Rehabilitation, Restrictions, and Return to Sport After Cartilage Procedures

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Abstract: The ability to return to sport (RTS) after articular cartilage injury is of vital importance to athletes. Discussing the likelihood of returning to sport with patients is necessary, yet patients should be informed of the heterogeneous nature of the variables associated with successful RTS and the methodologic limitations behind current RTS rate estimates. Patient-specific factors affecting RTS are numerous and, in most cases, their isolated effect on RTS rates have yet to be examined and will remain difficult to do so. The purpose of this review is to discuss current RTS rates, explore factors leading to successful RTS, and examine the variability in physical therapy protocols after cartilage procedures, including microfracture, osteochondral allograft transplantation (OCA), autologous chondrocyte implantation (ACI), and meniscal allograft transplantation (MAT). The senior author's postoperative protocols will also be presented, as with a discussion on using RTS as a metric of patient and procedural success. Overall, there is significant variation in reported RTS rates among procedures examined, and providers must continue managing patient expectations when discussing treatment options.

Cartilage defects of the knee remain a challenging problem to address, especially when treating younger patient populations who are interested in returning to high-level activities that are currently unavailable to them because of their levels of activity-related pain that impairs performance.[1] Many treatment options do exist, yet there is no established "gold standard," and more than one option might yield a successful outcome with high degrees of patient satisfaction and a legitimate return to sport (RTS). This uncertainty may be troubling to patients who are at a vulnerable point in their athletic career. A similar level of ambiguity is found within the postoperative

rehabilitation protocols after surgical intervention for the treatment of cartilage injuries. Specifically, there is a limited body of clinical investigation into the efficacy of different physical therapy protocols. Therefore most rehabilitation protocols are guided by anecdotal evidence that is surgeon specific.

Despite few comparisons of postoperative protocols, examining RTS rates and timelines has become a popular topic in the sports medicine literature. Several variables besides differing rehabilitation protocols and the documented time an athlete returns to play may introduce bias into reported rates and therefore make them less reliable. Potential confounders include small sample sizes, use of publicly available data for athlete injuries and performance, and lack of standardization among return to prior performance outcome measures. Future studies may be able to address these limitations, yet there are additional factors impacting RTS that will never be controllable, such as patient-specific goals, financial implications, and coaching decisions. Regardless of current research limitations, patients will continue to ask whether they will be able to return to sport and how their performance will be impacted after surgery. The purpose of this review is to discuss current RTS rates, explore factors leading to successful RTS, and examine the variability in physical therapy protocols after cartilage procedures, including microfracture, osteochondral allograft transplantation (OCA), autologous chondrocyte implantation (ACI), and meniscal

allograft transplantation (MAT). The senior author's postoperative protocols will also be presented, as with a discussion on using RTS rates as a metric of patient and procedural success.

RTS for Nonoperative Management

Unlike ligamentous injuries, cartilage lesions in isolation do not prevent athletes from participating. Although they can be disabling when symptomatic, clinically silent focal cartilage defects have been found in many asymptomatic patients. The prevalence of asymptomatic lesions may be as high as 60% in those evaluated by arthroscopy.[2] In professional and recreational athletes evaluated by magnetic resonance imaging, the rate of asymptomatic lesions ranges from 41% to 47%.[3,4] There is no current guideline on when to treat asymptomatic lesions, and research offers mixed outcomes when they are present. A study by Widuchowski et al.[5] found no difference in long-term clinical outcomes in patients with and without high-grade chondral lesions after ACL reconstruction.[5] However, these lesions are associated with greater annual loss in cartilage volume, which may correlate with the future formation of osteoarthritis.[6] Further long-term studies may help elucidate whether these lesions need to be addressed when first encountered in a patient if asymptomatic, but the current sentiment is to observe these lesions offering no real intervention.

When a patient has pain that limits their exercise capacity or activities of daily living, the first step in evaluation requires comprehensive assessment for concomitant pathology—such as ligamentous injury, meniscal tear, or malalignment—which may be the underlying source of discomfort. Concomitant pathology may impair cartilage restoration, cause additional pain, and should be contemplated at the time of cartilage repair if such a procedure is required.[7] However, first-line intervention for isolated cartilage defects commonly includes restriction of activity, bracing, physical therapy, and possibly the implementation of orthobiologics to manage symptoms.[8,9] Patients must be educated that despite the definition of an articular cartilage defect or meniscal deficiency, there is a paucity of literature associated with disease progression should patients remain active at an elite level.

