SCIENTIFIC ARTICLE

Outcomes of Osteochondral Autograft Transplantation in Pediatric Patients With Osteochondritis Dissecans of the Capitellum

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Purpose To assess the outcomes of osteochondral autograft transplantations in the treatment of osteochondritis dissecans of the capitellum in the pediatric population.

Methods Between 2011 and 2016, 15 patients who had undergone osteochondral autograft transplantation at a mean age of 13.7 years at surgery were identified. The donor site was from the superolateral, non—weight-bearing surface of the lateral femoral condyle of the ipsilateral knee.

Results Mean follow-up was 29.5 months, with no patients lost to follow-up. Mean arc of motion increased significantly from 121.9° preoperatively to 139.1° postoperatively. All 9 elite athletes returned to sports at an elite level: 7 returned to the same level of competition in the same sport, 1 retired from gymnastics due to multiple injuries but began diving at an elite level, and 1 retired from baseball unrelated to elbow symptoms but continued hockey at the same level. Of the 4 recreational athletes, all returned to sport. There were no intraoperative complications. The symptoms resolved completely in all but 2 patients, who improved over their preoperative condition. The donor site knee pain resolved in all patients at an average of 2.3 months. Postoperative imaging demonstrated the healing and incorporation of the plug in all patients.

Conclusions In the treatment of osteochondritis dissecans of the capitellum, osteochondral autograft transplantation demonstrates excellent clinical and radiographic outcomes, with minimal short-term donor site morbidity and a high level of return to the sport. *(J Hand Surg Am. 2021;■(■):1.e1-e15. Copyright © 2021 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Therapeutic IV.

Key words Autograft, Capitellum, OATs, Osteochondritis Dissecans.

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OSTEOCHONDRITIS DISSECANS (OCD) of the capitellum is a leading cause of elbow disability in young throwing athletes and gymnasts, among others.[1–5] Microtrauma and excessive valgus extension stress on the relatively hypovascular midportion of the capitellum may cause avascular necrosis, leading to subchondral bone loss. The unsupported cartilage then degrades, resulting in instability of the articular surface.[1–5] Patients commonly present with pain, decreased motion, and mechanical symptoms in the affected elbow, typically the dominant extremity.[1,4]

Failure to treat OCD can result in progressive degenerative changes, either from the loose bodies and flaps of cartilage damaging the intact cartilage or by the spread of the lesion.[6,7] Stable, early-stage lesions, particularly in the setting of an open physis, can be treated nonsurgically with immobilization.[7,8] Nonsurgical treatment is associated with poor prognosis in patients with advanced disease, unstable lesions, mechanical symptoms, or motion deficits.[6,9] The specific surgical intervention required remains controversial but includes debridement with the removal of loose bodies and one or more of microfracture, abrasion chondroplasty, reattachment of fragments, and osteotomies. These techniques may provide adequate short-term relief; however, the rate of return to sports has been unfavorable, and the risk of subsequent development of arthritis remains high.[1,2,4]

Brownlow et al[10] showed a return to sports in 81% of patients after arthroscopic debridement, but some pain persisted in 58% of patients and mechanical symptoms were seen in 38% of patients. Furthermore, the postoperative radiographs of 12 of 18 patients demonstrated flattening of the capitellum and degenerative changes in 6 patients. In the study by Bauer et al,[11] 61% of patients with large capitellar lesions who were treated by debridement demonstrated radiocapitellar arthritis on follow-up radiographs. Microfracture combined with debridement has shown reasonable short-term clinical results. Lewine et al[12] demonstrated a return to sport in 14 patients of their cohort of 21 patients. Tis et al[13] demonstrated 67% complete pain relief in their mixed group of microfracture, transhumeral drilling, and fragment fixation. A recent meta-analysis by Westermann et al[8] showed a combined 71% return to sport at the same level and 87% return to sports in general in patients treated with arthroscopic debridement with or without microfracture.

Fragment fixation in unstable, but nondisplaced, OCD lesions can also lead to good outcomes; Hennrikus et al[14] demonstrated the healing of the OCD lesion in 77% of patients, Kuwahata and Inoue[15] reported that the elbows of all 8 patients in their series were painless at 32 months postoperatively, Nobuta et al[16] reported that 25 of 28 patients were asymptomatic postoperatively, and Takeda et al[17] reported a return to sports in 9 of 11 baseball players. Although these reports are promising, excellent outcomes have not been universally reported. Kosaka et al[18] reported a 50% revision rate in their series. In the meta-analysis by Westermann et al,[8] a 64% return to sport at the same level and 68% overall return to sport was reported.[8]

More recently, osteochondral autograft transplantation (OAT) has demonstrated success in the management of knee and ankle osteochondral defects. As the use of OAT becomes more widespread, it is gaining momentum as a treatment option for capitellar OCD.[1–7,18–29] This treatment replaces the defective cartilage and bone with a structural graft that provides osseous support and replaces the full thickness hyaline cartilage with an intact lamina splendens. Early results from this procedure have shown success in reducing pain as well as increasing the range of motion of the affected elbow.[1–7,18–29]

The purpose of this study was to assess the outcomes with respect to pain relief, return to sport, and donor site morbidity of OAT procedures for capitellar OCD lesions in the pediatric population.

MATERIALS AND METHODS

Study design

A retrospective chart review was approved by the institutional review board prior to data collection in 15 patients who, between 2011 and 2016, underwent large-plug OAT at a mean age of 13.7 (range: 10–19, SD: 2.7) years for symptomatic, advanced lesions of capitellar OCD. This was a single surgeon, single tertiary center study.

