscus tear or a concomitant grade 3 ligamentous injury to another ligament in the knee. The protocol for this study was approved by the University of Delaware Human Subjects Review Board and informed consent was obtained from all subjects.

All subjects received 10 sessions of preoperative physical therapy. This cohort was part of a larger randomized clinical trial, described in depth elsewhere (Hartigan et al., 2009). The rehabilitation regimen consisted of a progressive isotonic and isokinetic strengthening exercises to maximize quadriceps strength in the involved limb using high loads and low repetitions (Manal & Snyder-Mackler, 1996). In addition to the strength training, 18 subjects also received specialized perturbation training (Fitzgerald et al., 2000c) to improve the neuromuscular control of the injured limb. No differences in return to sports rates (Hartigan et al., 2010) or measured variables (Table 2) existed between those patients who received perturbation training and those patients who did not; therefore, data from the perturbation and strength groups were pooled for this study. Functional and biomechanical data were collected before and following the completion of the preoperative intervention and 6 months after ACL reconstruction.

Return to sport (RTS) criteria were based upon the work of Fitzgerald and colleagues (Fitzgerald et al., 2000c). Passing RTS criteria required at least 90% symmetry between the injured and noninjured limb for quadriceps strength and four hop scores (single, crossed, and triple hops for distance and a 6 m timed hop) described by Noyes and colleagues (Noyes et al., 1991). In addition, passing RTS criteria required that the athletes score at least 90% on two self-report questionnaires: the Knee Outcome Survey—Activities of Daily Living Scale (KOS-ADLS) and the global rating scale. These questionnaires provide reliable, valid and responsive assessments of functional limitations of the knee during daily activities and global knee function compared with the level of function before the injury, respectively (Irrgang et al., 1998).

Three months after ACL reconstruction, athletes could attempt to pass criteria to return to sport if they had achieved four clinical milestones: knee effusion grade of 1+ or less; full knee range of motion compared to the uninvolved limb; quadriceps strength index of at least 80%; and no pain with hopping while braced. An athlete was unable to attempt to pass RTS criteria until they achieved these clinical milestones, regardless of the time since surgery. If the athlete was unable to score at least 90% on any of the RTS criterion, they did not pass and were not cleared to return to sport. Athletes were able to retest, every 2–4 weeks depending upon functional gains, until they achieve a passing score.

## Biomechanical Variables

Motion analyses were performed in accordance with previously described protocols (Hurd & Snyder-Mackler, 2007). Retro-reflective markers and tracking shells were affixed to the subjects' pelvis and lower extremities to track limb motion. A static standing calibration was collected before gait analysis. A passive, three-dimensional, eight-camera motion analysis system (Vicon, Oxford Metrics, London, England) was used to capture video data sampled at a frequency of 120 Hz and low-pass filtered at 6 Hz with a fourth-order, phase-corrected Butterworth filter.

Force data were acquired from a single six-component force platform (Bertec Corporation, Worthington, OH) and were sampled at 1080 Hz and filtered with a fourth-order, phase-corrected Butterworth filter with a low-pass cut-off frequency of 40 Hz (Hurd & Snyder-Mackler, 2007). Vertical ground reaction force was used to determine the stance phase of gait and Visual3d software v.3.77 (C-motion, Germantown, MD USA) was used for the calculation of joint angles and moments (Winter, 2005). Knee flexion moments measured at peak knee flexion angle during the stance phase of gait were expressed as external moments normalized to the product of body mass and height. Knee flexion moments at peak knee flexion were chosen as a variable of interest, as noncopers use an aberrant knee moment strategy at this instant in the gait cycle (Rudolph et al., 2001).

Several practice trials, at walking speeds within 1.4–1.6 m/s, were performed through a 13 m walkway to ensure consistent speed, proper foot contact with the force plate without targeting, and visualization of stance limb markers throughout the collection volume. Five usable walking trials were obtained to determine average knee joint angles and moments across the stance phase of gait normalized to 100% of stance. Subjects were required to match their baseline average speed (± 5%) at each follow-up data collection.

## Functional Outcome Measures

Quadriceps force was measured during a maximum isometric contraction on a dynamometer (KIN-COM; Chattanooga Corporation, Chattanooga, TN) with the burst superimposition test, described elsewhere (Kent-Braun & Le Blanc, 1996; Snyder-Mackler et al., 1995). Practice trials, the burst of electrical activity, and verbal encouragement were provided to ensure that a maximum voluntary effort was performed during the task (Chmielewski et al., 2004). Quadriceps strength is operationally defined in this article as the force produced from a maximal voluntary contraction of the quadriceps, before the application of the electrical stimulation during the burst superimposition. The force output was normalized to body mass index (N/BMI). The quadriceps index was defined as the interlimb symmetry of quadriceps strength (force produced by the quadriceps on the involved limb divided by the force produced by the quadriceps on the uninvolved limb and expressed as a percentage).

