VIDEO Abstract

Transarticular Versus Retroarticular Drilling of Stable Osteochondritis Dissecans of the Knee

A Prospective Multicenter Randomized Controlled Trial by the ROCK Group

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Background: When stable osteochondritis dissecans (OCD) lesions of the femoral condyle in a skeletally immature patient fail to heal with nonoperative methods, the standard of care treatment is condylar OCD drilling. Two primary OCD drilling techniques have been described, but no prospective studies have compared their relative effectiveness.

Purpose/Hypothesis: The purpose of this study was to compare the healing and function after transarticular drilling (TAD) with that after retroarticular drilling (RAD). It was hypothesized that there would be no difference in rate or time to healing, rate or time to return to sports, patient-reported outcomes (PROs), or secondary OCD-related surgery.

Study Design: Randomized controlled clinical trial; Level of evidence, 1.

Methods: Skeletally immature patients with magnetic resonance imaging–confirmed stable OCD lesions of the medial femoral condyle who did not demonstrate substantial healing after a minimum of 3 months of nonoperative treatment were prospectively enrolled by 1 of 17 surgeon-investigators at 1 of 14 centers. Patients were randomized to the TAD or RAD group. Tourniquet time, fluoroscopy time, and complications were compared between the treatment groups. Postoperatively, serial radiographs were obtained every 6 weeks to assess healing, and PROs were obtained at 6 months, 12 months, and 24 months.

Results: A total of 91 patients were included, consisting of 51 patients in the TAD and 40 patients in the RAD group, who were similar in age, sex distribution, and 2-year PRO response rate. Tourniquet time and fluoroscopy time were significantly shorter with TAD (mean, 38.1 minutes and 0.85 minutes, respectively) than RAD (mean, 48.2 minutes and 1.34 minutes respectively) (P = .02; P = .004). In the RAD group, chondral injury from K-wire passage into the intra-articular space was reported in 9 of 40 (22%) patients, but no associated postoperative clinical sequelae were identified in these patients. No significant differences between groups were detected in follow-up Pediatric–International Knee Documentation Committee, Lysholm, Marx Activity Scale, or Knee injury and Osteoarthritis Outcome Score Quality of Life scores. Healing parameters were superior at 6 months and 12 months in the TAD group, compared with the RAD group, and secondary OCD surgery occurred in 4% of patients who underwent TAD and 10% of patients who underwent RAD (P = .40). Patients in the TAD group returned to sports earlier than those in the RAD group (P = .049).

Conclusion: TAD showed shorter operative time and fluoroscopy time and superior healing parameters at 6 and 12 months, but no differences were seen in 24-month healing parameters or PROs at all follow-up time points, when compared with RAD.

Registration: NCT01754298 (ClinicalTrials.gov identifier).

Keywords: osteochondritis dissecans; knee OCD; pediatric sports medicine; OCD drilling; randomized controlled trial

Osteochondritis dissecans (OCD) has been recently redefined by an international OCD study group as a focal idiopathic alteration of subchondral bone with risk for instability and disruption of adjacent articular cartilage that may result in premature osteoarthritis.[9] The knee is by far the most common joint affected by OCD, with fewer

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cases reported in the elbow, ankle, and, much more rarely, other joints.[8,16,17,19] The most common presentation of knee OCD is a stable lesion on the lateral aspect of the medial femoral condyle in a skeletally immature adolescent or preadolescent athlete.[18] Stable lesions, with pathologic involvement limited to the subchondral bone, are differentiated from unstable lesions by the absence of any features of instability, which include chondral fissuring, disruption of the subchondral plate, or gross lesion mobility. For patients with open physes with stable OCD lesions, the standard of care for first-line treatment is nonoperative, consisting of weightbearing protection with crutches, activity modification, bracing, and physical therapy. However, there is great variation in the duration of these recommended measures, with varying importance placed on the different modalities and a period of observation and radiographic assessment for OCD healing that may range from 1 month to >1 year.[22,24]

Despite the established consensus to initially manage stable knee OCD in skeletally immature patients with nonoperative treatment, the rates of failed healing associated with such treatment are relatively high, with more methodologically rigorous studies suggesting that up to 34% to 43% of patients will ultimately require further intervention.[22,24] The standard of care for a stable OCD that does not achieve ongoing bony healing is therefore surgical treatment, consisting of arthroscopy for confirmation of lesion stability and OCD drilling.

Two different primary OCD drilling techniques have been utilized and studied over time. Transarticular drilling (TAD) is the more historical approach, using small K-wires advanced percutaneously, in retrograde, intra-articular fashion, through the articular cartilage and affected subchondral bone and into the deeper, healthy cancellous bone of the condyle.[2,10,11,15,20] Multiple K-wire passes, all placed within the visible or palpable margins of the lesion, as assessed arthroscopically, are utilized to perforate the sclerotic boundary of the lesion and establish bony channels for healing. Retroarticular drilling (RAD) is a relatively newer technique in which the K-wire perforations are made in anterograde, extra-articular fashion, down to the subchondral bone without perforating the articular cartilage.[5,6] The technique, which requires fluoroscopic guidance of K-wire position to ensure perforation into the lesion, has been shown to induce bony healing, similar to the TAD technique, but theoretically optimizes joint preservation by avoiding iatrogenic injury to the cartilage overlying the OCD lesion, which is inherent in the TAD technique.

While recent studies have shown good OCD healing rates, frequent return to sports, and excellent patient-reported outcomes (PROs) after both TAD[2,20] and RAD[4,7] techniques, comparative studies between the 2 techniques have been limited to systematic reviews[1,12] and level 5[15] literature. These studies detected minimal differences in TAD and RAD outcomes, perhaps in part because of small sample sizes, methodological limitations, and heterogeneity of the included studies. Such analytical challenges are typical of studies of orphan diseases or rare conditions,[3] such as knee OCD. The purpose of the current study, therefore, was to compare the outcomes of TAD versus RAD using the methodological rigor of an appropriately powered prospective randomized controlled trial of surgical techniques. The study sought to address the challenge of sample size and patient volume by harnessing the power of an international OCD study group of 17 surgeon-investigators from 14 academic centers[9] in 2 countries (at the time of study inception). The study hypothesis was that no difference would be detected between the 2 treatment groups in terms of variables relating to surgery, complications, healing, return to sports, activity levels, PROs, and secondary OCD-related surgeries.