To our knowledge, there are no large, randomized trials that adequately define RTS for nonoperative treatment of cartilage defects. There are case reports detailing nonoperative treatment for many common causes of cartilage defects.[10,11] However, because causes of chondral defects are numerous, it is beyond the scope of this review to discuss nonoperative rates of RTS for each. Instead, we will broadly discuss the RTS timelines for several commonly used cartilage procedures, including microfracture, OCA, ACI, and MAT.

RTS for Microfracture

Microfracture is one of the most common "cartilage procedures" performed in the United States because of its low cost, and the relative ease with which it can be performed as a single-stage procedure (Fig 1). Although simple, this procedure has been challenged recently because it is not a true restorative procedure, but rather a reparative cartilage procedure that attempts to generate fibrocartilage repair tissue rather than restore or regenerate the native surface with hyaline cartilage.[12] It does, however, remain a viable first-line option for management of symptomatic cartilage lesions, especially if the lesion is <2 cm^2.

An estimated 78,000 microfractures were performed in 2011 and have been widely utilized for recreational and professional athletes.[12-14] The procedure was initially developed by Richard Steadman in the 1990s, and the outcomes published by his group have been laudable.[15] In his cohort of elite skiers, there was a 95% RTS rate after microfracture.[16] However, recent investigations have shown less-promising results, with RTS rates averaging between 75% to 77%.[17,18] One advantage, though, is that microfracture does offer a quicker RTS timeline (8.6 months), compared to OCA (9.4 months) and ACI (11.6 months), which may make it a desirable strategy in athletes who are under time pressure to return to sport, with the understanding that further treatment may be required once their career ends or if their treatment should fail mid-career.[18]

Another outcome measure that is particularly important to the athlete is the possibility of returning to the same or higher level of play, known as return to prior performance (RPP). In 2019, Hurley et al.[18] reported that in patients who underwent microfracture surgery, RPP (62%) was consistent with other common treatment modalities, including OCA (59%) and ACI (57%). However, it is unclear which RPP metrics and sports were evaluated in this study. A systematic review by Campbell et al.[17] found a similar RPP for microfracture and included studies with many different methods of RPP evaluation including questionnaires, "power ratings," and games played per season, among others. However, several articles analyzed in their study used public databases for professional athlete injuries and therefore could not fully account for concomitant pathologies.[19,20]

In addition to concerns regarding RPP, postoperative physical therapy protocols are typically time-based and may not be specific to the patient's strength progression or relief of pain.[18] Hurley et al.[18] listed range of motion protocols from 39 studies and weight bearing in 47 studies after microfracture. Universally, range of motion was started within the first week after surgery. However, the decision to allow partial weightbearing is variable. About 55% of studies recommended the
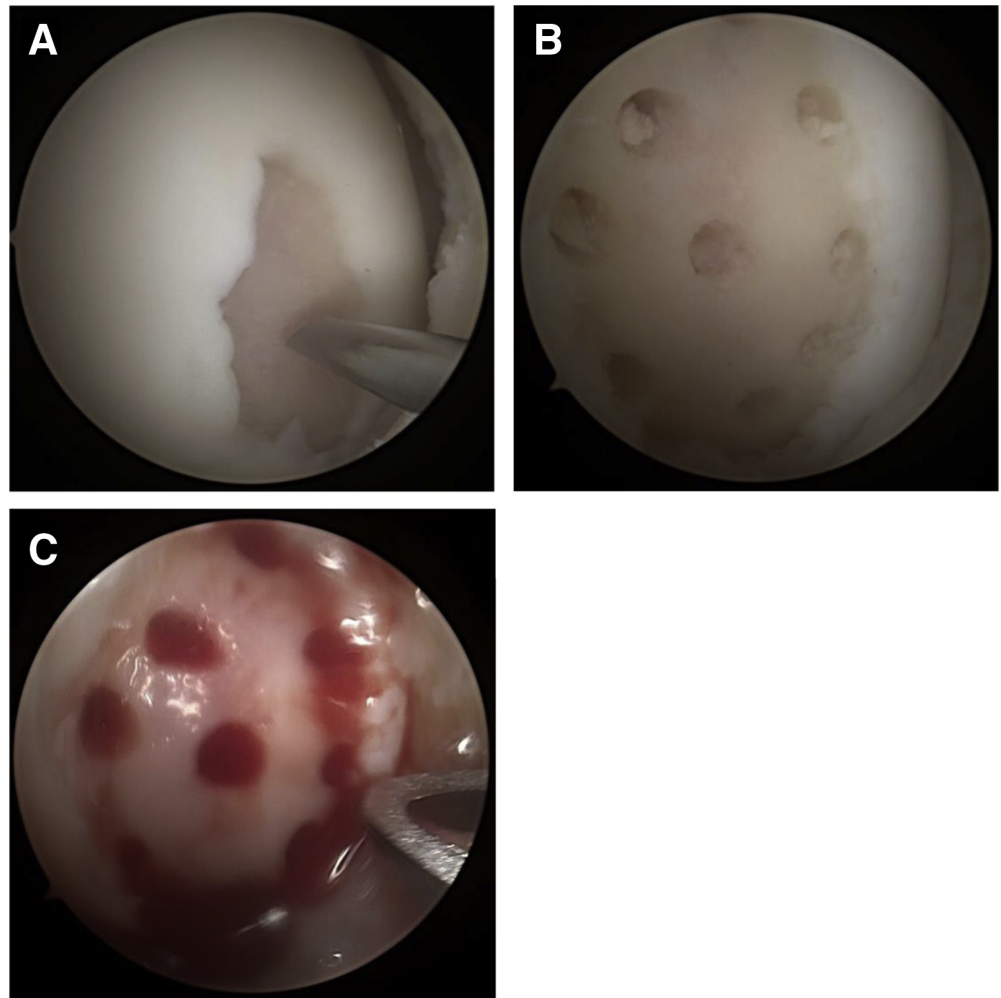
Fig 1. A full-thickness, focal cartilage defect on the medial femoral condyle of the left knee measuring 10 × 15 mm (A). The defect was treated with microfractures (B). Marrow elements were seen flowing out of fractures after removal of tourniquet (C).

