

Association Between Isokinetic Knee Strength and Perceived Function and Patient Satisfaction With Sports and Recreational Ability After Matrix-Induced Autologous Chondrocyte Implantation

Jay R. Ebert,*[†] PhD, Anne Smith,[‡] PhD, Gregory C. Janes,[§] MBBS, FRACS, and David J. Wood,^{||} MBBS, MS, FRCS, FRACS

Investigation performed at the University of Western Australia, Perth, Western Australia, Australia

Background: Returning to a sound level of activity after matrix-induced autologous chondrocyte implantation (MACI) is important to patients. Evaluating the patient's level of satisfaction with his or her sports and recreational ability is critical.

Purpose: To investigate (1) satisfaction with sports and recreational ability after MACI and (2) the role that knee strength plays in self-reported knee function and satisfaction.

Study Design: Case-control study; Level of evidence, 3.

Methods: Isokinetic knee strength was assessed in 97 patients at 1, 2, and 5 years after MACI to calculate hamstrings-quadriceps ratios and peak knee extensor and flexor torque limb symmetry indices (LSIs). The Sports and Recreation subscale of the Knee injury and Osteoarthritis Outcome Score (KOOS Sports/Rec) was completed. A satisfaction scale was used to evaluate how satisfied the patients were with their ability to return to recreational activities and their ability to participate in sport. Associations between knee strength LSI, KOOS Sports/Rec, and satisfaction with recreational and sporting activities were assessed through use of multivariable linear and logistic regression, with adjustment for confounders. Mediation analysis was conducted to assess the extent to which self-reported knee function mediated associations between strength LSI and satisfaction.

Results: Satisfaction with the ability to return to recreational activities was achieved in 82.4%, 85.6%, and 85.9% of patients at 1, 2, and 5 years, respectively, and satisfaction with sports participation was achieved in 55.7%, 73.2%, and 68.5% of patients at 1, 2, and 5 years, respectively. Knee extension torque LSIs were associated with KOOS Sports/Rec after adjustment for confounders over 1, 2, and 5 years (5-year regression coefficient, 6.0 points; 95% CI, 1.4-10.7; $P = .012$). KOOS Sports/Rec was associated with the likelihood of being satisfied at all time points (recreation: 5-year adjusted odds ratio [OR], 2.26; 95% CI, 1.48-3.46; $P < .001$; and sports: 5-year adjusted OR, 1.98; 95% CI, 1.47-2.68; $P < .001$). In a multivariable mediation model, the knee extension torque LSI was associated with satisfaction directly (standardized coefficient, 0.16; 95% CI, 0.03-0.28; $P = .017$) and indirectly via KOOS Sports/Rec (standardized coefficient, 0.19; 95% CI, 0.01-0.38; $P = .027$), the latter representing 55% of the total association of knee extension torque LSI with satisfaction.

Conclusion: Knee extensor symmetry was associated with satisfaction in recreational and sporting ability, both directly and indirectly, via self-reported sports and recreation-related knee function. Restoring strength deficits after MACI is important for achieving optimal outcomes.

Keywords: matrix-induced autologous chondrocyte implantation; return to activity; sports; knee strength; satisfaction

An array of surgical procedures exists for the treatment of symptomatic chondral knee defects, including osteochondral cylinder transfer (OCT) techniques (eg, osteoarticular transplantation system), marrow stimulation techniques

(eg, microfracture), and autologous chondrocyte implantation (ACI), all demonstrating clinical benefit.⁵⁴ OCT techniques involve whole-tissue transplant delivering a hyaline repair, albeit limited by donor site morbidity, and have shown acceptable outcomes in properly selected patients, although evidence regarding long-term outcomes is insufficient.³⁸ Microfracture, the most common procedure for treating cartilage defects,⁵² stimulates a healing response

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by exposing the subchondral bone marrow to create a blood clot that fills the chondral defect.⁵⁴ Good short-term outcomes have been demonstrated in young patients with small lesions, although longer term failure may be expected.³⁹ ACI is a cell-based treatment that aims to reproduce a hyaline-like repair tissue,⁵⁴ with third-generation techniques (matrix-induced ACI [MACI]) delivering these regenerative cells via a scaffold that is glued to the exposed subchondral bone. Studies have shown clinical superiority of MACI over procedures such as microfracture in the earlier stages and for up to 5 years after surgery.^{14,18,62}

MACI has demonstrated an encouraging capacity to reduce pain and symptoms and produce a hyaline-like tissue repair in patients with knee chondral defects.^{13,14,16,24,28,32} MACI also aims to return the patient to an active lifestyle.³³ As outlined by Zak et al,⁶⁹ in an active population such as those undergoing MACI, the reduction of symptoms is a primary goal of surgery. A return to preinjury activity levels is often expected by the patient²⁵ and may well define the overall success of the surgery.⁵³ Systematic reviews have reported varying return to sport (RTS) rates of 59% to 93%⁴² and 75% to 89%²⁰ after knee cartilage repair. Zak et al⁶⁹ reported that in a moderately active group of patients who underwent MACI, most were able to return to participation in recreational sports at a level and intensity similar to their preinjury level and intensity.

