Comprehensive Elbow Joint Morphology Changes in Surgically Treated Osteochondritis Dissecans of the Capitellum

Clinical Implications

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Background: Capitellar osteochondritis dissecans (OCD) frequently results in radial head enlargement. However, due to the elbow joint's complex anatomy, deformities likely extend beyond just the radial head.

Hypothesis/Purpose: It was hypothesized that in patients with OCD treated with surgery, imbalances in bone morphology during growth would affect the entire joint, leading to postoperative clinical symptoms. The purpose of this study was to test this hypothesis through a 3-dimensional evaluation of morphological changes.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: After retrospective identification, this study enrolled 47 patients who had undergone surgery, with a mean postoperative follow-up of 6.8 years. After in-person evaluation and bilateral computed tomography scanning, 3-dimensional bone models of the affected and contralateral elbows were created. The bone morphology of the radial head, the distal humerus, and the proximal ulna at the anatomic points were evaluated and compared between affected and contralateral sides. These measurements were correlated with clinical symptoms, and risk factors for these changes were identified.

Results: The mean age at examination was 20.6 ± 3.3 years and at surgery was 13.9 ± 1.3 years, with a mean follow-up of 6.8 ± 3.2 years. In the radial head, morphological enlargement was observed for radioulnar diameter (26.3 ± 1.9 vs 22.9 ± 1.5 mm; $P < .001$) and dorsovolar diameter (26.5 ± 1.9 vs 24.2 ± 1.5 mm; $P < .001$). In the humeral trochlea, enlargement was noted at the lateral trochlea (28.2 ± 1.7 vs 25.0 ± 1.3 mm; $P < .001$), trochlear groove (20.4 ± 1.7 vs 17.9 ± 1.6 mm; $P < .001$), and medial trochlea (30.5 ± 2.1 vs 25.5 ± 1.6 mm; $P < .001$) as well as the ulnar trochlear notch (28.2 ± 1.7 vs 25.0 ± 1.3 mm; $P < .001$). Restricted elbow flexion was associated with radial head enlargement in radioulnar and dorsovolar diameters ($R = 0.60$, $P < .001$; $R = 0.44$, $P = .002$). Lesion size was identified as a risk factor for these changes (odds ratio [OR], 1.36; $P = .019$), as was development of OCD during skeletal growth (OR, 0.82; $P = .006$).

Conclusion: Over mid- to long-term follow-up, the entire elbow joint underwent cylindrical-like morphological changes, leading to restricted motion. Enlargement typically developed during skeletal growth, with larger lesions resulting in more severe enlargement. Awareness of these natural postoperative changes is crucial, and it is clinically important to provide appropriate treatment during skeletal growth when treating OCD.

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Osteochondritis dissecans (OCD) of the capitellum is commonly observed in young athletes engaged in throwing sports such as baseball and weightbearing athletics such as gymnastics during their skeletal immaturity.[4,12,16,18,25] A relatively favorable course has been reported with appropriate surgical intervention, but a subset of patients still experience residual local pain and minor limitations in motion postoperatively.[1,13,15,22]

Capitellar OCD frequently exhibits enlargement of the radial head.[2,24] However, given the complex anatomic structure of the elbow joint, it is unlikely that deformities would be limited solely to the radial head. Instead, it is plausible that imbalances in bone morphology lead to alterations throughout the entire joint during growth. To date, no comprehensive investigation has been conducted regarding morphological changes throughout the elbow joint, nor has the relationship between these changes and clinical symptoms been elucidated. Understanding the postoperative natural history of these changes would provide valuable information for surgeons.

We hypothesized that imbalances in bone morphology during growth would affect the entire joint, leading to postoperative clinical symptoms. Therefore, in patients treated surgically for capitellar OCD who had medium- to long-term follow-up, this study aimed to clarify the morphological changes throughout the entire joint and their association with functional outcomes. Our specific aims were as follows:

1. Conduct a 3-dimensional (3D) evaluation of bone morphological changes throughout the elbow joint, comparing these changes with the contralateral side.
2. Investigate the effect of these morphological changes on postoperative clinical symptoms.
3. Identify the risk factors associated with the morphological changes.

METHODS

Study Setting

This study was conducted for patients with surgically treated capitellar OCD. We identified patients retrospectively for enrollment and invited them to return for clinical and radiographic evaluation. Institutional review board approval was obtained before study initiation. Written informed consent was obtained from all study participants.

Patient Enrollment

A total of 299 consecutive patients who were surgically treated for capitellar OCD between January 2002 and March 2022 were identified retrospectively through medical chart review. Patients were included if they had undergone surgery at least 3 years before the date of enrollment; 77 patients who did not meet this criterion were excluded. Of the remaining 222 patients, telephone interviews were conducted to screen for the absence of additional treatment or trauma to the elbows, and 48 patients agreed to participate. After 1 patient without sufficient quality of computed tomography (CT) data was excluded, 47 patients were ultimately enrolled in the study and underwent in-person evaluation and bilateral CT scan (Figure 1).

