Biological Knee Reconstruction for Combined Malalignment, Meniscal Deficiency, and Articular Cartilage Disease

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Purpose: The aim of this study was to analyze patient-reported outcomes in those undergoing the triad of simultaneous osteotomy, meniscal transplantation, and articular cartilage repair. **Methods:** Patients undergoing simultaneous meniscal transplantation, distal femoral or proximal tibial osteotomy, and articular cartilage surgery by a single surgeon (B.J.C.) were analyzed. Meniscal transplantation was performed using bone-in-slot techniques. Distal femoral and high tibial osteotomies were performed for valgus and varus malalignment, respectively. Microfracture, autologous chondrocyte implantation, and osteochondral autograft or allograft were performed for articular cartilage disease. Validated patient-reported and surgeon-measured outcomes were collected. Preoperative and postoperative outcomes and medial versus lateral disease were compared using Student *t* tests. **Results:** Eighteen participants (mean age, 34 ± 7.8 years; symptomatic patients, 7.4 ± 5.6 years; 2.4 ± 1.0 surgical procedures before study enrollment; mean follow-up, 6.5 ± 3.2 years) were analyzed. Two thirds of participants had medial compartment pathologic conditions and one third had lateral compartment pathologic processes. At final follow-up, there were statistically significant clinically meaningful improvements in International Knee Documentation Committee (IKDC) subjective classification, Lysholm score, and 4 Knee Injury and Osteoarthritis Outcome Score (KOOS) subscores. Postoperative 12-item short form (SF-12) physical and mental component scores were not significantly different from preoperative scores. The Kellgren-Lawrence classification grade was 1.5 ± 1.1 at 2.5 ± 3.0 years after surgery. There was a significantly higher preoperative SF-12 physical composite score (PCS) in participants with lateral compartment pathologic conditions (*v* medial compartment conditions) ($P = .011$). Although there were 13 reoperations in 10 patients (55.5% reoperation rate), only one patient was converted to knee arthroplasty (5.6%) and one to revision cartilage surgery and meniscal transplantation (5.6% revision rate). The most common complication was arthrofibrosis (16.7%). **Conclusions:** Statistically significant and clinically meaningful improvements in validated patient-reported clinical outcome scores at long-term follow-up were observed in 18 participants undergoing combined meniscal transplantation, osteotomy, and articular cartilage surgery. Although there was a low rate of cartilage or meniscal revision (or both) and total knee arthroplasty, there was a high rate of reoperation. There was no significant difference in outcomes between participants with medial versus lateral pathologic conditions. **Level of Evidence:** Level IV, therapeutic case series.

Osteoarthritis of the knee is a common cause of knee pain, loss of function, and disability in adults.[1] In patients in whom nonsurgical management has failed, both arthroplasty and nonarthroplasty techniques may be successful treatment options. There are many patient- and limb-specific factors that influence the development of osteoarthritis. Meniscal deficiency is a well-recognized risk factor for the development of knee osteoarthritis.[2] Both incidence and progression of osteoarthritis is affected by coronal plane alignment.[3] Varus and valgus malalignment increases incidence and progression of medial and lateral knee osteoarthritis, respectively.[3] Full-thickness chondral defects may progress to osteoarthritis.[4-6] In young patients, the combination of these comorbidities presents a significant challenge.

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Traditionally, chondral pathologic conditions or malalignment, or both, were contraindications to ipsi-compartmental meniscal allograft transplantation. Similarly, meniscal deficiency or malalignment, or both, were contraindications to ipsi-compartmental articular cartilage repair. This was recognized because of increased failure rates if these comorbidities remained unaddressed; repair is performed in a staged or concomitant fashion. Improvements in surgical technique and efficiency have allowed for the combination of these advanced procedures as a viable biological knee reconstruction option to avoid conventional arthroplasty.

Significant improvements in validated patient-reported outcomes have been reported in short-term follow-up with this "salvage" technique for unicompartmental arthritis in young patients.[7] However, the concern still exists with mid- and long-term follow-up for revision surgery and conversion to arthroplasty. The purpose of this study was to analyze patient-reported outcomes in those undergoing the triad of simultaneous osteotomy, meniscal transplantation, and articular cartilage repair for coronal plane malalignment, meniscal deficiency, and full-thickness chondral loss. The authors hypothesized that there would be statistically significant and clinically meaningful improvements in patient-reported outcomes after simultaneous osteotomy, meniscal transplantation, and articular cartilage repair, with low rates of revision meniscal, articular cartilage, or osteotomy surgery and conversion to arthroplasty at a minimum of 5 years after surgery.

