JSES Reviews, Reports, and Techniques ■ (2023) 1–7

Contents lists available at ScienceDirect

JSES Reviews, Reports, and Techniques

journal homepage: www.jsesreviewsreportstech.org

Extra-articular core tunneling and local autogenous bone grafting for osteochondritis dissecans lesion of the capitellum with intact articular cartilage and subchondral bone deficiency

Jared Bukowski, BS[a], James Padley, BS[b], Steven Chudik, MD[c,d,*]

[a]Midwestern University Chicago College of Osteopathic Medicine, Downers Grove, IL, USA
[b]Loyola University of Chicago, Stritch School of Medicine, Chicago, IL, USA
[c]OTRF, Westmont, IL, USA
[d]Hinsdale Orthopaedics/Illinois Bone and Joint Institute, Hindsdale, IL, USA

A R T I C L E I N F O

Keywords:
Osteochondritis dissecans
Stable OCD
Capitellum
Extra-articular
Local autograft

Osteochondritis dissecans (OCD) is characterized by subchondral bone injury, loss of support for overlying articular cartilage, and failure of the articular surface. OCD generally presents in patients older than 10 years old, most commonly in males between 12 and 17 years old.[10] One etiologic theory is that repetitive microtrauma compromises the subchondral bone's vascular supply, resulting in focal avascular necrosis and loss of mechanical support for the overlying cartilage.[2] Another theory is that repetitive loading results in a focal stress injury to the subchondral bone, which progresses to subsequent fracture, bone resorption, and loss of mechanical support for the chondral or osteochondral joint surface. OCD most commonly occurs in the knee and is also seen in the dominant elbows of overhead-throwing athletes resulting from valgus loading associated with throwing.[9,13] Early stages present with poorly localized pain and tenderness over the lateral elbow, which resolves with rest, while later stages may present with loss of extension, catching, and locking of the elbow.[13,2,5]

Treatment of OCD depends on the patient's skeletal maturity, the lesion's stability, and the condition of the subchondral bone and overlying articular cartilage.[13] We present the case of a 14-year-old baseball player with an OCD lesion of his right capitellum with partially intact, relatively stable cartilage surface, and insufficient subchondral bone that was successfully managed with drilling, extra-articular core tunneling, débridement, local autogenous bone grafting, and internal fixation. This case illustrates another potential option in the treatment algorithm for symptomatic OCD lesions with a salvageable articular cartilage surface and subchondral bone insufficiency. The current International Cartilage Repair Society (ICRS) OCD classification system describes the integrity of articular cartilage. This case also illustrates the utility of adding a subclassification to describe the adequacy of the subchondral bone and using all available staging modalities including plain radiographs, computed tomography (CT), magnetic resonance imaging (MRI), and arthroscopy.

Case report

A 14-year-old baseball player presented with a chief complaint of right posterolateral elbow pain for years that recently worsened and began to "click." The pain was exacerbated by throwing and improved with rest. Physical examination revealed no deformity, swelling, ecchymosis, or muscle atrophy. The passive range of motion was decreased by 10 degrees of extension and 15 degrees of flexion with pain at the end ranges of motion. Manual strength testing and varus, valgus, and rotational stability tests were normal. There was no palpable medial tenderness over the ulnar collateral ligament or valgus instability. There was tenderness to palpation over the capitellum with the elbow in full flexion.

Right elbow anteroposterior and lateral radiographs showed a significant lucency consistent with an OCD of the capitellum (Fig. 1 *A* and *B*). MRI revealed a nondisplaced osteochondral lesion of the capitellum measuring 0.5 x 1.8 x 1.0 cm in craniocaudal, anteroposterior, and transverse dimensions, respectively (Fig. 2 *A* and

Institutional review board approval was not required for this case report.
Patient consent was obtained for publication of this case report.

*Corresponding author: Steven Chudik, MD, Hinsdale Orthopaedics—Illinois Bone & Joint Institute, Loyola University Chicago, Stritch School of Medicine, 4809 Lawn Avenue, Western Springs, IL 60558, USA.
E-mail address: contactus@chudikmd.com (S. Chudik).