Patient Clinical Data Collection

At the time of the in-person evaluation and CT scanning, patients completed questionnaires regarding demographic characteristics and patient-reported outcome measures, including the Quick Disabilities of the Arm, Shoulder and Hand (QuickDASH) score, the Timmerman-Andrews score,[21] and the Patient-Rated Elbow Evaluation–Japanese version (PREE-J).[3,6,17] The current and preoperative demographic information included age, sex, height, weight, body mass index, dominant limb, sporting activity, and the age at which the sporting activity was started. Data on current and preoperative sporting activities were collected and categorized as baseball (pitcher and fielder) and weightbearing and nonweightbearing sports.

During the same evaluation session, patients were evaluated for physical conditions by a single experienced elbow surgeon with >10 years of practice. The presence of capitellar tenderness was recorded, and valgus or varus elbow stability was manually evaluated and graded on a 3-point scale: stable, moderately unstable, or grossly unstable.

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Ethical approval for this study was obtained from Japan Community Health Care Organization, Osaka Hospital (Approval No. 2021-015).

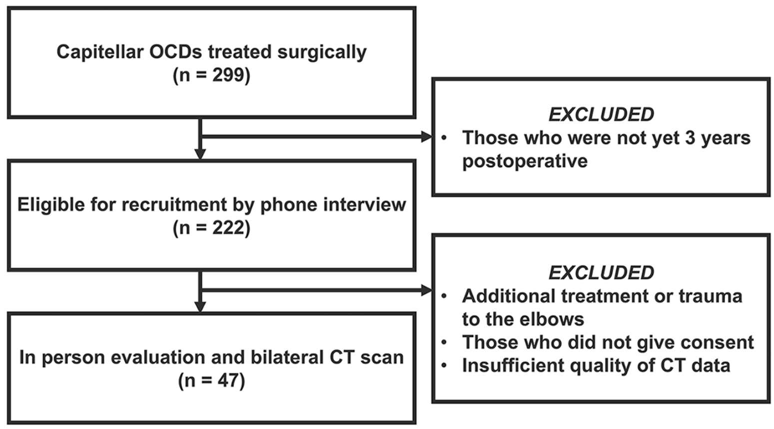

Figure 1. Flowchart of patient enrollment. CT, computed tomography; OCD, osteochondritis dissecans.

Additional information was collected regarding the presence of shoulder and wrist symptoms. Elbow (flexion/extension) and forearm (supination/pronation) ranges of motion on both operative and nonoperative sides were measured using a goniometer. Elbow motions were assessed with the forearm in the supinated position, whereas forearm motions were measured with the elbow in 90° of flexion. Grip strength was measured on both sides. The Mayo Elbow Performance Score (MEPS)[11] was also calculated.

Surgical Intervention and Related Outcomes

The decision to reconstruct the articular surface of the capitellum or to perform osteosynthesis or debride the lesion was based on intraoperative findings.[19,20] If the OCD lesion was stable, classified as International Cartilage Regeneration & Joint Preservation Society (ICRS) class I or II, osteosynthesis was performed using bone peg fixation, typically with a 20-mm cortical graft harvested from the ipsilateral olecranon. For unstable OCD lesions, classified as ICRS class III or IV, the specific procedure varied according to the diameter of the lesion: arthroscopic debridement with bone marrow stimulation was performed for lesions <10 mm; capitellar reconstruction using an anconeus muscle–pedicle bone graft with periosteal coverage was performed for lesions 10 to 15 mm; and capitellar reconstruction using an osteochondral autograft with costal cartilage was performed for lesions >15 mm.

The intraoperative findings for maximum diameter of the OCD lesion and ICRS grade were collected. Plain radiographic findings at the time of primary surgery were also collected, including lateral wall involvement and the status of the physis (open/closed). Patients were asked whether they were able to return to the same sport and when they were able to fully return to sporting activities. The information regarding the return to sporting activities was originally recorded based on the medical records at that time and was double-checked during this evaluation. Also, patients rated their satisfaction with treatment as very satisfied, satisfied, neither satisfied nor dissatisfied, dissatisfied, or very dissatisfied on a questionnaire.

3D CT Model Reconstruction

Patients underwent bilateral CT scanning, and 3D models were created for the postoperative morphological evaluation described below. A helical CT scanner (Revolution CT; GE Healthcare) was used to scan the full length of the upper limbs at full extension of the elbows and forearms maintained in supination. We used a low radiation–dose technique (slice thickness, 1.25 mm; pixel size, 0.75-0.85 mm; scan time, 0.5 s; scan pitch, 0.562:1; tube current, 20-150 mA; tube voltage, 120 kV), with a total dosage of 0.2 mSv per scan.[14] Digital data were saved and analyzed. The 3D surface models of bilateral humerus, ulna, and radius were created by a semiautomatic segmenting technique using image processing MvIndex/Bone Simulator software (Teijin Nakashima Medical).

