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Surgical management of osteochondritis dissecans of the knee

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Abstract Osteochondritis dissecans of the knee primarily affects subchondral bone, with a secondary effect on the overlying articular cartilage. This process can lead to pain, effusions, and loose body formation. While stable juvenile lesions often respond well to nonoperative management, unstable juvenile lesions, as well as symptomatic adult lesions, often require operative intervention. Short-term goals focus on symptomatic relief, while long-term expectations include the hope of preventing early-onset arthritis. Surgical options include debridement, loose body removal, microfracture, arthroscopic reduction and internal fixation, subchondral drilling, osteochondral autograft or allograft transplantation, and autologous chondrocyte implantation. Newer single-stage cell-based procedures have also been developed, utilizing mesenchymal stem cells and matrix augmentation. Proper treatment requires evaluation of both lesional (size, depth, stability) and patient (age, athletic level) characteristics.

Keywords Osteochondritis dissecans · Knee · Microfracture · Osteochondral autologous transplant · Drilling · Internal fixation · Allograft · Autologous chondrocyte implantation · Loose body · Surgical treatment · Cartilage

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Introduction

Osteochondritis dissecans (OCD) is an idiopathic disorder primarily affecting subchondral bone that results in destabilization of the affected subchondral bone and its overlying articular cartilage [1••, 2••, 3••, 4–6]. While lesions can occur in the elbow, ankle, and wrist, the most common site of involvement is the knee [7–9]. Specifically, the medial femoral condyle (70 %–80 %), lateral femoral condyle (15 %–20 %), and patella (5 %–10 %) are the common locations within the knee [10, 12]. OCD is twice as common in males, with bilateral lesions present in 12 %–30 % of cases [1••, 7, 11–15]. The incidence of lesions in asymptomatic patients has been demonstrated to be 0.015 %–0.03 %; therefore, the examiner must determine whether the lesion in question is the cause of the patient's pain [16••]. Arthroscopic evidence of OCD lesions is present in 1.2 % of patients with mechanical symptoms and unexplained effusions [13, 16••, 17]. Patients with evidence of a discoid lateral meniscus have an increased incidence of OCD lesions at 11 % [18, 19], likely secondary to repetitive microtrauma. The true incidence and prevalence may be underestimated, since many lesions are asymptomatic and diagnosed incidentally [20]. Many authors believe the incidence of OCD has been increasing in younger populations, which some attribute to earlier, more competitive participation in sports [16••, 21, 22].

Although OCD was first described over 100 years ago, there is no consensus on its etiology. Although the original nomenclature suggested a primary role for inflammation in OCD, histologic evidence has failed to support this theory [23]. Most authors now believe OCD to be due to repetitive microtrauma, although the etiology is likely multifactorial, with contributions from vascular insufficiency, genetic predisposition, ossification abnormalities, or endocrine dysfunction [1••, 2••, 3••, 4, 5, 24, 25]. As an example of repeat microtrauma, impingement of the tibial spine upon the lateral aspect of the medial femoral condyle with internal rotation has been suggested as a contributing factor to frequent lesions in this location. In particular, shear stress on the condyle from the tibial spine during high-impact sports ultimately may contribute to OCD formation [7, 25].

OCD lesions are generally divided into two main categories: juvenile (open physes) and adult (closed physes). This classification is important, since the treatment and prognosis of juvenile and adult OCD differ greatly. Most juvenile cases of OCD will heal well with nonoperative treatment, whereas adult OCD often necessitates surgical intervention [10, 26].

Clinical evaluation

The clinical presentation of OCD is nonspecific. It commonly presents with activity-exacerbated pain [27] and effusions [13, 20, 28]. Mechanical symptoms such as locking or catching may signify the presence of a loose body or advanced disease [3••, 13, 20, 29]. Thigh atrophy has also been reported as a reliable late finding, with OCD secondary to thigh disuse [6, 25, 30]. On examination, 23 %–44 % of patients may have a joint effusion, and between 40 % and 70 % can have point tenderness over the affected femoral condyle [11, 14, 27]. Select patients may have gait abnormalities such as obligate external rotation of the tibia to avoid impingement of the tibial spine on the lateral aspect of the medial femoral condyle [13, 25]. A similar phenomenon can be elicited on physical examination with the Wilson test [31], in which the examiner extends the knee from 90° to 30° against resistance while internally rotating the tibia. The test is considered positive when symptoms are reproduced by internal rotation and relieved by external rotation [6, 7]. While the sensitivity and specificity for this test are unknown, previous authors have anecdotally found it to be nondiagnostic [32].

Imaging

All patients should initially be evaluated with plain radiographs including weight-bearing anteroposterior, lateral, and Merchant views of the knee. A posteroanterior view at 45° of flexion, the Rosenberg view, is particularly useful for visualization of posterior femoral condyles. Radiographs can be used to determine lesion size, location, stability, and physeal status [7, 13, 25]. The typical radiographic pattern is a radiolucent line separating the defect from the epiphysis with an accompanying region of sclerosis. Bilateral lesions have been reported in 12 %–30 % of cases [14], and some authors recommend routine radiographic evaluation of the contralateral knee in all patients, while others limit this practice to skeletally immature patients [20, 25, 28, 33–35].