METHODS

Study Design

The study design was a prospective randomized controlled clinical trial (level 1) involving 17 surgeon-investigators at 14 different academic centers participating in the ROCK (Research in OsteoChondritis of the Knee) Group. The study group was established in 2010 to investigate the cause and determine the optimal treatment of knee OCD through

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clinical research. To ensure expertise with this rare condition, participating surgeon-members were required to meet criteria of performing a minimum volume of 10 OCD surgeries per year, regardless of OCD stage or presentation. After institutional review board approval, enrollment was initiated in January 2013 and halted in December 2017.

Patient Selection

Eligible study participants included skeletally immature patients between ages 9 and 15 years who were diagnosed at one of the study sites with stable OCD (Hefti stage 1 or 2 lesions[14]) of the medial femoral condyle, based on a review of radiographs and magnetic resonance imaging (MRI) of the knee by the treating surgeon-investigator. However, study enrollment was initiated only for patients who were scheduled to undergo arthroscopic OCD drilling. To be eligible for surgical intervention, study participants had to have undergone a minimum 3-month course of nonoperative treatment, consisting of sports cessation and restriction from impact activities, such as running or jumping, as well as a minimum 6-week period within that 3-month period of either nonweightbearing, casting, valgus unloader bracing, locked bracing or knee immobilizer use, or some combination thereof. Because of the variability in the nonoperative treatment approach to OCD, this minimum period of nonoperative treatment was selected by the study group, in the phase of study design, based on consensus methods, so as to ensure consistency across surgeons and minimization of the risks of unnecessary surgery. Because of the common challenge of differentiating true, pathological knee OCD from developmental variants of enchondral ossification of the distal femoral epiphyses, patients $\leq$8 years of age were excluded.[25] Additional exclusion criteria were unstable OCD lesions, locations other than the medial femoral condyle, knees with multifocal OCD, patients with closing or closed growth plates, lesions demonstrating healing during the course of nonsurgical intervention, patients with concomitant knee pathology that might confound knee function, a diagnosis of a metabolic bone disorder or sickle cell disease, and a history of prolonged corticosteroid or chemotherapy treatment. Informed consent was obtained from each eligible patient's parent or guardian before inclusion in the trial, and eligible participants were assigned a unique study identification.

Randomization

After informed consent, patients were randomized to 1 of 2 surgical techniques for drilling of their OCD lesion: TAD or RAD. A web-based block randomization system was developed by the doctoral-level non–surgeon investigator in the study group (G.D.M.), who supervised use of the system by all sites' research coordinators. When possible, randomization was carried out in the operating room after lesion stability was confirmed arthroscopically. For surgeons who did have research personnel available to perform randomization intraoperatively, this step was performed immediately preceding surgery. This process ultimately led to the exclusion of 9 patients after the time of enrollment: 1 case of failed randomization, 2 cases (1 TAD, 1 RAD) of intraoperative detection of multifocal lesions, and 6 cases (6 RAD) of instability determined during arthroscopy (Figure 1).

Surgical Techniques

Because some variability in the described surgical techniques existed in published studies of OCD drilling (both TAD and RAD), detailed protocols for the 2 procedures were developed a priori through a consensus decision-making technique by the group of participating surgeon-investigators. Before the initiation of enrollment at each study site, each site's surgeon(s) confirmed previous clinical experience and a technical comfort level with both drilling techniques. Moreover, all participating surgeons reviewed the existing OCD drilling literature and corroborated a perspective of clinical equipoise between the 2 techniques.

TAD was performed with a 0.045-inch K-wire advanced percutaneously, in retrograde, intra-articular fashion, through the articular cartilage and affected subchondral bone and into the deeper, healthy cancellous bone of the condyle. Each K-wire pass involved a new, nonspinning "push" of the tip of the wire through the cartilage, down to the subchondral bone margin, at which time the K-wire was spun with the wire driver approximately 15 to 20 mm across the affected bone. To minimize iatrogenic articular cartilage injury, while still generating an adequate number of channels to stimulate healing, a goal of 6 to 10 K-wire passes per square centimeter was attempted for all lesions. While the procedure is typically performed under arthroscopic visualization, and tactile feedback of chondral softening on the margins of the lesion with the arthroscopic probe generally allows for optimal localization of the OCD, use of fluoroscopy was permitted for any surgeons wanting to confirm lesion and/or K-wire location.

RAD of the medial femoral condyle was performed either percutaneously or through a small 1.0- to 1.5-cm incision in the area just proximal to the medial epicondyle. To adhere to the technique used by the participating surgeons before study participation, and because minimization of iatrogenic cartilage injury was inherent in the retroarticular technique, a larger-sized (0.062 inches) K-wire was used, with no limits placed on the number of wire passes. The perforations across the OCD boundary originated from the medial aspect of the condyle, with the K-wire introduced just distal to the physis and advanced through the bony condyle, in anterograde, extra-articular fashion, down to the subchondral bone, with the goal of avoiding perforation of the articular cartilage. However, to better understand if inadvertent iatrogenic articular cartilage damage may be associated with the technique, second-look arthroscopy was recommended after completion of the fluoroscopic-guided drilling portion of the procedure to investigate for pin tracts seen intra-articularly, the presence of which was recorded as part of the study protocol.

