Original Research

Medial Meniscectomy at the Time of ACL Reconstruction Is Associated With Postoperative Anterior Tibial Translation

A Retrospective Analysis

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Background: Medial meniscal pathology and management have not been associated with postoperative anterior tibial translation (ATT) after anterior cruciate ligament reconstruction (ACLR).

Purpose: The purpose of this study was to evaluate the role of medial meniscal injury and treatment on pre- and postoperative ATT in the setting of primary ACLR. More specifically, the association between repairable medial meniscal tears, medial meniscectomy, and postoperative ATT, along with rates of revision surgery, was examined.

Study Design: Cohort study; Level of evidence, 3.

Methods: A retrospective review was performed for patients who underwent ACLR between January 1, 2010 and December 31, 2015 at a single center. Descriptive data were obtained from an institutional database for a total of 396 patients included in this study and followed for 1 year postoperatively. Statistical analysis was performed to examine associations of meniscal treatment with postoperative ATT measurements made by KT-1000 arthrometer.

Results: A total of 243 patients underwent isolated ACLR with autograft, 72 patients underwent autograft ACLR and partial medial meniscectomy (MMx) (ACLR + MMx), and 81 patients underwent autograft ACLR and medial meniscal repair (MMR) (ACLR + MMR). Patients with ACLR + MMx had higher mean age and body mass index compared with patients in the other groups. Patients who underwent ACLR + MMx had greater postoperative side-to-side ATT compared with patients undergoing ACLR (1.55 mm vs 1.07 mm; $P = .04$) or patients undergoing ACLR + MMR (1.55 mm vs 1.01 mm; $P = .03$). The ACLR + MMx group was less likely to have symmetric (<3-mm side-to-side difference) postoperative ATT compared with the ACLR group (85% vs 93%; $P = .03$). There was no difference in postoperative ATT between ACLR and ACLR + MMR. Postoperative return to the operating room was greater in the ACLR + MRR group compared with the ACLR + MMx group (21.9% vs 8.2%; $P = .05$).

Conclusion: MMx at the time of ACLR led to higher postoperative ATT compared with isolated ACLR or ACLR + MMR.

Keywords: knee; ligaments; ACL; meniscus

Between 120,000 and 200,000 anterior cruciate ligament (ACL) injuries are estimated to occur each year at a rate of 30 to 78 per 100,000 person-years in the United States.[4,16,23,24,30,31] Approximately 100,000 ACL reconstructions (ACLRs) are performed annually, making ACLR one of the most common procedures performed by orthopaedic surgeons.[8]

Despite advances in technique and rehabilitation, ACLR has reported failure rates ranging from 4.5% to

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11% at 2 years postoperatively.[16,17,28,37] There are a large number of risk factors for failed ACLR, including technique, graft type, failure of graft incorporation, age, premature return to high-level activity, psychological readiness, and failure to identify or treat concomitant pathology.[2,10,17,21,37] Associated injuries to the collateral ligaments or coronal/sagittal plane deformities are frequently discussed with ACL graft failure.[19,25,29,34] Meniscal injuries may also be a source of anterior laxity after ACLR.[11,13] The importance of the meniscus as a secondary stabilizer is well understood from biomechanical studies showing that medial meniscal deficiency leads to increased anterior tibial translation (ATT) as well as increased force on the ACL graft in vitro.[20,35,36] It has also been shown that medial meniscal deficiency is associated with increased preoperative ATT.[11] It is therefore hypothesized that medial meniscal deficiency predisposes patients to increased postoperative ATT after ACLR and that medial meniscal repair (MMR) would have similar postoperative ATT to isolated ACLR. However, neither medial meniscal pathology nor its treatment have thus far been associated with postoperative ATT after ACLR.

The purpose of this study is to evaluate whether concomitant medial meniscal injuries and their subsequent management affects the postoperative ATT after ACLR. To answer this question, we designed a retrospective chart review analyzing pre- and postoperative arthrometry data. Our secondary objective was to evaluate the role played by graft choice in postoperative ATT. We hypothesized (1) that patients who underwent a partial medial meniscectomy (MMx) would have increased postoperative ATT compared with patients without medial meniscal pathology or compared with patients who underwent MMR and (2) that bone-patellar tendon-bone autografts would show less postoperative ATT compared with hamstring-gracilis tendon autografts.