Morphological Evaluation

The 3D models of the affected side and those of the mirror image of the contralateral side were used for analyses (Figure 2).[7-10] The affected models were superimposed onto mirrored contralateral models by using the parts other than the elbow joint as a reference, with a surface-based registration technique using an iterative closest point algorithm. In that position, anatomic planes and axes for contralateral sides were defined to measure the morphology of both the sides. All of the measurements were uniquely determined parameters as they were computer-generated, and they were normalized by the height of the individuals.

In the distal humerus, the circles were approximated to the lateral verge of the capitellum and medial verge of the trochlea, and the axis passing the centers of the circles was determined as the flexion-extension axis.[5] The axial plane was defined as the plane perpendicular to the plane that goes through the flexion-extension axis and passes the midpoint between the bottoms of the coronoid and

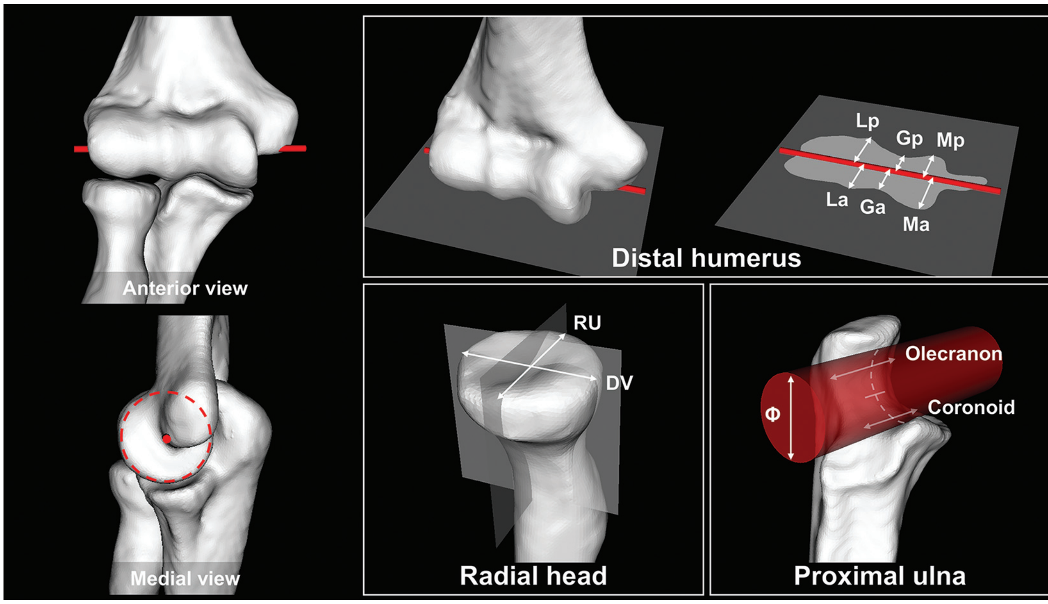

Figure 2. Schematic illustrations of the regions of interest. Measurement values represent the sum of the minimum interval distances for the anterior and posterior portions. DV, dorsovolar diameter; Ga + Gp, trochlear groove; La + Lp, lateral trochlea; Ma + Mp, medial trochlea; RU, radioulnar diameter; Φ, diameter of the cylinder.

olecranon fossae. By automatically measuring a minimum interval distance from the axis in the axial plane, we evaluated the bony size at the lateral trochlea, the trochlear groove, and the medial trochlea from measurements for the anterior and posterior portions.

In the radial head, the axis was defined by connecting the center of the dish of the radial head and the apex of the distal radial styloid. The plane, including this axis, was determined at the midpoint between the volar and dorsal rims of the sigmoid notch of the distal radius in the radioulnar direction. The radioulnar and dorsovolar diameters of the radial head were measured in this plane and in the plane perpendicular to this plane, respectively.

In the proximal ulna, a cylinder was computationally created in an automatic fashion according to morphological characteristics, which approximated the shape of the ulnar trochlear notch. The articular surface of the trochlear notch was divided into quadrants from the tips of the coronoid and olecranon, and the transverse diameters at the midpoint of the coronoid and olecranon were measured. The diameter of the cylinder (Φ) was also measured.

Statistical Analysis

JMP Pro Version 17.0 (SAS Institute Inc) was used to perform the statistical analyses. Significance was set to $P < .05$ for all tests.

The morphological measurements of the radial head, distal humerus, and proximal ulna and the elbow and forearm ranges of motion were compared between affected and contralateral sides using the Wilcoxon signed-rank test, adjusting for multiple comparisons with a Bonferroni correction.