## Statistical Analysis

Quadriceps strength, quadriceps index and knee flexion moments were measured at baseline testing, upon completion of the 10 preoperative physical therapy sessions, and 6 months after ACL reconstruction (Table 3). To address the first aim of the study, a binary logistic hierarchical regression was used to determine the predictive ability of age, quadriceps index and knee flexion moment on return to sport status 6 months postoperatively. Predictor variables were entered in order of age, quadriceps index, and knee flexion moment at peak knee flexion. This order allowed our nonmodifiable predictor of age to be accounted for first. Knee flexion moments were entered last to test whether this variable would significantly predict the ability to pass or fail RTS criteria after accounting for the strength variable. To address the second aim of the study, the magnitude of the change in quadriceps strength was calculated preoperatively (e.g., involved limb quadriceps force measured upon completion of the 10 preoperative physical therapy sessions minus the force measured at baseline). This change in preoperative quadriceps strength (N/BMI) between these two preoperative time points were used to predict postoperative return to sport rates. A binary logistic regression was used to test the hypothesis that patients who gained strength in the involved limb would have a greater return to sports rate at 6 months.

An independent *t* test was used to compare walking speeds between those who did and did not pass RTS criteria 6 months after ACL reconstruction. A Pearson correlation test was used to evaluate if the predictor variables for the first aim were independent from each other (Table 4). Independent *t* tests were used to determine if significant differences in postintervention (preoperative) variables existed between those who did and did not pass the RTS criteria six months after surgery (Table 5). After verifying that statistical assumptions of a regression were met, the three variables were entered into a binary logistic hierarchical regression.

## Results

Age, quadriceps strength index, and knee flexion moments in the involved limb during gait were significantly different between those who passed and failed RTS criteria when measured after the preoperative intervention (Table 5). Each of the predictor variables tested for this aim were independent of one another (Table 5). Each step of the binary logistic regression significantly added to the predictive ability of the model (Table 6). Walking speed was not different between those who passed RTS criteria (1.50 m/s +0.10) and those who failed return to sport criteria (1.57 m/s +0.11) at 6 months after ACL reconstruction ($p$ = .084).

Age alone correctly predicted 73% of those who failed RTS criteria, with older noncopers performing significantly worse (Age: odds ratio = 0.91). Adding quadriceps strength index into the model significantly improved the ability to predict 82% of those athletes who fail, with lower strength symmetry predicting greater failure (Quadriceps strength index: odds ratio = 1.066). Adding knee flexion moments significantly improved the model's ability to predict 69% of those who would pass RTS criteria, with higher knee flexion moments predicting greater success (Knee Moment: odds ratio = 219.254). Since a 1.0 unit increase in knee flexion moment during walking is not likely, the odds ratio for a 0.1 unit increase in knee flexion moment was 1.714. The final model, which used all three predictor variables, resulted in the highest $R^2$ value with 69% correct prediction of those who did pass RTS and 82% correct prediction of those who did not pass RTS criteria 6 months after surgery (Nagelkerke $R^2$ = .46; model $p < .001$) (Table 6).

Improvement in quadriceps strength after the pre-operative physical therapy intervention was also significantly predictive of RTS at 6 months (Nagelkerke $R^2$ = .156; model $p$ = .030). The model correctly predicted 63.2% of the patients who demonstrated increases in quadriceps strength as being more likely to return to sports at 6 months (odds ratio = 1.12). Similarly, patients who did not demonstrate strength gains after the preoperative intervention were more likely not to return to sports; the model correctly predicted 72.7% of patients who had a reduction or no change in quadriceps strength to fail RTS criteria at 6 months.

## Discussion

The results of this study helped to answer two important clinical questions. First, we determined that age, quadriceps strength symmetry and knee flexion moments in the involved limb were meaningful predictors of the ability to pass or fail RTS criteria 6 months after surgery. Second, those noncopers who did not improve in quadriceps strength during a preoperative strengthening physical therapy intervention were more likely to fail criteria to return to sports; conversely, those who improve their quadriceps strength preoperatively improve their chances at returning to sports within 6 months of ACL reconstruction. This supports our hypotheses that strength and biomechanical characteristics can predict postoperative function and preoperative interventions that maximize quadriceps strength may afford patients with optimal outcomes after surgery.