https://doi.org/10.1016/j.xrrt.2023.09.005

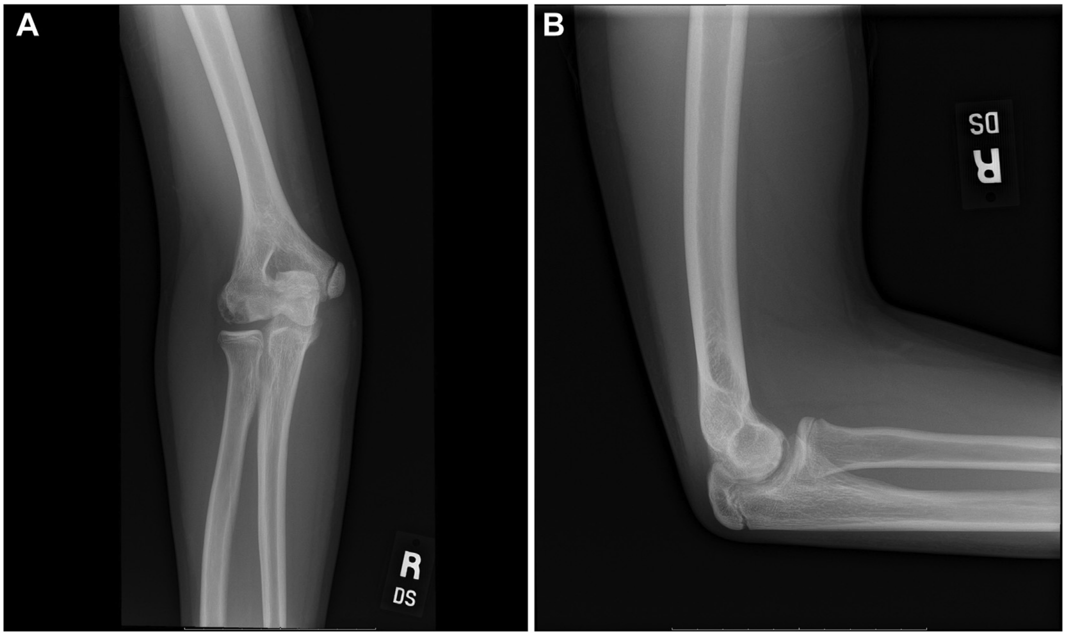

Figure 1 (**A, B**) Right elbow anteroposterior and lateral radiographs demonstrate a lucency of the capitellum ie, consistent with osteochondritis dissecans. A thin subchondral bone shell is visible.

B). Though the lesion was nondisplaced, there was significant bone marrow edema, cystic changes, bone resorption, and sclerotic borders within the lesion. After the MRI revealed a mature lesion with bone loss and potentially intact cartilage, a CT scan was performed to better define the extent of the bone resorption and evaluate for the presence of subchondral cortical bone. The CT scan revealed an OCD of the capitellum with significant bony resorption and a complete thin subchondral shell of bone, further supportive evidence for the presence of an intact articular cartilage surface (Fig. 3). There are cases where the CT scan is not needed so the senior author's (S.C.C.) practice is to start with the MRI to avoid unnecessary cost and exposure to radiation. However, in many cases where the MRI supports significant bone loss, sclerotic borders, and an intact cartilage surface, CT scan has proven useful to better define these OCD lesions and plan surgery.

Rest, cessation of all elbow loading activities, and physical therapy reduced the symptoms and allowed him to regain full passive elbow range of motion. Because of the maturity of the OCD lesion, significant loss of subchondral bone, mechanical symptoms, and inability to participate in desired activities, surgery was recommended to arthroscopically evaluate the condition of the cartilage and débride the lesion or repair the lesion with bone graft with or without internal fixation. Ten days prior to surgery, the patient completed the abbreviated version of the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire, QuickDASH, and recorded a score of 27.27.

Surgical technique

Diagnostic arthroscopy was performed in the lateral position to evaluate the condition of the articular cartilage. Slightly more than 20 cc of sterile saline was injected with a spinal needle through the mid-lateral portal site to distend the joint capsule. Anterior proximal medial and anterior proximal lateral arthroscopic portals were created with sharp skin incisions and deep blunt dissection. From these portals, the entire anterior compartment of the elbow was inspected. After placing an inflow cannula in the anterior compartment, posterior central and posterior-lateral portals were created in the same fashion to inspect the posterior compartments and medial and lateral gutters. The arthroscopic evaluation confirmed the suspicions based on imaging that the cartilage was nondisplaced over the lesion and had a limited peripheral area of partial thickness injury. The cartilage surface appeared stable and structurally intact upon arthroscopic examination and probing. The small superficial surface cartilage tear at the perimeter of the capitellar lesion was débrided back to smooth and stable borders with an arthroscopic shaver (Fig. 4).

Following the arthroscopic portion of the procedure, the shoulder was externally rotated, and the arm was placed on the large base of the fluoroscopic c-arm as a table. The posterolateral skin over the radio-capitellar compartment was incised, and deep dissection continued along the Kocher interval between the anconeus and the extensor carpi ulnaris muscles. A limited arthrotomy was created to visualize the capitellar joint surface without compromising the lateral ulnar collateral and annular ligaments. A limited amount of the triceps was elevated to expose the posterolateral distal humerus. Using fluoroscopic guidance and direct visualization, a 2.4 mm guide pin was drilled from the posterior distal lateral humerus to the center of the OCD lesion, perpendicular to the articular surface. (Fig. 5 *A* and *B*). A 7 mm diameter core reamer was then used to create a tunnel to the lesion and harvest a core of local autogenous bone graft from healthy bone proximal to the lesion (Fig. 6 *A* and *B*). The nonarticular sclerotic border of the OCD lesion was drilled with 0.054 mm k-wires, débrided with a curette, and irrigated. The subchondral aspect of the OCD was then grafted using the minced-up autologous bone from the core harvest, followed by the injectable demineralized bone matrix (DBM) to help fill the tunnel void. Then the tunnel's opening was plugged with the remaining 5 mm length of the autologous bone graft core harvest. Upon final inspection, the articular cartilage surface appeared firm and intact but a small peripheral crack with minimal instability was discovered at the lateral edge of the nonarticular surface of the capitellum which was not noticed upon initial inspection. There was no extrusion of the graft. To further stabilize the articular fragment, an absorbable pin was carefully inserted to capture the adjacent nonarticular lateral cortex of the articular