Most lesions require evaluation with magnetic resonance imaging (MRI) for full characterization, with T2 sequences being the most demonstrative [28, 36–38]. The De Smet criterion has been widely used, although its accuracy has been debated (Table 1). The original description reported 97 % sensitivity and 100 % specificity in determining fragment stability, where criterion 1 was present in 72 % of unstable lesions and criteria 2–4 were seen in 22 %–31 % of unstable lesions (Fig. 1a–d) [39]. While the sensitivity of MRI in determining lesion stability for both adults and juveniles has consistently been reported at 97 %–100 % [16••, 39, 40], the specificity of MRI has been quoted as 11 %–55 % [16••, 40, 41]. in juveniles versus 100 % in adults. This variation is likely due to differences in arthroscopic grading and patient population. However, lesional appearance on MRI inconsistently correlates with arthroscopic appearance and clinical symptoms [28, 36, 39, 42–44]. For instance, Samora et al. demonstrated only a 62.1 % agreement between Diapola's MRI and Guhl's arthroscopic grading for juvenile OCD [41].

Magnetic resonance arthrography and computed tomography (CT) are rarely used to evaluate OCD. While Kramer et al. reported an improvement in diagnostic accuracy from 57.4 % to 100 % in adults, using intra-articular gadolinium [45], others have been unable to reproduce these claims [46]. In patients with significant osseous defects, CT may be useful for lesion characterization and surgical planning, but it is not useful in determining lesional stability [20, 25].

The role of imaging for assessing outcomes of patients postoperatively is controversial. While some studies have found a strong correlation between postoperative imaging and clinical outcome [2••, 3••, 5, 47, 48••, 49, 50], others have been unable to substantiate this relationship [51–53]. The American Academy of Orthopedic Surgeons (AAOS) Clinical Practice Guidelines (CPG) from 2012 came to a consensus agreement that patients who remained symptomatic after OCD treatment should undergo reexamination with plain radiographs and, possibly, MRI [54].

Treatment decision making

The goal of knee OCD treatment, both nonoperative and operative, is to obtain a functional, painless knee [1••, 21, 55]. Factors that determine whether operative intervention is indicated include physeal status, fragment stability, presence of a loose body, the patient's goals

Table 1 De Smet magnetic resonance imaging criteria for determining osteochondritis dissecans (OCD) fragment stability [39]

1. A thin line of high signal intensity measuring 5 mm or more in length at the interface between the OCD lesion and the underlying bone
2. A discrete, round area of homogeneous high signal intensity 5 mm or more in diameter beneath the lesion
3. A focal defect with a width of 5 mm or more in the articular surface of the lesion
4. A high signal intensity line traversing the articular cartilage and subchondral bone plate into the lesion

and level of demand, and the size, stage, and depth of the lesion. Patients with juvenile OCD without a loose body can initially be managed nonoperatively due to the significant percentage of these patients that will heal spontaneously [7, 10, 25, 27, 30]. In a natural history study where 24 children with 31 OCD lesions of the knee were treated solely with activity modification, Sales de Gauzy et al. found complete resolution of pain at an average of 8 months without any evidence of osteoarthritis at an average of 5 years follow-up [27]. Linden evaluated 58 patients with juvenile OCD at a mean follow-up of 33 years from diagnosis and found that patients did not show early signs of osteoarthritis. However, those with adult OCD showed an onset of arthritis 10 years earlier than average [55]. Operative treatment is recommended in these adult patients to reduce symptoms related to the fragment or defect. This may have the added benefit of joint protection, although no studies to date have clearly demonstrated risk reduction in the long-term development of osteoarthritis with surgical treatment of adult OCD.

The method of treatment is based on both patient and lesion characteristics (Fig. 2). The treatment of unstable and displaced lesions is not guided by physeal status. Conversely, the treatment of stable lesions is based upon physeal status—specifically, that skeletally immature patients should be allowed a trial of conservative treatment for stable lesions.

Nonoperative treatment

Nonoperative treatment includes activity modification, weight-bearing limitation, anti-inflammatory medications, and a brief period of immobilization, all of which are structured to allow healing of the subchondral bone. More than 16 weeks of immobilization should be avoided, since this can lead to stiffness, atrophy, and cartilage degeneration and can interfere with healing [13, 25]. The AAOS CPGs were unable to specifically recommend any one particular nonoperative treatment option (casting, bracing, etc.) over another [28]. Contemporary treatment involves activity restriction with less emphasis on true immobilization given the detrimental effects immobilization has on periarticular tissues and surrounding muscle mass. Failure of nonoperative treatment is generally considered to be insufficient