METHODS

A retrospective review was performed for ACLR performed between January 1, 2010 and December 31, 2015. The date range was chosen to begin after surgeons in the practice had transitioned from transtibial to anteromedial drilling of the femoral socket. The end date for the study was a transition period after which patients did not routinely have postoperative KT-1000 arthrometry testing by an independent observer. Patient charts were identified from an institutional database of surgical procedures using Current Procedural Terminology codes for ACLR. Institutional review board approval was obtained before initiating the study.

Patient charts were reviewed using the electronic medical record. The independent variable was medial meniscal pathology and treatment: ACLR with or without MMx or MMR. Patient demographic variables included patient age, sex, date of birth, date of injury, date of surgery, body mass index (BMI), nicotine use, history of diabetes, prior surgical history, and preoperative side-to-side manual maximum difference (MMD) on the KT-1000 arthrometer. Surgical details included graft type and diameter, tibial and femoral fixation technique, medial and lateral meniscal pathology and treatment, and concomitant ligamentous pathology and treatment. Postoperative outcomes included revision ACLR, reoperation rate, and postoperative side-to-side MMD on the KT-1000 arthrometer.

Patients were included if they were ≥18 years old at the time of surgery with no prior history of ipsilateral knee surgery, undergoing primary ACLR with autograft hamstring or autograft patellar tendon using interference screw fixation on both femur and tibia. Patients were excluded if they had a history of prior meniscal procedures or underwent concomitant surgery to repair or reconstruct the collateral ligaments or the posterior cruciate ligament; underwent lateral extra-articular tenodesis; or underwent meniscal transplant. Patients were also excluded if they had a history of injury to the contralateral ACL or if they did not follow up for routine postoperative laxity examination.

ACLR was performed by 1 of 5 senior surgeons who performed ≥50 ACLRs annually. ACL graft fixation was performed on the femoral side with an interference screw with or without additional cortical suspensory fixation, based on surgeon preference. ACL graft fixation on the tibial side was performed with an interference screw with or without additional cortical suspensory fixation, based on surgeon preference. Meniscal treatment was performed based on the senior surgeons' intraoperative assessment, and meniscal repair was performed for all repairable tears. Statistical analysis was performed using intent-to-treat analysis rather than based on success or failure of meniscal repair. Postoperative rehabilitation for all patients, regardless of meniscal pathology or treatment, was early mobilization with weightbearing as tolerated in a range of motion brace locked in extension. Once patients demonstrated appropriate quadriceps function, the brace was

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Ethical approval for this study was obtained from Kaiser Permanente Southern California (ref No. 13339).

modified. Patients without meniscal pathology (isolated ACLR) and those who underwent MMx were allowed to wean from the brace once quadriceps function was appropriate. Patients who underwent MMR wore the brace for 6 weeks postoperatively and were restricted from deep knee flexion weightbearing (>90°) for 12 weeks postoperatively.

Patients undergoing ACLR were referred for pre- and postoperative laxity testing using a previously published protocol.[22] All patients treated by the group were referred to a single examiner who was trained to perform laxity testing using the KT-1000 arthrometer. The examiner was involved only in testing and was not involved in patient assessment or rehabilitation protocols. Examinations were performed before surgery, at 6 weeks postoperative, and every 6 weeks thereafter by the examiner until 6 months after surgery using the KT-1000 arthrometer. For patients with multiple differential postoperative MMD measurements, the highest value was used for analysis of postoperative ATT. The highest value was used because low values may underestimate laxity due to patient apprehension. Patients were assessed for symmetry of postoperative ATT using a threshold MMD of ≥3.0 mm.[9] The patient chart was reviewed for subsequent clinic notes and operative reports to determine if the patient returned to the operating room (OR) for ipsilateral or contralateral knee surgery.

A power analysis indicated that 177 patients would be needed to detect a difference of 0.5 mm in ATT at a power of 0.8 assuming an SD of 1.0 mm. Statistical analysis was performed using 2-sample *t* tests for continuous data and 2-sample proportion tests for binary data. Multinomial regression analysis was performed to examine the association of demographic variables with the medial meniscal treatment group including age at surgery, sex, BMI, delay to surgery, and nicotine use. Linear regression analysis was performed to examine the association of preoperative variables with postoperative laxity measurements including delayed surgery, medial meniscal treatment group, BMI, age at surgery, and graft type. Logistic regression analysis was performed to examine the association of preoperative variables with the rate of reoperation, including delayed surgery, medial meniscal treatment, BMI, age, and graft type. *P* values of <.05 were deemed significant. All statistical tests were performed in R using R Studio with the tidyverse, rstatix, and ggpubr (R package; Version 0.6.0) libraries.[26,27]

RESULTS

A total of 1299 charts were identified from the institutional database. After filtering for duplicates and excluding allograft reconstructions, 800 patients with concomitant ligament surgery, prior ipsilateral knee surgery, contralateral knee surgery, or a history of contralateral ACL injury were reviewed. Of this group, 405 patients were excluded on the basis that they had not been evaluated for pre- or postoperative laxity testing during their rehabilitation (Figure 1).