Postoperative Rehabilitation

All patients followed a standardized postoperative rehabilitation protocol, which called for use of crutches and

nonweightbearing status for 6 weeks, with outpatient physical therapy initiated at 2 weeks postoperatively, and range of motion exercises from 0° to 90° of flexion and straight-leg raises encouraged several times per day. Crutches were discontinued and weightbearing strengthening exercises were initiated at 6 weeks postoperatively, but no running was permitted until substantial healing was identified radiographically.

Follow-up

Study patients did not have additional clinic visits or any aspects of their care altered as part of their participation. Rather, the standard course of care was determined by each treating physician, which generally consisted of serial radiographs every 6 weeks after surgery to assess for ongoing, interval healing. Overall, patient data, presenting clinical data, radiologic characteristics, operative data, and follow-up clinical data and complications were recorded for each patient.

Healing at each follow-up visit was assessed on a radiology form completed by each surgeon-investigator using a continuous sliding scale (0-10) for each of the 2 criteria shown to be most reliable in a healing reliability study conducted by the study group[23]: ossification, which described the degree of radio-opacification of the appearance of the OCD lucency; and boundary, which described dissolution of the sclerotic separation between OCD and the deeper, healthy, normal-appearing cancellous bone. An additional healing assessment was included in the clinical follow-up form, with a designation of the lesion's current radiologic status, relative to previous follow-up visits, with the following options: (1) healed, (2) healing, (3) not healing, and (4) getting worse. Based on consensus within the study group that serial radiographic assessment, rather than MRI assessment, represented the gold standard approach, which was further substantiated by the previously described healing reliability study, postoperative MRI was not routinely obtained, particularly given challenges in some health systems to obtain insurance approval, other than preoperative studies for staging of OCD. The clinical follow-up form at each follow-up visit completed by the surgeon-investigator also inquired as to the presence of any complications (the presence of which triggered a detailed complication form), and whether the patient was cleared to return to sports, the decisions for which were not standardized based on study-specific criteria, but rather were individualized for each patient by the treating provider based on a combination of factors, such as radiographic appearance, postoperative time point, performance of postoperative rehabilitation goals, and clinical status (eg, presence of knee symptoms).

Several PRO questionnaires were distributed at baseline and 6-month, 12-month, and 24-month follow-up visits or via telephone-based or email-based outreach at the same time points, which included the Pediatric International Knee Documentation Committee (Pedi-IKDC) Subjective Knee Form, the Marx Activity Scale, the Lysholm form, and the Knee injury and Osteoarthritis Outcome Score Quality of Life (KOOS QOL) as part of their participation.

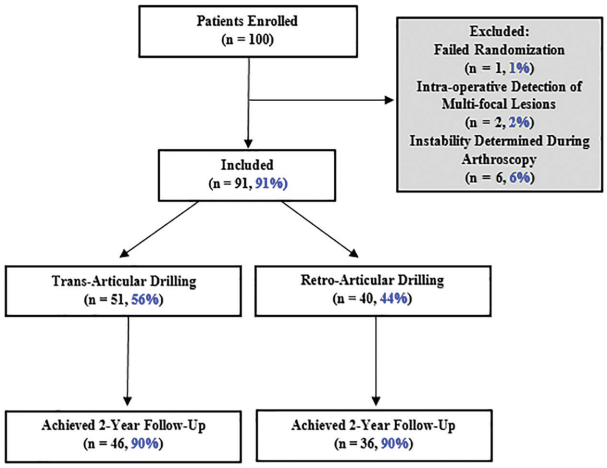

Figure 1. Study inclusion flowchart.

Statistical Analysis

De-identified data from all patients in the study were maintained by the primary study institution using the REDCap data management system.[13] All secondary sites had access to the study data through requests to the primary site.

An intention-to-treat analysis was carried out for the patients who were randomized to either the TAD or the RAD treatment group and subsequently maintained study eligibility. Patient, injury, and treatment characteristics were summarized for the cohort and compared by treatment group (TAD vs RAD). Continuous characteristics were compared using the Student *t* test or Wilcoxon rank-sum test, as appropriate, and categorical characteristics were compared using a chi-square test. For the primary study hypothesis, equivalence in PROs at 2-year follow-up was assessed using 2 one-sided Wilcoxon rank-sum tests and an equivalence margin up to an effect size of 0.7 with alpha set to 5%. The reported *P* value for equivalence testing is the larger of the 2 one-sided tests. As a widely used instrument modified from its adult form and validated for use in children, the Pedi-IKDC was selected as the primary outcome measure with which the power analysis would be performed. The difference in the change in each PRO over time across treatment groups was assessed using a nonlinear mixed-modeling analysis on rank-normalized PRO data to account for data skewness.

For secondary analyses, the rate of healing and the rate of sports clearance were assessed by estimating Kaplan-Meier curves and a log-rank test for survival across groups. In addition, Cox proportional hazards models were used to quantify any effect of treatment type on the rate of healing or return to sports. The proportional hazards assumption was assessed for each model, and no violations were detected. The proportion of patients who required a secondary surgery within the 2-year follow-up window was also compared across groups using a binary logistic regression model.

A priori power analysis had determined that to conduct 2 one-sided tests for equivalence in Pedi-IKDC score across

TABLE 1
Patient and Treatment Characteristics by Treatment Group[a]