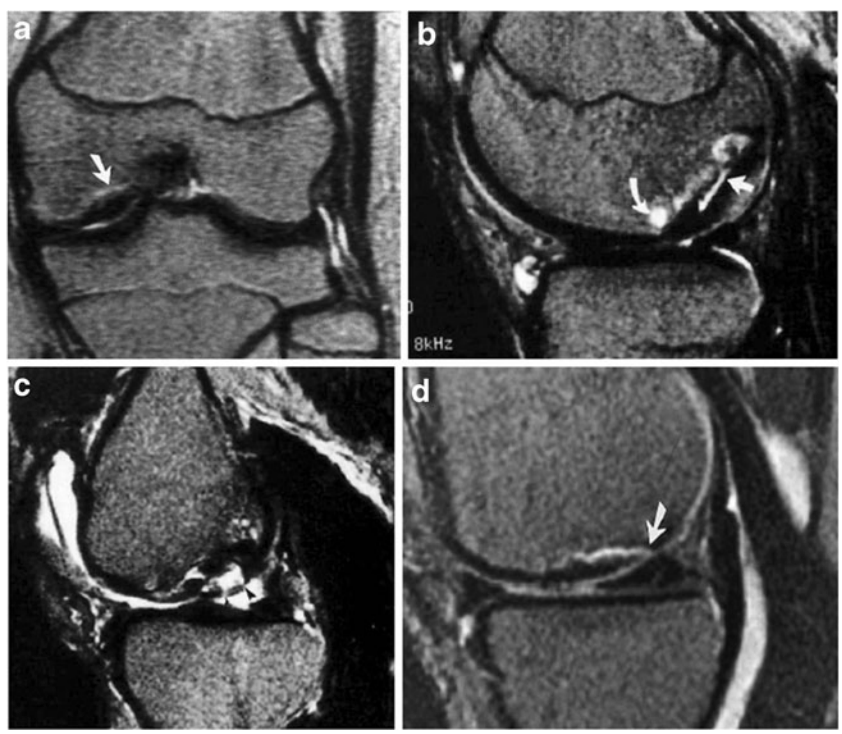

Fig. 1 **a** Coronal T2-weighted magnetic resonance image (MRI) shows a high signal intensity line (*arrowheads*) beneath the lesion [81]. **b** OCD of lateral femoral condyle with two signs of instability: Sagittal T2-weighted MRI shows a high signal intensity line (*straight arrow*; criterion 1) and a cystic area (*curved arrow*; criterion 2) beneath fragment [39]. **c** Unstable osteochondritis dissecans of the medial femoral condyle: This T2-weighted sagittal MRI image shows a large focal defect (*arrow*) in the weight-bearing portion of the articular surface [39]. **d** This sagittal T2-weighted MRI image shows a posterior cartilage fracture (*arrow*) [81]

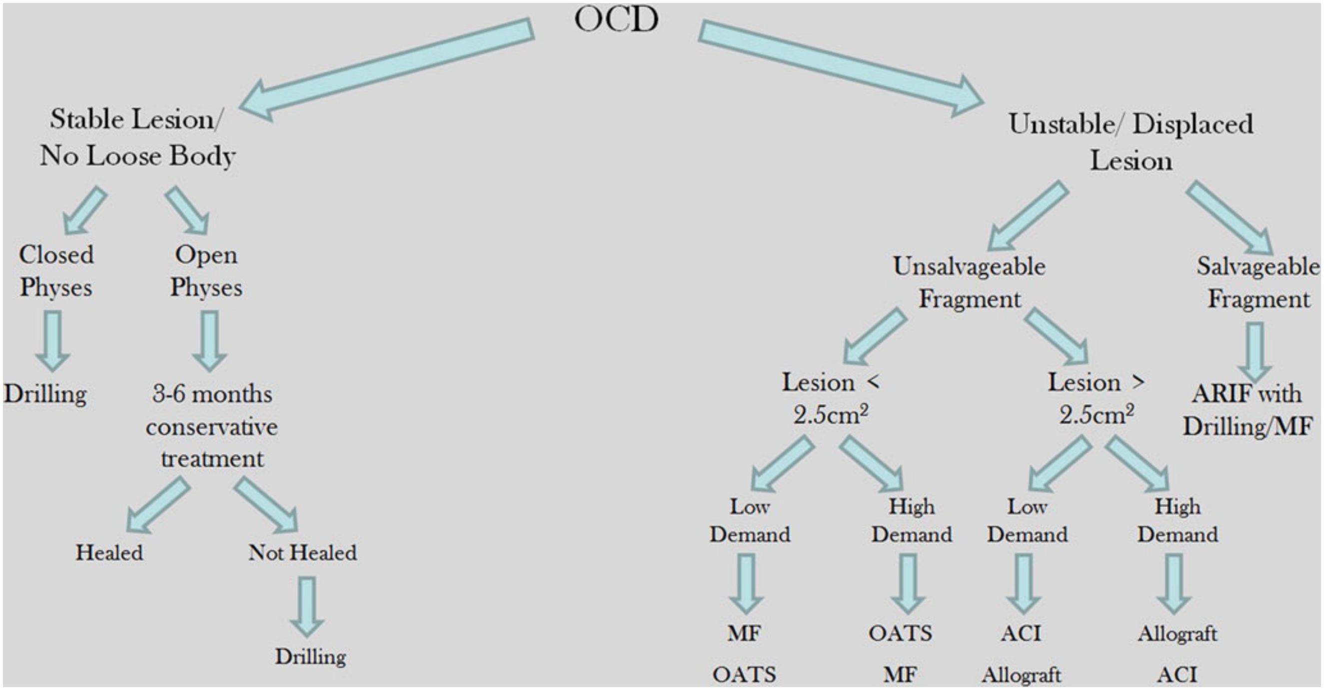

Fig. 2 Algorithm for treating knee osteochondritis dissecans. *Left*: Decision tree for stable lesions with no loose body present. *Right*: Framework for unstable/displaced lesions

symptom resolution at 3–6 months. If, at that time, the symptoms do not resolve or are not progressing steadily toward resolution, operative intervention should be considered [30]. Conservative treatment longer than 5 months from diagnosis should be avoided if possible, since Gudas et al. found worse outcomes in patients with a longer duration of preoperative symptoms [48••].

Operative treatment

While a variety of surgical options exist, no one method has emerged as the standard of care. Surgical treatment can be divided into the following categories: palliative, reparative, restorative, and reconstructive techniques. Palliative treatment largely consists of loose body removal, lesion debridement, or lesion excision and is typically combined with another technique. Although the AAOS CPGs on unsalvageable fragments are inconclusive, they recommend that both adult and juvenile patients with salvageable lesions be offered surgery [54]. Reparative techniques include direct repair/fixation of the osteochondral fragment, as well as those that attempt to generate fibrocartilage. Restorative techniques aim to restore hyaline cartilage and typically involve some level of cellular, chemical, or matrix-related augmentation. Finally, reconstructive techniques involve osteochondral grafting, where hyaline cartilage with underlying bone is implanted into the defect (Fig. 3). Regardless of the treatment type, the 2012 AAOS CPGs recommend that patients who receive surgical treatment should be offered physical therapy [54].