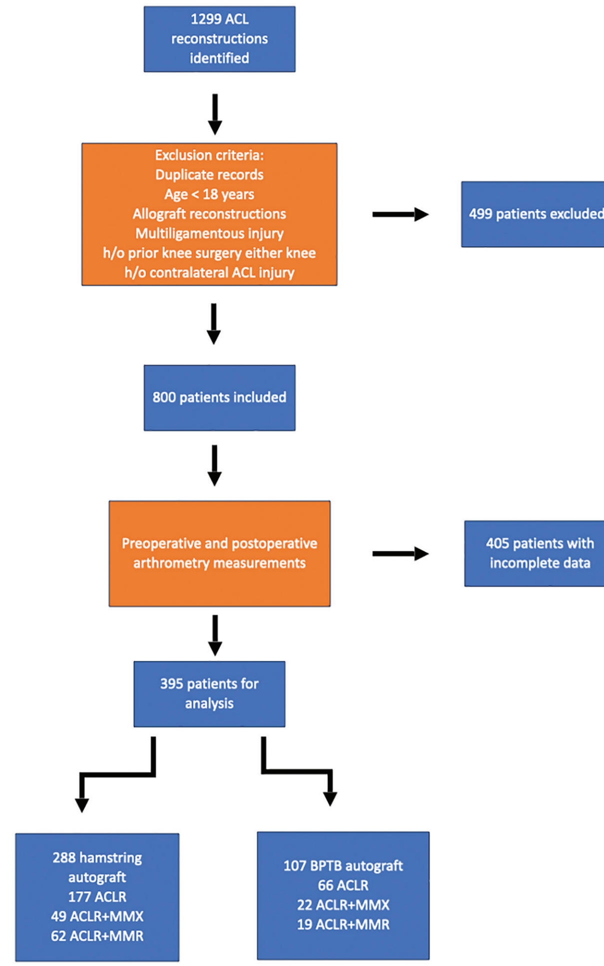

Figure 1. Flowchart for patient selection. ACL, anterior cruciate ligament; ACLR, ACL reconstruction; ACLR + MMx, ACLR with partial medial meniscectomy; ACLR + MMR, ACLR with medial meniscal repair; BPTB, bone-patellar tendon-bone; h/o, history of.

After exclusions, 395 patients with a mean age of 27.8 years (SD, 7.9 years) were available for analysis (Figure 1). A total of 288 patients underwent primary ACL reconstruction using hamstring tendon autograft, and 107 patients underwent primary ACLR with autograft patellar tendon; 243 patients underwent isolated ACLR with autograft, while 71 patients underwent autograft ACLR + MMx and 81 patients underwent autograft ACLR + MMR. There were 177 isolated ACLR, 49 ACLR + MMx, and 62 ACLR + MMR procedures for the hamstring tendon autograft group. There were 66 isolated ACLR, 22 ACLR + MMx, and 19 ACLR + MMR procedures for the patellar tendon autograft group.

Preoperative Differences Between Groups

There was no difference between groups in length of follow-up. The ACLR group had a mean of 20 weeks of

TABLE 1
Demographic Data[a]

	ACLR	MMx	MMR	ACLR vs MMx	ACLR vs MMR	MMx vs MMR
	Mean	Mean	Mean	*P*	*P*	*P*
Age	27.4 ± 8.0	30.4 ± 8.5	26.7 ± 6.4	**.01**	.40	**<.01**
Sex, female, %	29, (n = 242)	17, (n = 72)	33, (n = 82)	**.04**	.49	**.02**
BMI	26.3 ± 4.5	28.9 ± 4.9	27.6 ± 5.2	**<.01**	.06	.11
Time to OR, d	274 ± 741	563 ± 889	246 ± 273	**.02**	.63	**.01**
Nicotine use	11, (n = 242)	14, (n = 72)	9, (n = 82)	.60	.72	.42

[a]Data are presented as mean ± SD or percentage. ACLR, anterior cruciate ligament reconstruction; BMI, body mass index; MMR, medial meniscal repair; MMx, partial medial meniscectomy; OR, operating room.

postoperative measurements, the ACLR + MMR group had a mean of 19 weeks of postoperative measurements, and the ACLR + MMX group had a mean of 20 weeks of postoperative measurements (analysis of variance; P = .39).