initiation of weight bearing within the first week after surgery, yet 36% waited until after postoperative week 4.[18] Progression to full weight bearing typically began either at six weeks (53% of studies) or eight weeks (35% of studies). Only 11% of studies analyzed in the systematic review by Hurley et al.[18] considered a patient's symptoms as part of return to play criteria, and no study used strength as criteria. The heterogeneity likely reflects surgeon preference because, to our knowledge, there are no studies investigating the influence that varying physical therapy protocols have on RTS timelines and performance.

For microfracture performed on the femoral condyle, the senior author recommends that patients remain non-weightbearing when transitioning from one location to another until week 6, after which they are advanced to full weightbearing. A knee brace is locked in full extension at all times, with exception for non-weightbearing exercises (passive leg hangs, quad sets, and calf pumps). Continuous passive range of motion (CPM) begins immediately after surgery if it is a covered benefit, with progression to active assisted range of motion (AAROM) exercises in week 2, as tolerated (Table 1). Patellofemoral lesions that are not performed with a concomitant tibial tubercle realignment procedure are allowed to bear weight as tolerated immediately with initial use of the brace.

Notably, the senior author endorses precise defect preparation, creation of vertical walls at the defect host junction, fastidious elimination of the calcified layer, and drilling (rather than the use of an awl) that minimizes macroscopic disruption of the subchondral plate. Compared to standard microfracture with awl, microdrilling results in fewer revision surgeries and superior patient-reported outcomes (PROs).[21]

RTS for Osteochondral Allograft Transplant

Over the past 2 decades, osteochondral allografts have become a common[12,14] and effective[22,23] way to treat cartilage damage, especially in young, active adults. OCAs restore hyaline cartilage to the articular surface through the transplantation of deceased donor cartilage (Fig 2). It is a one-stage procedure that typically treats larger (>2 cm²), full-thickness osteochondral defects.