Palliative

Removal of loose body Osteochondral fragments can become detached and cause pain, locking, and catching. Removal generally provides excellent relief from mechanical symptoms, although it does not address the source lesion

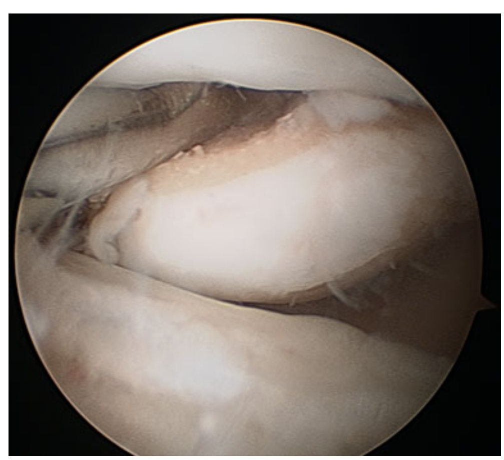

Fig. 3 Arthroscopic view of osteochondritis dissecans fragment with awl between fragment and underlying bone

and, thus, results are mixed. Pascual-Garrido et al. showed good results in nine patients, with only one failure for small (2.11 cm^2) adult OCD lesions, at an average of 4 years after loose body removal [56••]. Lim et al. [53] reported on 28 knees and demonstrated significant improvement in the Lysholm score, although they saw evidence of degenerative changes in the affected compartments during the third and fourth decades of life.

These studies demonstrate the efficacy of this technique in providing palliation; however, long-term follow-up (2–20 years) has been rated as fair or worse in up to 75 % of patients [50, 57]. Loose fragment removal can provide good initial pain and symptomatic relief but does not seem to have a long-lasting therapeutic effect (Table 2). A debridement or chondroplasty would seem to produce similar results. Thus, unless the defect is <2 cm^2, loose body excision combined with a reparative, restorative, or reconstructive technique to address the lesion itself should be considered on the basis of the interpretation of the long-term follow-up data. In reality, many patients feel normal following fragment removal and are reluctant to undergo secondary reconstructive procedures until they become symptomatic, especially because the true preventative value of early reconstruction on delaying or preventing the onset of late degenerative changes is unknown.

Reparative

Arthroscopic/open reduction and internal fixation Detached or hinged OCD fragments can be reduced arthroscopically and fixed with bioabsorable or nonabsorbable pins, nails, or screws. Fragment reduction is preceded by lesional debridement, curettage, and microfracture. After reduction and fluoroscopic confirmation of appropriate positioning, the lesion is provisionally fixed with a K-wire perpendicular to the lesion. Posterior lesions require increased knee flexion for this technique. The authors employ a cannulated system with metal screws ranging from 1.5 to 2.7 mm to achieve interfragmentary compression. Overtightening should be avoided to prevent fragment fracture (Fig. 4). The knee should be ranged after insertion to ensure that the fixation device is buried to prevent damage to the opposing tibial articular cartilage. If significant bone loss is present, preventing congruent fragment reduction, autologous tibial or iliac crest bone graft can be utilized [58]. Typically, metallic and nonabsorbable fixation devices are removed 8 weeks postoperatively to prevent future complication. Often this follows a period of protected weight bearing and use of continuous passive motion (CPM). Removal of cannulated screws can be aided by insertion of the guidewire first to avoid stripping the screw. After hardware removal, the area should be probed to examine stability, and loose fragments can be removed at that time. Removal of the hardware affords the surgeon the opportunity of an early second look arthroscopy to assess lesion healing prior to return to full activity. Return to higher impact activities is generally delayed another 8–12 weeks to ensure solid osseous union.

While bioabsorable implants do not require a second surgery for removal, complications include breakage and foreign body reaction with osteolysis and aseptic synovitis [59]. Increased nonunion rates, up to 33 %, have also been reported with bioabsorable devices [3••]. Weckstrom et al. [5] found significantly better radiographic and functional outcomes in patients arthroscopically treated with bioabsorable nails (73 % healing), as compared with bioabsorable pins (35 % healing). The barbed nature of the nails may provide better compressive forces and, thus, lead to superior healing [4]. However, it is the authors' preference to use nonabsorbable devices, including a minimum of two differentially pitched small-diameter metallic screws buried to the level of the subchondral plate.

Overall, this technique is preferred, since it preserves chondrocyte viability and provides excellent clinical outcomes. Specifically, fixed OCD fragments demonstrate decreased chondrocyte viability of only 4 %, as compared with native cartilage [60]. Prospective studies evaluating arthroscopic reduction and internal fixation have demonstrated significant improvements in several validated outcome scores [56••]. The literature supports this technique in unstable/displaced lesions of varying sizes with salvageable fragments.

Drilling This technique is recommended in stable lesions less than 2.5 cm^2. The goal of drilling is to stimulate the subchondral bone and, thus, create vascular channels from the underlying marrow, promoting the healing response. Subchondral lesions can be addressed through either a transarticular (antegrade) or a transphyseal (retrograde) approach. No current literature exists to suggest superiority of one technique over another [20]. Care should be taken to avoid intraoperative fragment dislodgement or fragmentation. Benefits of the transarticular method include avoidance of the physis and relative technical ease. An arthroscopically visualized 0.45-mm K-wire is inserted through an anteriomedial portal for a medial condylar lesion or an anterolateral portal for a lateral condylar lesion and is used to perforate the lesion via multiple entry points. Emergence of blood and adipose droplets from the drill holes confirms adequate depth of penetration. Disadvantages to this approach include more difficult access to posterior lesions