Table 1. Participant and Surgical Demographic Data

Number of participants	18
Men	13
Women	5
Right knees	13
Left knees	5
Age, yr	34 ± 7.8
Body mass index, kg/m^2	26.9 ± 4.32
Mass, kg	82.7 ± 18.7
Height, m	1.74 ± 0.091
Smoking status	
Yes	1
No	17
Length of preoperative duration of symptoms, yr	7.4 ± 5.6
Number of previous surgeries	2.4 ± 1.0
1 participant	4
2 participants	4
3 participants	8
4 participants	2
Length of clinical follow-up, yr	6.5 ± 3.2
Defect area, cm^2	4.6 ± 2.4
Cause, n	
Chondral defect	14
Osteochondritis dissecans	3
Avascular necrosis	1
Compartment affected, n	
Medial	12
Lateral	6
Meniscal allograft transplantation, n	
Medial (bridge-in-slot/bone plugs)	12 (11/1)
Lateral (bridge-in-slot)	6 (6)
Osteotomy, n	
Valgus-inducing, opening wedge proximal tibial	12
Varus-inducing, opening wedge distal femoral	6
Articular cartilage repair, n	
Microfracture	2
Autologous chondrocyte implantation	2
Osteochondral autograft	2
Osteochondral allograft	12

NOTE. Data are presented as n or as mean ± standard deviation.

Methods

Over an 11- year period from April 2001 to April 2012, a consecutive series of patients undergoing simultaneous meniscal transplantation, distal femoral or proximal tibial osteotomy, and articular cartilage surgery by a single surgeon (B.J.C.) were analyzed. Data were prospectively collected through an institutional review board–approved protocol and were retrospectively analyzed. Additionally, in patients without recent follow-up, both mail and telephone surveys were used for follow-up.

Inclusion criteria were any *symptomatic* adult (>18 years of age) with a postmeniscectomy compartment with full-thickness articular cartilage loss (femur or tibia, or both) (International Cartilage Repair Society III or IV) and coronal plane malalignment (>3° varus or valgus). Thus, all patients had undergone a minimum of one previous surgery (Table 1). Patients were deemed symptomatic if the location of their pain corresponded to the appropriate compartment. Patient body mass index was not used as an exclusion criterion in this investigation. Patients undergoing staged rather than simultaneous meniscal transplantation, osteotomy, and articular cartilage surgery were excluded. Asymptomatic patients with a known meniscectomized state, chondral pathologic condition, and malalignment did not undergo this surgical treatment. Those with cruciate or collateral deficiency, or both, and significant patellofemoral arthrosis or instability were excluded. Given the infrequency with which this triad of pathologic conditions and surgical treatment is undertaken, minimum follow-up length for this study was 1 year from the date of surgery (Table 1). This patient cohort included 7 patients who were enrolled in a previous study with shorter follow-up.[7] All patients were informed that their information would be published.

Before combined surgery, all patients had weight-bearing standing anteroposterior (AP), 45° flexed posteroanterior, 45° flexed lateral, merchant, and hip-to-ankle mechanical axis view radiographs with sizing markers. Additionally, before surgery, all patients had routine magnetic resonance imaging with axial, sagittal, and coronal sequences to assess articular cartilage,