Table 1. Rehabilitation Protocol for Select Cartilage Procedures

Procedure	Weightbearing	Brace	CPM	Exercises	Return to Sport-specific Activity
Microfracture of MFC	Non-weightbearing until week 6 with subsequent progression from partial to full weightbearing	Locked in full extension until week 2	Immediately until week 6	Immediate quad sets, calf pumps, passive leg hands with progression to PROM and AAROM as tolerated. Gait training and closed chain activities begin week 8. At 12 weeks, strengthen core, gluteal muscles, and hamstrings with progression to elliptical or pool if tolerated.	After 8 months
OCA of MFC	Heel touch immediately until week 6 with subsequent progression from partial to full weightbearing	Locked in full extension until week 2	Immediately until week 6	Immediate quad sets, calf pumps, passive leg hands with progression to PROM and AAROM as tolerated. Gait training and closed chain activities begin week 8. At 12 weeks, strengthen core, gluteal muscles, and hamstrings with progression to elliptical or pool if tolerated.	After 8 months
ACI of MFC	Non-weightbearing until week 6 with subsequent progression from partial to full weightbearing	Locked in full extension until week 2	Immediately until week 6	Immediate quad sets, calf pumps, passive leg hands with progression to PROM and AAROM as tolerated. Gait training and closed chain activities begin week 8. At 12 weeks, strengthen core, gluteal muscles, and hamstrings with progression to elliptical or pool if tolerated.	After 8 months
MAT	Heel touch weight bearing with crutches until week 6, when patients may progress to full weightbearing. No weightbearing with flexion >90° until week 8.	Locked in full extension until week 2. Afterwards, locked 0°-90° until week 8.	Limited to 90° until week 2	Immediate heel slides, quad sets, and patellar mobs until week 2. Heel raises and terminal knee extensions with knee brace until week 6. Progress closed chain activities starting week 8 and strengthen core, hips, and gluteal muscles. Begin elliptical and bike starting week 12 with swimming if tolerated at week 16.	Patient-specific, based on physical therapy progression.[*]

CPM, continuous passive range of motion; MFC, medial femoral condyle; PROM, patient-reported outcome measure; AAROM, active assisted range of motion; OCA, osteochondral allograft transplantation; ACI, autologous chondrocyte implantation; MAT, meniscal allograft transplantation.

Detailed postoperative rehabilitation protocol for microfracture, OCA, and ACI of the MFC. Additionally, the protocol after MAT is also described.

*Additional factors that may influence patient ability to return to sport include desired sports to participate in, resolution of symptoms, and others.
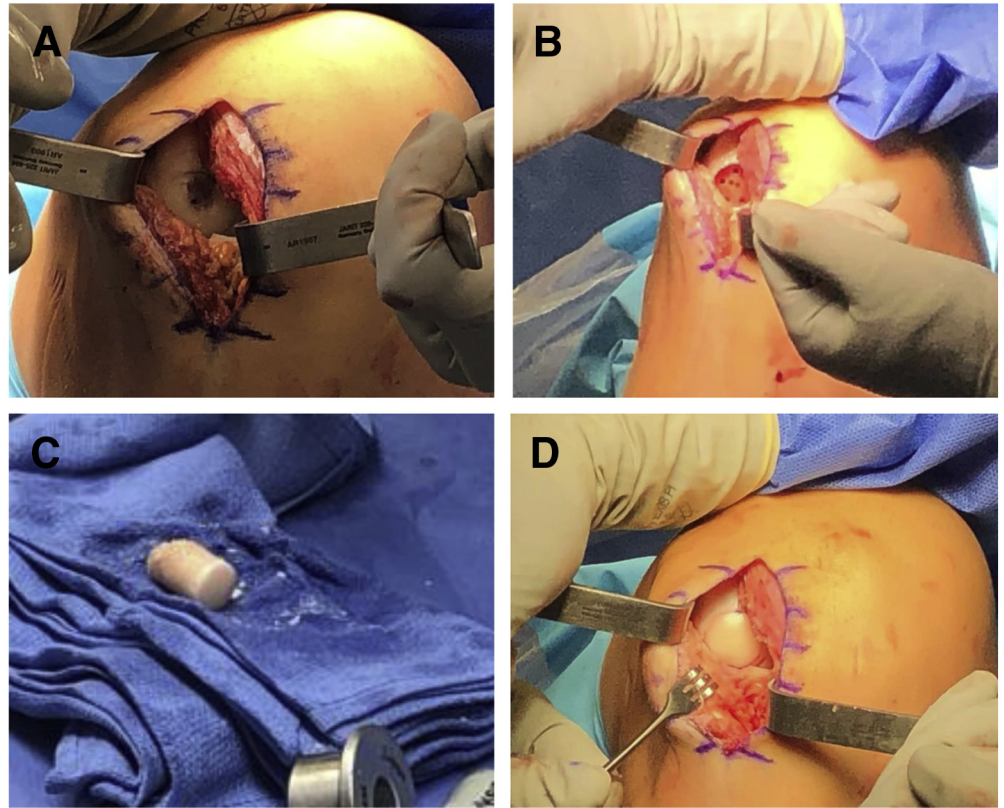
Fig 2. A lateral femoral condyle cartilage defect of the right knee (A) that was reamed (B) to a depth of 8 mm and subsequently treated with an osteochondral allograft plug (C, D).

