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DOES CONCOMITANT MENISCECTOMY OR MENISCAL REPAIR AFFECT THE RECOVERY OF QUADRICEPS FUNCTION POST-ACL RECONSTRUCTION?

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Abstract

PURPOSE—To determine the effect of concomitant meniscal surgery on the recovery of quadriceps activation and strength at a time when individuals return to sport following ACL reconstruction.

METHODS—Forty-six individuals that were cleared for participation following ACL reconstruction were invited to participate in this study. Participants were placed into groups according to surgical reports (ACL-only, n=24; Meniscal Repair, n=12; Meniscectomy, n=10). Quadriceps strength was quantified using isokinetic and isometric measures. Isokinetic strength was collected at 60°/second in concentric mode. Isometric strength was collected at 90° of knee flexion. Quadriceps activation was assessed using the burst superimposition technique and quantified via the central activation ratio. One-way ANOVAs were utilized to detect if differences existed in quadriceps activation and strength between groups. Where appropriate, *post hoc* Bonferroni multiple comparison procedures were used.

RESULTS—Quadriceps activation (P=n.s.) and strength (Isokinetic: P=n.s.; Isometric: P=n.s.) were not different between groups.

CONCLUSION—Concomitant meniscectomy or meniscal repair did not affect the recovery of quadriceps activation and strength at a time when individuals return to sport following ACL reconstruction. Though group differences in quadriceps function were not detected, all participants demonstrated levels of quadriceps activation failure that are below healthy individuals at a time when they were returned to sport. Given that persistent quadriceps activation failure is detrimental to knee function, rehabilitation protocols that target quadriceps activation failure should be developed and employed post-reconstruction.

LEVEL OF EVIDENCE—III

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Keywords

anterior cruciate ligament; knee; meniscus; quadriceps; rehabilitation

INTRODUCTION

The anterior cruciate ligament (ACL) is the most commonly disrupted ligament in the knee joint, however isolated ACL tears are uncommon [8]. Concomitant injuries to the menisci occur in approximately 64% to 77% [25,14] of individuals that experience ACL rupture and often necessitate surgical intervention. Though many research studies have investigated the consequences of ACL reconstruction on knee joint health, less is known about the additive effect of meniscal surgery on post-operative outcomes [15,20].

Quadriceps weakness is common and persists despite aggressive rehabilitation protocols in patients who have undergone ACL reconstruction [18]. This persistent weakness has been shown to have deleterious consequences on the knee joint, which negatively impacts quality of life [12] and has been found to contribute to the development of post-traumatic osteoarthritis [24]. Quadriceps activation failure, the inability to completely contract the quadriceps muscle due to altered neural signaling [7], has been identified as a mechanism that contributes to the lingering strength deficits following ACL injury and reconstruction [6]. Quadriceps activation failure is thought to cause strength deficits by limiting the ability for an individual to volitionally utilize their quadriceps muscle during activity [7]. The presence of quadriceps activation failure can significantly impact the rehabilitation process as a reduction in volitional activation can delay or even prevent effective quadriceps strengthening [19].

Quadriceps activation failure and quadriceps strength have been hypothesized to be influenced by the degree of knee joint trauma, with more trauma equaling more activation failure [4] and greater strength deficits [8]. Work by Hurley and colleagues [8] showed that patients with more extensive knee injuries (including meniscal trauma) had greater activation failure and less strength than the uninjured limb. Similarly, in patients with isolated meniscectomy, investigators have found greater quadriceps activation failure and reduced quadriceps strength as compared to healthy controls [1]. Thus, it seems that individuals with concomitant meniscal surgery and ACL reconstruction may demonstrate greater levels of quadriceps activation failure and more quadriceps weakness as compared to those with isolated ACL reconstruction. Despite the prevalence of concomitant meniscal surgery, few data exist examining the effects of such surgery on quadriceps muscle strength [15,20], while the effect of concomitant meniscal surgery on activation failure is unknown following ACL reconstruction.