Preoperative evaluation

Preoperative assessment included a history of symptoms and prior treatment, hand dominance, type, and level of sport participation. Examination evaluated elbow motion, mechanical blocks, pain, and instability. Standard orthogonal elbow radiographs, 45° flexion, and radial head views were evaluated (Fig. 1A). Magnetic resonance images were obtained preoperatively in all patients (Fig. 1B). Patients were indicated for diagnostic arthroscopy with possible OAT procedure if they failed at least 6 months of nonsurgical treatment, which included activity modification and immobilization, had persistent pain, and had unstable lesions visible on magnetic resonance imaging without regard to size.

Operative technique

Patients received general anesthesia and were placed in the lateral decubitus position. A

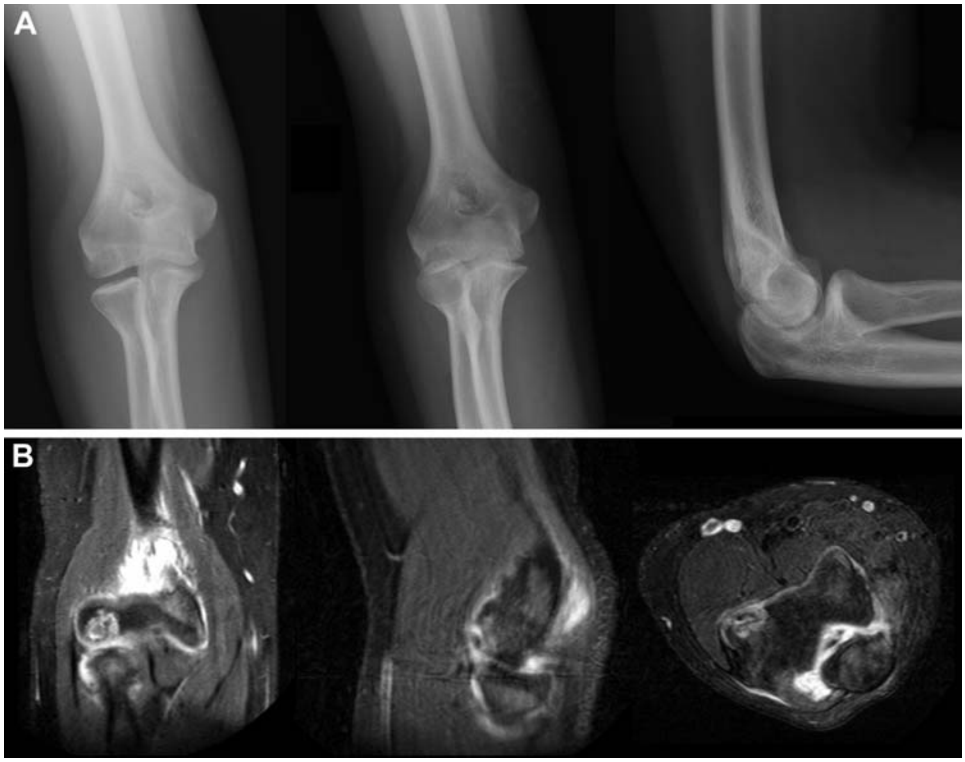

FIGURE 1: **A** Example preoperative anterior-posterior, lateral, and 45° flexion radiographs, demonstrating the capitellar OCD lesion. **B** Representative preoperative coronal, sagittal, and axial T2 fat-saturated magnetic resonance image demonstrating the OCD lesion.

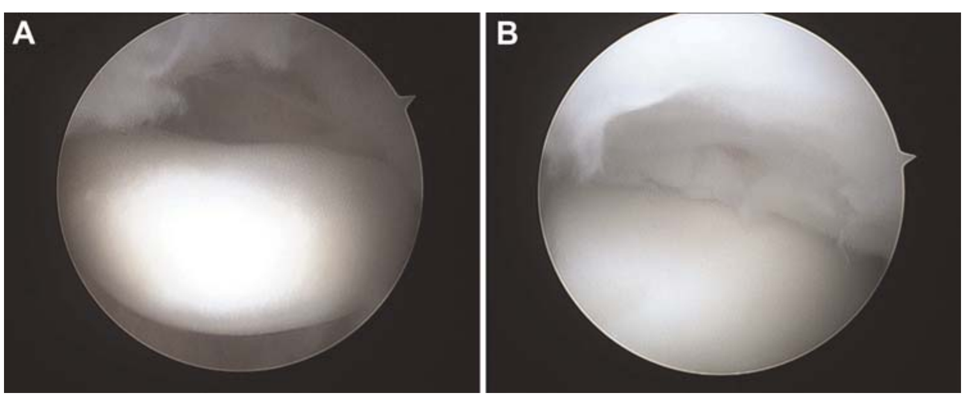

FIGURE 2: **A** A loose body in the lateral gutter identified by arthroscopic examination. **B** After removal, the OCD lesion could be seen in the center of the capitellum.

standard diagnostic elbow arthroscopy was performed under tourniquet. Synovitis and scar tissue were debrided, with the excision of loose bodies (Fig. 2A). The OCD lesion was identified, measured, and checked for stability and subchondral support (Fig. 2B). If the subchondral bone was involved, as seen in all unstable lesions, we proceeded with the OAT technique. Conversion to an arthrotomy was performed by connecting the soft spot portal to the posterolateral portal (Fig. 3A).

