

## Osteochondral transplantation in the elbow leads to good clinical and radiologic long-term results: an 8- to 14-year follow-up examination

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# Osteochondral Transplantation in the Elbow Leads to Good Clinical and Radiologic Long-term Results

## An 8- to 14-Year Follow-up Examination

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**Background:** In the long-term follow-up after debridement, microfracture, or drilling of osteochondral lesions in the elbow, subsequent osteoarthritis is a problem. Osteochondral transplantation for these defects has become a more common procedure. However, long-term results are unknown.

**Purpose:** This study was undertaken to evaluate long-term clinical and radiologic outcomes of advanced osteochondral lesions in the elbow treated with osteochondral transplantation.

**Study Design:** Case series; Level of evidence, 4.

**Methods:** The study included 8 patients with osteochondral lesions in the elbow who were treated by autologous osteochondral transplantation between 1996 and 2002. Patients (average age, 17 years) were evaluated pre- and postoperatively by Broberg-Morrey score to assess elbow function and by American Shoulder and Elbow Surgeons (ASES) score for pain analysis. In addition, radiographs (at the first postoperative day, and at 5-year and 10-year follow-up) and magnetic resonance images (8 to 12 weeks postoperatively, and at 5-year and 10-year follow-up) were made to evaluate the joint status. At last follow-up (range, 8-14 years postoperatively), 7 of 8 patients were seen for clinical examination and radiologic analysis.

**Results:** The Broberg-Morrey score increased from an average of  $75.9 \pm 13.1$  to  $96.4 \pm 2.4$  and ASES score significantly improved as follows: worst pain,  $7.9 \pm 1.1$  to  $1.6 \pm 1.9$ ; rest pain,  $3.14 \pm 2.7$  to  $0.6 \pm 1.5$ ; weight-lifting pain,  $7.6 \pm 0.8$  to  $3.1 \pm 1.6$ ; and repetitive movement pain,  $5.3 \pm 2.4$  to  $1.6 \pm 1.5$ . Compared with the contralateral side, there was a mean preoperative flexion lag of  $12.5^\circ \pm 11.6^\circ$ . At the final follow-up, flexion was free. The mean extension lag was reduced from average  $5.4^\circ \pm 5.7^\circ$  to  $0^\circ$ . Radiographs of 2 patients made at final follow-up showed mild signs of osteoarthritis (Kellgren and Lawrence grade I). Postoperative magnetic resonance images showed graft viability in all and a congruent chondral surface in 6 of 7 patients.

**Conclusion:** Clinical long-term results after osteochondral transplantation in the elbow are good to excellent and comparable with midterm results in the literature. Therefore, this technique is a reliable option for satisfactory long-term results regarding treatment of advanced osteochondral lesions in the elbow.

**Keywords:** osteochondral lesion; osteoarthritis; osteochondral transplantation; elbow

Osteochondral lesions mainly affect adolescent and young adult athletes engaged in repetitive overhead and upper

extremity weightbearing activities. Often, these lesions are found in the humeral capitellum of teenaged baseball players.<sup>16,45</sup> Different mechanisms have been discussed for pathogenesis of osteochondral lesions in the elbow.<sup>1,4,5,10,25,32,35,39</sup> In particular the repetitive compression by valgus extension overload is considered the main cause leading to osteochondral lesions of the capitellum.<sup>4,32</sup>

Early stages of osteochondral lesions in the elbow are usually managed nonoperatively, and good clinical results can be expected.<sup>42</sup> Lesions in patients with open growth plates are classified as stable if elbow mobility is good. In contrast, lesions in patients after epiphyseal plate closure are classified as unstable if elbow mobility is poor.<sup>41</sup> The lack of response to nonoperative treatment and the separation or fragmentation of the osteochondral lesion are generally

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TABLE 1  
Patients With Osteochondral Lesions in the Elbow<sup>a</sup>