Age was entered first into the model because it is a nonmodifiable risk factor. Middle-aged adults have poorer functional knee stability acutely after ACL rupture (Hurd et al., 2008c) and our results suggest that age continues to influence functional outcomes after ACL reconstruction. Athletes, coaches, and surgeons should be aware that age plays a role in function and recovery after ACL injury. Further research is warranted to determine whether older athletes need additional time or different rehabilitation protocols to improve the prognosis of returning to preinjury levels after ACL injury and reconstruction.

Quadriceps strength was added next to the model as preoperative quadriceps strength has been shown to influence functional outcomes in individuals with ACL deficiency and after ACL reconstruction (Eitzen et al., 2009; Hurd et al., 2008a; Keays et al., 2003; Lewek et al., 2002; Noyes et al., 1991). Our results confirm that both age and quadriceps strength influence functional abilities in the noncoper cohort and can successfully predict who will be more apt to fail RTS criteria postoperatively; age and quadriceps indices correctly predicted 82% of noncopers who failed RTS criteria. Age and quadriceps strength can be easily assessed preoperatively. Furthermore, noncopers can get stronger with intensive preoperative physical therapy (Hartigan et al., 2010), and this improvement in strength was also positively correlated with the ability to return to sports 6 months after surgery. Our results support the need for older individuals with quadriceps strength asymmetry to undergo rehabilitation to improve their quadriceps strength index before undergoing ACL reconstruction. Improving quadriceps strength symmetry and overall quadriceps force production preoperatively in older noncopers will increase the prognosis of passing criteria to return to sports 6 months after surgery.

Lastly, knee flexion moments were added to the binary logistic regression. After accounting for age and quadriceps strength, knee flexion moments further contributed to the prediction of passing RTS criteria postoperatively. Reduced knee flexion moments, prevalent in noncopers acutely after ACL injury (Rudolph et al., 2001), affect the ability of noncopers to pass RTS criteria postoperatively. Our results suggest that noncopers who do not reduce their involved limb's knee flexion moments preoperatively will be more likely to pass RTS criteria postoperatively. The question remains as to whether knee moments are modifiable in the noncoper cohort.

Our noncopers did not have the same number of attempts to pass the RTS criteria. Though few subjects passed the RTS criteria on their first attempt, most required multiple attempts to pass and more than half of these noncopers were unable to pass RTS criteria 6 months after ACL reconstruction (Hartigan et al., 2010). The standard of care, postoperative physical therapy, and goals to achieve clinical milestones to attempt and ultimately pass the RTS criteria were similar for all of our subjects. Noncopers are able to learn successful strategies over time and can return to sports even without undergoing ACL reconstruction (Moksnes et al., 2008). In fact, 70% of those who were classified as noncopers acutely after injury learned to cope without their ACL and returned to sports after 1 year of nonoperative treatment (Moksnes et al., 2008). Clearly, a successful strategy has been adopted by noncopers who return to sports participation. However, this strategy has yet to be determined.

Our findings indicate that preoperative knee moments are predictive of postoperative function, though we cannot infer whether noncopers can modify their neuromuscular control strategy at the peak knee flexion angle during the stance phase of gait. Symmetrical quadriceps strength does not guarantee symmetrical knee excursion during gait (Hartigan et al., 2009), nor does it ensure that athletes will pass RTS criteria (Hartigan et al., 2010). Our results indicate that noncopers' quadriceps strength indices are not related to knee flexion moments, suggesting that those who demonstrate the ability to generate greater knee flexion moments do not necessarily do so. The lack of a relationship between quadriceps strength and knee moments is possibly due to aberrant neuromuscular strategies demonstrated by noncopers' altered muscle firing patterns (Rudolph et al., 2001). Studies that include electromyography analyses are necessary to elucidate what neuromuscular strategies are used by our noncopers who demonstrated significantly higher external knee flexion moments. Noncopers make up the majority of the population with ACL rupture (Hurd et al., 2008b); however, our predictions are generalizable to the noncoper cohort only and not to copers.

Although patients who demonstrated an improvement in quadriceps strength demonstrated a greater ability to return to sports in 6 months, quadriceps strength gains only explained a small part of the variance of our subject population (Nagelkerke $R^2$ = .156). However, the high percentage of failure (72.7%) in those who did not demonstrate quadriceps strength gains preoperatively suggests the importance of addressing strength in this population. Further investigations are needed to elucidate what additional characteristics can be addressed during preoperative physical therapy to maximize postoperative outcomes and expedite the ability of athletes to return to high-level sporting activities.