The anconeus splitting approach was used, which enabled the direct visualization of the OCD lesion with full elbow flexion. The lesion was then debrided to a stable cartilage rim. Degenerative, sclerotic, and soft bone was debrided with care to avoid the violation of the physis (Fig. 3B). Next, the recipient harvester (Arthrex Osteochondral Autograft Transfer System; Arthrex) was used to harvest the smallest plug size that could resect the entire OCD lesion at the capitellum (Fig. 3C). A minimum depth of 10 mm was taken when possible, using fluoroscopy to avoid physeal violation.

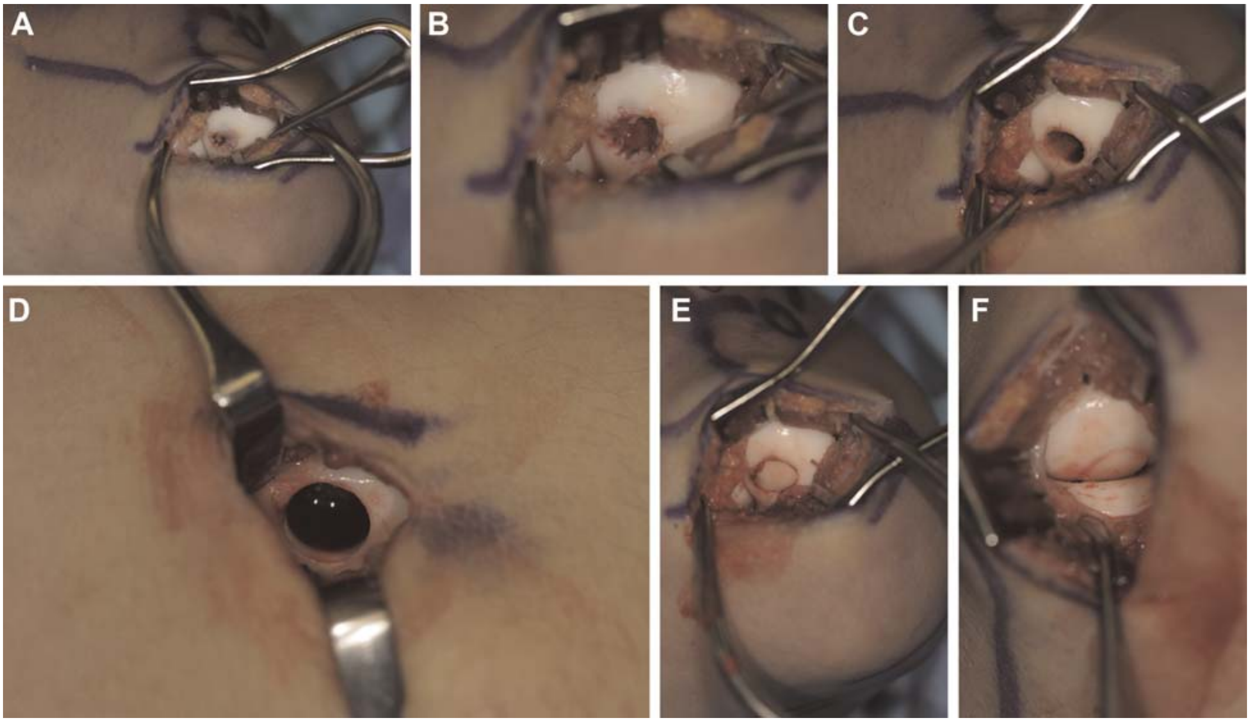

FIGURE 3: **A** An anconeus approach was made for the patient by connecting the posterolateral and soft-sport arthroscopy portals. **B** Debridement of the lesion was used to determine the full extent of the lesion. **C** A plug was removed from the capitellum to resect all affected bone and cartilage. **D** A 1-mm larger plug was then harvested from the superolateral corner of the lateral femoral condyle through a small incision. **E** The donor plug was then press-fit into the capitellar defect, assuring proper contour. **F** The elbow was then taken through a range of motion to confirm congruity and help with the contouring of the graft.

The donor plug was then harvested from the ipsilateral knee (Fig. 3D). A 2-cm anterolateral incision was made just lateral to the superior half of the patella. The retinaculum and capsule were sharply dissected to expose the superolateral aspect of the lateral femoral condyle. An osteochondral plug was harvested (Arthrex Osteochondral Autograft Transfer System; Arthrex) from the non−weight-bearing, superolateral portion of the lateral femoral condyle. The plug defect was filled with a bupivicaine and epinephrine-soaked gelfoam (Pfizer, Inc) or a bone graft substitute.

The harvested osteochondral plug was then press-fit into the prepared recipient site at the elbow, ensuring that the plug was anatomically contoured to the surrounding cartilage (Fig.3E). The elbow was flexed to approximately 45° to contact the radial head against the capitellum to fully seat the osteochondral plug and to check for congruity (Fig. 3F). Once the stability of the plug was confirmed, both the elbow and knee incisions were closed in a standard layered fashion, and the tourniquets were deflated. The knee was placed in a bulky dressing and an immobilizer in full extension. The elbow was immobilized in 45° to 60° of flexion to maintain contact between the radial head and the OAT.

Postoperative protocol

Patients were instructed to remove the knee immobilizer and begin gentle range of motion 2 weeks after surgery. At 4 weeks, the elbows of the patients were placed in an unlocked hinged elbow brace, with self-directed elbow range of motion exercises. Deep knee flexion and squatting was permitted at 6 weeks. By 3 months, patients were cleared for weight bearing and overhead activities, and a return to sports program was initiated with the goal of full participation at 6 months.