Patient	Age, y	Defect	Side	Dominant Side	Level of Sports		Graft Size, mm	Broberg-Morrey Pre/Post	ASES Worst Pre/Post	ASES Rest Pre/Post	ASES WL Pre/Post	ASES Repet Pre/Post	Lysholm Pre/Post	Follow-up, y
					Before Treatment	After Treatment								
1	15	Capitellum	R	R	Tennis (recreational)	Tennis (recreational)	10	76/95	6/2	2/0	8/4	4/2	100/100	14
2 <sup>b</sup>	21	Capitellum	L	R	Basketball (competitive)	Basketball (competitive)	11	79/100	5/2	1/0	5/0	3/0	100/100	7
3	15	Capitellum	L	R	Skiing (competitive)	Mountain infantry	9	87/100	8/0	2/0	8/0	8/0	100/100	11
4	15	Radial head	R	R	Tennis (competitive)	Tennis (competitive)	10	48/100	9/5	4/0	6/4	7/4	100/100	9
5	18	Capitellum	L	R	Gymnastics (competitive)	Gymnastics (competitive)	11	79/95	8/3	1/0	8/5	8/3	100/100	9
6	15	Trochlea	R	R	Volleyball (recreational)	Volleyball (recreational)	9	78/95	9/0	8/0	8/3	5/1	100/70	9
7	19	Capitellum	R	R	Soccer goalkeeper (competitive)	Body building	9	76/95	8/0	0/0	8/3	2/0	100/89	8
8	16	Capitellum	L	R	Volleyball (recreational)	Volleyball (recreational)	9	87/95	7/1	5/0	7/3	3/1	100/70	8

<sup>a</sup>Pre/Post, preoperative/postoperative; ASES, American Shoulder and Elbow Surgeons pain scores; WL, weight-lifting (pain); repet, repetitive movement.

<sup>b</sup>Patient was not able to evaluate clinically at the 10-year follow-up (2010); last follow-up for this patient was 7 years postoperative.

classified as indications for surgical therapy. Diverse surgical techniques have been described in the past including removal of free fragments, drilling, abrasion arthroplasty, closed-wedge osteotomy, and reattachment of the fragments.<sup>18,24,26,34,36,43</sup> Nevertheless, debridement procedures in particular often lead to insufficient clinical results and show a high risk of subsequent osteoarthritis.<sup>6,9</sup>

In the last several years, the autologous osteochondral transplantation method was introduced for treatment of advanced osteochondral lesions in the elbow.<sup>3,19,20,28,45</sup> In the present study, autologous osteochondral transplantation was performed in stage III or IV lesions according to the system of Dipaola et al.<sup>13,30</sup> Short-term to midterm results of this surgical technique in the elbow were encouraging in several studies, showing both good to excellent clinical results and no or less increase in degenerative radiologic changes.<sup>3,19,20,45</sup> However, no clinical results with an average follow-up of more than 5 years are reported in the literature. It was shown in the glenohumeral joint that in the long-term follow-up after osteochondral transplantation, degenerative changes increased.<sup>23</sup> This is one concern in the treatment of osteochondral lesions in the elbow. Another concern is possible donor-site morbidity in the long-term follow-up,<sup>33</sup> whereas after up to 5 years postoperatively, this was not a problem.<sup>3,21,31</sup>

The purpose of this study was to evaluate the clinical and radiologic long-term results of patients with advanced osteochondral lesions in the elbow treated by autologous osteochondral transplantation.

## MATERIALS AND METHODS

### Patients

Eight patients with advanced osteochondral lesions in the elbow, including the capitellum humeri (n = 6), the trochlea

(n = 1), and the radial head (n = 1), who were treated by autologous osteochondral transplantation between 1996 and 2002 were evaluated (Table 1). There were 4 women and 4 men with an average age of 17 years (range, 15-21 years) at the time of surgery. Affected were 4 left and 4 right elbows; all patients were right-hand dominant. Five patients were actively engaged in competitive sports (basketball, skiing, tennis, gymnastics, soccer). Two patients were playing volleyball and 1 was playing tennis at a recreational level. All patients had preoperative radiographs and MRI showing stage III or IV lesions classified by the staging system of Dipaola et al.<sup>13</sup> Six patients had failure of nonoperative treatment after more than 6 months, with consistent pain and functional elbow restrictions in activities of daily living. In 2 patients, previous surgeries had failed (refixation of a loose fragment in 1 patient and arthroscopic debridement in another). In the present study, the indications for osteochondral transplantation in the elbow were an unsuccessful nonoperative treatment longer than 6 months or failed previous surgery in combination with an osteochondral defect grade III (breached articular cartilage, high-signal T2 changes behind fragment) or IV (loose body with defect of articular surface) in the elbow according to the classification system of Dipaola et al.<sup>13</sup>