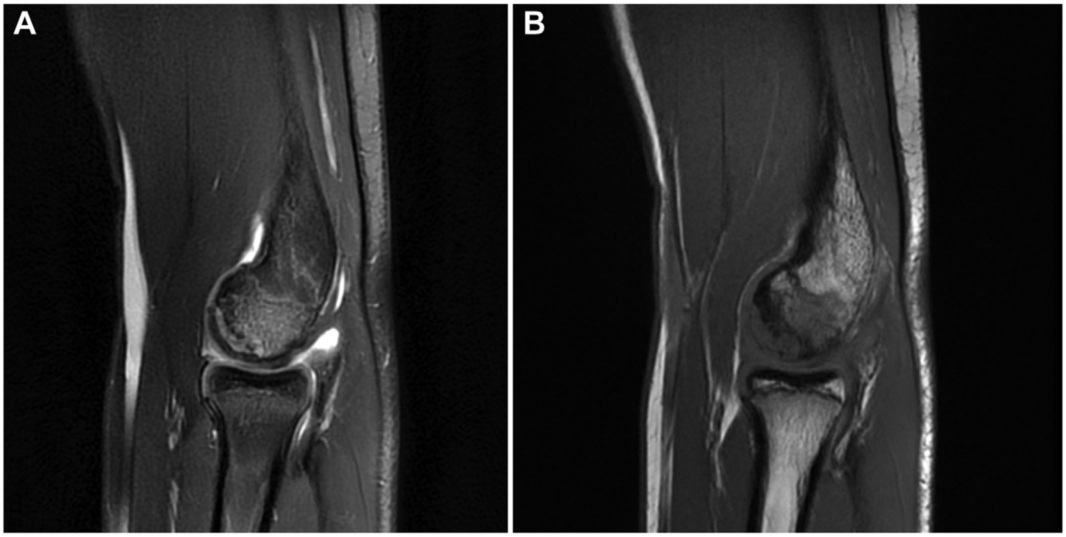

Figure 2 (**A, B**) Right elbow preoperative MRI demonstrates an OCD lesion of the capitellum with possibly intact articular surface with suspicion for loss of subchondral bone. *MRI*, magnetic resonance imaging; *OCD*, osteochondritis dissecans.

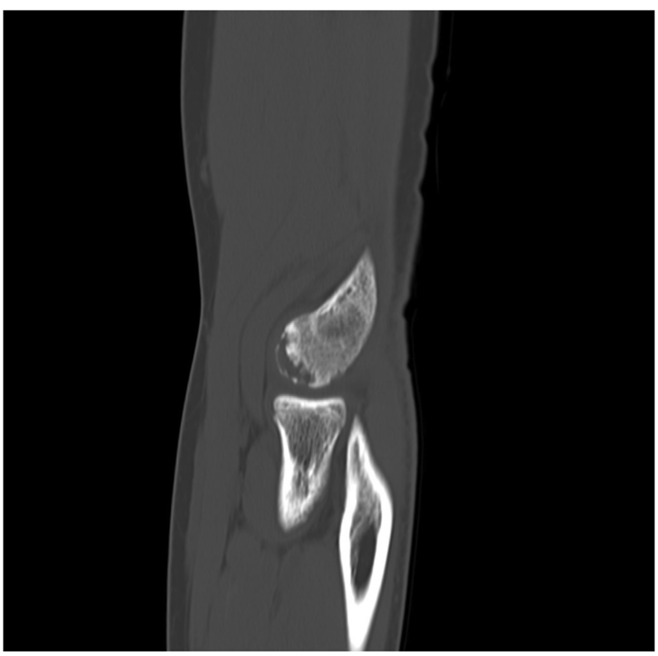

Figure 3 Right elbow CT scan demonstrates a significant OCD of the capitellum with bony resorption and possibly a complete thin subchondral bone shell suggesting the potential of an intact articular cartilage surface. *OCD*, osteochondritis dissecans. *CT*, computed tomography.

fragment and the intact distal humeral bone adjacent to the extra-articular tunnel. The surgical wound was then irrigated, closed, and dressed.

Postoperative care and rehabilitation

Postoperative care initially focused on graft healing and restoring passive range of motion to the upper extremity, followed by progressive loading of the healing bone, and gradually restoring functional strength to the upper extremity. After bone healing and restoring strength and motion, a gradual interval throwing program was completed to allow a safe return to sport.