A number of factors may contribute to patient satisfaction,^{21,23,41,47,64} and evaluating satisfaction after cartilage repair surgery is important given its benefit in determining the overall value of an orthopaedic surgical intervention.⁴⁰ Furthermore, evaluating patients' levels of satisfaction with their sports and recreation ability is critical given that this ability is important to patients. Ardern et al² reported that after anterior cruciate ligament reconstruction (ACLR), patients were more likely to be satisfied if they had returned to preinjury activity levels, and patients with perceived normal knee function were approximately twice as likely to return to their preinjury sporting level compared with those who had nearly normal (or abnormal) knee function.⁵ ACLR studies have also suggested that a certain level of physical functioning is needed to successfully participate in sports,^{5,35} although the role of strength and/or functional symmetry in patient satisfaction with activity has not been explored. Postoperatively, the restoration of lower limb muscle function, including isokinetic knee strength, is considered important for successful RTS or physical activity after ACLR^{1,10,45,49,66} and is likely to be of importance after MACI. Knee strength is commonly reported via limb symmetry indices (LSIs),⁶⁷ which present the strength of the

affected or operated limb as a percentage of the unaffected or nonoperated limb. Although knee strength deficiencies have been reported up to 5 years after MACI,^{29,33} the association between knee strength and higher level functional ability has not, nor has the association between knee strength and the patient's level of satisfaction with his or her sports and activity participation.

The primary aims of this study were to (1) investigate patients' satisfaction with their ability to perform recreational and sports activities up to 5 years after MACI and (2) investigate whether isokinetic knee strength LSIs are associated with satisfaction and, if so, explore whether the association is mediated by the degree of self-reported difficulty with higher level sports and recreation-related functional activities.

METHODS

Patients

A total of 97 patients (60 males, 37 females) were included in this study. All patients had undergone MACI between June 2004 and August 2012 to address localized, full-thickness medial or lateral femoral condylar defects to the knee. Patients underwent surgery by 5 orthopaedic surgeons (with ≥ 8 years of experience in orthopaedic practice) operating in 4 private hospitals. At the time of surgery, the patient cohort had a mean age of 36.8 years (range, 15-62 years), height of 1.75 m (range, 1.55-2.03 m), and body weight of 81.6 kg (range, 55.8-130.0 kg). The mean defect size at surgical implantation was 3.2 cm² (range, 1.0-10.0 cm²). Patients had undergone a mean of 1.3 (median, 1) prior surgical knee procedures (not including the first-stage knee chondral biopsy) and reported a duration of symptoms (DOS) of 7.9 years (range, 1-46 years). Of the 97 patients included in this analysis, 7 had concomitant surgical procedures at the time of MACI grafting, including ACLR (n = 2), posterior cruciate ligament reconstruction (n = 1), and partial meniscectomy (n = 4). Ethics approval for this study was obtained from the relevant hospital ethics committee.

MACI Surgical Technique

The surgical technique has been previously described.^{27,30,31} In brief, MACI is a 2-stage technique. The patients in the current study underwent arthroscopic surgery to harvest a sample of normal articular cartilage from the knee. Chondrocytes were then isolated from this chondral biopsy, cultured, and seeded onto a type I/III

*Address correspondence to Jay R. Ebert, PhD, School of Human Sciences (Exercise and Sport Science), University of Western Australia, 35 Stirling Highway, Crawley, 6009, Western Australia, Australia (email: jay.ebert@uwa.edu.au).

[†]School of Human Sciences (Exercise and Sport Science), University of Western Australia, Crawley, Perth, Western Australia, Australia.

[‡]School of Physiotherapy and Curtin Health Innovation Research Institute, Curtin University, Bentley, Perth, Western Australia, Australia.

[§]Perth Orthopaedic and Sports Medicine Centre, West Perth, Western Australia, Australia.

^{||}School of Surgery (Orthopaedics), University of Western Australia, Crawley, Perth, Western Australia, Australia.

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Ethical approval for this study was obtained from the Hollywood Private Hospital (HPH145) Human Research Ethics Committees (HREC).

collagen membrane (ACI-Maix Matricel GmbH) ex vivo over a 6- to 8-week period. At the time of second-stage implantation, the chondral defect was prepared by removing all damaged cartilage down to, but not through, the subchondral plate. The resultant defect was measured and used to shape the membrane, which was secured to the subchondral bone using fibrin glue. The wound was closed after assessment of graft stability.

Postoperative Rehabilitation

The postoperative rehabilitation program has been described previously in detail and was undertaken by all patients.³² Regardless of graft location (medial or lateral femoral condyle) and concomitant procedures, all patients underwent a standardized inpatient program that consisted of the following: continuous passive motion set at 0° to 30° on the operated knee within 12 to 24 hours after surgery, for a minimum of 1 hour daily; cryotherapy to control pain and edema; active ankle motion to encourage lower extremity circulation; and isometric contraction of the quadriceps, hamstrings, and gluteal muscles to maintain muscle activation and tone. All patients were educated on how to ambulate with 2 forearm crutches, allowing no more than 20% of body weight through the operated limb. All patients wore a hinged knee brace for 24 hours per day postoperatively.