Estimates show a twofold increase in the number of open osteochondral allografts done between 2007 and 2016.[12] Part of the popularity of OCAs is due to the ability to reliably improve PROs and longevity once the graft incorporates into host tissue.[24] A caveat with osteochondral allografts, however, is an associated high reoperation rate, which may range from 34% to 53%.[17,24] However, because it is used much less frequently in elite athletes than microfracture, data regarding RTS after OCA is relatively limited.

Similar to microfracture surgery, RTS after OCA is wide ranging.[17,18,25] In a meta-analysis of 7 studies conducted by Hurley et al.,[18] the average RTS after OCA was 77.1% (range, 58%-100%), whereas the average time elapsed until return to sport was 9.4 months (range, 7.9-14.0 months). One of the studies included in the meta-analysis conducted by Krych et al.,[25,26] which sought to identify risk factors associated with a delayed RTS among its participants. Among the 43 recreational and collegiate athletes (average age of 32.9 years), the authors found age greater than 25 years and duration of symptoms greater than 12 months were associated with an increased risk of not returning to full athletic activity. Interestingly, treatment with multiple OCA plugs, increased lesion area, or need for a concomitant procedure were not identified as statistically significant causes for a delayed RTS.[25,26] Riff and colleagues[27] compared a cohort of those who

underwent OCA following failed marrow stimulation against primary OCA. There were no differences in PROs between groups; however, RTS was not analyzed.[27] In a larger study by Nielsen et al.,[28] 142 recreational and highly competitive athletes (average age of 31.2 years) had a 75.2% RTS after OCA. Self-reported reasons for failure to RTS after surgery were most commonly due to pain or concern over reinjury (reported by 47% and 41% of those who did not RTS, respectively). However, 91% of patients were "satisfied" or "extremely satisfied" with the surgery. In contrast to the study conducted by Krych and colleagues,[25,26] Nielsen et al.[28] identified larger graft size as a cause of delayed RTS. Other factors identified included anatomic location and female sex.[28] Avoidance of causing further injury is a valid concern for patients, especially among those who have undergone multiple failed treatments of their cartilage lesion. However, it should not be a contraindication in those who are otherwise at low risk for OCA failure. Evidence-based rehabilitation protocols may help mitigate some of these concerns and thus increase RTS.

The aforementioned study by Hurley et al.[18] examined 5 studies to estimate patient RPP after OCA, with an average of 59.5% (range of 38.5%-100%). This was similar to patients who underwent microfracture (62.3%) and ACI (57.3%).[18] Data on RPP after OCA among elite athletes are very limited, and, to our
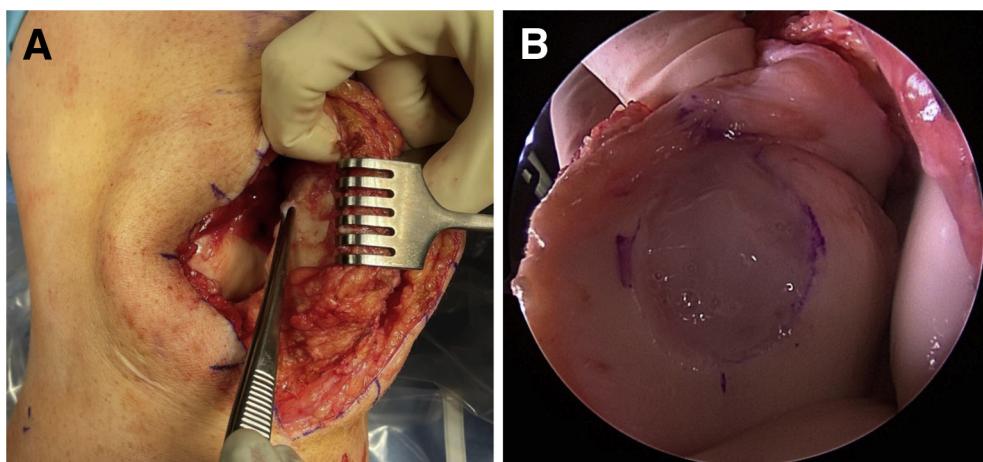
Fig 3. A focal cartilage defect on the patella of the left knee (A), which may be treated with a second-generation, matrix-assisted autologous chondrocyte implantation (MACI; B).

knowledge, there are no studies stratifying RPP by specific professional sports. A study by McCarthy and colleagues[29] investigated RTS rates among 13 athletes (collegiate and high school) who underwent OCA at an average age of 19.2 years and found an adjusted RTS of 77%, but provided no data on how patients performed when returning to sport. Balazs et al.[30] analyzed specific performance metrics in a group of 11 basketball players (7 collegiate and 4 professional) at an average age of 22.8 years. This cohort was found to have a RTS of 80%, with an average timeline of RTS of 14 months.[30] Although not meeting statistical significance, there was a uniform trend toward decreased postoperative statistical productivity among the cohort when compared to preoperative performance.