Follow-up

Patients were assessed at follow-up for elbow pain, mechanical symptoms, range of motion, elbow stability, and donor site symptoms. All athletes were evaluated for return to sport and level of competition. Follow-up radiographs were obtained.

Statistics

Preoperative and postoperative range of motion was compared using a paired *t* test, with statistical significance set at a value of $P < .05$. All means were reported with SD. We assigned a clinically significant difference of 10°, with an α error of 0.05 and power

TABLE 1. Summary of Results*

No.	Age	Sex	Sport	Level	Return to Sport?	Prior Treatment	Preoperative Elbow ROM	Postoperative Elbow ROM	△ ROM	Lesion Area mm2	No. of OAT Plugs	Reoperations
1	13	M	Swimming	Elite	Yes - Elite	Immobilization	5–145	0–145	5	156	3 (7, 6, and 6 mm)	None
2	10	F	Gymnastics/ Diving	Elite	Yes - Diving elite	Rest	10–120	0–150	40	81	1	Revision arthroscopy, chondral flap excision, and microfracture around OAT plug, which remained the best cartilage of the capitellum.
3	14	M	Farm labor	Rec	Yes	None	25–125	0–135	35	81	1	None
4	11	F	Gymnastics	Elite	Yes - Volleyball elite	Rest, 6 mo; immobilization	0–145	0–140	−5	64	1	None
5	10	F	Gymnastics	Elite	Yes - Elite	Rest, 3 mo; immobilization	5–140	0–150	15	84	2 (7, 5 mm)	None
6	13	F	Nonathlete	N/A	N/A	Rest, physical therapy	5–135	0–135	5	81	1	None
7	14	M	Nonathlete	N/A	N/A	Microfracture and loose body removal	5–135	10–130	−10	64	1	Arthroscopic debridement, olecranon impingement, and cyst deep to plug filled with calcium sulfate hydroxyapatite. Poor appearing cartilage around the OAT plug.

(Continued)

TABLE 1. Summary of Results* (Continued)

No.	Age	Sex	Sport	Level	Return to Sport?	Prior Treatment	Preoperative Elbow ROM	Postoperative Elbow ROM	△ ROM	Lesion Area mm2	No. of OAT Plugs	Reoperations
8	17	M	Basketball	Rec	Yes	Rest, immobilization	30–120	15–145	55	196	3 (6 mm)	None
9	14	M	Baseball, Hockey	Elite	Yes - Only hockey elite	Rest	10–135	5–127	10	196	2 (7 mm)	None
10	14	M	Tennis	Elite	Yes - Elite	Rest, physical therapy	N/A	0–145	N/A	100	1 (10 mm)	None
11	12	M	Basketball	Rec	Yes	Rest, immobilization	10–130	0–135	15	64	1 (8 mm)	None
12	15	M	Baseball	Elite	Yes - Elite	Rest	0–115	0–145	30	49	1 (7 mm)	None
13	17	M	Wrestling	Elite	Yes - Elite	N/A	N/A	0–150	N/A	64	1 (8 mm)	None
14	19	M	Weight lifting	Rec	Yes	Rest	15–140	15–145	20	100	1 (10 mm)	None
15	12	M	Baseball	Elite	Yes - Elite	Rest, immobilization	0–120	–5 to 150	35	81	1 (9 mm)	None

ROM, range of motion; N/A, not applicable; Rec, recreational.
*Full data table available as Appendix A (available on the *Journal's* Web site at www.jhandsurg.org).

TABLE 2. Summary of Preoperative to Postoperative Range of Motion Changes

Measure	Preoperative [range]	Postoperative [range]	SD	P Value	Notes
Flexion contracture (°)	9.2 [0−30]	2.7 [−5 to 15]	5.8	.014	
Passive flexion (°)	131.2 [115−145]	142.7 [130−155]	9.8	.011	
					Mean △ arc range of motion = 19.2
Range of motion arc (°)	121.9 [90−145]	139.1 [120−155]	15.5	.001	

FIGURE 4: Intraoperative photograph demonstrating a second-look anconeus split incision to deal with a new OCD lesion adjacent to the OAT plug. The cartilage of the OAT plug remained healthy, well contoured, and stable.

of 80%. Anticipating a 10° SD, a sample size of 16 patients was required for all parameters measured.

RESULTS

Descriptive statistics

Of the 15 patients (Table 1 and Appendix A [available on the Journal's Web site at www.jhandsurg.org]), none reported acute trauma to their elbow. Mean follow-up duration was 29.5 months (range: 7−64 months, SD: 17.5). Eleven patients were male and 4 were female. No patients were lost to follow-up. Thirteen patients were athletes: 9 were elite level (Olympic hopeful, college recruit, or comparable level competitors) and 4 were recreational. Two patients were non-athletes. The dominant extremity was affected in 9 patients, whereas the nondominant extremity was affected in 4 patients; 2 were unreported. Pain and decreased range of motion were present in all patients preoperatively. Mechanical symptoms, such as popping, locking, and clicking were present in 10 of 15 patients. The average passive preoperative arc of motion was 121.9° (range: 90° to 145°, SD: 15.5), with 131.2° (range: 115° to 145°, SD: 9.8) of flexion and 9.2° (range: 0° to 30°, SD: 9.2) of flexion contracture. All patients underwent a nonsurgical trial of rest and immobilization, and 1 patient underwent prior microfracture surgery. All patients had full elbow flexion and extension strength.