After hospital discharge, patients participated in a structured, supervised rehabilitation program for 12 weeks, with ongoing advice provided to patients for up to 12 months after surgery. An overview of the protocol is provided in Table 1; progressive weightbearing, knee range of motion, knee bracing, and exercise protocols were individually modified as required depending on the size of the lesion, any additional surgical procedures that may have been performed (although it was generally deemed that the MACI procedure required a more conservative progression than the concomitant procedures reported), and the presentation of clinical signs throughout the postoperative period reflective of overload (ie, pain and swelling).

Clinical Assessment

All 97 patients included in this analysis underwent clinical review, including completion of patient-reported outcome measures and the evaluation of peak isokinetic knee extensor and flexor strength assessment at 1 year (n = 97), 2 years (n = 97), and 5 years (n = 92) after surgery.

Patient-Reported Outcome Measures. The Knee injury and Osteoarthritis Outcome Score (KOOS) includes 42 questions across 5 domains: Pain, Symptoms, Activities of Daily Living, Sports and Recreation, and Knee-Related Quality of Life.⁶¹ This study used the Sports and Recreation (KOOS Sports/Rec) subscale, which evaluates the patient's degree of difficulty with higher level sports and recreation-related functional activities (squatting, running, jumping, twisting/pivoting, and kneeling) via a Likert response scale with descriptors *none*, *mild*, *moderate*, *severe*, and *extreme*. The KOOS has been recommended for use with patients undergoing cartilage repair,⁶⁰ has been used extensively

TABLE 1
Overview of Postoperative Weightbearing, Knee Range of Motion, and Exercise Rehabilitation Throughout the Recovery Timeline Undertaken by the Cohort Undergoing MACI^a

Postoperative Timeline	Rehabilitation Guidelines
1-3 weeks	Weightbearing: ≤20% BW (weeks 1-2) to 30% BW (week 3) Ambulatory aids: 2 forearm crutches used at all times Knee ROM: active knee ROM from 0°-30° (week 1) to 0°-90° (week 3) Knee bracing: hinged brace, 0°-30° (weeks 1-2) to 0°-45° (week 3) Treatment and rehabilitation overview: circulation, isometric, and straight leg exercises, passive and active knee flexion exercises, remedial massage, soft tissue and patellar mobilization, CPM, cryotherapy, and hydrotherapy (week 3)
4-6 weeks	Weightbearing: 40% BW (week 4) to 60% BW (week 6) Ambulatory aids: 1 crutch (week 6) or 2 crutches (weeks 4-5) used at all times Knee ROM: active knee ROM from 0°-110° (week 4) to 0°-125° (week 6) Knee bracing: 0°-60° (week 4), 0°-90° (week 5), full knee flexion (week 6) Treatment and rehabilitation overview: introduction of calf raises, weighted hip adduction and abduction, trunk strengthening, and recumbent cycling (week 5)
7-12 weeks	Weightbearing: 80% BW (week 7) to 100% BW (weeks 10-12) Ambulatory aids: 1 crutch (weeks 6-7) to no crutches (weeks 10-12) Knee ROM: full active knee ROM (week 7) Treatment and rehabilitation overview: introduction of proprioceptive and balance activities, upright cycling, walking, resistance, and CKC activities (eg, modified leg press)
3-6 months	Treatment and rehabilitation overview: introduction of OKC exercises (weighted leg extension) and more demanding CKC exercises (eg, squat, lunge, and step exercise variations), rowing ergometry, and elliptical trainers
6-9 months	Treatment and rehabilitation overview: increased difficulty of proprioceptive, OKC, and CKC exercises (with a single limb focus); introduction of controlled minitrampoline jogging as well as plyometric and jump-land exercises
9-12 months	Treatment and rehabilitation overview: increased difficulty and variation in exercises, introduction of jogging-running program and agility drills relevant to the patient's sport, return to competitive activity after 12 months

^aBW, body weight; CKC, closed kinetic chain; CPM, continuous passive motion; MACI, matrix-induced autologous chondrocyte implantation; OKC, open kinetic chain; ROM, range of motion.

in patients after chondrocyte implantation,[#] and has demonstrated validity and reliability in patients after cartilage repair surgery.¹⁷ The KOOS Sports/Rec subscale is more responsive to longer term outcomes after ACI, especially among active individuals, compared with other commonly used measures.⁴⁴

A patient satisfaction questionnaire was also used at 1, 2, and 5 years after surgery. Patients were asked (1) How satisfied are you with the results of your MACI knee surgery for improving your ability to return to recreational activities (such as walking, swimming, cycling, golf, dancing, etc)? and (2) How satisfied are you with the results of your MACI knee surgery for improving your ability to participate in sports (such as running, tennis, surfing, soccer, etc)? A Likert response scale was used with descriptors *very satisfied*, *somewhat satisfied*, *somewhat dissatisfied*, and *very dissatisfied*. The 2 satisfaction items used in this study were based on the self-administered patient satisfaction scale developed by Mahomed et al.⁵⁰ This is a 4-item scale that has demonstrated excellent internal consistency in patients who undergo knee arthroplasty, evaluating satisfaction with surgical results, pain improvement, improvement in the ability to work around the home, and recreational activities on the same Likert scale used in this study.