To assess the correlations of the morphological changes with elbow motions, we determined Spearman correlation coefficient (R) between flexion and extension restriction angles and the differences in measurements of the radial head, distal humerus, and proximal ulna. Correlation strength was classified as slight ($R < 0.2$), low ($0.2 \leq R < 0.4$), moderate ($0.4 \leq R < 0.7$), or high ($R \geq 0.7$).

To identify factors associated with morphological enlargement, we binarized the current cohort based on the severity of the enlargement. We used the hierarchical clustering approach using the Wald method to identify clusters exhibiting similar morphological enlargement across the elbow joint. Based on the results, 47 patients were categorized into 2 groups: the severe enlargement group (n = 22) and the mild enlargement group (n = 25) (Figure 3). We then performed a bivariate analysis using the Mann-Whitney U test or Pearson chi-square test, followed by a multivariable logistic regression analysis to determine the independent association of explanatory variables with the development of the morphological changes. Explanatory variables with a $P < .10$ in the bivariate analysis were entered into the multivariable analysis, controlling multicollinearity.

RESULTS

Patient Characteristics

The patient data are presented in Table 1. All patients were male. The mean age at the examination was 20.6 ±

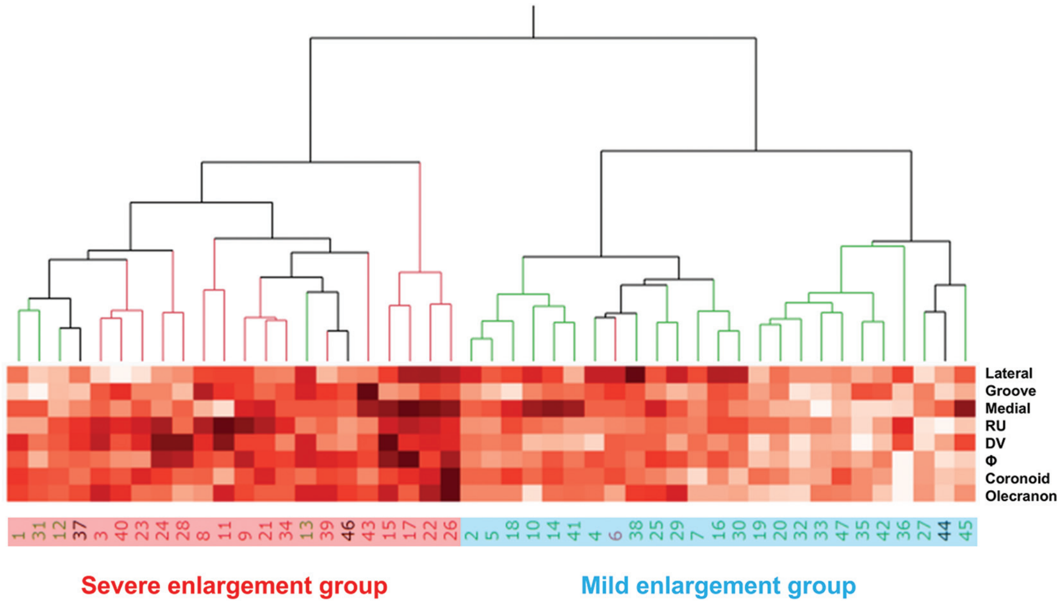

Figure 3. Hierarchical cluster analysis for all measurements in the radial head, distal humerus, and proximal ulna. A hierarchical clustering approach binarizes the severe enlargement group (red) and mild enlargement group (blue). DV, dorsovolar; RU, radioulnar; Φ, diameter of the cylinder.

TABLE 1
Patient Data (N = 47)[a]

Variables	At Evaluation	At Primary Surgery
Demographic characteristics		
Postoperative follow-up, y	6.8 ± 3.2	
Age, y	20.6 ± 3.3	13.9 ± 1.3
Sex		
Male	47 (100)	
Female	0 (0)	
Height, m	1.74 ± 0.07	1.69 ± 0.07
Weight, kg	71.7 ± 12.7	60.9 ± 10.0
Body mass index, kg/m^2	23.8 ± 4.1	21.3 ± 2.9
OCD on dominant limb	43 (91)	
Age at starting sport, y	8.2 ± 1.6	
Sporting activities		
Baseball	23 (49)	40 (85)
Pitcher	—	22 (47)
Fielder	—	18 (38)
Weightbearing	5 (11)	3 (6)
Nonweightbearing	20 (43)	4 (9)
Physical findings		
Complaints		
None	23 (49)	
Elbow pain	9 (19)	
Restricted motion	3 (6)	
Nonspecific complaints	12 (26)	
Capitellar tenderness	7 (15)	
Elbow joint stability		
Stable	47 (100)	
Moderately unstable	0 (0)	
Grossly unstable	0 (0)	

(continued)

TABLE 1
(continued)