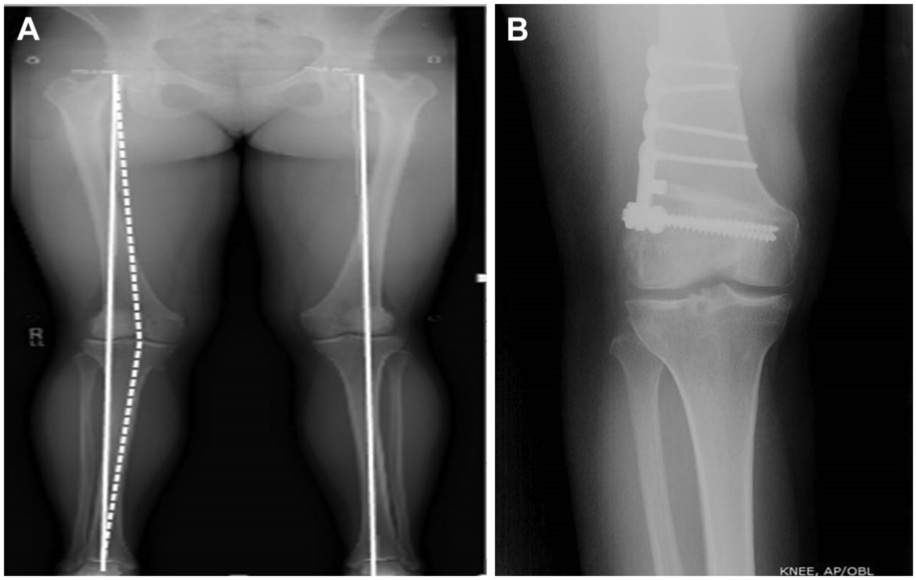

Fig 1. (A) Standing anteroposterior (AP) mechanical axis radiograph showing valgus deformity of the right knee. (B) Postoperative standing AP knee radiograph showing healed distal femoral varus-producing osteotomy with lateral plate fixation.

subchondral bone, menisci, and ligaments. Further, all patients' previous operative reports and arthroscopy photographs were reviewed. All patients were counseled regarding the risks and benefits of simultaneous versus staged procedures. Simultaneous surgery avoids multiple sequential rehabilitation periods for an extended length of time at the expense of increased surgical trauma. Staged surgery reduces the magnitude of surgical trauma at the expense of a lengthy rehabilitation program. After surgery, radiographs were analyzed for degenerative changes using the Kellgren-Lawrence classification.[8] Radiographs were obtained at 2 weeks, 3 months, and annually after surgery. However, if patients became symptomatic at other time points, radiographs were obtained.

Surgical Technique

Meniscal transplantation was the first procedure performed because of the significant varus or valgus stress required for graft passage, placement, and suture repair. If autologous chondrocyte implantation was performed, it was performed last to avoid disruption of the type I-III collagen or periosteal patch covering the implanted cells. Microfracture and osteochondral autografting or allografting was performed at any point during the surgery.

Opening wedge osteotomy techniques were performed for correction of coronal plane malalignment. For valgus deformity (Fig 1A), a varus-producing distal femoral osteotomy was performed (Fig 1B). For varus deformity (Fig 2A), a valgus-producing high/proximal tibial osteotomy (Fig 2B) was performed. Internal fixation was achieved using a low-profile titanium locking plate with 4.5-mm-diameter fully-threaded cortical screws on the articular surface/joint adjacent side and 6.5-mm-diameter fully-threaded cancellous screws on the nonjoint adjacent side (Tibial Opening Wedge Osteotomy Plate; Femoral Opening Wedge Osteotomy Plate; Arthrex, Naples, FL). The opened wedge was packed with local bone graft, demineralized bone

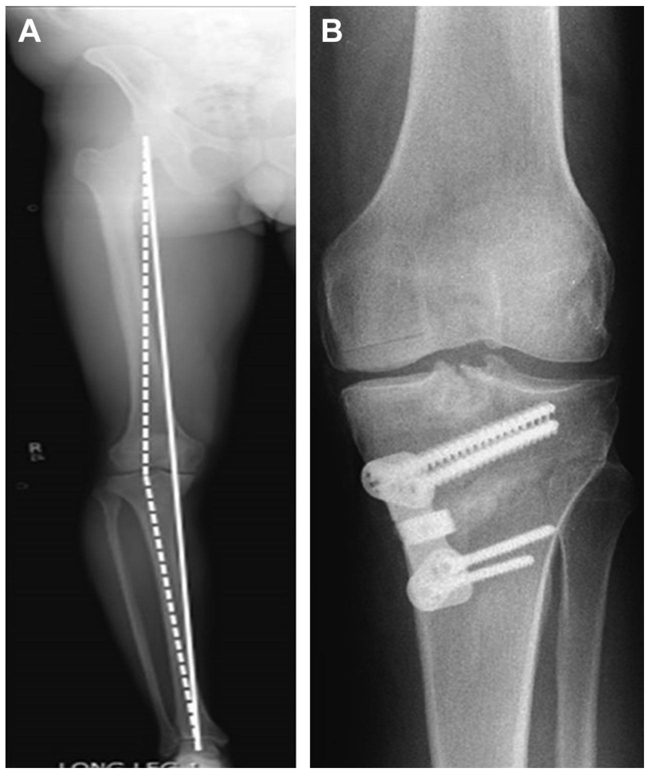

Fig 2. (A) Standing anteroposterior (AP) mechanical axis radiograph showing varus deformity of the right knee. (B) Postoperative standing AP knee radiograph showing healed high tibial valgus-producing osteotomy with medial plate fixation.