Isokinetic Knee Strength Evaluation. An isokinetic dynamometer (Isosport International) was used to evaluate peak knee extensor and flexor strength. Peak concentric knee extension and flexion strength were measured through a range of 0° to 90° of knee flexion, at a single isokinetic angular velocity of 90 deg/s. Each trial consisted of 4 repetitions: 3 low-intensity repetitions of knee extension and flexion, immediately followed by 1 maximal-effort test. After a practice trial on each limb, 2 test trials on each limb were undertaken, alternating between the nonoperated and operated limbs. All patients were asked to perform to their maximal effort, while verbal encouragement was provided, standardized across all assessments. Patients were given adequate rest between trials to minimize fatigue, although this was not standardized and was dependent on the patient's individual readiness to proceed.

LSIs were calculated for peak knee flexion and extension torque by dividing the peak values on the operated limb by those recorded on the nonoperated limb. The LSI is the most commonly reported parameter to determine the return of normal muscle strength and/or function⁶⁷; the underlying rationale is to ensure that the operated limb reaches an acceptable level in order to minimize the risk of overuse and/or further injury when a patient returns to sports or strenuous work.¹⁰ An LSI lower than 85% to 90% has been regarded as unsatisfactory for a variety of strength and functional tests and may suggest that it is unsafe for an individual to return to regular sports activity.^{46,51,55,58,66} The hamstrings to quadriceps ratio was also determined, which is calculated by dividing the peak concentric hamstrings torque by the peak concentric quadriceps torque.

Statistical Analysis

The number and proportion of participants endorsing each level of the Likert satisfaction scales at 1, 2, and 5 years were reported. Associations between knee strength measures and KOOS Sports/Rec were initially assessed through use of the Pearson correlation coefficient. Associations between knee strength measures and the 4-level ordinal variables—(1) satisfaction with sports and (2) satisfaction with recreation activities—were initially assessed by use of the Spearman correlation coefficient. To further assess these associations adjusted for potential confounders, multivariable linear (KOOS Sports/Rec) and logistic (Satisfaction) regression analyses were conducted for 1-, 2-, and 5-year outcomes. Bootstrapped standard errors (10,000 replications) were used to construct bias-corrected confidence intervals for linear regression models to account for slight departures from normality in KOOS Sports/Rec. Logistic regression with dichotomized sports and recreation satisfaction outcomes was used because ordinal logistic regression was not appropriate due to the small numbers in some response categories. All models were adjusted for age, sex, body mass index, DOS, defect size, compartment (medial or lateral), and number of prior procedures. Linearity of associations and absence of influential outliers were confirmed.

Logistic regression was also used to assess the degree of association between self-reported knee function (as measured by KOOS Sports/Rec) and dichotomized sports and recreation satisfaction outcomes. The extent to which associations between strength measures and satisfaction at 5 years after surgery were mediated by self-reported knee function (KOOS Sports/Rec) was assessed by use of mediation analysis. For this analysis, the 2 satisfaction scales for sports and recreation were added, and the resultant score was used as the outcome variable. Mediation analysis was conducted through use of Stata's *sem* command suite, with the indirect (mediated) association calculated via the product of coefficients approach. Standardized coefficients are presented with bootstrapped bias-corrected standard errors and confidence intervals (1000 repetitions). The path model was also adjusted for age, sex, DOS, and number of prior procedures, but these paths are not displayed in the results for simplicity.

Statistical analysis was performed with Stata/IC 15.0 for Windows (StataCorp LP), and statistical significance was determined at $P < .05$. The size of correlations was reported according to Cohen.²²

RESULTS

Table 2 demonstrates the patient demographics, including covariates and all strength and KOOS Sports/Rec measures at 1, 2, and 5 years after surgery.

Table 3 presents the number and proportion of patients in each satisfaction category for each satisfaction outcome.

Figure 1 presents the Pearson correlation coefficients with corresponding 95% CIs and P values for each knee strength measure with KOOS Sports/Rec at 1, 2, and 5

[#]References 15, 26, 32, 48, 56, 57, 59, 63, 68, 70.

years after surgery. Almost all knee strength measures displayed significant weak to moderate associations with KOOS Sports/Rec, with the exception of hamstrings-quadriceps ratio and the LSI for peak knee flexion torque at 5 years after surgery.

TABLE 2
Patient Demographics and Surgery or Injury History at the Time of Surgery, KOOS Sports/Rec Subscale Scores, and Strength Measures Throughout the Postoperative Timeline^a

Variable	Result
Patients, n	97
Defect location, n	
Medial femoral condyle	70
Lateral femoral condyle	27
Male sex, n (%)	60 (61.9)
Age, y	36.8 ± 11.3
Body mass index	26.6 ± 3.8
Duration of symptoms, y, median (IQR), range	6 (2-11), 1-46
No. of prior procedures, median (IQR), range	1 (0-2), 0-4
Defect size, cm ² , median (IQR), range	2.7 (1.5-4.0), 1.0-10.0
KOOS (Sports/Rec)	
Before surgery	27.9 ± 24.8
1 y	52.1 ± 29.9
2 y	64.8 ± 28.1
5 y	70.4 ± 26.8
Isokinetic knee extensor torque, LSI, %	
1 y	80.3 ± 22.8
2 y	86.2 ± 19.0
5 y	89.2 ± 14.2
Isokinetic knee flexor torque, LSI, %	
1 y	93.4 ± 22.8
2 y	99.5 ± 16.8
5 y	98.1 ± 17.8
Hamstrings-quadriceps ratio, %	
1 y	0.94 ± 0.55
2 y	0.90 ± 0.47
5 y	0.83 ± 0.33

^aValues are expressed as mean ± SD unless noted otherwise. IQR, interquartile range; KOOS, Knee injury and Osteoarthritis Outcome Score; LSI, limb symmetry index.