Variables	At Evaluation	At Primary Surgery
Range of motion, affected/contralateral, deg		
Elbow		
Flexion	132.6 ± 6.5/140.4 ± 4.0	
Extension	–3.0 ± 5.5/1.9 ± 3.4	
Forearm		
Supination	86.9 ± 4.4/87.9 ± 3.1	
Pronation	80.4 ± 6.6/83.0 ± 4.4	
Shoulder symptoms	0 (0)	
Wrist symptoms	0 (0)	
Grip strength, affected/contralateral, kg	40.9 ± 6.9/41.9 ± 7.0	
Surgery-related factors		
Procedures		
Osteochondral autograft transplant	21 (45)	
Anconeus muscle–pedicle bone grafting	12 (26)	
Bone peg fixation	4 (9)	
Arthroscopic debridement	10 (21)	
Size, maximum diameter, mm	14.0 ± 2.8	
Lateral wall involvement	33 (70)	
Open physis of the humerus	29 (62)	
ICRS OCD grade		
II	4 (9)	
III	18 (38)	
IV	22 (47)	
Unknown	3 (6)	
Time to full return to sport, mo	6.5 ± 2.5	
Satisfaction with surgery		
Very satisfied	33 (70)	
Satisfied	10 (21)	
Neither satisfied nor dissatisfied	4 (9)	
Dissatisfied	0 (0)	
Very dissatisfied	0 (0)	
Functional scores/patient-reported outcome measures		
MEPS, points	93.3 ± 12.2	
QuickDASH, points	6.7 ± 7.9	
Timmerman-Andrews score, points	181.5 ± 15.2	
PREE-J, points	5.9 ± 8.7	

[a]Data are expressed as mean ± SD or n (%). ICRS, International Cartilage Regeneration & Joint Preservation Society; MEPS, Mayo Elbow Performance Score; OCD, osteochondritis dissecans; PREE-J, Patient-Rated Elbow Evaluation–Japanese version; QuickDASH, Quick Disabilities of the Arm, Shoulder and Hand.

3.3 years and that at primary surgery was 13.9 ± 1.3 years, with a mean postoperative follow-up period of 6.8 ± 3.2 years. The primary sport was baseball for 40 patients (85%); weightbearing sports including gymnastics and throwing sports other than baseball, such as softball, for 3 patients (6%); and nonweightbearing sports for 4 patients (9%). The mean age at starting sport was 8.2 ± 1.6 years. At the evaluation, 23 patients (49%) did not have any complaints for their elbow, 9 patients (19%) had elbow pain, 3 patients (6%) reported restricted elbow motion, and 12 patients (26%) had nonspecific complaints, including catching sensations, discomfort after lifting heavy objects, or discomfort after use. The mean range of elbow flexion was 132.6° ± 6.5° on the affected side and 140.4° ± 4.0° on the contralateral side ($P < .001$). The mean range of elbow extension was −3.0° ± 5.5° on the affected side and 1.9° ± 3.4° on the contralateral side ($P < .001$). The mean ranges of forearm motion did not show any statistical difference in supination (86.9° ± 4.4° vs 87.9 ± 3.1°; $P = .575$) or pronation (80.4° ± 6.6° vs 83.0° ± 4.4°; $P = .058$) for the affected versus the contralateral side, respectively. The primary surgery included osteochondral autograft transplant in 21 patients (45%), anconeus muscle–pedicle bone grafting in 12 patients (26%), bone peg fixation in 4 patients (9%), and arthroscopic debridement in 10 patients (21%). The OCD lesions had a mean diameter of 14.0 ± 2.8 mm and were classified as ICRS grade II in 4 patients (9%), grade III in 18 patients (38%), and grade IV in 22 patients (47%). In total, 62% of patients had an open physis of the humerus at the time