Much like the case for microfracture surgery, there is a large deal of heterogeneity among rehabilitation protocols after OCA. For example, in 51 studies evaluated by Hurley et al.,[18] 13% of studies recommended patients begin partial weightbearing immediately, 23% studies waited to begin partial weightbearing until postoperative week 2, and 31% of studies recommended patients be non-weightbearing until postoperative week 6. The senior author prefers patients to maintain heel touch weightbearing until week 6 after surgery, then patients progress to full weightbearing as tolerated. For the first 2 weeks after OCA, a brace is locked in full extension between sessions of CPM and non-weightbearing exercises. The knee brace is discontinued after postoperative week 2, after which the patient may begin advancing through PROM and AAROM, as tolerated (Table 1). Patellofemoral lesions that are not performed with a concomitant tibial tubercle realignment procedure are allowed to bear weight as tolerated immediately with initial use of the brace.

Return to Sport for Autologous Chondrocyte Implantation

Similar to OCA, autologous chondrocyte implantation (ACI) is a restorative treatment that can be used for larger cartilage lesions ($>2cm^2$; Fig 3). A drawback to ACI, however, is that the surgery requires 2 stages: an initial biopsy of the patient's cartilage and subsequent cultured chondrocyte implantation weeks later. Historically, the implant was placed underneath several covers, including periosteal or porcine collagen-derived covers. Brittberg et al.[31] was the first to report on the use of ACI in humans in 1994, and since then the procedure has gained popularity.[14] High reoperation rates eventually led to the development of matrix-assisted ACI (MACI), a second-generation ACI which has successfully reduced failure and the need for reoperation when compared with first-generation ACI techniques.[32] RTS potential after ACI appears comparable to that of OCA and is superior to microfracture, especially for defects larger than 2 cm^2. Campbell and colleagues[17] analyzed 7 studies, including first- and second-generation ACI, and found an overall RTS of 84% following surgery. For microfracture, the reported RTS rate was 75% (11 studies analyzed), whereas OCA had an RTS of 88% (only 1 study included).[17] To contrast with microfracture, ACI had a longer average RTS timeline, with an average of 16 months, compared to 8.6 months and 9.6 months after microfracture and OCA, respectively.[17,18]

Several studies have found RPP following ACI to be analogous with those of both OCA and microfracture. Hurley et al.[18] found an RPP rate of 57% after ACI, which was similar to that of OCA (59.5%) and microfracture (62.3%).[18] Kon et al.[33] compared 41 elite soccer players treated with second-generation ACI or microfracture and found comparable rates of RPP (67%
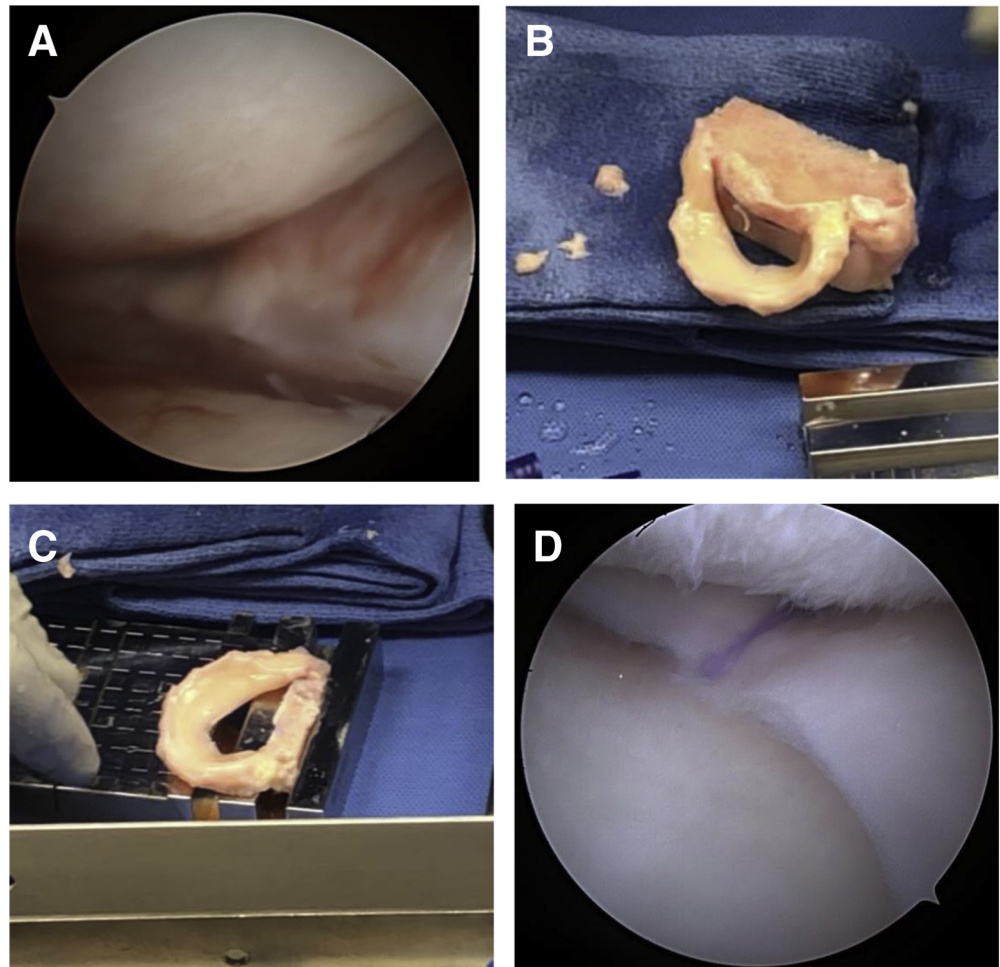
Fig 4. A meniscus-deficient right knee (A) that was a candidate for medial meniscal allograft transplantation (MAT). The allograft was prepared (B) in bone-slot fashion (C) and successfully transplanted (D).