Figures 2 and 3 present the Spearman correlation coefficients with corresponding 95% CIs and *P* values for each knee strength measure with satisfaction with recreation (Figure 2) and satisfaction with sports (Figure 3). Evidence indicated weak associations between the LSI for peak knee extension torque and the participants' satisfaction with recreation at 2 and 5 years and between the LSI for peak knee flexion torque and participants' satisfaction with recreation at 5 years (Figure 2). As well, evidence indicated weak associations between the LSI for peak knee extension torque and satisfaction with sports at 1 and 5 years and between the LSI for peak knee flexion torque and satisfaction with sports at 1 and 2 years (Figure 3).

Table 4 presents the adjusted regression coefficients for separate linear regression equations for KOOS Sports/Rec for each strength measure at 1, 2, and 5 years after surgery. Most measures remained statistically significantly associated with the KOOS Sports/Rec after adjustment for covariates. The LSI for peak knee extension torque was consistently associated with KOOS Sports/Rec over time; an increase in 10% of the LSI for peak knee extension torque was associated with an increase in KOOS Sports/Rec of 3.7, 4.4, and 6.0 points over 1, 2, and 5 years, respectively.

Table 4 also presents adjusted odds ratios (ORs) for separate logistic regression models for participants' satisfaction with recreation and satisfaction with sports for each strength measure at 1, 2, and 5 years after surgery. The only significant associations were for the LSI for peak knee extension and flexion torque with both satisfaction measures at 5 years and for the LSI for peak knee flexion torque and participants' satisfaction with sports at 2 years. The LSI for peak knee extension torque was more strongly associated with satisfaction with recreation (OR, 3.69; 95% CI, 1.70-8.00) than with satisfaction with sports (OR, 2.06; 95% CI, 1.33-3.02) at 5 years, and these associations were stronger than those for the LSI for peak knee flexion torque (satisfaction with recreation: OR, 1.82; 95% CI, 1.13-2.92; satisfaction with sport: OR, 1.38; 95% CI, 1.01-1.87).

Table 5 presents the adjusted odds ratios for KOOS Sports/Rec with each satisfaction outcome at 1, 2, and 5 years after surgery. Significant associations were observed for all time points for both satisfaction measures, with the strongest associations observed at 5 years after surgery. An increase in the KOOS Sports/Rec of 10 points was associated with a proportional increase in the odds of being

TABLE 3
Number and Proportion of Patients in Each Satisfaction Category at 1, 2, and 5 Years After Surgery^a

Time	Very Satisfied	Somewhat Satisfied	Somewhat Dissatisfied	Very Dissatisfied
Satisfaction with improvement in the ability to return to recreational activities				
1 y	37 (38.1)	43 (44.3)	13 (13.4)	4 (4.1)
2 y	55 (56.7)	28 (28.9)	10 (10.3)	4 (4.1)
5 y	52 (56.5)	27 (29.4)	7 (7.6)	6 (6.5)
Satisfaction with improvement in the ability to participate in sports				
1 y	16 (16.5)	38 (39.2)	30 (30.9)	13 (13.4)
2 y	27 (27.8)	44 (45.4)	14 (14.4)	12 (12.4)
5 y	32 (34.8)	31 (33.7)	14 (15.2)	15 (16.3)

^aValues are expressed as n (%).

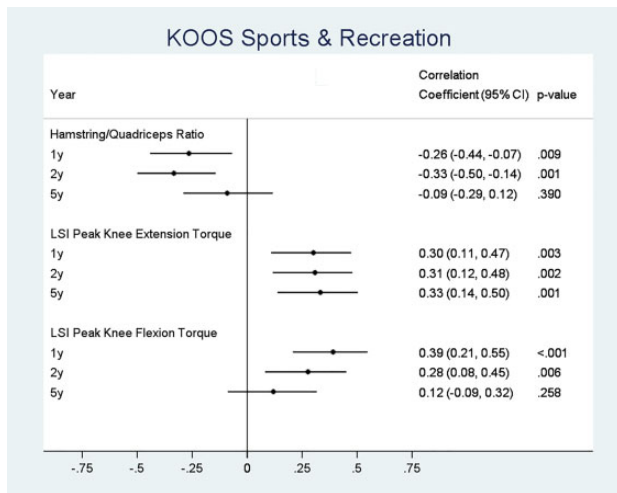


Figure 1. Pearson correlation coefficients, 95% CIs, and *P* values for the unadjusted associations between the Knee Injury and Osteoarthritis Outcome Score (KOOS) Sports and Recreation subscale and knee strength measures. LSI, limb symmetry index.