### Operative Technique

Surgery was performed in all patients by the senior author (A.B.I.). The operative technique was described previously. Briefly, the patient was positioned supine on the operating table under general anesthesia. A tourniquet was placed on the affected upper arm. Mostly, a lateral approach with a longitudinal incision extending from the lateral epicondyle along the radial head and the anconeus muscle was used. The fascia was split between the anconeus and

extensor carpi ulnaris muscles. The joint capsule was exposed and then longitudinally incised anterior to the radial head. The annular ligament was preserved. A proximal release (with later repair) of the lateral collateral ligament was necessary to access lesions that were centrally located in the capitellum or in the radial head. In the case of a dorsal capitellum lesion, a dorsoradial approach was used and for an anterior capitellum lesion, an anterolateral approach was used. Usually the defect was well exposed in full elbow extension. However, for dorsal capitellum lesions, the exposure was better in flexion. The size of the lesion was measured and the defect was excised as a cylindrical bone plug, with use of a special device (Osteochondral Autograft Transfer System [OATS], Arthrex, Naples, Florida). Subsequently, an osteochondral cylindrical donor graft was harvested from the non-weightbearing area<sup>2,3</sup> of the proximal lateral femoral condyle of the ipsilateral knee through a small lateral parapatellar arthrotomy. The obtained cylinder of appropriate depth was then transplanted and press-fit into the recipient site of the elbow. Because of different cartilage thicknesses between knee<sup>11,14</sup> and elbow joints,<sup>40</sup> it was important to consider this for the implantation of the osteochondral graft to achieve cartilage congruity. As a result, both the subchondral bone of graft and host were often not congruent.

### Postoperative Management

The postoperative regimen involved free passive range of elbow motion, emphasizing full flexion and extension for 2 weeks, and then active range of motion was free. Weightbearing or lifting of heavy loads was restricted for at least 6 weeks. Weightbearing on the knee was allowed as tolerated.

### EVALUATION

Eight patients were evaluated at an average follow-up of 10 years (range, 8-14 years) after surgery. One patient (patient 2) was only evaluated by a telephone call at the 10-year follow-up. He was not willing to come for clinical examination and radiologic analysis at this time. Seven of 8 patients were seen pre- and postoperatively in the outpatient clinic at last follow-up. For the study evaluation, personal interviews and physical examinations were carried out by an independent investigator not involved in the patients' initial surgical management. The examination included the range of motion of the elbow, the assessment of Broberg-Morrey scores for functional outcome, and patient self-evaluation of American Shoulder and Elbow Surgeons (ASES) scores for analysis of pain. The ipsilateral knee was additionally examined for donor-site morbidity (Lysholm score). Follow-up radiographs were taken on the first postoperative day and at 5-year follow-up and at 10-year follow-up; an MRI scan was acquired 8 to 12 weeks postoperatively, at the 5-year follow-up (exception at 5-year follow-up: patient 1), and at 10-year follow-up evaluation (exception at 10-year follow-up: patient 2) to control

ingrowth, positioning, viability of the transplanted graft, and degenerative changes.<sup>27</sup>

### Statistical Analysis

Statistical analysis was performed using a paired *t* test to determine the effect of osteochondral transplantation for the treatment of osteochondral lesions in the elbow on objective and subjective scores. Significance was set at  $P < .05$ .