and 75%, respectively). The study also revealed that, much like RTS timelines, there was a significantly increased RPP timeline after ACI (12.5 months), compared to microfracture (8.0 months).[33]

The extended RTS timeline after ACI and its second-generation procedures may be shortened because recent evidence regarding physical therapy protocols suggest that patients may be able to RTS earlier with more intense and accelerated rehabilitation. A study by Della Villa et al.[34] compared clinical success after MACI using a standard rehabilitation protocol against those who completed the standard protocol and additional specialized on-field rehabilitation and isokinetic exercises. Patients who completed on-field rehabilitation and isokinetic exercises had significantly earlier RTS compared to those who only did the standard protocol (mean 10.6 months and 12.4 months, respectively).[34] This was consistent with findings from Ebert et al.,[35] who found improved PROs and functional assessments among patients who engaged in full weight-bearing at 8 weeks after surgery following MACI, compared to those who started full weightbearing at 10 weeks after operation.[35]

Protocols for weightbearing after ACI typically begin with partial weightbearing either during the first (40.5%) or sixth (31.0%) week after surgery, as reported in the systematic review by Hurley et al.[18] Full weightbearing is more variable and may start at postoperative week 6 (25%), 8 (20%), or 10 (25%). After ACI, the senior author prefers that patients are nonweightbearing until week 6 after surgery; then patients progress to full weightbearing as tolerated. Similar to OCA, patients will be kept exclusively in a brace locked in full extension for the first 2 weeks, with exceptions made only for non-weightbearing exercises and CPM. Patients are started on PROM and AAROM, as tolerated, after the knee brace is removed during postoperative week two (Table 1). Patellofemoral lesions that are not performed with a concomitant tibial tubercle realignment procedure are allowed to bear weight as tolerated immediately with initial use of the brace over the first 6 weeks after surgery.

RTS for MAT

Menisci have many functions within the knee, including shock absorption, distribution of shear stress,

and joint stabilization. Meniscal injuries are common among young athletes and elderly patients, with an annual incidence as high as 70 per 100,000 inhabitants.[36] Surgical management of meniscal injuries vary in complexity; potential options include removal, repair, and replacement via allograft transplantation. Recently, there has been a trend away from debridement and toward meniscal repair because of an evolving understanding of kinematics and long-term outcomes in a meniscal-deficient knee.[37] Meanwhile, MAT is typically reserved for those with either refractory pain after meniscectomy or as a concomitant procedure during revision ACL reconstruction or articular cartilage repair in a meniscus-deficient knee (Fig 4). Although MAT long-term outcomes have been promising,[38] it is still only recommended with caution for athletes because of increased risk of reoperation and longer recovery times.[39]