Characteristic	Transarticular Drilling Group (n = 51)	Retroarticular Drilling Group (n = 40)	*P* Value
Age, y	12.6 ± 1.4	12 ± 1.2	.05
Skeletal age, y (n = 49)	13 ± 1.3	12.4 ± 1.5	.18
Male sex	37 (73)	22 (55)	.08
BMI percentile	68 (37-96)	75 (60-96)	.32
Race			.28
White	33 (65)	32 (80)	
Black or African American	13 (25)	7 (18)	
Asian	2 (4)	1 (3)	
Other or unknown	3 (6)	0 (0)	
Ethnicity			>.99
Not Hispanic	46 (94)	37 (95)	
Hispanic	3 (6)	2 (5)	
Left side	25 (49)	0 (0)	.70
Family history of OCD			.72
Yes	1 (2)	2 (5)	
No	43 (84)	33 (83)	
Unknown	7 (14)	5 (13)	
Preoperative pain	40 (78)	30 (75)	.57
Weeks of nonoperative management			
Activity restrictions (n = 69)	15.1 ± 7.7	16.4 ± 11.0	.57
Nonweightbearing (n = 35)	7.1 ± 4.3	7.5 ± 4.3	.77
Knee brace (n = 64)	10.6 ± 6.9	9.6 ± 5.9	.52
Cylinder casting (n = 4)	7	5.3 ± 1.2	>.99
Physical therapy (n = 24)	11.3 ± 6.7	6.7 ± 4.2	.10
Other (home exercise program, calcium/vitamin D supplementation) treatments (n = 3)	2	4 ± 2.8	>.99
Days from diagnosis to surgery	235.9 (112-268)	206 (108-182)	.53
Additional surgery performed			
Notch drilling	1 (2)	1 (3)	
K-wire size, inches			
0.045	50 (98)	0	
0.062	1 (2)	40 (100)	
No. of K-wire passes	11.6 ± 3.8	13.7 ± 6.1	.53
Tourniquet used	39	34	.31
Tourniquet time, min	38.1 ± 12.9	48.2 ± 20.3	.02
Lesion size per MRI scan, mm^2	471.8 (245-458)	428 (251-536)	.70
Depth of legion per MRI scan, mm	7.2 ± 3.7	6.1 ± 2.5	.15
Coronal location			.75
Lateral	9 (20)	7 (23)	
Central	31 (69)	19 (61)	
Intercondyle	5 (11)	5 (16)	
Sagittal location			.93
Central	41 (91)	29 (88)	
Posterior	4 (9)	4 (12)	

[a]Data are presented as n (%), mean ± SD, or median (IQR). BMI, body mass index; MRI, magnetic resonance imaging; OCD, osteochondritis dissecans.

treatment groups, samples of 40 per group would provide 80% power for an equivalence margin for an effect size of 0.7 (comparable with a difference of about 10 points assuming an SD of 15) with alpha set to 5%. After follow-up, there were 46 and 36 patients in the TAD and RAD groups, respectively. Post hoc power analysis determined that these sample sizes would provide 81% power for the test described above.

RESULTS

Patient Characteristics

Over the 5-year study period, 91 study patients were enrolled and included in the final study analysis, consisting of 51 patients who underwent TAD and 40 patients

TABLE 2
Outcomes by Time and Treatment Group[a]

	Transarticular Drilling Group		Retroarticular Drilling Group		
Outcome	n	Median (IQR)	n	Median (IQR)	*P* Value
Pedi-IKDC					
Baseline	51	64 (52-77)	39	67 (55-83)	.67
6 mo	33	91 (78-98)	32	95 (88-99)	.16
12 mo	32	92 (86-99)	25	97 (85-99)	.88
24 mo	46	97 (88-100)	36	97 (80-100)	.60
Marx Activity Scale					
Baseline	50	13 (4-16)	38	13 (6-16)	.62
6 mo	32	12 (4-16)	31	12 (6-16)	.77
12 mo	30	15 (5-16)	22	13 (4-16)	.46
24 mo	46	15 (12-16)	35	14 (10-16)	.51
Lysholm					
Baseline	50	73 (63-87)	33	68 (54-85)	.44
6 mo	30	96 (90-100)	29	100 (90-100)	.61
12 mo	31	100 (94-100)	21	100 (90-100)	.97
24 mo	44	99 (91-100)	36	95 (86-100)	.41
KOOS QOL					
Baseline	50	41 (25-56)	38	38 (19-44)	.39
6 mo	33	69 (44-88)	30	72 (58-92)	.59
12 mo	32	94 (75-100)	24	84 (62-100)	.45
24 mo	46	94 (70-100)	36	81 (62-97)	.14

[a]IQR, interquartile range; KOOS QOL, Knee injury and Osteoarthritis Outcome Score Quality of Life; Pedi-IKDC, Pediatric International Knee Documentation Committee.

who underwent RAD, respectively (Figure 1). Features of the 2 groups were similar (Table 1), including skeletal age, race, ethnicity, sex distribution, body mass index, and 2-year PRO response rate, which was 90% in both groups. In addition, no differences were seen between groups, in terms of family history of OCD, preoperative pain, time from diagnosis to surgery, or duration of nonoperative treatment before surgery.

Lesion Characteristics

Lesion size (Table 1) was a median of 472 mm^2 in the TAD group, which was not statistically different from 428 mm^2 in the RAD group ($P = .70$). Likewise, there were no differences between groups in the mean depth of the lesions or the distributions of the lesions in the medial femoral condyle, in either the coronal or the sagittal plane.

Surgical Characteristics

Tourniquet time and fluoroscopy time (Table 1) were significantly shorter with TAD (mean, 38.1 minutes and 0.85 minutes, respectively) than RAD (mean, 48.2 minutes and 1.34 minutes, respectively) ($P = .02$; $P = .004$). For TAD lesions, a 0.045-inch K-wire was used in 50 cases, while a 0.062-inch K-wire was used in 1 case, based on equipment availability. For RAD lesions, a 0.062-inch K-wire was used in all cases. The mean number of K-wire passes was 11.6 for TAD lesions and 13.7 for RAD lesions ($P = .53$). Additional drilling through the intercondylar notch was performed, at the surgeon's discretion, in 1 TAD case and 1 RAD case.

Complications

The only complications related to the surgery that were reported during the study period were 2 separate cases of superficial wound infections in the RAD group, both of which resolved with oral antibiotic treatment and local wound care. In the RAD group, chondral injury from K-wire passage into the intra-articular space was reported in 9 of 40 (22%) patients, but there were no reported clinical sequelae associated with this finding.