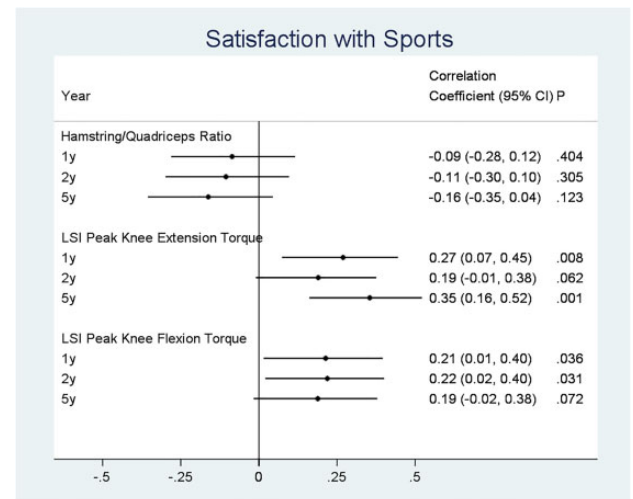


Figure 3. Spearman correlation coefficients, 95% CIs, and *P* values for the unadjusted associations between the 4-point satisfaction scale (sporting ability) with knee strength measures. LSI, limb symmetry index.

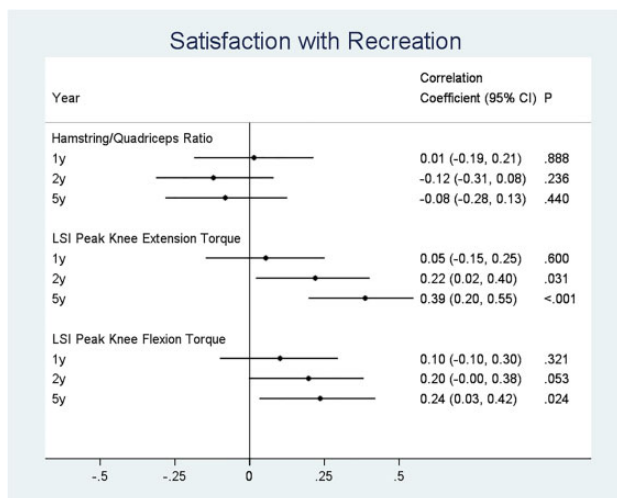


Figure 2. Spearman correlation coefficients, 95% CIs, and *P* values for the unadjusted associations between the 4-point satisfaction scale (recreational ability) with knee strength measures. LSI, limb symmetry index.

satisfied with recreation of 2.26 (95% CI, 1.48-3.46) and with sports of 1.98 (95% CI, 1.47-2.68).

Because the LSIs for peak knee extension and flexion torque were significantly associated with both satisfaction outcomes at 5 years, the mediating role of self-reported knee function in the association between LSI strength measures and the combined satisfaction scale at 5 years was tested, the results of which are depicted in Figure 4. This shows that the LSI for peak knee extension torque was significantly associated with KOOS Sports/Rec (standardized regression coefficient, 0.29; 95% CI, 0.01-0.58; *P* = .044), and in turn, KOOS Sports/Rec was associated with

satisfaction (0.65; 95% CI, 0.51-0.80; *P* < .001), resulting in a significant indirect (mediated) association of 0.19 (95% CI, 0.01-0.38; *P* = .027) for the LSI for peak knee extension torque. However, KOOS Sports/Rec only partially mediated this association, as there was still a significant direct association between the LSI for peak knee extension torque and satisfaction (0.16; 95% CI, 0.03-0.28; *P* = .017). Of the total association between the LSI for peak knee extension torque and satisfaction (0.35), 55% was mediated by KOOS Sports/Rec. After adjustment for the LSI for peak knee extension torque, the LSI for peak knee flexion torque was not significantly associated with either KOOS Sports/Rec (0.02; 95% CI, -0.18 to 0.28; *P* = .828) or satisfaction (0.11; 95% CI, -0.05 to 0.24; *P* = .178). Of the total variance in satisfaction, 56% was explained by a combination of KOOS Sports/Rec, the knee extension LSI, and covariates (age, sex, DOS, and number of prior procedures). However, only a small proportion of variance in satisfaction was explained by the knee extension LSI: 4% uniquely and 14% via shared variance with KOOS Sports/Rec.

DISCUSSION

MACI has demonstrated encouraging outcomes for reducing pain and symptoms and regenerating a hyaline-like tissue repair in patients with symptomatic knee cartilage defects.^{13,14,16,24,28,32} A further goal is to return patients to a normally active lifestyle,³³ although little is known about patients' satisfaction with their level of postoperative sports and recreational activity. Restoration of lower limb muscle function including isokinetic knee strength is considered important for a successful RTS or physical activity.^{1,10,45,49,66} The most important finding of the current study was that knee strength symmetry, with particular reference to knee extensor (quadriceps) strength, was

TABLE 4
Associations Between Strength Measures and KOOS Sports and Recreation Subscale Score, Satisfaction With Recreation, and Satisfaction With Sports at 1, 2, and 5 Years After Surgery^a