Given that previous evidence suggests that greater trauma to the knee results in greater quadriceps activation failure [4], it seems plausible that concomitant meniscectomy and meniscal repair may induce an even greater amount of activation failure than isolated ACL reconstruction, which may alter the recovery of quadriceps strength. Thus, it is important for clinicians to understand the effect that meniscal repair or meniscectomy has on the recovery of quadriceps activation and strength as this information can help improve outcomes post-

surgery. To our knowledge, this is the first investigation to examine the potential additive effect of concomitant meniscectomy or meniscal repair on neural alterations and strength post-reconstruction. Data generated from this investigation is clinically relevant, as it can help determine if more focused rehabilitation protocols need to be developed for individuals with concurrent meniscal surgery. As such, the primary purpose of this investigation was to determine the effect of meniscal repair and meniscectomy on the recovery of quadriceps activation and strength at a time when individuals are cleared to go back to sport following ACL reconstruction.

MATERIALS AND METHODS

Participants

Forty-six individuals that have been cleared for participation following ACL reconstruction were invited to participate in this retrospective study (Table 1). Potential participants were excluded if they: had a previous history of surgery (other than the ACL reconstruction) to either knee, suffered a previous ACL injury, or had a known heart condition. Pregnant females were also excluded. Surgical reports were obtained to report any concomitant meniscal damage that required surgical intervention (Table 1).

The details of the post-operative rehabilitation protocol can be found in Appendix 1. All participants completed a standard post-operative rehabilitation at one orthopedic outpatient clinic that consisted of two to three physical therapy appointments per week that began during the first post-operative week following surgery and concluded approximately six months-post surgery. In general, the rehabilitation protocol emphasized full knee extension range of motion immediately and knee flexion as tolerated, progression of functional exercises, quadriceps re-education and muscle strengthening. Variation between rehabilitation protocols existed based on concomitant meniscal surgery, effusion, quadriceps control, gait, age and individual's response to treatment.

Return to Sport

All participants were tested for quadriceps strength and activation once they had been cleared by their orthopedic surgeon to return to sport. Return to sport required patients to complete a basic three-week agility program and a leg press test. To pass the leg press test, the clinical protocols requires that patients need to complete at least 15 repetitions at 100% of body weight with the involved limb from a resting neutral position to a depth of 90° of knee flexion. If a patient was unable to successfully pass the leg press test or did not complete the agility program their clearance for participation was delayed until both of these criteria were met.

Quadriceps Activation Measurement

Quadriceps activation failure was quantified using the central activation ratio (CAR) assessed via the superimposed burst (SIB) technique [21]. To record the joint torque produced during SIB testing, patients were positioned in an isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, Shirley, NY, USA) with their hips flexed to 90°, their back supported, and their ACL limb and torso strapped securely into the dynamometer. SIB

testing was initiated by asking participants to perform maximal voluntary isometric contractions (MVICs), while their ACL limb was flexed to 90° and with two minutes rest between each trial. There was no limit to the number of MVIC trials a participant could perform, but contractions were ceased when an improvement in torque was no longer evident. This procedure helped to ensure that each participant's MVIC was achieved and has been used by others [17]. Verbal encouragement and visual feedback of the real-time torque output were also provided to help facilitate maximal effort. Once maximal knee extension torque was achieved, participants were asked to perform an additional MVIC and maintain this contraction for approximately five seconds. A custom written LabVIEW (LabVIEW version 8.5, National Instruments, Austin, TX, USA) program was set to deliver a supramaximal electrical stimulus (100 pulses per second, 600 microsecond pulse duration, 100 millisecond phase duration, and 130 volts) to the quadriceps via a Grass S88 Dual Output Square Pulse Stimulator (S88, Grass Technologies, West Warrick, RI, USA) with an SIU8T Transformer Stimulus Isolation Unit (SIU8T, Grass Technologies, West Warrick, RI, USA) attached [22]. The stimuli were delivered through two self-adhesive electrodes (Dura-Stick II [7×13 cm] Chattanooga Group, Hixson, TN, USA) applied proximally over the vastus lateralis and distally over the vastus medialis once the MVIC was reached and subsequently dropped by one Newton meter. Automated stimulus delivery was utilized because it has been shown to improve stimulus timing and thus reduce measurement error [11]. Quadriceps activation failure was determined using the CAR formula (Equation 1). The participant's peak torque generated immediately prior to the delivery of the electrical stimulus was divided by the peak torque generated as a result of the electrical stimulus (SIB). A CAR of 100 was used to represent complete quadriceps activation or no QAF [10]. The average CAR across three trials was used for statistical analysis.