Table 2 Synopsis of the last 10 years of literature regarding surgical management of knee osteochondritis dissecans

Treatment	Study	# Patients	Defect area/depth	Average age in years / % open physes	Follow Up	Type of Follow Up (scoring system)	Miscellaneous
ACI	Cole et al. [69]	32	A= 5.4 cm^2 D = -	30.5 / 12.5 %	43.2 months	Post-Op Modified Cincinati: 6.8	
	Ochs et al. [2••]	26	A = 5.3 cm^2 D = 8.7 mm	29.2 / 0 %	39.8 months	Avg Post-Op Lysholm: 76.9 % excellent/good Avg Post-Op IKDC: 78.4 Avg Post-Op Tegner: 4.6	Bone Graft
	Peterson et al. [70••]	58	A = 5.7 cm^2 D = 7.8 mm	26.4 / 60 %	5.6 years	Avg Post-Op Modified Cincinatti: 9.8 Avg Post-Op Tegner-Wallgren: 10.2	51 ACI 7 Sandwich technique (when depth > 8–10 mm)
	Steinhagen et al. [15]	21	A = 6.57 cm^2 D = –	29.33 / 0 %	36 months	Median Post-Op Lysholm: 90.14 Avg Post-Op IKDC: 70.29 Post-Op Clinical Grading Score: 85.7 % excellent/good	Bone Graft
	Vijayan et al. [71]	14	A = 7.2 cm^2 D = ≥ 8 mm	23.6 / -	5.2 years	Avg Post-Op Modified Cincinati: 82.8 Avg Post-Op VAS: 1.7	Bone Graft
OATS	Ollat et al. [75]	142	A = 1.7 cm^2 D = –	26 / 0 %	8 years	Avg Post-Op IKDC score: 76.4 Hughston: 73.3 % excellent/good	open and arthroscopic
	Miniaci [76]	20	A = – D = –	14.3 / 55 %	3.4 years	IKDC Post: 95 % normal, 5 % nearly normal VAS Post: 0	Mosacioplasty with dowels as biologic splint
	Navarro et al. [81]	11	A = – D = –	16 / 63.63 %	48 months	Hughston: 90.9 % excellent/good	
ARIF/ORIF	Magnussen et al. [4]	12	A = 3.5 cm^2 D = –	19.2 / 42 %	9.2 years	Mean KOOS: Pain: 87.8, other symptoms: 81.8; ADL: 93.1 sports & recreation: 74; QOL: 61.9	metal screws
	Weckstrom et al. [5]	28	A = Pin: 461 mm^2 A = Nail: 426 mm^2 D (both) = –	Pin: 20 / 0 % Nail: 21 / 0 %	5.4 years	Median VAS (Pin): 3.5 Median VAS (Nail): 1.5	19 ARIF w/ bioabsorable pins 11 ARIF w/ bioabsorable nails Implants: 19 pins, 11 nails
	Lintz et al. [82]	7	A = 528 mm^2 (median) D = –	21 (median) / 0 %	27 months	Median Post Op Hughston: 4 Median Post-Op IKDC: 78 %	metal screws and bone graft
	Millington et al. [3••]	18	A = 24 × 22 mm D = –	19 / 0 %	59 months	Avg Post-Op Lysholm (failures): 78.5; Avg Post-Oop Lysholm (non-failures): 88.3 Avg Post-Op IKDC (failures): 68.6 Avg Post-Op IKDC (non-failures): 89	11 ARIF w/ bioabsorable implants 7 ORIF w/ bioabsorable implants Implants: 11 nails, 3 pins, 2 darts, 1 screw, 1 screw & dart
Drilling	Lim et al. [53]	23	A = 2.1 cm^2 D = –	27 / 0 %	14 years	Avg Post-Op Lysholm: 87.3 Median Post-Op Tegner: 5 Hughston: 68 % excellent/good	Excision of Loose Body & subchondral drilling w/ K-wire
	Yonetani et al. [51]	18	A = 2.7 cm^2	12 / 100 %	30 months	Avg Post-Op Lysholm: 99.5	Antegrade Drilling

Table 2 (continued)

Treatment	Study	# Patients	Defect area/depth	Average age in years / % open physes	Follow Up	Type of Follow Up (scoring system)	Miscellaneous
			D = –				
	Louisia et al. [47]	24	A = Juvenile: 6.04 cm^3 A = Adult: 6.69 cm^3 D (both) = –	Juvenile: 13.8 / 100 % Adult: 20.8 / 0 %	9 years	Hughston Juvenile: 82 % excellent/good, 6 % fair, 12 % poor Hughston Adult: 50 % good, 50 % poor	Antegrade Drilling
	Kocher et al. [83]	23	A = 18 cm^2 D = –	12.3 / 100 %	3.9 years	Avg Post-Op Lysholm: 92.8	Transarticular arthroscopic drilling
Excision	Wright et al. [50]	17	A = – D = –	26 / 0 %	8.9 years	Hughston: 35 % good/excellent	
One-Stage Cell Based Procedure	Vannini et al. [49]	6	A = 4.6 cm^3 D = –	16 / 100 %	3 years	Avg Post-Op IKDC: 96.5	
	Buda et al. [72]	20	A = – D = –	– / 0 %	29 months	Avg Post-Op IKDC: 90.4 Avg Post-Op KOOS: 93.3	
Bone Cartilage Paste Graft	Stone et al. [73]	125	A = 28.6 cm^2 D = –	46 / 0 %	51.5 months	IKDC and Tegner scores all significantly increased	
Osteochondral Scaffold	Kon et al. [52]	28	A = 2.9 cm^2 D = –	35.3 / 0 %	2 years	Avg Post-Op Tegner: 4 Avg Post-Op IKDC: 85.7	
Multiple Procedures	Gudas et al. [48••]	47	A = OAT: 3.2 cm^2 A = Microfracture 3.17 cm^2 D(both) = –	OAT: 14.64 / 100 % Microfracture: 14.09 / 100 %	4.2 years	ICRS Questionairre: OAT at 1 year: 92 % good/excellent Microfracture at 1 year: 86 % good/excellent OAT at 4.2 years: 83 % good/excellent Microfracture at 4.2 years: 63 % good/excellent	25 OATS (arthroscopic) -graft from medial/lateral trochlea 22 Microfracture
	Pascual et al. [56••]	46	A = Overall: 4.5 cm^2 A = Allograft: 2.4 cm^2 A = ARIF: 2.14 cm^2 A = Loose Body Reomval: 2.11 cm^2 A = Microfracture: 1 cm^2 A = ACI: 2.26 cm^2 D (all) = –	34 / 0 %	4 years	Statistically significant improvement on all scales: Noyes, Tegner, Lysholm, IKDC, KOOS, and Short Form-12 (SF-12).	Osteochondral Allograft ARIF (non-absorable) Loose body removal Microfracture ACI Debridement