There were significant differences between the MMx group and the other 2 groups preoperatively (Table 1). Compared with the isolated ACLR group, the ACLR + MMx group was older (30.4 vs 27.4 years; P = .01), had higher BMI (28.9 vs 26.3 kg/m^2; $P < .01$), was less likely to be female (16.7% vs 28.9%; P = .04), and had a longer time from injury to the OR (563 vs 274 days; P = .02). Compared with ACLR + MMR, the ACLR + MMx group was older (30.4 vs 26.7 years; $P < .01$), was less likely to be female (16.7% vs 32.9%; P = .02), and had a longer time from injury to the OR (563 vs 246 days; P = .01). There were no differences between the ACLR and ACLR + MMR groups, and there was no difference between any groups in the rate of nicotine use.

Multinomial regression was performed to identify factors associated with the treatment groups. A positive correlation was seen between increasing age and ACLR + MMx (coefficient, 0.0448; P = .01). Increasing BMI was positively correlated with both ACLR + MMx (coefficient, 0.1098; $P <$ .01) and ACLR + MMR (coefficient, 0.0609; P = .03). No association was seen for time from injury to the OR, patient sex, or use of nicotine for any group. Pearson correlation test showed an association between time from injury to the OR and age (df = 389; $P < .01$). Two-sample t tests showed that male patients had higher BMI than female patients (27.6 vs 25.7 kg/m^2; $P < .01$).

Postoperative Outcomes

ACLR Alone Versus ACLR + MMx. The ACLR + MMx group had significantly greater preoperative ATT compared with the ACLR group (MMD: 7.46 mm vs 6.48 mm; $P < .01$) (Table 2). The ACLR + MMx group also had significantly greater postoperative ATT compared with the ACLR group (MMD: 1.6 mm vs 1.07 mm; P = .04). Postoperatively, a higher proportion of patients in the ACLR group had an MMD <3 mm (93% vs 84.5%; P = .03). There was no difference between the 2 groups in the rate of return to the OR.

ACLR Alone Versus ACLR + MMR. There were no significant differences between the 2 groups in preoperative ATT, postoperative ATT, or rates of return to the OR (Table 2).

ACLR + MMx Versus ACLR + MMR. There were no significant differences between the 2 groups in preoperative ATT. The ACLR + MMx group showed significantly higher postoperative ATT compared with the ACLR + MMR group (MMD: 1.6 mm vs 1.01 mm; P = .02) (Table 2). There was no difference between groups for the proportion of patients with postoperative MMD <3 mm. The ACLR + MMR group had a higher rate of return to the OR (23.2% vs 9.9%; P = .03).

Return to the OR

Postoperative return to the OR was significantly greater for the ACLR + MMR group compared with ACLR + MMx (23% vs 10%; P = .03). No difference was seen between ACLR versus ACLR + MMx or ACLR versus ACLR + MMR. Indications for return to the OR are reported in Table 3.

Regression Analysis

Linear regression analysis was performed for postoperative MMD using time from injury to the OR, medial meniscal treatment group, graft type, age, and BMI as predictive factors. Associations were seen with preoperative MMD (coefficient, 0.12; P = .004), with age (coefficient, –0.03; P = .008), with graft type (patellar tendon autograft coefficient, –0.44; P = .029), and with the medial meniscal treatment group (ACLR + MMx coefficient, 0.49; P = .048). The regression showed positive correlations for preoperative MMD and medial meniscal treatment. Each additional 1 mm of preoperative MMD was associated with increased postoperative MMD of 0.12 mm. MMx was associated with a 0.49-mm increase in postoperative MMD. Each additional year of age predicted a decreased postoperative MMD of 0.03 mm. Use of patellar tendon autograft was protective; a patellar tendon autograft was associated with a decrease of 0.44 mm in postoperative MMD. No association was shown for BMI or time from injury to the OR. Regression analysis results with confidence intervals are summarized in Table 4.