Intraoperative results

The average lesion size determined intraoperatively was 97.4 mm^2 (range: 49−196, SD: 47.0). Loose bodies were present in 7 patients, and there was a synovial plica in 3 patients. A single osteochondral donor plug was used for 11 patients. Two patients required 2 plugs, and 2 patients required 3 plugs. A single plug was used for all lesions that were less than 11 mm in diameter. Within the study period, 2 patients demonstrated healed OCD lesions at the time of arthroscopy and did not require further intervention and were excluded from this study. None of the patients underwent microfracture because all patients demonstrated the involvement of the cartilage and subchondral bone, our criteria for the OAT technique.

Postoperative results

There were no intraoperative or postoperative complications. None of the patients experienced neurologic deficits, infections, or instability. All patients maintained full elbow flexion and extension strength.

All patients improved from surgery (Table 2). All 9 elite athletes returned to sports at an elite level, but only 7 returned to the same level of competition in the same sport. Of the other 2 patients, 1 retired from gymnastics due to the development of new bilateral elbow OCD lesions, bilateral epiphyseolysis of the distal radial physis, and a contralateral knee injury but began diving at an elite, national level, and 1 retired from baseball pitching but continued playing hockey at the same level in order to concentrate on college and semi-professional hockey career. Both patients had lesions more than 1 cm in diameter, requiring multiple plugs. All patients with a single plug returned to their same level at the same sport. Of the 4 recreational athletes, all returned to sport.

Two patients required subsequent surgeries and both underwent revision debridement; one received calcium sulfate hydroxyapatite to backfill a cyst behind a well-healed OAT (Fig. 4) and 1 underwent microfracture surgery in the proximity of the well-healed OAT, removal of loose body, and excision of redundant capsule. For both the patients who underwent revision, the previously placed OAT plug was the best appearing cartilage of the capitellum, with Outerbridge grade 1 damage in the plug and grade 2 in the surrounding visible capitellum. Two patients had symptoms or imaging suggestive of a possible loose body, but upon latest follow-up, they had improved to the point that they declined further treatment due to minimal symptoms. Thirteen of the 15 patients had a complete resolution of pain at final follow-up at an average of 29.5 months postoperatively (range: 7−64, SD: 17.5 months). Donor site knee pain resolved in all patients at an average of 2.3 months (range: 1−6, SD: 1.3), with no residual functional deficits.

DISCUSSION

Smith et al[28] reported success with the debridement of OCD lesions of the capitellum that were less than 1 cm^2 in the short- and mid-term follow-up but suggested that fragment fixation or OAT may be more appropriate for larger lesions, given their poor results with debridement.[28] However, the majority of existing data on OAT come from the Japanese experience with the mosaicplasty technique, which is performed with multiple small (3.5-mm diameter) osteochondral plugs on young baseball players.[7,19,21] In the United States, the patient population is more diverse, with many other sports represented. There is also a bias toward using a single large plug whenever possible.[8,21,30] A recent report by Bae et al[30] using our previously reported technique on the treatment of advanced capitellar OCD lesions with large-plug osteochondral grafts has shown excellent short-term outcomes, with a 100% return to general sports participation after 6 months.[9] Their results are comparable with our results and other published results.[1,2,4−7,18,20−29]

We used a single plug whenever possible (11 of 15 patients), but patients with larger deficits (>1 cm) required multiple plugs. Our results suggest that in the short-term, residual donor site morbidity is low, regardless of whether single or multiple plugs are harvested. A meta-analysis of 5 capitellar OAT studies noted only a single case of mild anterior knee pain associated with stair climbing.[8] Several reports, however, document morbidity in donor knees when used for OAT in other joints.[31−33] Given a lack of long-term data, donor site morbidity remains a concern.

Mirzayan and Lim[23] performed osteochondral allograft transplantation in 9 male baseball players demonstrating excellent clinical outcomes and 100% return to throwing despite 2 reoperations. These authors argue that the risk of donor site morbidity outweighs the theoretically decreased healing potential of allograft transfers, small risk of disease transmission, and increased cost of the graft. Moreover, they experienced hesitation from parents and patients for operating on a healthy knee.[23]

Another alternative that has been described in several small series is the use of costal osteochondral plugs.[6,22,24−26] Although the results are promising, most orthopedic surgeons in the United States are less familiar with operating on the ribs and dealing with the potential complications such as pneumothorax. Furthermore, the hyaline cartilage cap on an osteochondral plug from the ribs is notably thicker than that of the femoral condyle, which usually necessitates the shaving of the superficial layers in order to conform the graft to the remainder of the capitellum.[6,9,26] This results in the removal of the lamina splendens, which is the layer of cartilage most resistant to shear and high tensile forces, raising the question of the long-term durability of costal OAT.[9]

Overall, despite the relatively low patient numbers and no direct comparisons with alternative surgical strategies, OAT for OCD of the capitellum has shown promise. In a meta-analysis comparing debridement with microfracture, fragment fixation, and OAT in capitellar OCDs, patient-reported outcomes and range of motion were similar among groups.[8] Return to sports was significantly better for the OAT technique, with 95% of patients returning to sport and 94% to their previous level compared with 87% and 71% for microfracture, respectively. Fragment fixation had the least favorable outcomes, with 68% of patients returning to sport and 64% to their previous level. The authors of that study postulate that these results reflect the degree to which the diseased tissue is addressed in each procedure, with OAT completely replacing both diseased subchondral bone and hyaline cartilage.