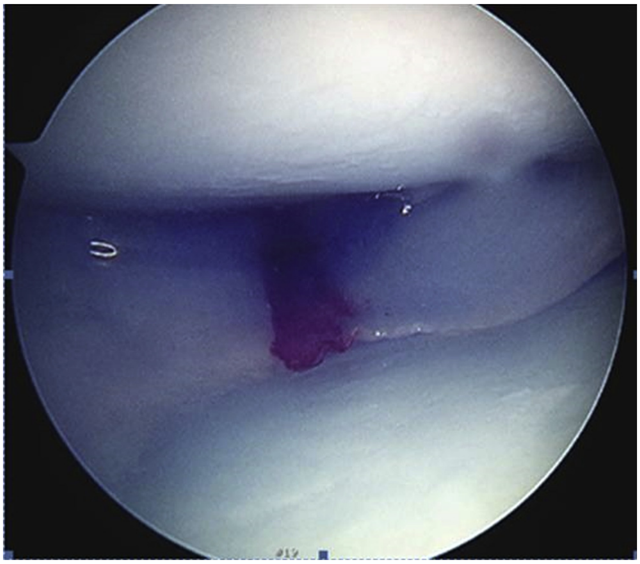

Fig 3. Arthroscopic photograph of medial meniscal transplant in left knee.

matrix (StimuBlast DBM; Arthrex, Naples, FL), allograft bone chips, tricortical iliac crest allograft, and platelet-rich plasma. The degree of correction was determined preoperatively to unload the affected compartment to 62% tibial width from the affected compartment.[9] From 2005 to the present, meniscal transplantation was performed using the bridge-in-slot technique. Before 2005, medial meniscal transplantation was performed using a double bone plug technique, and lateral meniscal transplantation was performed using a keyhole technique. Grafts were fresh frozen for preservation. Grafts were placed into a slot 8 mm in width and 10 mm in depth and fixed with a 7-mm-diameter biocomposite interference screw (Biocomposite Interference Screw [70% polylactic acid, 30% biphasic calcium phosphate], Arthrex, Naples, FL) placed on the far side of the bone bridge. Once seated, the meniscus was repaired inside-out with No. 2-0 high-strength nonabsorbable suture (Fig 3).

Selection of articular cartilage technique was based on a patient-, limb-, and defect-specific algorithm.[10] Microfracture was performed using the arthroscopic technique described by Steadman et al.[11] Osteochondral autografting was performed using a donor site from the lesser weight-bearing medial or lateral trochlea, with press-fit grafting of the plugs flush to the recipient site. Osteochondral allografting was performed with fresh dowel allograft (graft age 14 to 28 days). If secure press-fit fixation was unable to be achieved, a centrally placed bioabsorbable screw (Arthrex, Naples, FL) was added for security. Autologous chondrocyte implantation was performed through 2-stage arthroscopic first-stage biopsy and second-stage arthrotomy and cell implantation using an off-label type I-III collagen membrane cover with suture and fibrin glue fixation.

Postoperative Rehabilitation

After surgery, patients were placed in a cryotherapy-compression cooling device and hinged knee brace. Non—weight-bearing precautions were used for the first 6 postoperative weeks in addition to 6 hours daily continuous passive motion. Formal physical therapy was commenced on suture removal about 10 days after surgery. Weight-bearing was initiated 6 weeks postoperatively. Return to most activities of daily living was initiated at 3 months, with cutting and twisting at 4 months (meniscal healing), return to impact or ballistic activities (or both), at 8 months (osteochondral allograft integration), and return to activities without restrictions at 12 months. Decisions pertaining to return to sport were individualized and based on patient acceptance of the relative sport-specific risk for reinjury.

Clinical outcomes assessed after surgery included physical examination assessment of effusion, tenderness, and atrophy and measurements of motion and strength. Questionnaires administered included the 12-item short form (SF-12), International Knee Documentation Committee (IKDC) subjective form, Knee injury and Osteoarthritis Outcome Score (KOOS) subscores, and Lysholm knee scores. Descriptive statistics were calculated. Continuous data were reported as mean $\pm$ standard deviation and categorical data as frequency. Pre- versus postoperative outcome score comparisons were made using Student t tests. Statistical significance was defined as $P < .05$. All statistical analysis was performed using PASW Statistics, student version 18 (SPSS, Chicago, IL).