TABLE 2
Analysis of ACLR Outcomes Depending on Medial Meniscal Pathology[a]

	ACLR vs ACLR + MMx		
	ACLR	ACLR + MMX	P
Preop MMD, mm	**6.5 ± 2.1**	**7.5 ± 2.1**	**<.01**
Postop MMD, mm	**1.1 ± 1.4**	**1.6 ± 1.7**	**.04**
MMD <3, mm	**93**	**85**	**.03**
Return to OR	14	10	.32
	ACLR vs ACLR + MMR		
	ACLR	ACLR + MMR	P
Preop MMD, mm	6.5 ± 2.1	6.9 ± 2.4	.21
Postop MMD, mm	1.1 ± 1.4	1.0 ± 0.8	.70
MMD <3, mm	93	93	.92
Return to OR	14	23	.07
	ACLR + MMx vs ACLR + MMR		
	ACLR + MMX	ACLR + MMR	P
Preop MMD, mm	7.5 ± 2.1	6.9 ± 2.4	.10
Postop MMD, mm	**1.6 ± 1.7**	**1.0 ± 0.8**	**.02**
MMD <3, mm	85	93	.11
Return to OR	**10**	**23**	**.03**

[a]Data are presented as mean ± SD or percentage. Significant p values indicated in bold text. ACLR, anterior cruciate ligament reconstruction; MMD, manual maximum difference; MMR, medial meniscal repair; MMx, partial medial meniscectomy; OR, operating room; Postop, postoperative; Preop, preoperative.

TABLE 3
Summary of Indications for Return to OR by Graft Type[a]

	Hamstring Tendon Autograft			Patellar Tendon Autograft		
	ACLR (n = 177)	ACLR + MMx (n = 49)	ACLR + MMR (n = 62)	ACLR (n = 66)	ACLR + MMx (n = 22)	ACLR + MMR (n = 19)
Revision ACLR	6	0	0	0	1	0
Arthroscopic debridement	11	2	8	3	2	5
Arthrofibrosis	3	0	1	5	0	1
Infection	1	1	1	0	0	0
Revision meniscal repair	0	0	1	0	0	0
Symptomatic implant	1	0	1	0	0	0
Total	22 (12)	3 (6)	12 (19)	8 (12)	3 (14)	6 (32)

[a]Data are presented as n or n (%).ACLR, anterior cruciate ligament reconstruction; MMR, medial meniscal repair; MMx, partial medial meniscectomy; OR, operating room.

Logistic regression analysis was performed for the outcome of return to the OR using preoperative MMD, postoperative MMD, medial meniscal treatment group, age, BMI, and graft type as predictive factors. Associations were seen with MMR (coefficient, 0.81; $P = .024$) and postoperative MMD (coefficient, 0.25; $P < .001$). The regression implies that an MMR was associated with a 1.2-fold higher chance of return to the OR. For each 1-mm increase in postoperative MMD, there was a 2.8-fold higher chance of return to the OR. No association was shown for preoperative MMD, age, BMI, time from injury to the OR, or graft type. Regression analysis results with confidence intervals are summarized in Table 5.

The analysis was repeated with lateral meniscal treatment groups, and no association was shown between lateral meniscal treatment and any of the variables.

TABLE 4
Linear Regression Analysis of Postoperative MMD With Coefficient[a]

	Coefficient	95% CI	P
Preoperative MMD	0.12	0.04 to 0.19	**.004**
Delay to surgery	**.000007737**	–0.0002 to 0.0003	.950
Medial meniscal repair	–0.16	–0.60 to 0.27	.459
Partial medial meniscectomy	0.49	0.005 to 0.97	**.048**
BMI	–0.02	–0.05 to 0.02	.392
Age	–0.03	–0.05 to −0.01	**.008**
BPTB autograft	–0.44	–0.83 to −0.05	**.029**

[a]BMI, body mass index; BPTB, bone-patellar tendon-bone; MMD, manual maximum difference. Significant p values indicated in bold text.

TABLE 5
Logistic Regression Analysis of Rates of Return to OR With Coefficient[a]

	Coefficient	95% CI	P
Preoperative MMD	–0.069	–0.23 to 0.08	.377
Delay to surgery	**–0.000755**	–0.002 to 0.0001	.239
Medial meniscal repair	0.81	0.09 to 1.50	**.025**
Partial medial meniscectomy	–0.40	–1.51 to 0.57	.450
BMI	**0.00233**	–0.06 to 0.06	.941
Age	–0.019	–0.07 to 0.02	.398
BPTB autograft	0.40	–0.30 to 1.08	.248
Postoperative MMD	0.35	0.20 to 0.51	<**.001**

[a]BMI, body mass index; BPTB, bone-patellar tendon-bone; MMD, manual maximum difference; OR, operating room. Significant p values indicated in bold text.