## Conclusion

Our findings enhance the ability to predict which noncopers will be successful in passing RTS criteria or not after ACL reconstruction. Aberrant preoperative knee moments and asymmetrical quadriceps force appear to contribute to an athlete's ability to pass and fail return to sports criteria postoperatively, respectively. Though age cannot be modified, athletes need to be counseled that passing rigorous criteria deemed necessary to return to sport after ACL reconstruction can be more challenging as one ages. Focusing on increasing quadriceps strength preoperatively, especially in our older athletic population of noncopers, may improve their ability to pass RTS criteria postoperatively.

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**Table 1**

Subject demographics

| | **Mean (*SD*)** | **Ranges** |
|---|---|---|
| Age (years) | 28.6 (10.3) | 14–48 |
| BMI (kg/m$^2$) | 28.9 (5.2) | 21.1–44.7 |
| Injury to Screen (weeks) | 8.9 (8.5) | 1–37 |
| Gender | 11 females; 27 males | |

Abbreviations: BMI = body mass index.

## Table 2

Preoperative group comparisons

| | Perturbation | Strength | *p* Values |
|---|---|---|---|
| Walking Speed (m/s) | 1.53 (0.13) | 1.54 (0.09) | 0.782 |
| Age (years) | 27.5 (10.4) | 29.4 (10.4) | 0.588 |
| Quadriceps Index (%) | 90.5 (10.8) | 93.2 (17.9) | 0.595 |
| Knee Moments (N·m/kg·m) | 0.386 (0.177) | 0.310 (0.156) | 0.168 |

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**Table 3**

Means (*SD*) for quadriceps strength, quadriceps strength index, and knee moments over time

| | Involved Limb Quadriceps Strength (N/BMI) | Quadriceps Strength Index (%) | Involved Knee Flexion Moment (N·m/kg·m) |
|---|---|---|---|
| Baseline | 36.5 (12.8) | 87.5 (12.6) | 0.32 (0.16) |
| Following 10 preoperative PT sessions | 38.9 (15.3) | 92.0 (15.1) | 0.34 (0.17) |
| Six months after ACL reconstruction | 40.2 (13.6) | 95.2 (13.1) | 0.38 (0.15) |

## Table 4

Pearson correlations

| | | Age | Quadriceps Index | Knee Moments |
|---|---|---|---|---|
| Age | Pearson Correlation | 1 | −.269 | −146 |
| | Sig. (2-tailed) | — | .102 | .382 |
| | Number | 38 | 38 | 38 |
| Quadriceps Index | Pearson Correlation | −269 | 1 | .304 |
| | Sig. (2-tailed) | .102 | — | .063 |
| | Number | 38 | 38 | 38 |
| Knee moments | Pearson Correlation | −146 | .304 | 1 |
| | Sig. (2-tailed) | .382 | .063 | — |
| | Number | 38 | 38 | 38 |

**Table 5**

Preoperative variables of those who do and do not pass return to sport (RTS) criteria at 6 months

| **Predictors** | **Fail RTS 6 months (*SD*)** | **Pass RTS 6 months (*SD*)** | ***p* Value** |
|---|---|---|---|
| Age (years) | 32.1 (9.5) | 23.6 (9.4) | 0.01 * |
| Quadriceps Strength Index (%) | 86.7 (12) | 99.2 (16) | 0.01 * |
| Involved Knee Flexion Moment at Peak Knee Flexion (N·m/kg·m) | 0.29 (0.16) | 0.41 (0.15) | 0.017 * |

* $P < 0.05$.

## Table 6

Hierarchical binary logistic regression using variables collected after the preoperative intervention

| | | | | | Percent Correct | | |
|---|---|---|---|---|---|---|---|
| **Steps** | **Step $p$ Value** | **Model $p$ Value** | **Odds Ratio** | **Nagelkerke $R^2$** | **Fail** | **Pass** | **Overall** |
| Age | 0.008 | <0.008 | 0.91 | 0.225 | 73 | 63 | 68 |
| Age and QI | 0.028 | <0.003 | 1.066 | 0.358 | 82 | 56 | 69 |
| Age, QI, KFM | 0.042 | <0.001 | 219.254 | 0.46 | 82 | 69 | 76 |

Abbreviations: QI = quadriceps index; KFM = knee flexion moment.