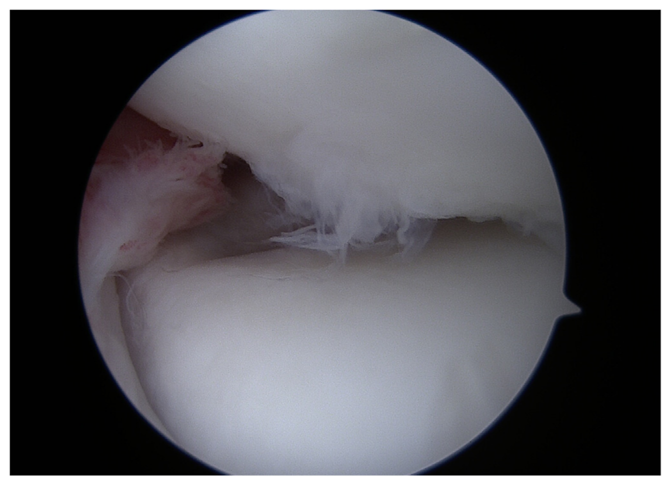

Figure 4 Right elbow arthroscopic image demonstrates a surface cartilage tear and intact articular surface of both the capitellum with limited fraying of cartilage at perimeter of OCD lesion. *OCD*, osteochondritis dissecans.

For the first six weeks postoperatively, the elbow was immobilized in a sling and the patient was instructed to avoid active elbow range of motion and upper extremity weight-bearing activities. The patient attended formal physical therapy for supervision and instruction 1-2 times per week for the first six weeks. The patient performed passive elbow range of motion exercises (supination, pronation, flexion, extension) and active shoulder, wrist, and finger range of motion exercises with the elbow immobilized.

For weeks seven through twelve, the sling was discontinued following clinical and radiographic evidence for initial healing, ie, the patient was pain-free, regained full passive elbow range of motion, experienced no palpable tenderness over the capitellum, and the x-rays revealed progressive signs of healing. Active elbow range of motion and gentle activities of daily living were allowed. During weeks seven through twelve, the patient continued formal physical therapy for supervision 1-2 times per week.

For weeks thirteen and beyond, the patient performed gradual progressive resistance exercises for the hand, wrist, elbow, and shoulder and gradually resumed sport-specific training at formal physical therapy 2-3 times per week.

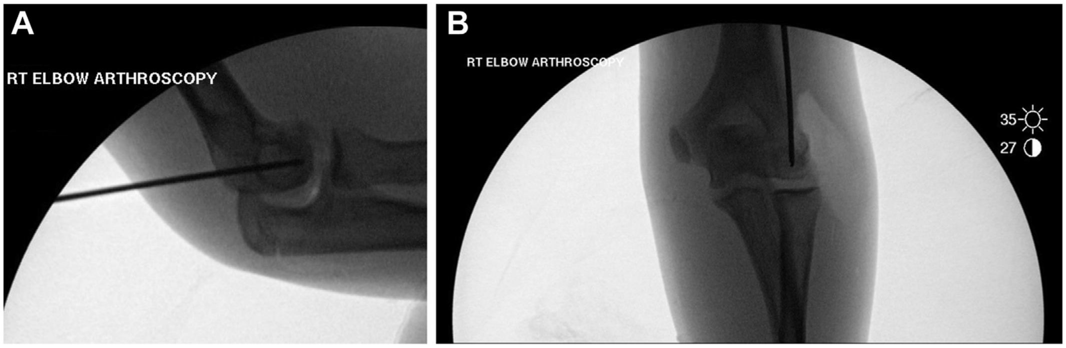

Figure 5 (**A, B**) Right elbow intraoperative anterior to posterior and lateral fluoroscopic radiographs demonstrate the placement of guide pin from the posterior distal humerus to the center of the OCD lesion perpendicular to its articular surface. *OCD*, osteochondritis dissecans.