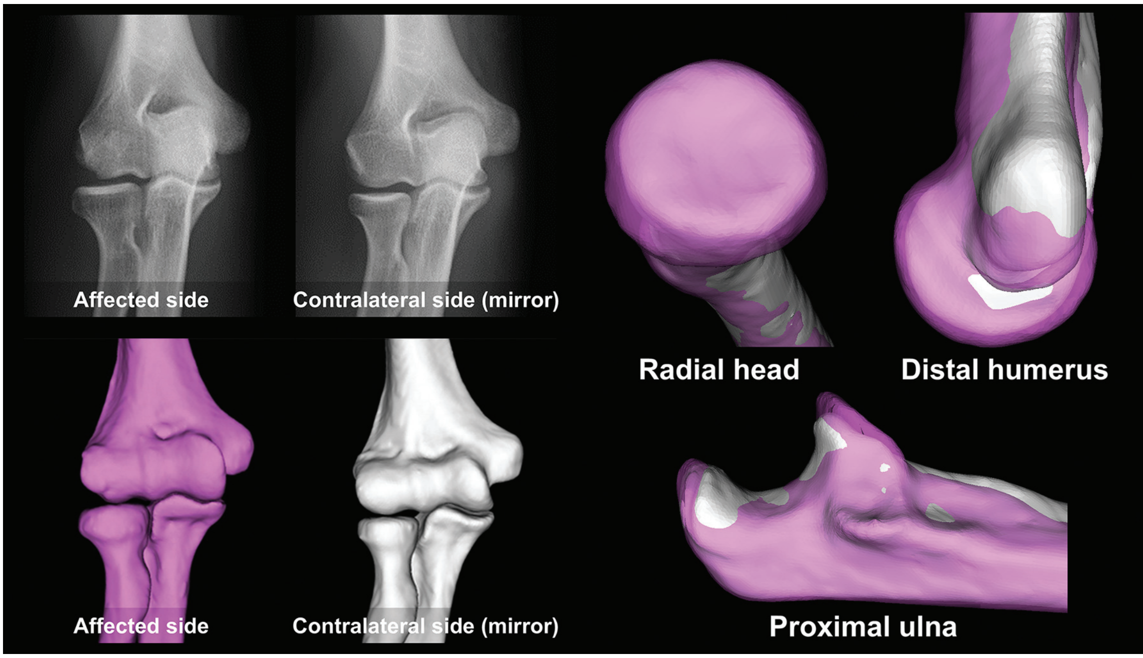

Figure 4. 3D morphologies of the elbow joint.

of surgery. We noted that 36 patients (77%) were able to return to same sport, and the mean time to full return to sport was 6.5 ± 2.5 months.

Morphology Analysis

In the radial head, the measurements for the affected side were greater than those of the contralateral side for radioulnar diameter (26.3 ± 1.9 vs 22.9 ± 1.5 mm; $P < .001$) and dorsovolar diameter (26.5 ± 1.9 vs 24.2 ± 1.5 mm; $P < .001$). In the distal humerus, the measurements for the affected side were greater than those of the contralateral side at the lateral trochlea (28.2 ± 1.7 vs 25.0 ± 1.3 mm; $P < .001$), the trochlear groove (20.4 ± 1.7 vs 17.9 ± 1.6 mm; $P < .001$), and the medial trochlea (30.5 ± 2.1 vs 25.5 ± 1.6 mm; $P < .001$). In the proximal ulna, the measurements for the affected side were greater than those of the contralateral side for Φ (28.2 ± 1.7 vs 25.0 ± 1.3 mm; $P < .001$), the coronoid (20.4 ± 1.7 vs 17.9 ± 1.6 mm; $P < .001$), and the olecranon (30.5 ± 2.1 vs 25.5 ± 1.6 mm; $P < .001$) (Figure 4 and Table 2).

Correlation Analysis

In flexion motion, differences in radioulnar and dorsovolar diameters of the radial head were moderately correlated with elbow flexion restriction (R = 0.60 and $P < .001$; R = 0.44 and P = .002, respectively). In extension motion, differences in measurements of the coronoid and the olecranon showed moderate to low correlation with the elbow extension restriction (R = 0.40 and P = .006; R = 0.35, and P = .017) (Table 3).

TABLE 2
Comparison of Morphological Measurements[a]

Variable	Affected Side (n = 47)	Contralateral Side (n = 47)	*P*
Radial head			
Radioulnar	26.3 ± 1.9	22.9 ± 1.5	**<.001**
Dorsovolar	26.5 ± 1.9	24.2 ± 1.5	**<.001**
Distal humerus			
Lateral trochlea	28.2 ± 1.7	25.0 ± 1.3	**<.001**
Trochlear groove	20.4 ± 1.7	17.9 ± 1.6	**<.001**
Medial trochlea	30.5 ± 2.1	25.5 ± 1.6	**<.001**
Proxima ulna			
Φ	11.8 ± 1.1	9.9 ± 0.9	**<.001**
Coronoid	24.8 ± 3.0	22.6 ± 1.9	**<.001**
Olecranon	25.9 ± 2.7	22.3 ± 1.5	**<.001**

[a]Data are expressed in millimeters as mean ± SD. Data were normalized by the height of the individuals. Bold type indicates significant *P* values ($P < .05$). Φ, diameter of the cylinder.

Factors Associated With Bony Enlargement

Demographic and surgery-related variables for patients who developed bony enlargement and those who did not are shown in Table 4. To control for multicollinearity between highly correlated variables, we excluded age at surgery, focusing on the amount of height gained between the time of primary surgery and the CT scan/evaluation. Variables with a P value <.10, including height increase and OCD lesion size, were included in the multivariable analysis. An increase in height (odds ratio [OR], 0.82; P = .006) and OCD size (OR, 1.36; P = .019) were independently associated with development of bony enlargement (Table 5).