$$\text{Central Activation Ratio} = \left(\frac{\text{MVIC}}{\text{MVIC}+\text{SIB}}\right) * 100 \quad \text{Equation 1}$$

Quadriceps Strength Measurements

Quadriceps strength was assessed utilizing isokinetic and isometric measurements. To accomplish this, participants were positioned in the isokinetic dynamometer using the same methods as previously described. Isokinetic strength was measured by asking participants to perform three maximal concentric knee actions at a speed of 60°/second. Isometric strength was assessed using the average of three maximal voluntary isometric trials (MVICs) that were collected just prior to the delivery of the electrical stimulus during SIB testing. The average torque across the isokinetic and MVIC trials were normalized to body mass and averaged for statistical analysis.

This investigation was approved by the University of Michigan IRBMED (Approval # HUM00016184). Prior to testing, all participants provided written informed consent.

Statistical Analysis

Participants were retrospectively placed into groups according to surgical reports (Table 1) and One-way Analysis of Variance tests were utilized to detect differences in quadriceps

activation and strength (isokinetic and MVIC), subject demographics, and time to return to sport. Where appropriate, *post hoc* Bonferroni multiple comparison procedures were used. The alpha level was set *a priori* at P≤0.05. Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) software version 21.0 (IBM Corp., Armonk, NY, USA).

To determine the clinical meaningfulness of our results, standardized effect sizes (Cohen's *d* = (meniscectomy or meniscal repair – ACL-only)/pooled standard deviation)) and 95 % confidence intervals (95% CI) were calculated to assess differences in quadriceps strength and activation between the meniscectomy and/or meniscal repair groups as compared to isolated ACL reconstruction. Effect sizes were interpreted using the guidelines describe by Cohen [3] with values less than 0.5 interpreted as *weak*; values ranging from 0.5 to 0.79 interpreted as *moderate* and values greater than 0.8 interpreted as *strong*.

RESULTS

Subject Demographics

No difference in subject demographics was found between groups (age: P=n.s.; height: P=n.s.; mass P=n.s., Table 1).

Quadriceps Activation

Quadriceps activation was not different between groups (P=n.s., Table 2). Weak effect sizes with 95% CI that cross zero were found between the meniscectomy and ACL-only groups (Cohen d=0.42, 95% CI=−0.32, 1.17), as well as between the meniscal repair and ACL-only groups (Cohen d=0.13, 95% CI=−0.57, 0.82) indicating that a clinically irrelevant difference between quadriceps activation was found between groups.

Quadriceps Strength

Quadriceps isokinetic and MVIC strength was not different between groups (Isokinetic: P=n.s.; MVIC: P=n.s., Table 2). Moderate to strong effect sizes were detected between the meniscectomy and ACL-only groups (Isokinetic: Cohen d=0.88, 95% CI=0.12, 1.65; Isometric: Cohen d=0.69, 95% CI=−0.07, 1.44). Whereas weak effect sizes with 95% CI that cross zero were found between the meniscal repair and ACL-only groups (Isokinetic: Cohen d=0.45, 95% CI=−0.25, 1.15; Isometric: Cohen d=0.08, 95% CI=−0.61, 0.78). The isokinetic strength measure between the meniscectomy and ACL-only group was the only effect size measure with a 95% CI that did not cross zero, indicating that a trend towards greater isokinetic strength in the meniscectomy group was found. However this difference was not found to be statistically significant and the width of the CI was large, indicating wide variability in this measurement.