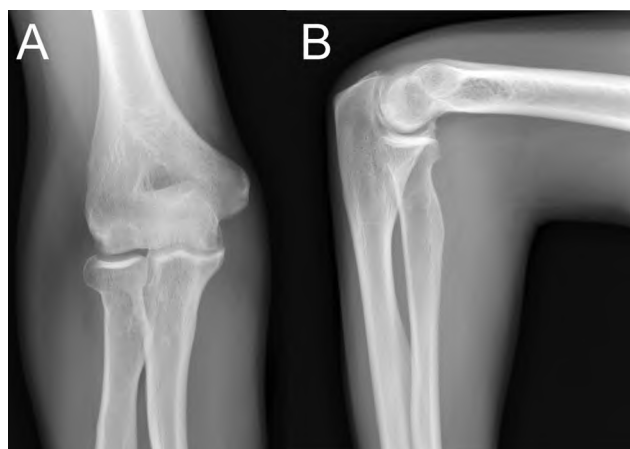
### RESULTS

Seven patients returned for evaluation after an average follow-up of 10 years (range, 8-14 years). One patient (patient 2; Table 1) could only be evaluated by a telephone call. He was completely free of symptoms in the treated elbow and the donor knee. The clinical and radiologic outcomes are summarized in Tables 1 and 2. The average diameter of the defect was  $9.9 \pm 1.0$  mm (range, 9-11 mm). In every case, the transplantation of 1 autologous osteochondral cylinder was sufficient to cover the defect. At the final follow-up visit, the extension lag was reduced from  $5.4^\circ \pm 5.7^\circ$  (range,  $0^\circ$ - $15^\circ$  preoperatively) to  $0^\circ$  postoperatively; flexion was increased by  $12.5^\circ \pm 11.6^\circ$  (range,  $0^\circ$ - $30^\circ$ ) and was equal to the contralateral side in all patients. The Broberg-Morrey score increased significantly from preoperative  $75.9 \pm 13.1$  to  $96.4 \pm 2.4$  ( $P < .0091$ ) and pain was significantly reduced measured by the ASES score (worst pain,  $7.9 \pm 1.1$  to  $1.6 \pm 1.9$ ,  $P < .0001$ ; rest pain,  $3.14 \pm 2.7$  to  $0.6 \pm 1.5$ ,  $P < .0298$ ; weight-lifting pain,  $7.6 \pm 0.8$  to  $3.1 \pm 1.6$ ,  $P < .0004$ ; repetitive movement pain,  $5.3 \pm 2.4$  to  $1.6 \pm 1.5$ ,  $P < .0026$ ). In radiographs of patients 1 and 3 taken at the 10-year follow-up visit, minimal signs of osteoarthritis were detected; the radiographs of all other patients were without any degenerative changes (Figures 1 and 2). In patient 3, small osteolytic lesions and cortical irregularities at the lateral (radial) condyle were seen. In patient 1, very small cortical irregularities of the lateral (radial) condyle were detected. There was no joint narrowing in radiographs of any patient. In addition, according to the staging system of Kellgren and Lawrence,<sup>22</sup> the grade of osteoarthritis was analyzed. Radiographs of patients 1 and 3 showed grade I osteoarthritis. In every patient, the last MRI showed graft viability and full integration of the transplant (Figure 3). A slightly incongruent chondral surface was seen in 1 patient (patient 1; Table 1, Figure 4). In 3 patients (patients 1, 3, and 6), subchondral cysts were seen (Table 2) and in 2 of them (patients 3 and 6), an additional subchondral edema was seen. In patients 1 and 3, cartilage lesions of the capitellum and in patients 1, 3, 4, and 7 cartilage lesions of the radius were seen on MRI. These lesions were detected by an increase of the cartilage T2 signal. In addition, in patient 3, there was a partial-thickness defect of transplanted cartilage (Noyes score II<sup>15</sup>). However, because of different cartilage thicknesses in the elbow and knee joint, it is difficult to detect a partial-thickness defect. Therefore, it is necessary to analyze cartilage quality in MRI at different time points. In comparison with previous MRI analyses (8-12 weeks and

TABLE 2  
Radiologic Results of MRI and Radiograph Imaging at 10-Year Follow-up Visit<sup>a</sup>

Patient	Integration	Vitality	Incongruency	Cysts	Edema	Noyes Score Capitellum/ Trochlea, 0-IV	Noyes Score Radius, 0-IV	Osteoarthritis Kellgren- Lawrence, 0-IV
1	Complete	Complete	Yes	Yes	No	I	I	I
2	X	X	X	X	X	X	X	X
3	Complete	Complete	No	Yes	Yes	II	I	I
4	Complete	Complete	No	No	No	0	I	0
5	Complete	Complete	No	No	No	0	0	0
6	Complete	Complete	No	Yes	Yes	0	0	0
7	Complete	Complete	No	No	No	0	I	0
8	Complete	Complete	No	No	No	0	0	0

<sup>a</sup>X indicates no radiologic examination at 10-year follow-up (2010).