Patient-Reported Outcomes

At the 2-year follow-up, PRO data were complete for 46 TAD and 36 RAD patients (Table 2). One patient had been lost to follow-up before 6 months, 4 patients were lost to follow-up before 1 year, and 4 patients were lost to follow-up before 2 years.

No difference in Pedi-IKDC scores was detected across the groups at the 2-year follow-up ($P = .60$), and scores were determined equivalent to within an effect size of 0.7 ($P < .001$). No difference in Marx Activity Scale was detected across the groups at the 2-year follow-up ($P = .51$), and scores were determined equivalent to within an effect size of 0.7 ($P = .002$). No difference in Lysholm score was detected across the groups at the 2-year follow-up ($P = .41$), and scores were determined equivalent to within an

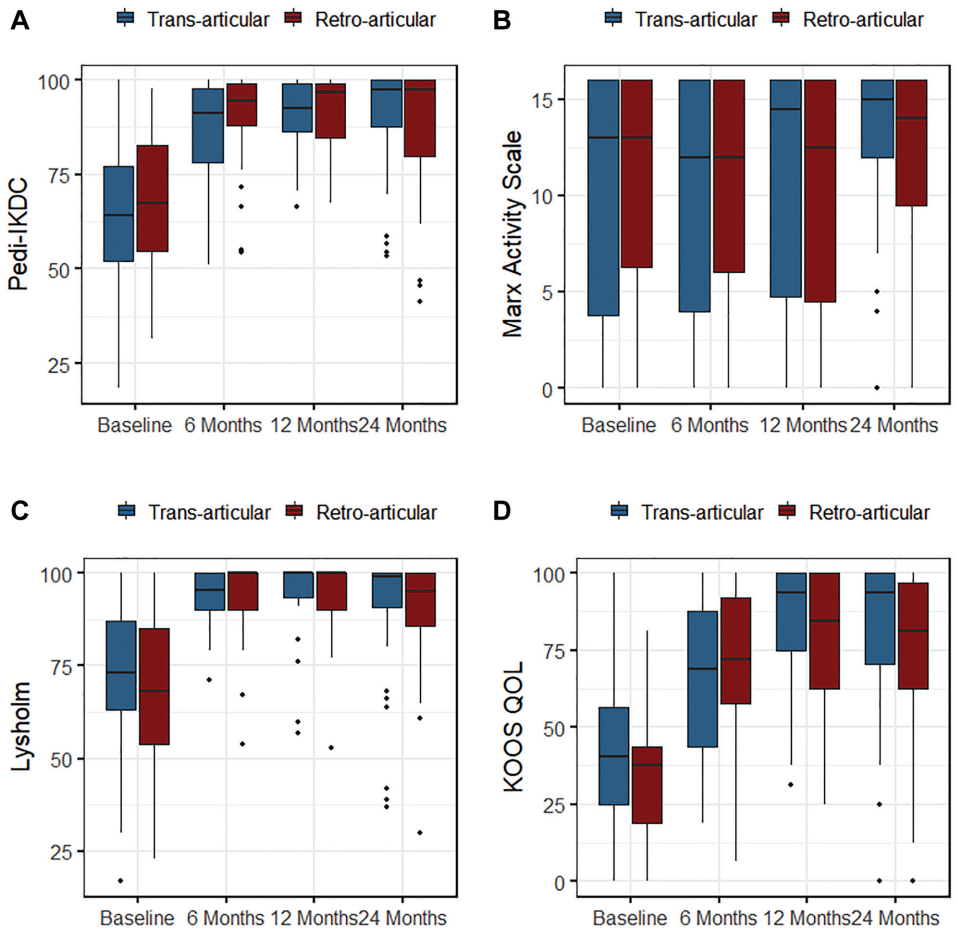

Figure 2. Change in patient-reported outcomes over time by treatment group. Dots represent values outside of the SD range. Crosses represent mean values. KOOS QOL, Knee injury and Osteoarthritis Outcome Score Quality of Life; Pedi-IKDC, Pediatric International Knee Documentation Committee.

effect size of 0.7 ($P < .001$). No difference in KOOS QOL was detected across the groups at the 2-year follow-up ($P = .60$), and scores were determined equivalent to within an effect size of 0.7 ($P = .01$).

PROs were also compared at baseline and 6 months, 12 months, and 24 months postoperatively (Figure 2), with no significant differences detected between treatment groups at any time point for any PRO.

Healing

The healing parameters of ossification of the lucency of the lesion and dissolution of the sclerotic boundary of the lesion were also analyzed at baseline and 6 months, 12 months, and 24 months postoperatively (Figure 3). Significantly greater median ossification and boundary healing scores were seen in the TAD group than the RAD group at 6 months (9 vs 8; $P = .04$) and 12 months (10 vs 8; $P = .02$) postoperatively, but this difference resolved by 24 months (10 vs 10; $P = .64$).

A total of 62 patients (62/91; 68.1%; 95% CI, 57.4%-77.3%) achieved a radiographic status of being healed at a median of 36 weeks. Follow-up in those who did not achieve healed status was a median of 109 weeks. Of the patients who underwent TAD, 36 (36/51; 71%; 95% CI, 56.0%-82.1%) achieved radiographic healed status at a median of 35 weeks, while 26 (26/40; 65%; 95% CI, 48.3%-78.9%) patients who underwent RAD achieved radiographic healed status at a median of 36 weeks. Cox modeling found no difference in the rate of patients who healed across treatment groups ($P = .78$).