Covariate	KOOS Sports and Recreation ^b		Satisfaction: Recreation ^c		Satisfaction: Sports ^c	
	Regression Coefficient (95% CI) ^d	P Value	Odds Ratio (95% CI)	P Value	Odds Ratio (95% CI)	P Value
Hamstrings-quadriceps ratio^e						
1 y	-1.5 (-2.3 to -0.5)	.005	1.08 (0.89 to 1.32)	.442	0.93 (0.84 to 1.03)	.157
2 y	-0.9 (-3.5 to 1.7)	.513	0.90 (0.81 to 1.01)	.063	0.95 (0.86 to 1.04)	.255
5 y	-0.3 (-3.8 to 3.2)	.869	0.85 (0.71 to 1.02)	.083	0.97 (0.84 to 1.12)	.642
Peak knee extension torque (LSI)^e						
1 y	3.7 (0.9 to 6.5)	.010	0.94 (0.74 to 1.21)	.653	1.19 (0.97 to 1.45)	.090
2 y	4.4 (0.7 to 8.1)	.019	1.27 (0.93 to 1.74)	.131	1.24 (0.95 to 1.62)	.110
5 y	6.0 (1.4 to 10.7)	.012	3.69 (1.70 to 8.00)	.001	2.06 (1.33 to 3.02)	.001
Peak knee flexion torque (LSI)^e						
1 y	4.5 (2.3 to 6.7)	<.001	1.21 (0.93 to 1.56)	.159	1.17 (0.96 to 1.42)	.116
2 y	5.1 (1.6 to 8.5)	.004	1.36 (0.90 to 2.05)	.145	1.53 (1.08 to 2.18)	.018
5 y	2.5 (-1.2 to 6.3)	.179	1.82 (1.13 to 2.92)	.013	1.38 (1.01 to 1.87)	.040

^aKOOS, Knee injury and Osteoarthritis Outcome Score; LSI, limb symmetry index.

^bLinear regression model for LSI adjusted for age, duration of symptoms, size of defect, compartment, and number of prior procedures.

^cLogistic regression models for LSI adjusted for age, duration of symptoms, size of defect, compartment, and number of prior procedures.

^dBootstrapped SEs (10,000 replications); bias-corrected CIs are reported.

^eRegression coefficients and odds ratios are referenced to a 10% increase in each strength ratio.

TABLE 5
Associations Between KOOS Sports and Recreation Subscale Score and Satisfaction With Recreation and Satisfaction With Sports at 1, 2, and 5 Years After Surgery^a

KOOS Sports/Rec ^c	Satisfaction: Recreation ^b		Satisfaction: Sports ^b	
	Odds Ratio (95% CI)	P Value	Odds Ratio (95% CI)	P Value
1 y	1.35 (1.09 to 1.66)	.006	1.48 (1.21 to 1.79)	<.001
2 y	1.42 (1.14 to 1.78)	.002	1.50 (1.22 to 1.84)	<.001
5 y	2.26 (1.48 to 3.46)	<.001	1.98 (1.47 to 2.68)	<.001

^aKOOS, Knee injury and Osteoarthritis Outcome Score; Sports/Rec, Sports and Recreation subscale.

^bModels adjusted for age, sex, body mass index, duration of symptoms, size of defect, compartment, and number of prior procedures.

^cKOOS score divided by 10 (ie, odds ratios represent the proportional increase in odds for satisfaction per 10-point increase in KOOS).

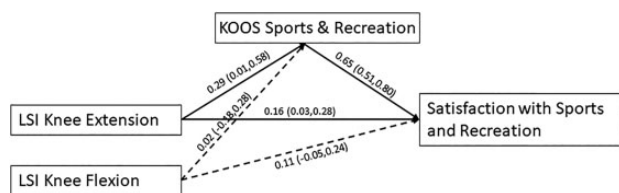


Figure 4. Mediation analysis results showing direct and indirect associations. Values are standardized regression coefficients with bootstrapped bias-corrected CIs. Solid lines represent statistically significant coefficients ($P < .05$), and dashed lines represent coefficients that were not statistically significant ($P > .05$). KOOS, Knee injury and Osteoarthritis Outcome Score; LSI, limb symmetry index.

significantly associated with self-reported knee function and patient satisfaction with returning to recreational activities and participating in sports.

The majority of patients in the current study were satisfied with their ability to return to recreational activities by 1 year (82% of patients), which had increased to 86% of patients by 5 years. However, only 56% of patients were satisfied with their ability to participate in sports at 1 year after surgery, which increased to 73% at 2 years (and decreased to 69% by 5 years). Zak et al⁶⁹ reported that at 5 years after MACI, 74% of patients had returned to at least their preinjury level of sports participation, although the rate of RTS after a range of knee cartilage repair procedures has been reported to range from 59% to 93% (ACI, marrow stimulation, and OCT techniques).^{20,42}