A area, *D* depth [2••, 3••, 4, 5, 15, 47, 48••, 49–53, 56••, 68, 70••, 71–73, 76, 77, 82–84] and violation of the articular cartilage surface with subsequent fibrocartilage (inferior mechanical properties, as compared with hyaline cartilage) fill.

The retrograde approach requires image intensification or use of an anterior cruciate ligament guide. While technically more challenging, this approach does not violate the articular cartilage and allows easier access to posterior lesions. Previous authors have described the use of intraoperative MRI guidance with an 80 % relief of symptoms and return to normal physical activity at an average of 3 years follow-up [61••]. Electromagnetic navigation systems are under investigation [62, 63].

Long-term follow-up has demonstrated the superiority of drilling in skeletally immature patients, as compared with adults. Specifically, they are more likely to experience symptomatic relief [47], with up to 100 % return to activities in juvenile patients [51].

Microfracture Microfracture allows extrusion of marrow elements into the lesion, stimulating fibrocartilage fill. It is most effective in lesions smaller than 2.5 cm^2 [48••], although current research has not elucidated a maximal depth for which microfracture has its greatest likelihood of success. Hence, small, unstable lesions in low-demand patients can likely be effectively treated with microfracture. First, the lesion is debrided to a stable cartilage rim. Next, the calcified cartilage layer is removed with a curette [64]. The subchondral bone is then perforated with a microfracture awl. These perforations should be as close together as possible without breaking into adjacent holes—approximately 2–3 mm apart. The awl should penetrate deep enough (2–4 mm) that blood and fat droplets extrude from the holes upon removal of the awl. These droplets contain pluripotent stem cells and growth factors from the marrow (Fig. 5). Postoperatively, restricted weight bearing helps to ensure adhesion of the fibrocartilage clot to the defect, while CPM encourages improved tissue formation. While short-term outcomes are generally excellent, the durability of outcomes has been limited, possibly due to the inferior ability of fibrocartilage to withstand shear stress, as compared with articular cartilage [65].

Gudas [48••] randomized 50 skeletally immature patients to either microfracture or OATS for treatment of femoral condylar OCD. The average lesional size in the microfracture group was 3.17 cm^2, similar to the 3.2 cm^2 of the OATS group. At 1 year, both groups had good or excellent results in their functional and objective assessment, but at 4.2 years, the OATS group maintained an 83 % good or excellent result, while the microfracture group dropped to 63 %. Failure rates were 41 % in the microfracture group and 0 % in the OATS group, with an inverse relationship between defect size and outcome in the microfracture group (patients with lesions >3 cm^2 did worse than those with

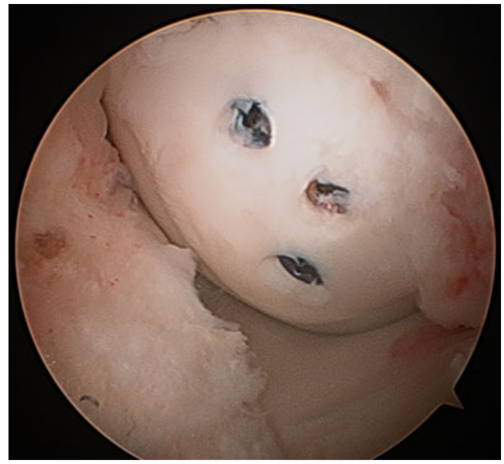

Fig. 4 Arthroscopic view of final product of an arthroscopic reduction and internal fixation using 3 Accutrack screws to secure an osteochondritis dissecans fragment in place

lesions <2 cm^2), without a similar relationship in the OATS group. Only 14 % of patients in the microfracture group returned to their preinjury level at 4.2 years versus 81 % in the OATS group. As has been mentioned, this study analyzed 2- to 4-cm^2 lesions, larger than the recommended size of 2.5 cm^2. This reinforces the effectiveness of microfracture in treating lesions smaller than 2.5 cm^2 and highlights its shortcomings in lesions larger than 3 cm [2••].