Return to Sports

A total of 81 patients (81/91; 89%; 95% CI, 80.3%-94.3%) were cleared for return to sports at a median of 22 weeks. Follow-up in those who had not received return-to-sports clearance was a median of 109 weeks. Of the patients who underwent TAD, 47 (47/51; 92%; 95% CI, 80.3%-97.5%) received clearance for return to sports at a median of 4.1 months, while 34 (34/40; 85%; 95% CI, 69.5%-93.8%) of the patients who underwent RAD received clearance for return to sports at a median of 5.8 months. Kaplan-Meier

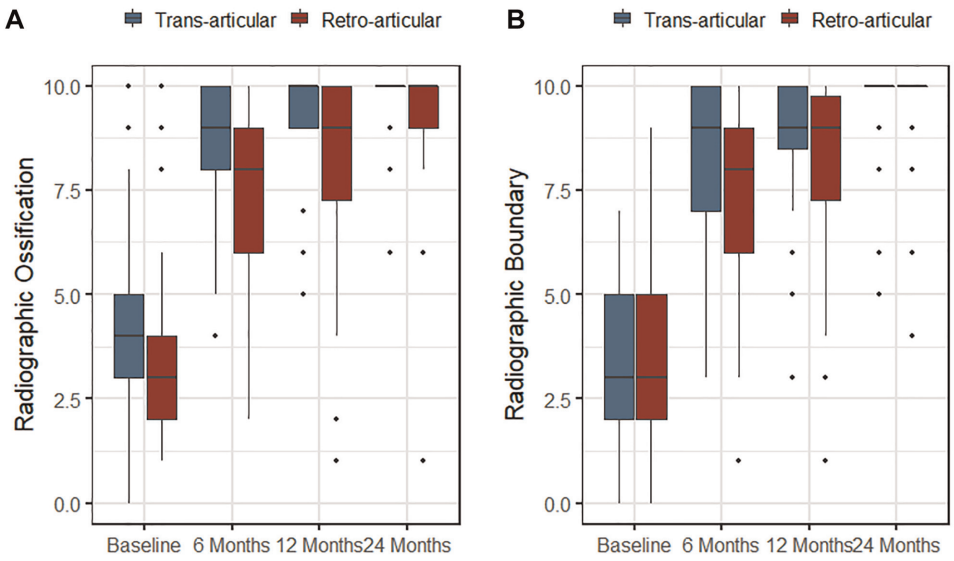

Figure 3. Change in radiographic healing parameters over time by treatment group. Dots represent values outside of the SD range. Crosses represent mean values.

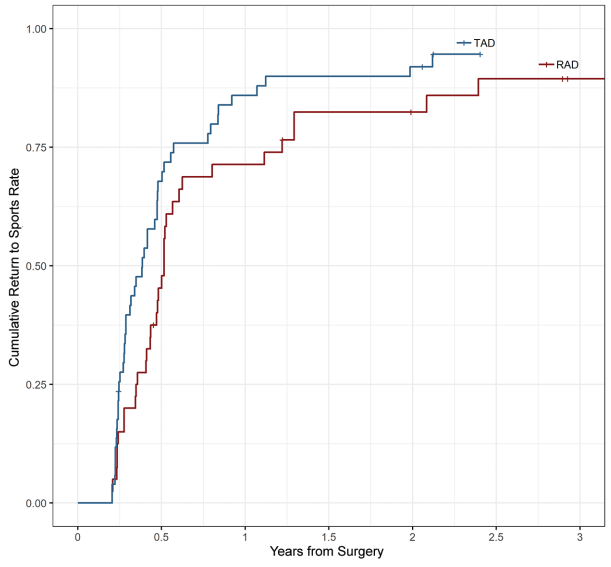

Figure 4. Kaplan-Meier analysis demonstrating return to sports in transarticular drilling (TAD) and retroarticular drilling (RAD) groups over time.

analysis (Figure 4) demonstrated that patients who underwent TAD returned to sports earlier than patients who underwent RAD (P = .049).

Secondary Surgery

Six patients (6/91; 7%; 95% CI, 2.7%-14.3%) underwent secondary surgery for further treatment of the OCD lesion. Two TAD cases (2/51; 4%; 95% CI, 0.7%-14.6%) underwent revision TAD, while the 4 secondary OCD surgeries in patients who underwent RAD (4/40; 10%; 95% CI, 3.3%-24.6%) consisted of 2 cases of TAD and 2 cases of OCD fixation and TAD. The comparison between treatment cohorts did not show a statistically significant difference (P = .40).

DISCUSSION

The current randomized controlled trial demonstrated that for skeletally immature patients with stable knee OCD lesions who had failed to achieve healing with nonoperative methods, both TAD and RAD yielded excellent patient-reported functional outcome measures, which were similar between treatment groups at all time points. Notably, there was a significant improvement in the primary outcome measure, the Pedi-IKDC score, from baseline values to 6 months postoperatively, which further improved at 12 months and 24 months. Because the median 6-month scores were 91 and 95 in the TAD and RAD groups, respectively, both of which exceed age-based normative values for the instrument in a general population,[21] the study demonstrated that children affected by this condition regained excellent knee function within a relatively short time after surgical treatment and maintained such function over time. As more active, athletic populations tend to report higher anatomic region–specific scores than less active populations, the relatively high reported scores of the study cohort, which likely consisted of high rates of adolescent and preadolescent athletes, based on epidemiologic studies of knee OCD populations, were not surprising. Previous OCD studies of both TAD[2,20] and RAD[4] have demonstrated similar PRO improvement, although generally only at the final follow-up and without the detailed course of multiple collection times. The

current data, therefore, may assist surgeons for OCD in setting expectations for timelines in improvement with patients and their families.