Return to Sport

No difference in time to return to sport was found between groups (P=n.s., Table 1).

DISCUSSION

The primary purpose of this investigation was to determine the effect of concomitant meniscal repair and meniscectomy on the recovery of quadriceps activation and strength at a time when individuals are cleared to go back to sport following ACL reconstruction. Gaining a better understanding of the effect that concomitant meniscal surgery has on post-operative quadriceps function can help to identify if alterations in current ACL rehabilitation protocols need to be made in order to address deficits that may exist in these populations. The most important finding was that patients that undergo meniscectomy or meniscal repair in concert with ACL reconstruction do not demonstrate differences in quadriceps activation or strength as compared to those that experience an isolated ACL reconstruction. This data is clinically relevant as it indicates that post-operative differences in quadriceps function do not exists between individuals with concomitant meniscal injuries and ACL reconstruction and should aid in future scientific studies investigating the deleterious consequences of quadriceps dysfunction post-reconstruction.

Quadriceps Activation

Our results indicate that quadriceps activation failure is not different between individuals that experience concomitant meniscectomy, meniscal repair and isolated ACL reconstruction. Thus, concurrent meniscal surgery with ACL reconstruction does not seem to alter the ability for an individual to volitionally utilize their quadriceps muscle during activity at a time when they are returned to sport. To our knowledge, this is the first study to analyze this relationship. This result was somewhat surprising given that previous research in individuals with extensive knee injuries [8] and with isolated meniscectomies [1] have found extremely high levels of quadriceps activation failure (CAR ~59.5%; [8] CAR~80.9% [1]) that are well below what is typically found in an isolated ACL injured (CAR~87.3% [6,2]) and reconstructed populations (CAR~87.6% [6]). Given that additional meniscal surgical procedures would likely lead to a greater disruption of free nerve endings and mechanoreceptors that are located in the horns and outer two-thirds of the body of the menisci [5] we had anticipated that the disruption of these sensory afferents would cause greater levels of quadriceps activation failure as compared to isolated ACL reconstruction [23]. Though it is not entirely clear as to why individuals with concomitant meniscal surgery did not demonstrate higher levels of activation failure, it is possible that regeneration of mechanoreceptors may have occurred following meniscal repair or meniscectomy. Though evidence of meniscal regeneration has only been found in rabbit animal models [13], it has been shown that proprioception improves following partial meniscectomies in human knees [9]. Clinically, this increase in proprioception may indicate that mechanoreceptor regeneration could occur following surgery. As such, it is possible that mechanoreceptor regeneration may have occurred following meniscal repair and meniscectomy, which improved the volitional muscle activation among groups with meniscal procedures. However, due to the fact that we did not directly measure alterations in mechanoreceptor regeneration this theory should be interpreted with caution. The use of an automated torque-based trigger stimulator used in this study to detect quadriceps activation failure may also help to explain why our work did not detect high levels of activation failure in our patient groups. Recent work by Krishnan et al. [11] have shown that an automated stimulus delivery

improves stimulus timing and reduces measurement error. Thus, the difference in measurement technique could have accounted for some potential differences between our results and others studies that used manual triggering of the stimulus to detect quadriceps activation failure [8].