DISCUSSION

The most important result of this study is the finding that medial meniscal pathology and treatment affected postoperative ATT after ACLR—specifically, that an irreparable medial meniscal tear and subsequent MMx were risk factors for increased postoperative MMD measured by the KT-1000 arthrometer. Medial meniscal tears, especially of the posterior horn, have been associated with increased ATT in vitro and have been associated with preoperative ATT. With that said, this is the first study to our knowledge which demonstrates that performing a medial meniscectomy at the time of ACLR is associated with postoperative ATT.[11,20,35,36]

Interestingly, MMR showed improved postoperative ATT compared with meniscectomy and no difference compared with isolated ACLR. Recent shifts in the treatment of meniscal pathology that trend toward repair and preservation instead of partial meniscectomy have been associated with chondroprotective effects.[18] Status of the medial meniscus at the time of ACLR has previously been shown to be predictive of future arthritis but was not associated with postoperative laxity or revision ACLR in our data. Our study is the first to demonstrate an association between medial meniscal pathology and postoperative ATT after ACLR.

However, there were significant differences in demographics between groups that may have biased outcomes. Specifically, the ACLR + MMx group was older, more male predominant, and had a longer interval from injury to surgery than either the ACLR or the ACLR + MMR groups. Additionally, the ACLR + MMx group had a higher BMI than the ACLR group but not the ACLR + MMR group. These differences likely reflect the treating surgeons' indications for meniscal repair and their assessment of whether a tear is repairable. The higher rate of return to the OR in the ACLR + MMR group is most likely related to failed meniscal healing and return to the OR for debridement or revision meniscal repair.

In the present study, regression analysis implies a role of the ACL graft type in postoperative ATT. Patellar tendon autograft is protective against increased ATT after ACLR. Patellar tendon autograft offers a well-established advantage over hamstring tendon autograft for postoperative outcomes including postoperative ATT, postoperative asymmetric pivot shift, revision rates, and reoperation rates.[7,38] Our results indicate that surgeons may consider the potential for higher postoperative ATT when selecting a graft for patients with an irreparable medial meniscal tear.

Several previous studies have suggested a positive correlation between delay to ACLR, preoperative ATT, postoperative ATT, and medial meniscal tears.[1,5,6,33] However, a recent study has challenged this prevailing wisdom in adult patients.[12] Our results are similar to the results of Gupta et al[12]; while there were differences between study groups for time from injury to surgery, there was no association between time to the OR and medial meniscal tears on regression analysis. Instead, age was separately associated with both medial meniscal tears and time to reconstruction, so there may be a confounding effect. Our result adds to data from the literature showing that counseling, bracing, and rehabilitation can be effective in preventing new meniscal tears in the ACL-deficient knee.[3,14,15,32]

The 0.5-mm increased ATT in the ACLR + MMx group is similar to the difference in ATT that has been reported between hamstring and patellar tendon autografts.[38] The magnitude of differences in ATT may be less important than the percentage of patients who return to near-normal (<3 mm) side-to-side ATT postoperatively. In our study, this 0.5-mm reduction in ATT corresponded to an additional 8% of the ACLR group returning to near-normal ATT compared with the ACLR + MMx group (93% vs 85%, respectively).

Strengths and Limitations

The strengths of our study include a large sample size with nearly 300 hamstring tendon autograft and 100 patellar tendon autograft reconstructions, a variety of surgeons, and consistent postoperative examination by a single independent examiner. However, there were several limitations. The patient study population was a small community practice setting. Our conclusions were limited by the retrospective nature of our study. Our population was chosen to be as homogeneous as possible, and inferences beyond the study demographics and clinical setting should be limited. Despite this, our study groups showed differences in preoperative demographics. The study population did not include skeletally immature patients, autograft quadriceps tendon, allograft reconstruction, or suspensory fixation. We did not include patient-reported outcomes and there was a significant loss of patients who did not have adequate follow-up to be included in the study.

CONCLUSION

MMx at the time of ACLR led to higher postoperative ATT compared with isolated ACLR or ACLR + MMR.

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