TABLE 3
Correlation Analysis[a]

Variable	Flexion Restriction		Extension Restriction	
	R	*P*	*R*	*P*
Radial head				
Radioulnar	0.60	**<.001**	0.23	.118
Dorsovolar	0.44	**.002**	0.13	.372
Distal humerus				
Lateral trochlea	0.23	.117	0.09	.546
Trochlear groove	0.10	.489	–0.13	.387
Medial trochlea	0.11	.460	–0.07	.627
Proximal ulna				
Φ	–0.02	.899	–0.08	.614
Coronoid	0.10	.524	0.40	**.006**
Olecranon	0.02	.891	0.35	**.017**

[a]Bold type indicates significant *P* values ($P < .05$). Φ, diameter of the cylinder.

DISCUSSION

This study investigated bone morphological changes in 47 cases of OCD surgery over the midterm to long term, examining the correlation with clinical symptoms and risk factors for these changes. Results showed enlargement not only in the radial head but also in the humeral trochlea and ulnar trochlear notch, indicating that the entire elbow joint morphologically changes like a cylinder. These changes were associated with flexion-extension range limitations, and lesion size was also identified as a risk factor. Additionally, developing OCD during skeletal growth may pose a risk for these morphological changes.

Although radial head enlargement associated with OCD has been previously recognized,[2,24] the current study is the first to reveal morphological enlargement in the humeroulnar joint (humeral trochlea and ulnar trochlea). Although radial head changes are easily captured on radiographs, these changes at the humeroulnar joint are not as easily detected, possibly contributing to their underrecognition.

The current findings showed that the entire elbow joint undergoes cylindrical-like morphological changes. Possible

TABLE 4
Bivariate Analysis[a]

Variable	Severe Enlargement Group (n = 22)	Mild Enlargement Group (n = 25)	*P*
Demographic characteristics			
Age at surgery, y	14.2 ± 1.2	13.4 ± 1.3	**.041**
Follow-up, y	6.4 ± 3.4	7.1 ± 2.7	.126
Increase in height, cm	4.7 ± 3.4	9.1 ± 7.1	**.049**
Sporting activities			.754
Baseball (pitcher)	10 (45)	12 (48)	
Baseball (fielder)	9 (41)	11 (44)	
Weightbearing	1 (5)	0 (0)	
Nonweightbearing	3 (9)	2 (8)	
Sporting activities after returning			.258
Baseball (pitcher)	0 (0)	3 (12)	
Baseball (fielder)	14 (64)	16 (64)	
Weightbearing	1 (5)	0 (0)	
Nonweightbearing	7 (32)	6 (24)	
Age at starting sport, y	8.1 ± 1.6	8.3 ± 1.6	.613
Surgery-related factors			
Procedures			.364
Osteochondral autograft transplant	9 (41)	12 (48)	
Anconeus muscle–pedicle bone grafting	8 (36)	4 (16)	
Bone peg fixation	2 (9)	2 (8)	
Arthroscopic debridement	3 (14)	7 (28)	
Size, maximum diameter, mm	14.8 ± 3.1	13.3 ± 2.2	**.097**
Lateral wall involvement	13 (59)	20 (80)	.118
Open physis of the humerus	13 (60)	16 (64)	.730
ICRS OCD grade			.649
II	1 (5)	3 (12)	
III	8 (40)	10 (42)	
IV	11 (55)	11 (46)	
Unknown	2 (9)	1 (4)	
Time to full return to sport, mo	5.7 ± 2.1	6.8 ± 3.0	.425

[a]Data are expressed as mean ± SD or n (%). Bold type indicates significant *P* values ($P < .10$). ICRS, International Cartilage Regeneration & Joint Preservation Society; OCD, osteochondritis dissecans.

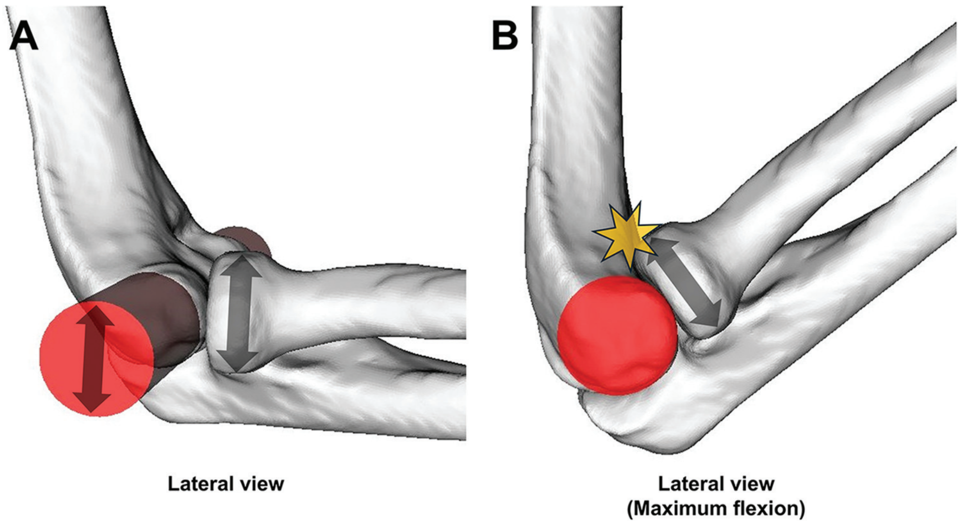

Figure 5. 3D illustrations showing (A) cylindrical enlargement of the elbow bones and (B) collision at the maximum flexion position.