Results

Eighteen participants (mean age, 34 ± 7.8 years) met inclusion criteria and were analyzed (Table 1). Thirteen participants were men. Participants were symptomatic for 7.4 ± 5.6 years and had undergone 2.4 ± 1.0 surgical procedures before combined osteotomy, meniscal transplantation, and articular cartilage surgery. Mean duration of follow-up was 6.5 ± 3.2 years. Twelve participants had medial compartment pathologic conditions versus 6 lateral compartment pathologic conditions. Twelve participants underwent osteochondral allografting for cartilage restoration. Preoperatively, participants with medial compartment disease had 7.5° ± 2.0° varus corrected to 1.2° ± 1.5° postoperatively (mean correction, 8.7° ± 1.8°). For participants with lateral compartment disease, the mean correction was 6.8° ± 1.5° (6.1° ± 1.0° valgus preoperatively to 0.7° ± 0.5° postoperatively). Flexion range of motion improved from 6 weeks to 2 years postoperatively (Fig 4). Kellgren-Lawrence classification grade was 1.5 ± 1.1 at 2.5 ± 3.0 years after surgery.

At final follow-up (mean, 6.5 years), there were significant improvements in IKDC subjective, Lysholm, and KOOS pain, KOOS activities of daily living, KOOS sports and recreation, and KOOS quality of life scores

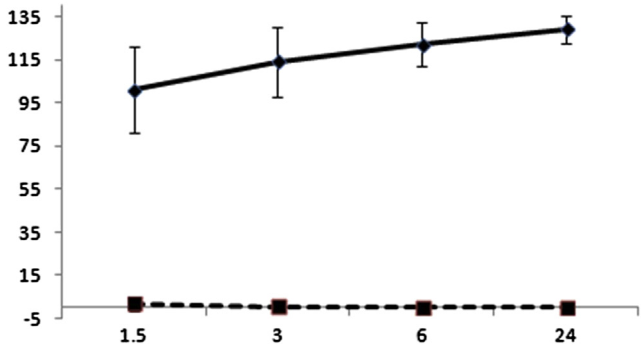

Fig 4. Knee range of motion in flexion (solid line) and extension (dotted line) at 1.5, 3, 6, and 24 months after surgery.

(Table 2). At 2-year follow-up, there were significant improvements in Lysholm and KOOS quality of life scores. Postoperative SF-12 physical and mental component scores were not significantly different from preoperative scores.

Preoperatively and at final follow-up, there were no significant differences in Lysholm, IKDC subjective, and KOOS subscores or in SF-12 mental component scores (MSCs) between participants with medial and those with lateral unicompartmental pathologic conditions. Preoperatively, there was a significantly higher SF-12 PCS in participants with lateral pathologic conditions ($P = .011$). This difference in SF-12 PCS was not observed at final follow-up.

Complications and Reoperations

There were 13 reoperations in 10 patients (Table 3). Only one patient was converted to total knee arthroplasty. One patient had revision cartilage surgery and meniscal transplantation. The most common complication was arthrofibrosis (5 cases in 3 patients) (Table 2). Most of these patients responded favorably to revision surgery, and their final outcomes were included in their most recent follow-up data for purposes of this analysis.

Table 3. Complications and Reoperations After Surgery

Reoperations	
Total knee arthroplasty	1 (60 mo)
Revision osteochondral allograft	1 (16 mo)
Revision microfracture	1 (12 mo)
Revision lateral meniscal transplantation	1 (16 mo)
Incision and drainage for infection	1 (23 d)
Removal of hardware	4 (6, 6, 9, and 16 mo)
Arthroscopic lysis of adhesions, manipulation	5 (3, 6, 6, 9, and 15 mo)
Second-look arthroscopy for pain	5 (3, 6, 9, 12, and 12 mo)
Complications	
Arthrofibrosis	5 (arthroscopic lysis of adhesions, manipulation)
Painful hardware	4 (removal of hardware)
Deep infection	1 (incision and drainage, antibiotic therapy)
Superficial infection	1 (antibiotic therapy)
Osteotomy nonunion (high tibial osteotomy)	1 (nonoperative care)
Saphenous neuritis	1 (nonoperative care)

NOTE. Data in parentheses under Reoperations show the time durations after the index surgery (osteotomy, meniscal transplantation, and cartilage repair). Data in parentheses under Complications indicate the treatment for the listed complication.