Restorative

Autologous chondrocyte implantation Current evidence dictates that autologous chondrocyte implantation (ACI) is most effective in OCD lesions larger than 2.5 cm^2 in low-demand patients. ACI is a two-stage cellularly based autograft technique [66, 67]. The first stage involves an arthroscopic biopsy (150–500 mg) from healthy cartilage in the non-weight-bearing region of the intercondylar

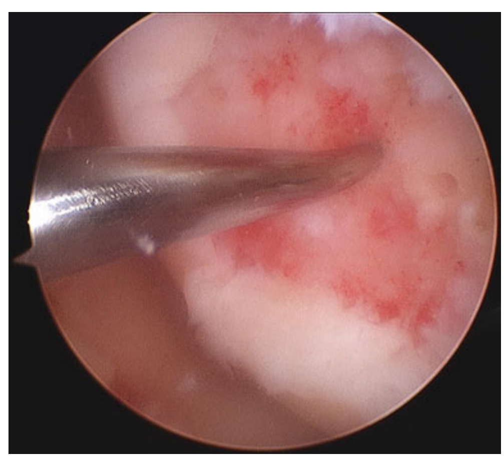

Fig. 5 Arthroscopic view of osteochondritis dissecans lesion undergoing microfracture

notch. Cartilage from a damaged fragment should not be used in the harvest. These cells are grown in vitro over 4–6 weeks, at which point the patient returns for implantation. During this procedure, the calcified cartilage is removed, and the lesion is debrided to stable vertical walls. The defect is covered with a synthetic collagen membrane that is sutured to the healthy edges of the debrided defect. Fibrin glue is then used to seal the edges, and the cultured cells are injected beneath the patch. One edge is left open until the cells are injected. The remaining defect is then securely closed with sutures and glue. The construct is delicate and, as such, is treated similarly to microfracture and OATS, with weight-bearing restrictions for 6 weeks and immediate CPM.

While not necessary in lesions with a depth of less than 8 mm, ACI can be combined with autologous bone grafting for defects that are deeper than 8–10 mm [68]. Bone grafting can be performed at the time of harvest arthroscopy or during cartilage implantation. An additional periosteal or synthetic collagen patch is sutured or glued to the implanted bone graft, and then, as was described above, another patch is sutured and glued over this patch and the cells are injected in between the two patches. This variant is called the *sandwich technique*. Although the authors prefer the suture technique to secure the patch to the bone graft, current evidence does not suggest a superiority of either the suture or the glue technique. More recent techniques include the use of a synthetic collagen patch to avoid symptomatic graft hypertrophy commonly seen with periosteal patches, requiring reoperation in 25.7 % of cases [69].

Cole et al. [70••], in a review of 40 patients treated with ACI who had previously failed at least one non-ACI procedure for OCD of the knee, reported statistically significant improvements in several outcome scores. Many authors have reviewed ACI plus bone grafting and have found good or excellent results in 73 %–86 % of patients [2••, 15]. Peterson et al. (71) reported on 58 patients who underwent ACI for their knee OCD and found 91 % good or excellent results at 2–10 years. Seven of their patients underwent the sandwich technique, while the other 51 were treated solely with ACI. Vijayan et al. [68]recently evaluated matrix-associated ACI, which is a variant of the sandwich technique where both patches are synthetic collagen and are preloaded with the cartilage cells before implantation. They showed 86 % good or excellent results at 5.2 years in 15 patients, all with a defect depth of at least 8 mm.

Other cellular techniques

Several variations of the ACI technique exist. In "one-step" bone marrow derived cellular transplant, venous blood is obtained from the patient 1 day prior to surgery and converted into platelet rich fibrin gel. On the day of surgery, bone marrow aspirate is harvested from the posterior iliac crest and processed to obtain a concentrate containing nucleated cells. The concentrate is then loaded onto a hyaluronic acid membrane scaffold. After routine debridement, the scaffold is loaded into the defect followed by the fibrin gel. Two recent studies have evaluated this technique and reported statistically significant improvement in several outcome scores, as well as improvement on MRI [49, 72]. Although these preliminary results for lesions averaging smaller than 5 cm^3 are promising, the cost of this procedure may be prohibitive.

Bone cartilage paste grafting has been used to augment the microfracture technique. Articular cartilage and cancellous bone are harvested from the intercondylar notch and morselized into a paste that is then held in place over the defect for 1–2 min. The entire defect is not filled with the paste; rather, the paste is impacted such that it penetrates into the holes made by the awl [1••]. Stone et al. [73]found an 85.6 % success rate at 12 years, with defects averaging 28.6 cm^2 years, using this technique to treat knee cartilage defects. However, they noticed only a minimal amount of hyaline cartilage formation in the paste when biopsied.

New techniques making use of biomimetic osteochondral scaffolds are currently investigational. In these techniques, microfracture is combined with placement of a three-dimensional, composite, trilayered structure that mimics osteochondral anatomy to promote formation of hyaline cartilage. Kon et al. [52]looked at 28 patients with osteochondral defects, 6 of whom had OCD lesions, and at 2 years they showed complete filling of the cartilage and complete integration of the graft in 70 % of the cases. Graft loosening and graft hypertrophy were reported in one case each, and better early clinical results were seen in patients with lesions located on the femoral condyles, as opposed to the patella. The results are applicable to lesions <3 cm^2. Longer-term results in a larger number of patients are necessary to validate this technique.

Lastly, both the DeNovo natural tissue graft (Zimmer, Warsaw, IN/ISTO, St Louis, MO) and DeNovo engineered tissue graft (Zimmer, Warsaw, IN/ISTO, St Louis, MO) are under investigation. Both grafts are generated from juvenile cartilage cells, which have a greater anabolic capacity than does adult tissue [74] and are easy to implant in a single-stage procedure using a fibrin sealant for fixation. No outcomes have been reported to date.