**Figure 1.** Postoperative radiographs, AP (A) and lateral (B), of the right elbow in patient 1 showing minimal degenerative changes 14 years after osteochondral transplantation in the capitellum.



**Figure 2.** Postoperative radiographs, AP (A) and lateral (B), of the left elbow in patient 3 showing minimal signs of osteoarthritis 11 years after osteochondral transplantation in the capitellum. Arrow indicates a loose body.

5 years postoperatively), there was a detectable loss of cartilage thickness only in patient 3.

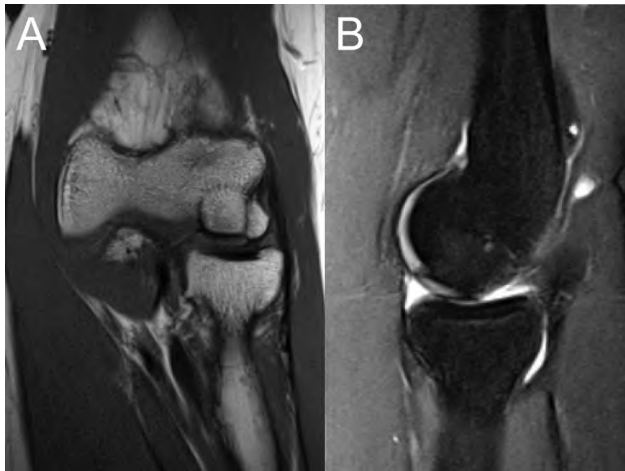
No additional surgical procedure was necessary in any patient. All patients returned to sports without limitations. However, 2 of the 8 changed discipline and activity level, not because of the clinical outcome but because of their age and work requirements. Three patients complained casually about mild pain in the donor knee at the 10-year follow-up visit. The Lysholm score for the donor knee was  $89.9 \pm 14.14$  (range, 70-100) at this time. All patients were satisfied and would undergo the same procedure again.

## DISCUSSION

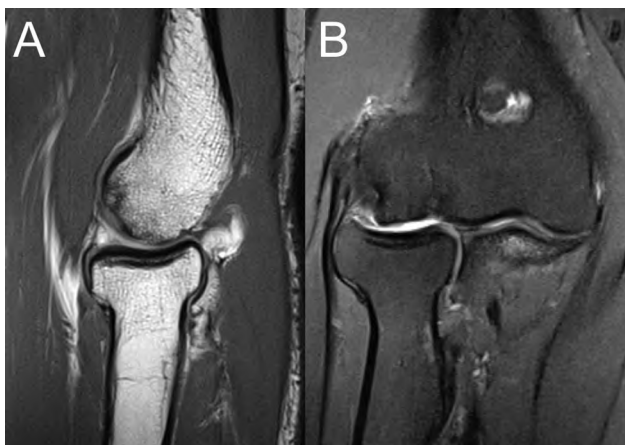
The clinical results (Broberg-Morrey and ASES scores) of the current study were good to excellent after osteochondral transplantation in the elbow at 10-year follow-up (range, 8-14 years). In MRI, all transplants were viable and integrated and there were only minimal signs of

osteoarthritis in radiographs of 2 patients. An incongruent chondral surface was seen in 1 patient. Small subchondral cysts were found in 3 patients and subchondral edema in 2 patients. However, these radiologic findings did not correlate with clinical results. For example, the clinically "worst" patient had the "best" radiographs and MRI. These results are comparable with those of a current published study for osteochondral transplantation in the talus. Imhoff et al<sup>17</sup> detected cysts of the subchondral bone, similar to our patients, without any correlation to clinical outcomes.

Osteochondral lesions in early stages in young patients often heal with nonoperative treatment.<sup>42</sup> If nonoperative treatment fails,<sup>3,41</sup> patients can have persistent pain and reduced range of motion because of the presence of loose bodies in the joint and surgical intervention may become necessary. Sometimes loose fragments can be reattached.<sup>26</sup> Several treatment options have been described, such as



**Figure 3.** Postoperative MRI scans, T1 coronal (A) and T2 sagittal (B), of the left elbow in patient 5 taken 9 years after osteochondral transplantation in the capitellum. MRI shows graft viability and a congruent chondral surface, and no detection of subchondral cysts or bone edema.