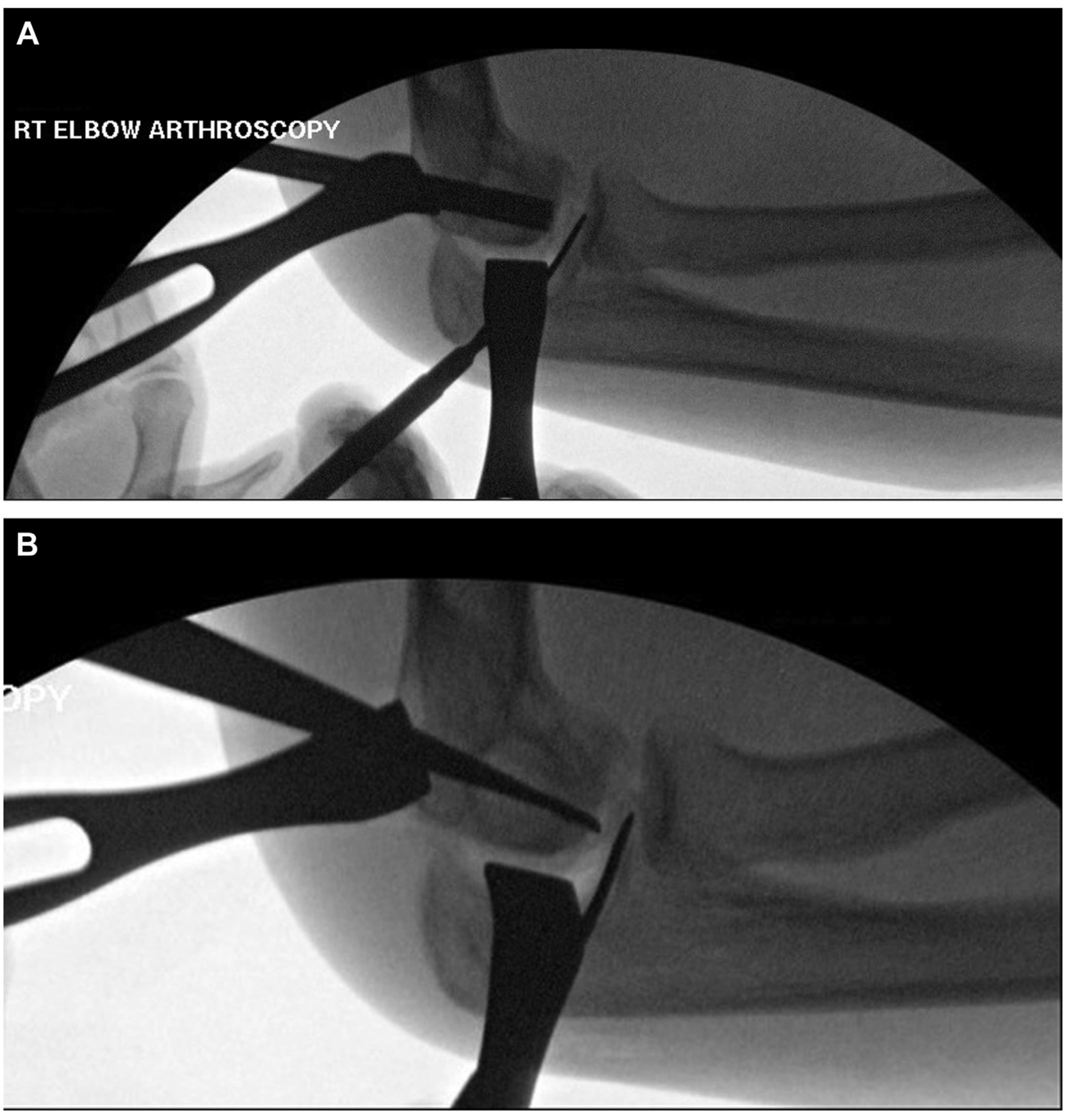

Figure 6 (**A, B**) Right elbow intraoperative fluoroscopic radiographs demonstrate extra-articular tunneling to the capitellar lesion, débridement, and bone grafting.

At 6 months postoperatively, the patient began a 6-week interval throwing program and a gradual return to hitting before returning to sport. Elbow radiographs revealed healing of the lesion (Fig. 7 *A* and *B*). The patient experienced a full return to the previous level of play. He recorded a QuickDash score of 0.00 at 32 months postoperatively, a marked improvement from the preoperative