The present study is 1 of the only 3 studies focused on the large-plug technique for the treatment of capitellar OCD lesions in the pediatric population and is unique in that it involves a larger cohort of mostly elite athletes representing a diversity of sports. [20,30] One major limitation of this study is that we did not include validated patient-reported outcome measures. However, there is no validated outcome measure for our patient population as measures of elbow function are either directed at activities of daily living or are only validated for throwing sports.[34] For example, the Disabilities of the Arm, Shoulder, and Hand has been shown by Lyons et al[20] and Hsu et al[35] to have a ceiling effect in this population. The Timmerman/Andrews measure generates an arbitrarily derived score which was used by Bae et al,[30] but has not been assessed for validity, accuracy, precision, or reproducibility.[36] Our data capture all but the edema component of the Timmerman/Andrews measure and additionally report on the outcome of greatest concern to competitive athletes: return to sports. For the 2 non-athletes, their goal was the resolution of pain. The diversity of sports participation could also be considered a limitation as we were not able to evaluate any single sports cohort. Finally, while the majority of our patients required a single plug OAT, there were some that were treated with multiple plugs due to lesion size; our study was not sufficiently powered to determine the difference between these treatments.

Despite these limitations, our results demonstrate that OAT demonstrates excellent clinical and radiographic outcomes as well as a high rate of return to sport, with minimal donor site morbidity. However, not all patients returned to their previous level of sport, indicating that we still have much to learn about the disease process and treatment variations.

REFERENCES

1. Ansah P, Vogt S, Ueblacker P, Martinek V, Woertler K, Imhoff AB. Osteochondral transplantation to treat osteochondral lesions in the elbow. *J Bone Joint Surg Am*. 2007;89(10):2188−2194.
2. Ovesen J, Olsen BS, Johannsen HV. The clinical outcomes of mosaicplasty in the treatment of osteochondritis dissecans of the distal humeral capitellum of young athletes. *J Shoulder Elbow Surg*. 2011;20(5):813−818.
3. Vogt S, Siebenlist S, Hensler D, et al. Osteochondral transplantation in the elbow leads to good clinical and radiologic long-term results: an 8- to 14-year follow-up examination. *Am J Sports Med*. 2011;39(12):2619−2625.
4. Wahegaonkar AL, Doi K, Hattori Y, Addosooki A. Technique of osteochondral autograft transplantation mosaicplasty for capitellar osteochondritis dissecans. *J Hand Surg Am*. 2007;32(9):1454−1461.
5. Yadao MA, Field LD, Savoie FH III. Osteochondritis dissecans of the elbow. *Instr Course Lect*. 2004;53:599−606.
6. Shimada K, Tanaka H, Matsumoto T, et al. Cylindrical costal osteochondral autograft for reconstruction of large defects of the capitellum due to osteochondritis dissecans. *J Bone Joint Surg Am*. 2012;94(11):992−1002.
7. Yamamoto Y, Ishibashi Y, Tsuda E, Sato H, Toh S. Osteochondral autograft transplantation for osteochondritis dissecans of the elbow in juvenile baseball players: minimum 2-year follow-up. *Am J Sports Med*. 2006;34(5):714−720.
8. Westermann RW, Hancock KJ, Buckwalter JA, Kopp B, Glass N, Wolf BR. Return to sport after operative management of osteochondritis dissecans of the capitellum: a systematic review and meta-analysis. *Orthop J Sports Med*. 2016;4(6):2325967116654651.
9. Zlotolow DA, Bae DS. Osteochondral autograft transplantation in the elbow. *J Hand Surg Am*. 2014;39(2):368−372.
10. Brownlow HC, O'Connor-Read LM, Perko M. Arthroscopic treatment of osteochondritis dissecans of the capitellum. *Knee Surg Sports Traumatol Arthrosc*. 2006;14(2):198−202.
11. Bauer M, Jonsson K, Josefsson PO, Lindén B. Osteochondritis dissecans of the elbow. A long-term follow-up study. *Clin Orthop Relat Res*. 1992;284:156−160.
12. Lewine EB, Miller PE, Micheli LJ, Waters PM, Bae DS. Early results of drilling and/or microfracture for Grade IV osteochondritis dissecans of the capitellum. *J Pediatr Orthop*. 2016;36(8):803−809.
13. Tis JE, Edmonds EW, Bastrom T, Chambers HG. Short-term results of arthroscopic treatment of osteochondritis dissecans in skeletally immature patients. *J Pediatr Orthop*. 2012;32(3):226−231.
14. Hennrikus WP, Miller PE, Micheli LJ, Waters PM, Bae DS. Internal fixation of unstable in situ osteochondritis dissecans lesions of the capitellum. *J Pediatr Orthop*. 2015;35(5):467−473.
15. Kuwahata Y, Inoue G. Osteochondritis dissecans of the elbow managed by Herbert screw fixation. *Orthopedics*. 1998;21(4):449−451.
16. Nobuta S, Ogawa K, Sato K, Nakagawa T, Hatori M, Itoi E. Clinical outcome of fragment fixation for osteochondritis dissecans of the elbow. *Ups J Med Sci*. 2008;113(2):201−208.
17. Takeda H, Watarai K, Matsushita T, Saito T, Terashima Y. A surgical treatment for unstable osteochondritis dissecans lesions of the humeral capitellum in adolescent baseball players. *Am J Sports Med*. 2002;30(5):713−717.
18. Kosaka M, Nakase J, Takahashi R, et al. Outcomes and failure factors in surgical treatment for osteochondritis dissecans of the capitellum. *J Pediatr Orthop*. 2013;33(7):719−724.
19. Iwasaki N, Kato H, Ishikawa J, Saitoh S, Minami A. Autologous osteochondral mosaicplasty for capitellar osteochondritis dissecans in teenaged patients. *Am J Sports Med*. 2006;34(8):1233−1239.
20. Lyons ML, Werner BC, Gluck JS, et al. Osteochondral autograft plug transfer for treatment of osteochondritis dissecans of the capitellum in adolescent athletes. *J Shoulder Elbow Surg*. 2015;24(7):1098−1105.
21. 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(9):2122−2127.
22. Mihara K, Suzuki K, Makiuchi D, Nishinaka N, Yamaguchi K, Tsutsui H. Surgical treatment for osteochondritis dissecans of the humeral capitellum. *J Shoulder Elbow Surg*. 2010;19(1):31−37.
23. Mirzayan R, Lim MJ. Fresh osteochondral allograft transplantation for osteochondritis dissecans of the capitellum in baseball players. *J Shoulder Elbow Surg*. 2016;25(11):1839−1847.
24. Oka Y, Ikeda M. Treatment of severe osteochondritis dissecans of the elbow using osteochondral grafts from a rib. *J Bone Joint Surg Br*. 2001;83(5):738−739.
25. Sato K, Mio F, Hosoya T, Ito Y. Two cases with osteochondritis dissecans of the capitulum humeri treated with costal osteochondral graft transplantation. *J Shoulder Elbow Surg*. 2003;12(4):403−407.
26. Sato K, Nakamura T, Toyama Y, Ikegami H. Costal osteochondral grafts for osteochondritis dissecans of the capitulum humeri. *Tech Hand Up Extrem Surg*. 2008;12(2):85−91.
27. Shimada K, Yoshida T, Nakata K, Hamada M, Akita S. Reconstruction with an osteochondral autograft for advanced osteochondritis dissecans of the elbow. *Clin Orthop Relat Res*. 2005;435:140−147.
28. Smith MV, Bedi A, Chen NC. Surgical treatment for osteochondritis dissecans of the capitellum. *Sports Health*. 2012;4(5):425−432.