Discussion

The principal findings of this retrospective case series of 18 participants undergoing simultaneous meniscal transplantation, osteotomy, and articular cartilage repair have shown statistically significant and clinically meaningful improvements in validated patient-reported clinical outcome scores at a mean 6.5 year follow-up. Although there was a high rate of reoperation (56%), most procedures were for arthrofibrosis, hardware removal, and painful knees resulting from unknown reasons. One participant was converted to total knee arthroplasty (5.6%) and one participant to revision meniscal transplantation and articular cartilage repair (5.6%). There was no significant difference in

Table 2. Postoperative Clinical Outcomes, Reoperations, and Complications

Scale	Preoperative	2 Years Postoperatively	Final Follow-up	*P* Value (2 Years/Final Follow-up)
IKDC subjective	29.1 ± 11.1	48.3 ± 23.0	49.2 ± 15.3	.126/.001
KOOS				
Pain	45.9 ± 17.2	66.6 ± 26.7	69.2 ± 20.2	.123/.003
Symptoms	51.0 ± 15.8	53.0 ± 21.4	57.8 ± 16.4	.806/.277
Activities of daily living	59.8 ± 21.1	75.3 ± 22.6	77.2 ± 15.6	.153/.025
Sport	16.3 ± 16.4	32.5 ± 34.0	33.3 ± 17.9	.305/.014
Quality of life	15.2 ± 16.0	37.5 ± 20.5	41.6 ± 22.9	.014/.001
Lysholm	35.6 ± 17.7	64.0 ± 22.3	67.2 ± 17.3	.005/<.001
SF-12				
Physical component	37.8 ± 8.00	37.5 ± 9.49	39.1 ± 6.23	.996/.603
Mental component	48.8 ± 11.1	51.9 ± 12.7	46.5 ± 14.5	.578/.629

NOTE. Data presented as mean ± standard deviation unless otherwise indicated. Final follow-up is 6.5 ± 3.2 years after surgery.
IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; SF-12, 12-item short form 12.

validated patient-reported clinical outcomes between participants with medial versus lateral pathologic conditions.

The management of articular cartilage disease, meniscal deficiency, and malalignment is complex and multifactorial. Individually, successful clinical outcomes have been seen with articular cartilage restoration,[12-14] meniscal transplantation,[15,16] and realignment coronal plane osteotomy.[17] In combined articular cartilage surgery and meniscal transplantation, statistically significant and clinically meaningful improvements in clinical outcomes have been observed.[16] At a mean of 5 years of follow-up after meniscal transplantation in 172 participants (40% isolated and 60% combined with either osteotomy or cartilage repair), McCormick et al.[18] reported an excellent graft survival rate (95%) but also a high reoperation rate (32%) at a mean of 21 months after meniscal transplantation. Of the reoperations performed, 59% were arthroscopic debridements. In a separate but related study, Abrams et al.[19] reported statistically significant and clinically meaningful improvements in 32 participants who had undergone combined meniscal transplantation and osteochondral allografting with a 4.2-year mean follow-up. Similarly, there was a high reoperation rate (25%), but no patients required revision meniscal and articular cartilage surgery.[19] In the current investigation, low rates of failure were also observed, but nearly half (49%) of all participants underwent at least one reoperation. One patient had 3 reoperations for arthrofibrosis (3, 8, and 15 months after the index operation), one patient had 2 reoperations (second-look arthroscopy for partial lateral meniscectomy at 12 months after index operation, followed by revision lateral meniscal transplantation and revision lateral femoral condyle osteochondral allografting at 16 months), and 8 patients had one reoperation each (Table 3). Given that the minimal clinically important difference for IKDC subjective score is 11.5 in the setting of knee injury, the improvements in the current investigation are not only statistically significant but also clinically meaningful.[20] The minimal detectable change for KOOS subscores ranges from 5 to 12 in the setting of knee injury. Thus, the KOOS subscore improvements are also clinically meaningful.[20] The minimal detectable change for the Lysholm score is 8.9.[21] However, this is after anterior cruciate ligament reconstruction. Nonetheless, the differences in Lysholm score are likely clinically meaningful.