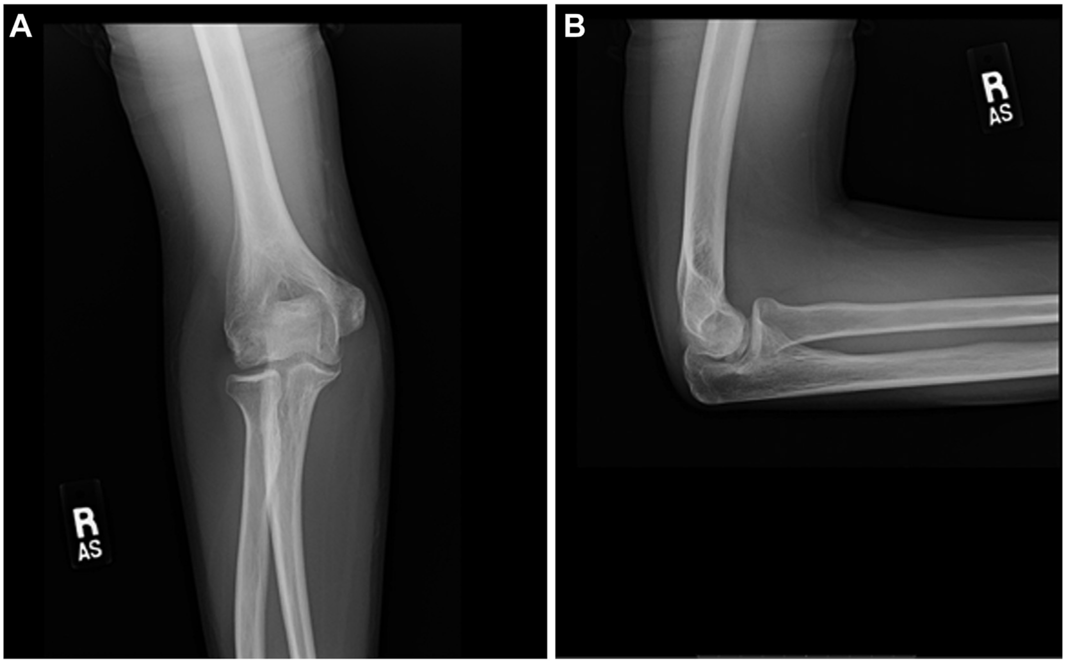

Figure 7 (**A, B**) Right elbow anteroposterior and lateral radiographs taken at 6 months postoperative which demonstrated healing of the osteochondral defect.

score of 27.27. The 14-year-old patient is now seventeen and signed with an elite Division I collegiate baseball program and is considering entering the professional draft.

Discussion

We describe a successful cartilage-preserving extra-articular technique of local autogenous bone grafting and repair of OCD lesions of the capitellum with salvageable intact articular cartilage and insufficient subchondral bone. Success was determined radiographically with healing on plain radiographs and clinically by a pain-free return to the previous level of sport. This technique is appealing because it preserves the native articular cartilage.

Historically, classification systems for OCD have been based on a single imaging modality. The Minami[17] classification system is based on plain radiographs, the Itsubo[7] classification system on MRI, and the Clanton and Delee[4] classification system on CT and the popular[8] ICRS classification system is based on arthroscopic evaluation (Table I).

The ICRS system classifies lesions according to the stability of the lesion and integrity of the articular cartilage. This case illustrates the benefit and importance of using all available diagnostic modalities to best assess the stability of the lesion and the integrity of the articular cartilage as well as the subchondral bone. Modifying the ICRS system to include an extra subclassification describing the subchondral bone would extend its applicability and better guide treatment options (Table II). With the proposed updates, this lesion would be characterized as a type IB OCD lesion.

Treatment options for OCD lesions generally include débridement, microfracture or drilling, autologous matrix-induced chondrogenesis, autologous and allogenic osteochondral transfer, cartilage transplantation, and autologous chondrocyte implantation.[13,18] Nonoperative management is the preferred treatment for stable lesions,[13] but up to 54% of patients will not improve from nonoperative treatment.[22,5] Accordingly, Logli et al[12] recently proposed a treatment algorithm that included operative management for patients with stable lesions who have been symptomatic for more than 3-6 months. Primary surgical management for stable lesions is débridement and bone marrow stimulation via microfracture or drilling, with 80%-90% of patients eventually returning to sport, although a more recent study suggests only 55%-75% of patients return to preinjury levels of play after microfracture.[16,2]

For large OCD lesions, like in this case, greater than 10-15 mm, the articular surface should ideally be preserved or replaced through extra-articular or osteochondral autograft procedures.[11,14] Osteochondral autologous transfer (OAT) procedures typically involve replacing cartilage and subchondral bone with plugs from the femoral condyle or costochondral junction.[14,15,20] This procedure is associated with satisfactory to excellent outcomes for more extensive OCD lesions with instability.[1,18] A review by Matsuura et al[15] found that in patients with unstable OCD lesions treated with the OAT procedure, 81 of 86 patients returned to previous level of sport with a mean follow-up of 43 months. A systematic review by Westermann et al[23] comparing patient's return to sport after operative management of capitellar OCD lesions found return to previous level of sport was highest with OAT procedures (94% at mean follow-up 35.0 months) compared with débridement and marrow stimulation procedures (71%) or OCD fixation surgeries (64%).

Despite the reported positive long-term outcomes, the OAT procedure has associated risks including donor site morbidity and incomplete restoration of joint congruity and tribology at the graft recipient site.[18] While large or unstable cartilage defects in OCD lesions can benefit from the OAT procedure, large OCD lesions with stable or salvageable articular cartilage may be better addressed with local extra-articular bone grafting techniques to avoid donor site morbidity, disruption of the intact cartilage surface, and replacement with nonlocal cartilage with different thickness and load-bearing properties which does not integrate to the adjacent native cartilage.

In OCD lesions with sufficient subchondral bone, marrow stimulation via extra-articular drilling remains a good treatment option. When insufficient subchondral bone is present, the outcome of this case supports the potential use of extra-articular

Table I
ICRS classification of osteochondritis dissecans lesions.[18]

Classification	Criteria
Type I	Stable lesion with a continuous but softened area covered by intact articular cartilage
Type II	Lesion with partial articular cartilage discontinuity, stable when probed
Type III	Lesion with complete articular cartilage discontinuity, but no dislocation ("dead *in situ*")
Type IV	Empty defect, or defect with a dislocated or loose fragment within the bed.

ICRS, International Cartilage Repair Society.