Even though many patients treated with MAT may choose to limit their activities out of concern over reinjury, RTS for those deciding to participate in sports are promising. Grassi et al.[40] found an average RTS rate among recreational and professional athletes of 77% of following MAT (range, 72%-83%), with a mean time to RTS of 9.2 months (range, 7.3-16.5 months). PROs significantly increased among the 5 studies analyzed in this meta-analysis.[40] Neither the bone-plug nor the bone-bridge MAT surgical techniques were found to be associated with treatment failure. Additional accounts for inability to RTS have been described by Cvetanovich and colleagues.[41] In a group of recreational and competitive athletes (average age 28.9 years) treated with MAT using the bone bridge technique, the rate of RTS was 75.6% with an average time to RTS of 12.6 months.[41] Interestingly, preoperative body mass index, age, sex, worker's compensation status, or participation as a competitive athlete had no association with decreased RTS rates. Instead, the most common patient reported-reason for not RTS was the desire to prevent further damage and avoid pain with activity. Nevertheless, 77% of patients were satisfied overall with their surgery.

After MAT, RPP is similar to that of microfracture, OCA, and ACI. Grassi and colleagues[40] analyzed 7 studies, including a military service member population, and found a RPP of 67% (range: 39.0%-85.7%). One study included in the metanalysis examined a small cohort of professional soccer players treated with MAT and found an impressive RPP of 75% at a 36 month follow up, as determined by Tegner score. An additional 17% of their cohort were still playing soccer, but at the semiprofessional level.[42] In comparison to many other studies of RPP for professional athletes, this case series was performed at a single institution and adequately reported concomitant surgeries for each patient.

To contrast with other procedures described in this review, there are no studies examining the heterogeneity of weightbearing and physical therapy protocols after MAT. However, the variations found in microfracture, OCA, and ACI protocols are likely also found after MAT, because there are no studies, presently, comparing intensity or duration of protocols on clinical and functional outcomes after MAT. The senior author has previously published on patients who were able to begin immediate weightbearing as tolerated after MAT and identified a failure rate of 16%, which is consistent with other reported failure rates.[40] RTS was not analyzed, but PROs significantly improved at 2-year follow-up.

After MAT, the senior author prefers that patients have a knee brace locked in full extension for the first 2 weeks, then limited to 90° flexion until postoperative week 8—after which it is discontinued. Patients are started on immediate PROM and AAROM limited to 90° of flexion, although weightbearing with flexion past 90° is restricted until postoperative week 8. Non-weightbearing exercises begin immediately after surgery and progress as tolerated (Table 1).

Limitations in RTS as a Metric

Engaging in sports has numerous health benefits and provide a medium to socialize, compete, improve self-esteem, develop leadership qualities, and more. It should come as no surprise, then, that one of the first questions a patient asks after an injury is "When can I get back to playing sports?" Although an answer to this question is necessary to provide, because of the multifactorial nature of returning to sport, it is paramount that patients understand all relevant clinical outcomes—not just the RTS rate. Reoperation rates, treatment failure rates, return to preinjury level of participation, and PROs should all be communicated to the patient for them to make an informed decision regarding their treatment plan. Patients should also be advised that reported RTS rates may not be applicable to every personal circumstance because there are no current, large-scale studies that stratify RTS by sport or level of competitiveness. For studies that analyze RTS among professional athletes, the use of public information to evaluate an athlete's injury and performance after surgery may neglect to consider important factors surrounding a RTS, like concomitant pathologies or surgical technique used. Additionally, RTS and RPP are frequently subject to confounding bias from coaching decisions, financial implications, external pressure from teammates, and other variables that are inherently difficult to account for such as roster changes, contract implications, and athlete preferences. Further recommendations to improve RTS research methodology have been suggested by professional associations, such as the NBA Research Committee.[43] Presently, components of RTS that can be controlled, such as comparisons of different rehabilitation protocols, have limited clinical evidence and display significant heterogeneity.

Conclusion

There is significant variation in reported RTS rates among procedures examined, and providers must continue managing patient expectations when discussing treatment options. Ultimately, the ability of a patient to return to sport after surgery will continue to be a litmus test used by patients and researchers to judge the success of a procedure. To the dismay of medical providers and patients eager to hear whether they have the opportunity to eventually return to sport, it is impossible to measure or control each factor that leads to a successful RTS. However, further study of components within the purview of medical care, such as how differing postoperative rehabilitation protocols affect clinical outcomes following surgery, are warranted to better equip medical providers with the tools to deliver the highest care possible to patients.

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