Importantly, there were minimal complications reported in association with either OCD drilling technique. As the first prospective randomized controlled trial to our knowledge investigating these techniques, an important responsibility of the study group was realized in assessing the safety of a surgical intervention most commonly applied to children. Given the differences in the technical nature of the 2 different techniques, it was expected that tourniquet time and fluoroscopy time would be significantly longer in the RAD technique. These 2 parameters are interrelated, in that the introduction of the fluoroscopy machine—whether a large or mini C-arm, both of which were used, depending on surgeon preference and institutional availability—into the operative field, while maintaining sterile conditions, and completion and assessment of images typically add to the tourniquet time and overall operative time. Advocates of the TAD technique may point to such disadvantages of RAD, as longer tourniquet time is well-established as a risk for other complications. Moreover, RAD is more likely to introduce radiation exposure, or have more prolonged radiation exposure, to both the patient and the operating room staff. While not one of the variables assessed in the current study, there are also additional costs associated with the use of fluoroscopy. Advocates of the RAD technique would counter that the entire philosophical approach to OCD management centers around joint preservation, a principle that is violated by the iatrogenic K-wire passes through the articular cartilage in TAD. Such surgeons may contend, from a patient safety perspective, that the additional tourniquet and fluoroscopy time are well worth the investment in protection of the chondrocytes of the condyle, which is a bearing surface that may be predisposed to chronic degenerative changes in the face of any disruption, regardless of how small. However, as longer-term follow-up studies of patients undergoing OCD drilling are essentially absent from the literature, these concerns remain theoretical. Moreover, when the incidence of unexpected iatrogenic chondral injury during the RAD technique was investigated in the current study, articular surface perforation was detected in 22% of cases, during at least 1 of the K-wire passes down to the subchondral bone. While no clinical sequelae were associated with this finding, such frequency among a group of relatively high–volume surgeons for OCD slightly undermines one relative advantage of RAD, compared with TAD, in terms of joint preservation principles.

TAD advocates may also point to the effectiveness of the procedure, in terms of bony healing, as demonstrated in the current results. Interestingly, the rates of lesions that were deemed healed were not statistically significantly different between the 2 treatment groups in the current study. However, the designation of a lesion's being healed versus healing (or "no different") is a subjective measure, the validity for which was not established before the study, nor was it included in the study group's healing reliability study. Conversely, when the previously established[23] healing parameters of ossification and boundary dissolution were assessed at each time point, TAD was found to have superior healing features to RAD at 6 months and 12 months postoperatively. Although the groups eventually demonstrated similar healing features by 24 months, the earlier differences may be clinically significant enough to warrant adoption or preference for the TAD technique. In other words, because radiographic OCD healing, even more than general knee function or the presence of symptoms, is often used as the most influential factor in returning patients with OCD to previous levels of activity, including sports and impact activities, many patients and providers might select the procedure that provides the earliest and most reliable path to healing. In the current landscape of youth sports culture, and with growing recognition of the importance of physical activity to adolescent athletes' social lives, emotional and psychological health, and overall mental and physical well-being, even several months may make an important difference for some patients and families. As expected from the healing metric findings, clearance to return to sports occurred earlier in the TAD group, at 4.1 months, than the RAD group, at 5.8 months. While this difference was shown to be statistically significant through Kaplan-Meier analysis, it may also be clinically significant, as 2 additional months out of sports can be quite psychologically impactful for adolescents. The reasons for superior or faster healing in the TAD group are not clearly elucidated by the study but may relate to the basic technical factor of greater reliability in TAD, relative to RAD, to effectively target the K-wire passes through all subregions of a given OCD lesion. The margins of a stable OCD have been shown to be palpable with the arthroscopic assessment, even with "cue ball" lesions, by the ROCK arthroscopy classification system. Therefore, the surgical target may be more clearly appreciable in TAD than RAD, which requires fluoroscopic confirmation of K-wire position, ideally in 2 planes for maximum accuracy, which can be technically burdensome or time-consuming, as shown by the longer operating room times in RAD revealed in the study. The previously discussed rate of passes into the articular cartilage in RAD cases may also speak to accuracy challenges with the technique. For as many instances as there are of overadvancement of a K-wire through the cartilage of the lesion, there may be just as many instances of underadvancement of the K-wire, which may leave an uninterrupted sclerotic boundary or undisturbed, persistently unhealthy cancellous subchondral bone.

An additional noteworthy finding was the revision drilling surgery rates between the groups. While the current study was adequately powered to detect a difference in the Pedi-IKDC score, which was selected as the primary outcome, treatment group sample sizes may not have been adequate to detect differences in other metrics, particularly categorical metrics, such as revision surgery. While the 10% rate in the RAD group compared with the 4% rate in the TAD group should be interpreted as no different, future studies may better detect whether the same technical factors affecting differences in healing time might also affect rates of revision surgery.

Several other study limitations warrant mention, perhaps the most important of which is the relatively short

overall follow-up. While we are not aware of any previous prospective OCD studies with a minimum 2-year follow-up, the study period does not allow for assessment of long-term joint health, OCD recurrence, or the onset of degenerative joint disease over time. Such variables are particularly important for the 2 treatments being studied, given that TAD has the disadvantage of the inherent feature of multiple K-wire perforations being placed through the articular cartilage, which may accelerate a chronic process of at least focal chondral degradation, if not more diffuse joint involvement. As important as such a study might be for our understanding of the natural history of surgically treated OCD, it would be equally challenging in its methods. Patients with OCD, because of their age and activity level, represent a uniquely mobile patient subpopulation. Therefore, follow-up into the adult decades would require meticulously designed longitudinal studies with unique resources. For example, despite obtaining 90% follow-up in both study treatment groups, in terms of PROs, a number of patients, including many who were ultimately reached for PROs through telephone and email outreach efforts, were lost to follow-up earlier in the postoperative schedule, yielding a relatively low rate of patients who were followed until achieving healed status or returning to sport. Another limitation is the lack of detailed athletic data of the study population, most of whom demonstrated eventual activity levels suggestive of competitive athletic involvement. Assessing the distribution of sports, and the degree to which return to sports was achieved at the preoperative level, would have broadened our understanding of stable OCD populations and their response to treatment. Finally, the study did not comprehensively investigate the nonoperative course of patients before enrollment in the surgical trial, such as the presence or severity of patient symptoms throughout their nonoperative course, nor the risk factors for failure to heal with nonoperative methods. Such a prospective study is critical to better elucidate the role and timing of nonoperative treatment, which should remain the gold standard for primary treatment of stable lesions in skeletally mature patients, the majority of whom demonstrate healing without surgery, based on a well-established body of OCD literature. Determining the effectiveness of specific modalities, such as weightbearing protection versus brace use versus cast use (the rates of which were relatively low, despite inherent advantages in compliance), remains a focus of future studies for the current study group.