**Figure 4.** Postoperative MRI scans, T1 sagittal (A) and T2 coronal (B), of the right elbow in patient 1 taken 14 years after osteochondral transplantation in the capitellum. MRI shows graft viability and a slight incongruent surface, and detected a subchondral cyst in the transplanted graft.

debridement, microfracture, or drilling of the defect to induce replacement tissue.<sup>7-9,36</sup> Overall long-term results of these methods are not satisfying. Bauer et al<sup>6</sup> reported more than 50% of patients with reduced range of motion, radiologic signs of osteoarthritis, and increase of the radial head diameter. Brownlow et al<sup>9</sup> reported in 2006 about 29 patients with osteochondral defects of the capitellum and arthroscopic debridement. After 77 months, the majority of patients had mild or no pain. However, 38% had recurrence of locking or catching. Radiographs of 18 patients with mild or moderate tenderness over the capitellum identified evidence of flattening of the capitellum in 12

patients, degenerative changes in 6 patients, and loose bodies in 5 patients.

Short- to medium-term follow-up studies of osteochondral transplantation in the elbow have shown overall good to excellent clinical and radiologic results. In 2001, Nakagawa et al<sup>29</sup> reported on osteochondral grafting and arthroplasty in 1 case with end-stage osteochondritis dissecans achieving a good result at a follow-up of 35 months. Yamamoto et al<sup>45</sup> described an osteochondral autograft transplantation for osteochondritis dissecans in the elbow in juvenile baseball players who had a good outcome after a minimum 2-year follow-up interval. In addition, Tsuda et al<sup>44</sup> reported a successful outcome in a series of non-throwing athletes but with a short follow-up. In our previously published study,<sup>3</sup> in which we reported on patients 2 through 8 of the present case series, radiographs documented no increase of radial head diameter or development of osteoarthritis. The postoperative MRI showed graft viability in all cases. In MRI and radiographs, there were no signs of osteoarthritis. All patients returned to free range of motion and full weightbearing. Even though they returned to sports without limitation, 2 of 7 changed discipline and level. This was not caused by the clinical outcome of the surgical procedure but because of their age and work requirements.

To our knowledge, a long-term follow-up of osteochondral transplantation in the elbow has not been published in the literature. Kircher et al<sup>23</sup> reported an increase in degenerative changes in the glenohumeral joint 9 years after autologous osteochondral transplantation in contrast to their first examination after 3 years.<sup>38</sup> However, the clinical results were good.

The present study has some limitations, including the small number of patients. Furthermore, this study did not involve baseball players. Osteochondral lesions of the capitellum are often found in teenaged baseball players. Because of higher loading and impact to the elbow joint,<sup>16,32</sup> the outcomes of patients playing baseball might be different from nonthrowing athletes as reported in our series.

It is possible that metabolic differences of chondrocytes in the elbow and knee exist, because these differences were already found in different regions of a single joint (eg, the knee<sup>37</sup>). However, until now there is no proof of differences between the elbow and knee regarding chondrocyte metabolism. Such differences may influence the long-term survival of the transplanted cartilage.

An obvious disadvantage of the described procedure is the necessity to expose the knee joint. After a mean follow-up of 5 years, no patient complained about knee pain or functional problems. In contrast, after a mean follow-up of 10 years, 3 patients had sometimes mild knee pain and a decreased Lysholm score compared with preoperative levels (without additional trauma). Our results for the Lysholm score ( $89.9 \pm 14.14$ ) are slightly unfavorable when compared with normal subjects. Demirdjian et al<sup>12</sup> administered the Lysholm score to a normal population consisting of 418 individuals with an average age of 17.6 years. For male participants, the Lysholm score

was on average 99.1, and for females it was 97.2. However, 8 to 14 years postoperatively, there could be also age- or work-related reasons for a declined Lysholm score (body-builder, patient 7; waitress, patients 6 and 8).

## CONCLUSION

The transplantation of autologous osteochondral cylinders provides the opportunity to repair advanced osteochondral lesions with hyaline cartilage and to restore the subchondral bone. The clinical long-term results are particularly encouraging, although mild signs of osteoarthritis were detected in 2 patients. Compared with other surgical techniques like microfracture or debridement in the literature, clinical results are better and degenerative changes are less in our patients.