Quadriceps Strength

Quadriceps strength (isokinetic and MVIC) was not found to be different between groups at a time when individuals were returned to sport. This finding is in agreement with previous work by Øiestad and colleagues [15] who examined individuals at six months post-reconstruction. This data is important given that the quadriceps muscle plays a pivotal role in the dynamic stabilization of the knee joint. Though our data is in agreement with strength outcomes reported at a time when individuals return to sport, more longitudinal data seems to indicate that strength deficits between groups can occur at later time points. Øiestad et al. [15] noted that while no differences in quadriceps strength existed in patients at six months post-surgery, greater deficits emerged later in individuals with concomitant injury (i.e. chondral lesions, meniscal tears, collateral ligament damage) at one, two, and 10–15 years post-surgery as compared to isolated ACL reconstruction. Alternatively, work by Shelbourne and colleagues [20] found that there was no difference in quadriceps strength, range of motion, and performance during single-legged hop tests five to 15 years post-surgery in individuals that had experienced meniscectomy and/or articular cartilage damage as compared to isolated ACL reconstruction. Hence, though our return to play data is in agreement with the current literature, indicating the strength deficits do not exist between individuals with isolated ACL reconstruction and meniscal procedures, the long-term impact of concomitant meniscal surgery on quadriceps strength remains unclear. Furthermore, because pre-operative data was not collected, it is possible that the meniscal repair or meniscectomy group experienced a greater magnitude of strength deficits, or that these individuals were not able to restore their pre-operative strength. Ultimately, more longitudinal research that compares pre-operative strength is needed to either confirm or refute the results of our work and the work of others [15,20].

Return to Sport

Time to return to sport was not different between groups. Thus, though range of motion and weight bearing restrictions often slow the initial stages of rehabilitation for individuals with concomitant meniscal injury; it does not seem to significantly prolong the rehabilitation process. However, it is important not over generalize these results, which were obtained from participants with only patellar tendon grafts and at one orthopedic clinic. If testing had included patients from multiple clinics and/or grafts it is possible that differences between time to return to sport may have differed based on clinic-to-clinic individualized rehabilitation protocols.

Clinical Significance

It is important to highlight that all participants demonstrated greater level of quadriceps activation failure as compared to healthy individuals [6] at a time when they were cleared to go back into participation (Table 2). Though the clinical significance of this result is not entirely clear, it is known that quadriceps activation failure negatively affects strength [7]

and it has been hypothesized that prolonged quadriceps activation failure is a contributing factor to the early onset of osteoarthritis [16]. Thus, more effective rehabilitation protocols that are capable of removing quadriceps activation failure need to be developed in order to help promote the recovery of quadriceps strength as well as potentially improve long-term knee joint health, regardless of concomitant surgery. Secondly, at time patients return to sport it does not seem concomitant meniscectomy or repair results in a longer rehabilitation as compared to isolated ACL reconstruction. Importantly, given the preliminary nature of this investigation, it is pertinent that future work that more comprehensively examines the effects of concomitant meniscectomy on post-operative quadriceps function is performed. Within these investigations, it would be ideal for researchers to recruit larger samples sizes so they could have adequate power to examine the effect of gender, variations in post-operative rehabilitation protocols and graft type on the recovery of quadriceps function.

Conclusion

Quadriceps activation and strength is not different in individuals that experience concomitant meniscectomy or meniscal repair as compared to isolated ACL reconstruction at a time when they return to sport. Importantly, though group differences were not detected, all participants demonstrated levels of quadriceps activation failure that are below healthy individuals at a time when they were returned to sport. Thus, rehabilitation protocols that target quadriceps activation failure should be developed and employed to improve quadriceps function.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Participant Demographics (mean±SD)

	Concomitant Injury (n=46 total)		
	ACL-only (n=24)	**Meniscal Repair (n=12)**	**Meniscectomy (n=10)**
Sex	Female=13	Female=4	Female=2
	Male=11	Male=8	Male=8
Age (yrs)	19.9±5.7	19.6±4.33	20.8±6.7
Height (m)	1.7±0.1	1.77±0.1	1.77±0.1
Mass (kg)	77.0±15.8	74.5±10.3	81.2±19.9
Return to Sport (months)	7.1±1.1	7.5±1.3	7.6±1.3

Table 2

Quadriceps Activation and Strength (mean±SD)

Measure		ACL-only	Meniscal Repair	Meniscectomy
Quadriceps Activation (CAR)		83.9±10.4	85.2±9.2	88.2±9.1
Quadriceps Strength (Nm/kg)	Isokinetic	1.2±0.3	1.3±0.4	1.5±0.5
	Isometric	2.0±0.6	2.1±0.6	2.4±0.4

Abbreviations: CAR; central activation ratio