CONCLUSION

For skeletally immature patients with stable knee OCD lesions who fail to achieve healing with nonoperative methods, both transarticular and retroarticular OCD drilling techniques demonstrated good rates of postoperative healing and excellent functional outcome measures, which were similar between treatment groups at all time points. TAD was associated with shorter tourniquet times and fluoroscopy times, earlier return to sports, and superior healing parameters at 6 and 12 months, compared with RAD, but these differences were resolved by 24 months. Long-term follow-up studies assessing the implications of TAD on adult cartilage health are needed to elucidate whether these short-term technical and healing advantages are outweighed by the potential risk of degenerative joint disease.

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REFERENCES

1. Abouassaly M, Peterson D, Salci L, et al. Surgical management of osteochondritis dissecans of the knee in the paediatric population:

a systematic review addressing surgical techniques. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(6):1216-1224.
2. Anderson AF, Richards DB, Pagnani MJ, Hovis WD. Antegrade drilling for osteochondritis dissecans of the knee. *Arthroscopy*. 1997;13(3):319-324.
3. Augustine EF, Adams HR, Mink JW. Clinical trials in rare disease: challenges and opportunities. *J Child Neurol*. 2013;28(9):1142-1150.
4. Boughanem J, Riaz R, Patel RM, Sarwark JF. Functional and radiographic outcomes of juvenile osteochondritis dissecans of the knee treated with extra-articular retrograde drilling. *Am J Sports Med*. 2011;39(10):2212-2217.
5. Chambers HG, Nelson SC. Technical note: arthroscopically assisted extraarticular drilling for osteochondritis dissecans of the knee. In: Micheli LJ, Kocher MS, eds. *The Pediatric and Adolescent Knee*. Saunders; 2006:276-283.
6. Donaldson LD, Wojtys EM. Extraarticular drilling for stable osteochondritis dissecans in the skeletally immature knee. *J Pediatr Orthop*. 2008;28(8):831-835.
7. Edmonds EW, Albright J, Bastrom T, Chambers HG. Outcomes of extra-articular, intra-epiphyseal drilling for osteochondritis dissecans of the knee. *J Pediatr Orthop*. 2010;30(8):870-878.
8. Edmonds EW, Heyworth BE. Osteochondritis dissecans of the shoulder and hip. *Clin Sports Med*. 2014;33(2):285-294.
9. Edmonds EW, Shea KG. Osteochondritis dissecans: editorial comment. *Clin Orthop Relat Res*. 2013;471(4):1105-1106.
10. Guhl JF. Arthroscopic treatment of osteochondritis dissecans. *Clin Orthop Relat Res*. 1982;167:65-74.
11. Guhl JF. Arthroscopic treatment of osteochondritis dissecans: preliminary report. *Orthop Clin North Am*. 1979;10(3):671-683.
12. Gunton MJ, Carey JL, Shaw CR, Murnaghan ML. Drilling juvenile osteochondritis dissecans: retro- or transarticular? *Clin Orthop Relat Res*. 2013;471(4):1144-1151.
13. Harris PA, Taylor R, Thielke R, et al. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform*. 2009;42(2):377-381.
14. Hefti F, Beguiristain J, Krauspe R, et al. Osteochondritis dissecans: a multicenter study of the European Pediatric Orthopedic Society. *J Pediatr Orthop B*. 1999;8(4):231-245.
15. Heyworth BE, Edmonds EW, Murnaghan ML, Kocher MS. Drilling techniques for osteochondritis dissecans. *Clin Sports Med*. 2014;33(2):305-312.
16. Heyworth BE, Kocher MS. Osteochondritis dissecans of the knee. *JBJS Rev*. 2015;3(7):e1.
17. Kessler JI, Jacobs JC Jr, Cannamela PC, Weiss JM, Shea KG. Demographics and epidemiology of osteochondritis dissecans of the elbow among children and adolescents. *Orthop J Sports Med*. 2018;6(12):2325967118815846.
18. Kessler JI, Nikizad H, Shea KG, et al. The demographics and epidemiology of osteochondritis dissecans of the knee in children and adolescents. *Am J Sports Med*. 2014;42(2):320-326.
19. Kessler JI, Weiss JM, Nikizad H, et al. Osteochondritis dissecans of the ankle in children and adolescents: demographics and epidemiology. *Am J Sports Med*. 2014;42(9):2165-2171.
20. Kocher MS, Micheli LJ, Yaniv M, et al. Functional and radiographic outcome of juvenile osteochondritis dissecans of the knee treated with transarticular arthroscopic drilling. *Am J Sports Med*. 2001;29(5):562-566.
21. Nasreddine AY, Connell PL, Kalish LA, et al. The Pediatric International Knee Documentation Committee (Pedi-IKDC) Subjective Knee Evaluation Form: normative data. *Am J Sports Med*. 2017;45(3):527-534.
22. Tepolt FA, Kalish LA, Heyworth BE, Kocher MS. Nonoperative treatment of stable juvenile osteochondritis dissecans of the knee: effectiveness of unloader bracing. *J Pediatr Orthop B*. 2020;29(1):81-89.
23. Wall EJ, Milewski MD, Carey JL, et al. The reliability of assessing radiographic healing of osteochondritis dissecans of the knee. *Am J Sports Med*. 2017;45(6):1370-1375.
24. Wall EJ, Vourazeris J, Myer GD, et al. The healing potential of stable juvenile osteochondritis dissecans knee lesions. *J Bone Joint Surg Am*. 2008;90(12):2655-2664.
25. Zbojniewicz AM, Laor T. Imaging of osteochondritis dissecans. *Clin Sports Med*. 2014;33(2):221-250.