## REFERENCES

- Adams JE. Injury to the throwing arm. A study of traumatic changes in the elbow joints of boy baseball players. *Calif Med*. 1965;102:127-132.
- Ahmad CS, Cohen ZA, Levine WN, Ateshian GA, Mow VC. Biomechanical and topographic considerations for autologous osteochondral grafting in the knee. *Am J Sports Med*. 2001;29(2):201-206.
- 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.
- Azar FM, Andrews JR, Wilk KE, Groh D. Operative treatment of ulnar collateral ligament injuries of the elbow in athletes. *Am J Sports Med*. 2000;28(1):16-23.
- Barnes DA, Tullos HS. An analysis of 100 symptomatic baseball players. *Am J Sports Med*. 1978;6(2):62-67.
- Bauer M, Jonsson K, Josefsson PO, Linden B. Osteochondritis dissecans of the elbow. A long-term follow-up study. *Clin Orthop Relat Res*. 1992;284:156-160.
- Baumgarten TE, Andrews JR, Satterwhite YE. The arthroscopic classification and treatment of osteochondritis dissecans of the capitellum. *Am J Sports Med*. 1998;26(4):520-523.
- Bradley JP, Petrie RS. Osteochondritis dissecans of the humeral capitellum: diagnosis and treatment. *Clin Sports Med*. 2001;20(3):565-590.
- 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.
- Campbell CJ, Ranawat CS. Osteochondritis dissecans: the question of etiology. *J Trauma*. 1966;6(2):201-221.
- Cohen ZA, McCarthy DM, Kwak SD, et al. Knee cartilage topography, thickness, and contact areas from MRI: in-vitro calibration and in-vivo measurements. *Osteoarthritis Cartilage*. 1999;7(1):95-109.
- Demirdjian AM, Petrie SG, Guanche CA, Thomas KA. The outcomes of two knee scoring questionnaires in a normal population. *Am J Sports Med*. 1998;26(1):46-51.
- Dipaola JD, Nelson DW, Colville MR. Characterizing osteochondral lesions by magnetic resonance imaging. *Arthroscopy*. 1991;7(1):101-104.
- Eckstein F, Muller S, Faber SC, Englmeier KH, Reiser M, Putz R. Side differences of knee joint cartilage volume, thickness, and surface area, and correlation with lower limb dominance—an MRI-based study. *Osteoarthritis Cartilage*. 2002;10(12):914-921.
- Gold GE, Chen CA, Koo S, Hargreaves BA, Bangerter NK. Recent advances in MRI of articular cartilage. *AJR Am J Roentgenol*. 2009;193(3):628-638.
- Harada M, Takahara M, Mura N, Sasaki J, Ito T, Ogino T. Risk factors for elbow injuries among young baseball players. *J Shoulder Elbow Surg*. 2010;19(4):502-507.
- Imhoff AB, Paul J, Ottinger B, et al. Osteochondral transplantation of the talus: long-term clinical and magnetic resonance imaging evaluation. *Am J Sports Med*. 2011;39(7):1487-1493.
- Inoue G. Bilateral osteochondritis dissecans of the elbow treated by Herbert screw fixation. *Br J Sports Med*. 1991;25(3):142-144.
- Iwasaki N, Kato H, Ishikawa J, Masuko T, Funakoshi T, Minami A. Autologous osteochondral mosaicplasty for osteochondritis dissecans of the elbow in teenage athletes. *J Bone Joint Surg Am*. 2009;91(10):2359-2366.
- 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.
- Iwasaki N, Kato H, Kamishima T, Suenaga N, Minami A. Donor site evaluation after autologous osteochondral mosaicplasty for cartilaginous lesions of the elbow joint. *Am J Sports Med*. 2007;35(12):2096-2100.
- Kellgren JH, Lawrence JS. Radiological assessment of osteoarthrosis. *Ann Rheum Dis*. 1957;16(4):494-502.
- Kircher J, Patzer T, Magosch P, Lichtenberg S, Habermeyer P. Osteochondral autologous transplantation for the treatment of full-thickness cartilage defects of the shoulder: results at nine years. *J Bone Joint Surg Br*. 2009;91(4):499-503.
- Kiyoshige Y, Takagi M, Yuasa K, Hamasaki M. Closed-wedge osteotomy for osteochondritis dissecans of the capitellum: a 7- to 12-year follow-up. *Am J Sports Med*. 2000;28(4):534-537.