Reconstructive

Osteochondral autograft transplant (OATS)

OATS is most effective in lesions smaller than 2.5 cm^2 in high-demand patients. This technique transfers both articular cartilage and subchondral bone from a non-weight-bearing area of the knee to the site of the defect. The OCD lesion is first prepared into a round shape with excision of all diseased bone and cartilage. Dowels (termed *mosaicplasty* if more than one plug is used) of healthy cartilage and underlying bone are then harvested from the nonarticulating superior lateral femoral condyle or medial/lateral trochlea, matching the size of the defect. The dowel(s) is (are) press-fit into the defect until flush with the surrounding cartilage. Implantation should be performed with a larger number of less forceful impacts to increase chondrocyte survival [75]. Limitations to this technique include the relative scarcity of donor cartilage, difficulties in restoring normal condylar contour, and donor site morbidity [1••, 48••]. It is for these reasons that larger lesions are preferentially treated with allograft. Smaller lesions and lesions of the medial femoral condyle treated with OATS have better clinical outcomes than those of the lateral condyle or patellofemoral compartment [76]. Achieving surface congruency is technically challenging, especially with the use of multiple grafts, and inevitably results in fibrocartilage fill in the interstices. Hence, the authors prefer to use a single plug, with either autograft for smaller lesions or allograft in larger lesions, whenever possible.

Ollat et al. (76) conducted a multicenter, retrospective study of 142 OATS procedures, 61 performed for OCD. At 8 years, the authors found 72.5 % good or excellent results. Miniaci et al. [77] reported on a variant of the OATS technique for treating OCD in which they drilled though the center of an unstable fragment into subchondral bone and placed a dowel through the artificially created hole to obtain primary fixation of the fragment. They then used subsequent dowels to augment this fixation on the peripheral aspects of the OCD fragment, creating a biologic splint for the unstable fragment. At an average of 3.4 years, all 20 patients were pain free, and 100 % had normal or nearly normal knees, although they did not comment on lesion area/depth.

Osteochondral allografting

Osteochondral allografting is indicated for lesions too large to be accommodated by OATS, as well as lesions that have failed other restorative techniques. Briefly, the OCD lesion in the recipient knee is debrided, and sclerotic bone is removed, such that a cylindrical hole is created and healthy surrounding bone and cartilage remain at the periphery (Fig. 6a, b). One or more cylindrical bone plugs with the overlying articular cartilage are harvested from a fresh, viable, and size- and age-matched cadaveric specimen in the same area as the lesion on the recipient knee to match surface congruity and thickness. The graft is ideally press-fit (Fig. 6c), with augmentation using bioabsorable compression screws or headless variable pitch titanium screws if necessary.

Several studies have used validated outcome scores and patient satisfaction rate to demonstrate the success of osteochondral allografting at 2- to 4-year follow-up [29, 56••, 78]. Krych et al. [79]reported an 88 % return to sport rate at a 2.5-year follow-up in 43 athletes who underwent osteochondral allografting, although only 12 % of the lesions were due to OCD. Garret [80] reported a 94 % success rate at an average of 3 years postoperatively in adult patients treated with press-fit osteochondral allografts for lateral femoral condylar OCD. Therefore, lesions larger than 2.5 cm^2 in high-demand patients should be treated with allograft.

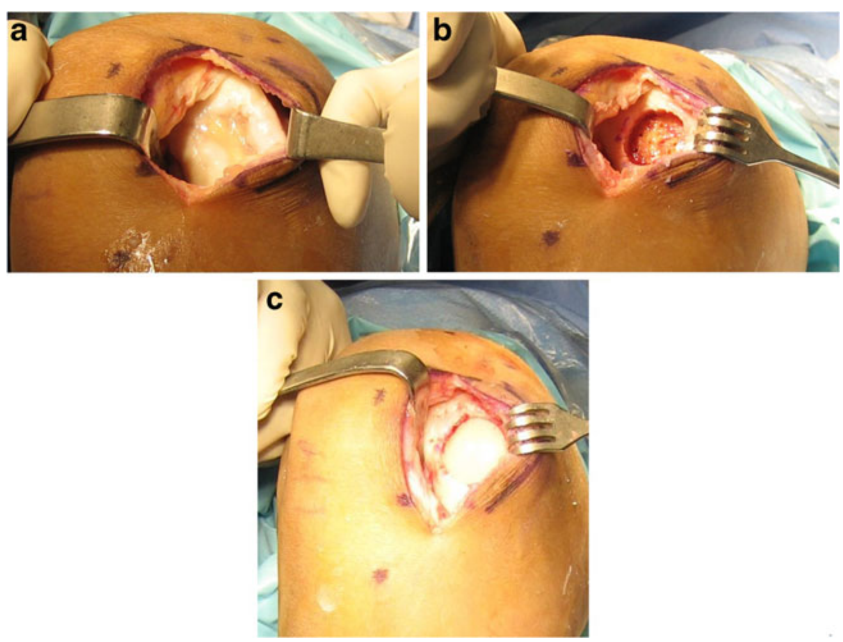

Fig. 6 **a** Intraoperative clinical photograph of an osteochondritis dissecans lesion of the medial femoral condyle. **b** Intraoperative clinical photograph after lesional preparation. **c** Intraoperative clinical photograph after placement of an osteochondral allograft restoring continuity of the articular cartilage

Conclusion

A variety of operative techniques exist to address OCD lesions, and treatment selection depends upon physeal status, fragment stability, and lesional size. Superior outcomes are observed in skeletally immature patients, males, smaller lesions, and a shorter duration of preoperative symptoms. Small, stable juvenile lesions can be considered for a trial of nonoperative treatment. If there is a salvageable fragment, drilling with arthroscopic fixation of the fragment can be attempted. If fragment salvage is not possible, a variety of restorative procedures exist, and procedure selection depends upon the size and depth of the lesion. Adequately powered randomized controlled trials will be necessary to determine which of these procedures best addresses these lesions.

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