Table II
Proposed update to ICRS classification of osteochondritis dissecans lesions to include the integrity of the subchondral bone.

Classification	Criteria
Type I	Stable lesion with a continuous but softened area covered by intact articular cartilage.
Type II	Lesion with partial articular cartilage discontinuity, stable when probed.
Type III	Lesion with complete articular cartilage discontinuity, but no dislocation ("dead *in situ*")
Type IV	Empty defect, or defect with a dislocated or loose fragment within the bed.
Subclassification	**Criteria**
A	Sufficient subchondral bone
B	Insufficient subchondral bone

ICRS, International Cartilage Repair Society.

local autologous bone grafting as a treatment option for large OCD lesions of the capitellum with bone insufficiency and salvageable articular cartilage.

The primary objective of this surgery was to restore the insufficient subchondral bone to re-establish mechanical support for overlying cartilage. We chose a local autologous bone graft to restore the insufficient subchondral bone stock and DBM to backfill the tunnel to limit donor site morbidity associated with distant autograft harvest. The iliac crest is a common site for autologous bone grafts, but up to 19%-31% of patients will have persistent pain at the donor site 2 years after surgery.[6,21] Reports of recycled grafting of minced local autologous bone graft have not previously been published for OCD treatment; however, it has become a standard for bone regeneration in spinal fusion surgeries because of its osteoconductive properties, osteoinductive growth factors, morphogenic proteins, and osteogenic factors.[3,19] Additionally, collagen fibers in the DBM form a 3D framework for vascular and osteoprogenitor cell ingrowth.[24] For these reasons and its injectable properties, DBM was used to backfill the remainder of the core tunnel and stimulate the regeneration of healthy bone after surgery.

The extra-articular approach is indicated as long as there remains an intact or reparable joint surface sufficient to contain a subchondral bone graft regardless of the condition of the cartilage. The surface must be salvageable and sufficiently stable to allow an early postoperative range of motion. Lesions where the surface is unstable and can be opened and closed like a door and stabilized which allow a direct articular-sided approach may not require an extra-articular approach. However, the extra-articular tunnel with a core reamer would still be of benefit to obtain a local autogenous source of bone graft and access limiting further injury to the articular surface.

Conclusion

Cartilage-preserving extra-articular core reaming and local autogenous bone grafting and repair is a potential solution for OCD lesions with insufficient subchondral bone and salvageable intact articular cartilage stable to probing on arthroscopic exam. OCD classification systems would be improved by including an assessment of the articular cartilage and subchondral bone based on multiple diagnostic modalities, including plain radiographs, CT, MRI, and arthroscopy. In the future, computer and robotic navigation based on imaging modalities may be a powerful tool to help surgeons create safe extra-articular approaches to OCD lesions with insufficient subchondral bone and an intact or reparable joint surface while avoiding injury to the surrounding articular and physeal cartilage. More clinical research is needed to evaluate the long-term outcomes of this less invasive cartilage-preserving extra-articular approach.

Disclaimers:

Funding: Funding for publication is provided by the Orthopedic Surgery and Sports Medicine Teaching and Research Foundation (OTRF).
Conflicts of interest: The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.
Patient consent: Obtained.

References

1. Ayzenberg M, Clippinger B, Slate EL, Kozin SH, Zlotolow DA. Outcomes of osteochondral autograft transplantation in pediatric patients with osteochondritis dissecans of the capitellum. J Hand Surg Am 2021;46:1028.e1-1028.e15. https://doi.org/10.1016/j.jhsa.2021.02.024.
2. van Bergen CJ, van den Ende KI, Ten Brinke B, Eygendaal D. Osteochondritis dissecans of the capitellum in adolescents. World J Orthop 2016;7:102-8. https://doi.org/10.1177/03635465990270060701.
3. Betz RR, Lavelle WF, Samdani AF. Bone grafting options in children. Spine (Phila Pa 1976) 2010;35:1648-54. https://doi.org/10.1097/BRS.0b013e3181ce8f4b.
4. Clanton TO, DeLee JC. Osteochondritis dissecans. History, pathophysiology and current treatment concepts. Clin Orthop Relat Res 1982;167:50-64.
5. van den Ende KIM, McIntosh AL, Adams JE, Steinmann SP. Osteochondritis dissecans of the capitellum: a review of the literature and a distal ulnar portal. Arthroscopy 2011;27:122-8. https://doi.org/10.1016/j.arthro.2010.08.008.
6. Goulet JA, Senunas LE, DeSilva GL, Greenfield ML. Autogenous iliac crest bone graft. Complications and functional assessment. Clin Orthop Relat Res 1997;339:76-81.
7. Itsubo T, Murakami N, Uemura K, Nakamura K, Hayashi M, Uchiyama S, et al. Magnetic resonance imaging staging to evaluate the stability of capitellar osteochondritis dissecans lesions. Am J Sports Med 2014;42:1972-7. https://doi.org/10.1177/0363546514532604.
8. [cited 2022 Feb 2]. Available from: ICRS_evaluation.pdf [Internet] https://cartilage.org/content/uploads/2014/10/ICRS_evaluation.pdf.
9. Kida Y, Morihara T, Kotoura Y, Hojo T, Tachiiri H, Sukenari T, et al. Prevalence and clinical characteristics of osteochondritis dissecans of the humeral capitellum among adolescent baseball players. Am J Sports Med 2014;42:1963-71. https://doi.org/10.1177/0363546514536843.
10. Kobayashi K, Burton KJ, Rodner C, Smith B, Caputo AE. Lateral compression injuries in the pediatric elbow: Panner's disease and osteochondritis dissecans of the capitellum. J Am Acad Orthop Surg 2004;12:246-54. https://doi.org/10.5435/00124635-200407000-00005.
11. Kraeutler MJ, Aliberti GM, Scillia AJ, McCarty EC, Mulcahey MK. Microfracture vs. drilling of articular cartilage defects: a systematic review of the basic science evidence. Orthop J Sports Med 2020;8, 2325967120945313. https://doi.org/10.1177/2325967120945313.
12. Logli AL, Leland DP, Bernard CD, Sanchez-Sotelo J, Morrey ME, O'Driscoll SW, et al. Capitellar osteochondritis dissecans lesions of the elbow: a systematic