- Kusumi T, Ishibashi Y, Tsuda E, et al. Osteochondritis dissecans of the elbow: histopathological assessment of the articular cartilage and subchondral bone with emphasis on their damage and repair. *Pathol Int*. 2006;56(10):604-612.
- Kuwahata Y, Inoue G. Osteochondritis dissecans of the elbow managed by Herbert screw fixation. *Orthopedics*. 1998;21(4):449-451.
- Link TM, Mischung J, Wortler K, Burkart A, Rummeny EJ, Imhoff AB. Normal and pathological MR findings in osteochondral autografts with longitudinal follow-up. *Eur Radiol*. 2006;16(1):88-96.
- Miyamoto W, Yamamoto S, Kii R, Uchio Y. Oblique osteochondral plugs transplantation technique for osteochondritis dissecans of the elbow joint. *Knee Surg Sports Traumatol Arthrosc*. 2009;17(2):204-208.
- Nakagawa Y, Matsusue Y, Ikeda N, Asada Y, Nakamura T. Osteochondral grafting and arthroplasty for end-stage osteochondritis dissecans of the capitellum: a case report and review of the literature. *Am J Sports Med*. 2001;29(5):650-655.
- Nelson DW, DiPaola J, Colville M, Schmidgall J. Osteochondritis dissecans of the talus and knee: prospective comparison of MR and arthroscopic classifications. *J Comput Assist Tomogr*. 1990;14(5):804-808.
- Nishimura A, Morita A, Fukuda A, Kato K, Sudo A. Functional recovery of the donor knee after autologous osteochondral transplantation for capitellar osteochondritis dissecans. *Am J Sports Med*. 2011;39(4):838-842.
- Pappas AM, Zawacki RM, Sullivan TJ. Biomechanics of baseball pitching: a preliminary report. *Am J Sports Med*. 1985;13(4):216-222.
- Paul J, Sagstetter A, Kriner M, Imhoff AB, Spang J, Hinterwimmer S. Donor-site morbidity after osteochondral autologous transplantation for lesions of the talus. *J Bone Joint Surg Am*. 2009;91(7):1683-1688.
- Peterson RK, Savoie FH 3rd, Field LD. Osteochondritis dissecans of the elbow. *Instr Course Lect*. 1999;48:393-398.
- Petrie PW. Aetiology of osteochondritis dissecans. Failure to establish a familial background. *J Bone Joint Surg Br*. 1977;59(3):366-367.
- Ruch DS, Cory JW, Poehling GG. The arthroscopic management of osteochondritis dissecans of the adolescent elbow. *Arthroscopy*. 1998;14(8):797-803.
- Salzmann GM, Buchberger MS, Stoddart MJ, et al. Varying regional topology within knee articular chondrocytes under simulated in vivo conditions. *Tissue Eng Part A*. 2011;17(3-4):451-461.
- Scheibel M, Bartl C, Magosch P, Lichtenberg S, Habermeyer P. Osteochondral autologous transplantation for the treatment of

- full-thickness articular cartilage defects of the shoulder. *J Bone Joint Surg Br.* 2004;86(7):991-997.
39. Schenck RC Jr, Athanasiou KA, Constantinides G, Gomez E. A biomechanical analysis of articular cartilage of the human elbow and a potential relationship to osteochondritis dissecans. *Clin Orthop Relat Res.* 1994;299:305-312.
40. Springer V, Graichen H, Stammberger T, Englmeier KH, Reiser M, Eckstein F. Noninvasive analysis of cartilage volume and cartilage thickness in the human elbow joint using MRI [in German]. *Ann Anat.* 1998;180(4):331-338.
41. Takahara M, Mura N, Sasaki J, Harada M, Ogino T. Classification, treatment, and outcome of osteochondritis dissecans of the humeral capitellum. *J Bone Joint Surg Am.* 2007;89(6):1205-1214.
42. 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(6):728-732.
43. Takahara M, Ogino T, Sasaki I, Kato H, Minami A, Kaneda K. Long term outcome of osteochondritis dissecans of the humeral capitellum. *Clin Orthop Relat Res.* 1999;363:108-115.
44. 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.
45. 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.