The only previous study to report on simultaneous osteotomy, meniscal transplantation, and articular cartilage surgery was an earlier follow-up on a select number of participants from this current investigation,[7] which adds more than 4 more years of mean follow-up and 11 more participants. The earlier study reported significant improvements in Lysholm, IKDC subjective, and all KOOS subscores except the sport and recreation subscore. These findings mirror those of the current investigation (except the KOOS sport and recreation subscore). The earlier study also reported no significant improvements in SF-12 PCSs and MCSs, also reported in the current investigation. Similarly, a cohort of combined meniscal transplantation and articular cartilage surgery showed significant improvements in IKDC, KOOS, and Lysholm scores, with no significant improvement in SF-12 PCS or MCS.[22] A separate cohort of combined meniscal transplantation and osteochondral allografting showed significant improvements in IKDC, KOOS, Lysholm, and SF-12 PCS but no difference in SF-12 MCS.[19] The reason for improvements in knee-specific patient-reported outcomes but no consistent improvement in SF-12 general health quality of life is currently unknown. These findings conclude that patients' short-term (2 years) postoperative improvements are durable to long-term follow-up (6 years).

In patients with this triad of pathologic conditions (meniscal deficiency, malalignment, and articular cartilage disease), the timing of one or all of the components of the combined surgery (meniscal transplantation, osteotomy, and articular cartilage repair) is controversial.[23] On the staged sequential surgery side, the amount of surgical morbidity (i.e., operative time, anesthesia, blood loss) is reduced per operative case at the expense of more than one surgical procedure. On the simultaneous surgery side, the amount of surgical morbidity is increased, with the need for an additional requisite surgery obviated. The decision for staged versus simultaneous surgery is multifactorial, individualized, and based on patient informed consent and surgeon skill and comfort level. Because the rate of repeated surgery is elevated (with low meniscal surgery revision) after isolated meniscal transplantation[18] and meniscal transplantation combined with one other concomitant procedure,[16,18,19] the reoperation rate observed in this current investigation is not surprising. Although it is possible that a reduction in surgical morbidity by performing this combined surgery in a staged fashion rather than simultaneously may reduce this reoperation rate, the literature has not conclusively shown this. The most common reasons for reoperation in both the staged and simultaneous groups are debridement of articular cartilage or meniscus, or both, and lysis of adhesions. The rate of revision meniscal or articular cartilage surgery, or both, in both staged and simultaneous groups is low.

Limitations

There are limitations inherent to this retrospective case series prone to selection and transfer bias. It is a single-surgeon series of simultaneous advanced reconstructive techniques that may not be universally applicable to all surgeons' experience and comfort level. We are not aware of any study that compares simultaneous or staged combined osteotomy, meniscal transplantation, and articular cartilage repair. Some surgeons may be more comfortable staging these techniques to reduce operative time and potential morbidity. The exclusion of participants undergoing staged, rather than simultaneous, techniques limits the generalizability of the study's outcomes. Another limitation is the limited radiographic follow-up in these participants at earlier time points. Nonetheless, the authors do not feel that radiographic evaluation is compulsory unless the patient is symptomatic ("treat the patient and not the radiograph"), because radiographs do not always correlate with patient symptoms. Sagittal plane tibial slope after high tibial osteotomy may influence patient outcomes, because anterior plate placement may increase posterior slope and translation of the femoral condyles on the tibial plateau. This places undue stress on meniscal allografts, repaired articular cartilage, and reconstructed cruciate ligaments. However, tibial slope was unable to be specifically evaluated in the current investigation because of the lack of radiographic follow-up. Because these patients are very young with complicated diagnoses, long-term follow-up is necessary and still lacking. Only long-term follow-up with direct comparisons to a similar group of untreated patients will be able to ascertain the ability of these salvage procedures to halt the progression of degenerative arthritis and delay arthroplasty while preserving improved pain, motion, function, and activity levels.

Conclusions

Statistically significant and clinically meaningful improvements in validated patient-reported clinical outcome scores at long-term follow-up were observed in 18 participants undergoing combined meniscal transplantation, osteotomy, and articular cartilage surgery. Although there was a low rate of cartilage or meniscal revision (or both) and total knee arthroplasty, there was a high rate of reoperation. There was no significant difference in outcomes between participants with medial versus lateral pathologic conditions.

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