review of osteochondral graft reconstruction options. Arthroscopy 2020;36: 1747-64. https://doi.org/10.1016/j.arthro.2020.01.037.

13. Looney AM, Rigor PD, Bodendorfer BM. Evaluation and management of elbow injuries in the adolescent overhead athlete. SAGE Open Med 2021;9, 20503121211003360. https://doi.org/10.1177/20503121211003362.
14. Maruyama M, Takahara M, Harada M, Satake H, Takagi M. Outcomes of an open autologous osteochondral plug graft for capitellar osteochondritis dissecans: time to return to sports. Am J Sports Med 2014;42:2122-7. https://doi.org/10.1177/0363546514538759.
15. Matsuura T, Hashimoto Y, Nishino K, Nishida Y, Takahashi S, Shimada N. Comparison of clinical and radiographic outcomes between central and lateral lesions after osteochondral autograft transplantation for osteochondritis dissecans of the humeral capitellum. Am J Sports Med 2017;45:3331-9. https://doi.org/10.1177/0363546517730358.
16. McLaughlin RJ, Leland DP, Bernard CD, Sanchez-Sotelo J, Morrey ME, O'Driscoll SW, et al. Both debridement and microfracture produce excellent results for osteochondritis dissecans lesions of the capitellum: a systematic review. Arthrosc Sports Med Rehabil 2021;3:e593-603. https://doi.org/10.1016/j.asmr.2020.10.002.
17. Minami M, Nakashita K, Ishii S, Usui M, Muramatsu I, Ogino T, et al. Twenty-five cases of osteochondritis dissecans of the elbow. Rinsho Seikeigeka 1979;14:805-10.
18. Ophoven C, Wagner FC, Izadpanah K, Jaeger M, Salzmann GM, Gladbach B, et al. Autologous minced cartilage implantation for arthroscopic one-stage treatment of osteochondritis dissecans of the elbow. Arthrosc Tech 2022;11: e435-40. https://doi.org/10.1016/j.eats.2021.11.013.
19. Salamanna F, Tschon M, Borsari V, Pagani S, Martini L, Fini M. Spinal fusion procedures in the adult and young population: a systematic review on allogenic bone and synthetic grafts when compared to autologous bone. J Mater Sci Mater Med 2020;31:51. https://doi.org/10.1007/s10856-020-06389-3.
20. Sato K, Iwamoto T, Matsumura N, Suzuki T, Nishiwaki Y, Oka Y, et al. Costal osteochondral autograft for advanced osteochondritis dissecans of the humeral capitellum in adolescent and young adult athletes: clinical outcomes with a mean follow-up of 4.8 years. J Bone Joint Surg Am 2018;100:903-13. https://doi.org/10.2106/JBJS.17.01035.
21. Skaggs DL, Samuelson MA, Hale JM, Kay RM, Tolo VT. Complications of posterior iliac crest bone grafting in spine surgery in children. Spine 2000;25: 2400-2.
22. Takahara M, Ogino T, Fukushima S, Tsuchida H, Kaneda K. Nonoperative treatment of osteochondritis dissecans of the humeral capitellum. Am J Sports Med 1999;27:728-32.
23. Westermann RW, Hancock KJ, Buckwalter JA, Kopp B, Glass N, Wolf BR. Return to sport after operative management of osteochondritis dissecans of the capitellum. Orthop J Sports Med 2016;4, 232596711665465. https://doi.org/10.1177/2325967116654651.
24. Zhang H, Yang L, Yang X-G, Wang F, Feng J-T, Hua K-C, et al. Demineralized bone matrix carriers and their clinical applications: an overview. Orthop Surg 2019;11:725-37. https://doi.org/10.1111/os.12509.