TABLE 5
Multivariable Logistic Regression Analysis[a]

Variable	Odds Ratio	95% CI	*P*
Increase in height	0.82	0.70-0.97	**.006**
Size, maximum diameter	1.36	1.02-1.80	**.019**

[a]Bold type indicates significant p values ($P < .05$).

causes of this enlargement include a biological reaction due to incongruity of the radiocapitellar joint or hyperplasia induced by mechanical stimulation. Interestingly, cylindrical changes were observed beyond the radiocapitellar joint onto the ulnar side (Figure 5A). This suggests that the enlargement of the radial head expanded the flexion arc and that the diameter of the humeral trochlear and ulnar trochlear notch subsequently expanded to adapt to this change. Another possibility is that hypertrophy of the entire elbow may have occurred due to response to surgical trauma and repetitive loading stress during throwing, with valgus instability possibly playing a role as well.

Radial head enlargement showed a significant correlation with flexion range of motion. These enlarged regions likely cause impingement during flexion, leading to a restriction in flexion range of motion (Figure 5B). Additionally, extension range limitations were correlated with the widening of the trochlea. It is likely that trochlear width is associated with osteoarthritic changes, reflecting extension limitations due to joint incongruity. The expansion of the trochlear diameter is considered a hypertrophic change, whereas the increase in trochlear width likely reflects the formation of osteophytes, which are characteristic of a throwing elbow. Generally, OCD surgery does not result in significant functional impairment, as evidenced by favorable QuickDASH scores in this cohort. One possible explanation for this is the adaptation to joint congruency that occurs during skeletal growth. Another possibility is that the motion limitations may be attributed to factors other than bony deformities, such as soft tissue problems. Alternatively, the amount of motion loss may not restrict performance. However, given these correlation results, it is possible that these bone morphological changes accompanied by bony impingement may progress to osteoarthritis over the long term, and some of the cases already exhibited degeneration and functional impairments. Surgeons should be aware of this potential progression of degenerative changes in the postoperative elbow, and careful follow-up is essential when arthritic changes are identified.

Multivariate logistic regression analysis identified limited height growth, or postgrowth phase, as a risk factor for enlargement. This is likely due to the joint incongruity caused by OCD persisting through skeletal growth. Conversely, if the radiocapitellar joint is reconstructed surgically and the patient can go through skeletal growth in a proper loading environment, deformation may be prevented. This supports the concept that in patients with larger OCD lesions, capitellar articulation should be reconstructed. In addition, lesion size was identified as a risk factor for enlargement, emphasizing the importance of early detection of OCD to prevent subsequent deformities. Another implication is that it may be advisable to pursue nonoperative treatment to reduce the lesion size before proceeding with surgical interventions.

Limitations

Our study has several limitations. First, we analyzed data only from patients who underwent surgery. As a result, a possible contradiction arises: less height growth correlates with more morphological changes, despite earlier OCD diagnosis being associated with greater remodeling potential. To clarify this point, a comparison with OCD cases treated nonoperatively would be necessary. Second, a referral bias might have occurred, as patients with favorable postoperative courses might have been more likely to participate in this study, potentially leading to different patterns of morphological changes compared with others. Third, it is not possible to determine within the current cohort whether the morphological changes were caused by the stress of surgery or specifically by the OCD lesions. A longitudinal study that includes preoperative evaluations is needed to clarify this point. However, considering that developing OCD during skeletal growth was a risk factor for morphological changes, having OCD for a longer period during the growth phase may promote deformity, indicating a direct effect caused by OCD. The findings from our mid- to long-term follow-up may provide new insights into this issue. Fourth, there may be differences between the dominant and nondominant hands,[23] as throwing athletes can exhibit side-to-side differences in joint morphology. A stronger external control group, such as baseball players without OCD lesions, would provide more robust comparisons to help eliminate the effect of throwing on morphological changes.

CONCLUSION

Mid- to long-term follow-up of patients after OCD surgery indicated that not only the radial head but the entire elbow joint undergoes cylindrical-like bone morphological changes. These alterations were associated with flexion-extension range limitations. Enlargement tended to be greater in patients who had less remaining skeletal growth at the time of surgery, and larger lesion sizes were associated with greater enlargement.

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