29. Tsuda E, Ishibashi Y, Sato H, Yamamoto Y, Toh S. Osteochondral autograft transplantation for osteochondritis dissecans of the capitellum in nonthrowing athletes. *Arthroscopy*. 2005;21(10):1270.
30. Bae DS, Ingall EM, Miller PE, Eisenberg K. Early results of single-plug autologous osteochondral grafting for osteochondritis dissecans of the capitellum in adolescents. *J Pediatr Orthop*. 2020;40(2):78−85.
31. LaPrade RF, Botker JC. Donor-site morbidity after osteochondral autograft transfer procedures. *Arthroscopy*. 2004;20(7):e69−e73.
32. Matricali GA, Dereymaeker GP, Luyten FP. Donor site morbidity after articular cartilage repair procedures: a review. *Acta Orthop Belg*. 2010;76(5):669−674.
33. Nakagawa Y, Mukai S, Setoguchi Y, Goto T, Furukawa T, Nakamura T. Clinical outcomes of donor sites after osteochondral graft harvest from healthy knees. *Orthop J Sports Med*. 2017;5(10):2325967117732525.
34. Smith MV, Calfee RP, Baumgarten KM, Brophy RH, Wright RW. Upper extremity-specific measures of disability and outcomes in orthopaedic surgery. *J Bone Joint Surg Am*. 2012;94(3):277−285.
35. Hsu JE, Nacke E, Park MJ, Sennett BJ, Huffman GR. The disabilities of the arm, shoulder, and hand questionnaire in intercollegiate athletes: validity limited by ceiling effect. *J Shoulder Elbow Surg*. 2010;19(3):349−354.
36. Timmerman LA, Andrews JR. Arthroscopic treatment of post-traumatic elbow pain and stiffness. *Am J Sports Med*. 1994;22(2):230−235.

Appendix A

TABLE E1. Raw Data Part A

#	F/u (mo)	Age	Sex	Dominant Hand	Side of Sx	Sport	Sport Level	Return to Sport?	Symptoms	Prior Tx	Op Findings	Lesion Size
1	12	13	M	RHD	R	Swimming	Elite (Olympic trials)	Yes - elite	Pain, locking	Immobilization	OCD	13 × 12 mm
2	63	10	F	RHD	R	Gymnast/diving	Elite (won diving nationals)	Yes - elite	Pain, locking, limited ROM	Rest	OCD + LB	9 × 9 mm
3	25	14	M	RHD	L	Farm labor	Recreational	Yes	Pain, limited ROM, locking, crepitus	Rest	OCD + LB	9 × 9 mm
4	28	11	F	RHD	L	Gymnastics	Elite (Level 7)	Yes - elite Vollyball	Pain	Rest, 6 mos. immobilization	OCD	8 × 8 mm
5	24	10	F	RHD	R	Gymnastics	Elite (Level 7)	Yes - elite	Pain, locking	Rest, 3 mos. immobilization	OCD	7 × 12 mm
6	12	13	F	RHD	R	Nonathlete	N/A	N/A	Pain, locking	Rest, PT	OCD	9 × 9 mm
7	15	14	M	RHD	L	Nonathlete	N/A	N/A	Pain, locking	Microfx and LB removal	OCD + LB + plica	8 × 8 mm
8	7	17	M	LHD (Sports w/ R)	R	Basketball	Recreational	Yes	Pain catching	Rest, immobilization	OCD + LB + phytes	14 × 14 mm
9	64	14	M	RHD	R	Baseball (pitcher), hockey	Elite	Yes - only hockey elite	Pain	Rest	OCD + LB × 3	14 × 14 mm
10	37	14	M	RHD	R	Tennis	Elite	Yes - elite	Pain	Rest, PT	OCD	10 × 10 mm
11	36	12	M	RHD	R	Basketball	Recreational	Yes	Pain, locking	Rest, immobilization	OCD	8 × 8 mm
12	37	15	M	RHD	R	Baseball	Elite (not pitching)	Yes - elite	Pain, locking	Rest	OCD + LB × 4, synovitis	7 × 7 mm
13	40	17	M	N/A	L	Wrestling	Elite	Yes - elite	Pain, limited ROM	Rest	OCD + plica + phytes	8 × 8 mm