In the current study, the majority of knee strength measures (particularly knee extension) displayed significant associations with self-reported knee function, evaluated via the KOOS Sports/Rec subscale. The LSI for peak knee extension torque was consistently associated with the KOOS Sports/Rec subscale throughout the postoperative timeline. Postoperative restoration of lower limb muscle function including isokinetic knee strength is considered

important for successful RTS or physical activity after ACLR^{1,10,45,49,66} and is likely to be important after MACI. Unlike patients with ACLR, who generally experience acute trauma and undergo immediate reconstruction, patients with articular cartilage repair often have a longer preoperative DOS⁶⁰ and, in addition to requiring a lengthy period of conservative rehabilitation, need to restore their postoperative strength to provide ongoing knee joint support. Although knee strength deficiencies have been reported up to 5 years after MACI,^{29,33} the association between knee strength and higher level functional ability has not been previously reported. Nevertheless, despite the aforementioned significant associations, correlations between strength measures and the KOOS Sports/Rec subscale were only weak to moderate,²² suggesting that a range of other factors contribute to the patients' higher level functional ability. The KOOS Sports/Rec subscale asks patients to answer based on their perceived difficulty with higher level functional activities (running, jumping, turning or twisting on the injured or operated knee, kneeling, and squatting), and other factors such as pain and lack of active range of movement and proprioception may also contribute, whereas the item "kneeling" may be additionally affected by anterior knee sensitivity and/or discomfort. These factors were not evaluated as part of this study.

The LSI for peak knee extension torque was associated with satisfaction with return to recreational activities (at 2 and 5 years) and with the ability to participate in sports (at 1 and 5 years). This was further supported in the mediation analysis, highlighting a significant indirect association between the LSI for peak knee extension torque and patient satisfaction with activity, via self-reported knee function. This finding was largely expected when considering the requirement of good knee (and lower limb) function to be confident in participating in sporting activities and the requirement of adequate lower limb strength to permit adequate higher level function. Nevertheless, there are likely other factors not evaluated in the current study that directly or indirectly influence a patient's level of satisfaction with sports and recreation, which were not lower limb strength or knee function related. A range of contextual and psychological factors may influence the development of lower limb strength and have been shown to influence higher level functioning and RTS after ACLR.^{3,5,6} Kinesiophobia is related to knee function after surgery,⁴³ whereas persistent symptoms, fear of reinjury, and family and occupational demands have also been acknowledged.³⁷ Some of these may be indirectly associated with surgery (ie, fear of reinjury, requirement of further surgery should a subsequent injury be encountered) and could influence the patient's ability to return to recreational and sporting activities, as well as his or her subsequent satisfaction in doing so.

Certain limitations are acknowledged in this study. First, this study could have been improved by measuring actual recreational and sporting activity, and future research may seek to use activity diaries and/or activity monitoring to more accurately assess activity level. However, the primary purpose of this study was to evaluate the

influence of isokinetic knee strength symmetry on self-reported knee function and patient satisfaction with postoperative recreational and sporting ability.

Second, the current study sought to investigate cross-sectional associations between strength, self-reported knee function, and satisfaction with recreation and sports rather than examine associations between construct changes over time. Nevertheless, as outlined by Graham et al,⁴⁰ issues can arise when satisfaction is used as an outcome measure. A recent systematic review concluded that despite common belief, expectations have a small effect, if any, on satisfaction after total knee replacement¹²; however, without interviewing the patients in this study, we have no way of knowing the extent to which a response shift (reconceptualization, reprioritization, or recalibration) influenced their report of satisfaction¹¹ or how their satisfaction levels relate to their expectations before or after surgery.

Third, we used the KOOS Sports/Rec subscale to evaluate self-reported knee function. Other patient-reported outcome measures of activity, such as the Tegner activity scale,⁶⁵ have been used to measure activity. However, the KOOS has proven valid, reliable, and responsive to treatment after cartilage repair,⁶⁰ and the KOOS Sports/Rec subscale has demonstrated a high level of responsiveness to longer term outcomes after ACI.⁴⁴

Fourth, it may have been of benefit to the current study to obtain preoperative measurements of both activity level and strength to acquire baseline values, which were not obtained. However, preoperative measurement is challenging in patients who undergo MACI and/or cartilage repair, because they often present with a long DOS, as was the case in the current study (almost 8 years). Therefore, any preoperative strength and activity measures may be biased due to factors concomitant to strength, including persistent pain, anticipation of pain and flares, and apprehension to maximally exert oneself during isokinetic strength testing.

Fifth, a range of factors may contribute to a patient's ability to return to higher level activity and/or sport after MACI, including surgical characteristics (defect size and/or location), as well as after knee surgery in general, including patient demographics (eg, age, body weight), diligence and intensity of postoperative rehabilitation, patient motivation to RTS, psychological factors, and other occupational, family, and/or health-related reasons.^{3-9,19,34,36} Many of these factors were not assessed specifically in the current study. Furthermore, we acknowledge that strength can be influenced by a range of factors, including the rehabilitation program that patients undertake and their commitment and diligence with regard to that program and their inherent improvement. In the current study, each patient's commitment to rehabilitation, particularly after the more intensive initial 12 weeks, was not closely monitored in this study, and rehabilitation compliance was not assessed.

CONCLUSION

These results demonstrate that knee strength symmetry, with particular reference to knee extensor (quadriceps) strength, is significantly associated with self-reported knee

function (as measured by KOOS Sports/Rec) and patient satisfaction with returning to recreational activities and participating in sports. Resolution of persistent knee strength deficits will optimize knee function and satisfaction with sports and recreation participation.

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