(Continued)

TABLE E1. Raw Data Part A (Continued)

#	F/u (mo)	Age	Sex	Dominant Hand	Side of Sx	Sport	Sport Level	Return to Sport?	Symptoms	Prior Tx	Op Findings	Lesion Size
14	11	19	M	N/A	R	Weight lifting	Recreational	Yes	Pain	Rest	OCD + LB + phytes	10 × 10 mm
15	31	12	M	LHD	L	Baseball (pitcher/ fielder)	Elite	Yes - elite	Pain, locking	Rest, immobilization	OCD + plica	9 × 9 mm

LB, loose body; LHD, left hand dominant; N/A, not applicable; OCD, osteochondritis dissecans; PT, physical therapy; RHD, right hand dominant; Rx, medications; Sx, surgery.

TABLE E2. Raw Data Part B

#	Lesion Area mm2	Plug #	Knee Pain Resolution (mo)	Pre op Elbow ROM	Pre op Arc ROM	Pre Op Flex	Pre Op Ext	Post op Elbow ROM	Post op Arc ROM	Post Op Flex	Post Op Ext	△ ROM	Reoperations
1	156	3 (7, 6, 6 mm)	3	5–145	140	145	5	0–145	145	145	0	5	None
2	81	1	1	10–120	110	120	10	0–150	150	150	0	40	Revision elbow arthroscopy, cartilage flap excision, and microfracture of capitellum around prior OATs. Removal of loose bodies with open debridement and excision of redundant capsule for symptoms of locking. Plug appeared to be the best cartilage of the capitellum.
3	81	1	1	25–125	100	125	25	0–135	135	135	0	35	None
4	64	1	1.5	0–145	145	145	0	0–140	140	140	0	-5	None
5	84	2 (7, 5 mm)	1.5	5–140	135	140	5	0–150	150	150	0	15	None
6	81	1	3	5–135	130	135	5	0–135	135	135	0	5	None
7	64	1	2	5–135	130	135	5	10–130	120	130	10	-10	Arthroscopic debridement, olecranon impingement, cyst deep to plug filled with calcium sulfate hydroxyapatite. Poor appearing cartilage around the OAT plug
8	196	3 (6 mm)	3	30–120	90	120	30	15–145	130	145	15	55	None
9	196		1	10–135	125	135	10	5–127	122	135	5	10	None

(Continued)

TABLE E2. Raw Data Part B (Continued)

#	Lesion Area mm2	Plug #	Knee Pain Resolution (mo)	Pre op Elbow ROM	Pre op Arc ROM	Pre Op Flex	Pre Op Ext	Post op Elbow ROM	Post op Arc ROM	Post Op Flex	Post Op Ext	△ ROM	Reoperations
		2 (7 mm)											
10	100	1	6	N/A	N/A	N/A	N/A	0–145	145	145	0	N/A	None
11	64	1	1	10–130	120	130	10	0–135	135	135	0	15	None
12	49	1	2.5	0–115	115	115	0	0–145	145	145	0	30	None
13	64	1	1.5	**N/A**	**N/A**	**N/A**	**N/A**	0–150	150	150	0	N/A	None
14	100	1	2.5	15–140	125	140	15	15–145	130	145	15	20	None
15	81	1	3.25	0–120	120	120	0	-5–150	155	155	-5	35	None

△, change; N/A, not applicable; OATs, osteochondral autograft transplantations; ROM, range of motion.

TABLE E3. Raw Data Part C

Statistics	Follow-up	Age	Sex	HD	Side	Elite Sports	Level	Return to Elite sport	Op Findings in Addition to OCD
AVG	29.5	13.7	M = 11	R = 11	R = 10	Gymnastics (2)	Elite = 8	Yes = 9/9 elite	Loose body (7)
MIN	7	10	F = 4	L = 2	L = 5	Swimming/diving (2)	Recreational = 4		Osteophytes (3)
MAX	64	19		Unlisted = 2	Dom = 9	Baseball (3)	Nonathlete = 2	**Return to Rec Sport**	Plica (3)
SD	17.53					Wrestling (1)		Yes = 4/4	
						Tennis (1)			
						Hockey (1)		**Nonathlete = 2**	
						Recreational			
						Weightlifting (1)			
						Basketball (2)			
						No sport (2)			
						Farmer (1)			

AVG, average; MAX, maximum; MIN, minimum; OCD, osteochondritis dissecans.

TABLE E4. Raw Data Part D

Statistics	Lesion area mm^2	Plug #	knee Pain Resolution (mo)	Pre op Arc ROM	Pre op Flex	Pre op Ext	Post op Arc ROM	Post op Flex	Post op Ext	△ ROM
AVG	97.4	1.4	2.3	121.9	131.2	9.2	139.1	142.7	2.7	19.2
MIN	49	1	1	90	115	0	120	130	-5	-10
MAX	196	3	6	145	145	30	155	155	15	55
SD	47.01945		1.332961258	15.4837			10.649391			

△, change; AVG, average; MAX, maximum; MIN, minimum; ROM, range of motion.