



The morphologic change of the elbow with flexion contracture in upper obstetric brachial plexus palsy

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Background: Contracture of the elbow after obstetric brachial plexus palsy (OBPP) is well known; however, details of the 3-dimensional (3D) morphologic changes in the elbow joint in OBPP have not been clarified. This study aimed to clarify the 3D morphologic changes in the elbow joint by focusing on the distal humerus with flexion contracture in upper OBPP. We tested the hypothesis that the shape of the distal humerus with flexion contracture in upper OBPP is hypoplastic in the trochlea, capitellum, and olecranon fossa.

Methods: We retrospectively studied 20 patients with elbow flexion contracture and residual OBPP. The approximate radius of the distal humerus, the shortest distance between the olecranon and coronoid fossa, and the size of the olecranon fossa were measured and compared between the affected and normal sides using 3D bone models to assess the distal humerus morphology.

Results: The average radius of the distal humerus was smaller on the affected side than on the normal side. Furthermore, the average distance between the olecranon and coronoid fossa was greater and the average size of the olecranon fossa was smaller on the affected side than on the normal side. The size of the distal humerus was significantly smaller and the olecranon fossa was significantly shallower on the affected side.

Conclusions: Consistent with our original hypothesis, the distal humerus with flexion contracture in upper OBPP was hypoplastic. The shallow olecranon fossa might prevent full extension of the elbow even though soft tissue contracture release is performed. We recommend evaluation of the morphology of the olecranon fossa to determine the treatment plan for elbow flexion contracture with OBPP.

Level of evidence: Anatomy Study; Imaging

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Keywords: Obstetric brachial plexus palsy; upper extremity; flexion contracture of the elbow; morphologic change of elbow; three-dimensional analysis; hypoplasia

This study was approved by the Institutional Review Board of the Academic Clinical Research Center of Osaka University (No. 14179) and followed the tenets of the Declaration of Helsinki as revised in 2000. Each author certifies that his or her institution approved the human protocol for this investigation, all investigations were conducted in conformity with

ethical principles of research, and informed consent was obtained from all study participants.

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Obstetric brachial plexus palsy (OBPP) occurs in approximately 3 of every 1000 births.^{1,11,13,16,31} In general, a minor stretch injury shows full recovery of function within the first few months.^{2,6} By contrast, a small number of cases had a considerable traction injury that led to permanent deficits in strength and motion of the upper extremity.^{2,6} Secondary deformities after residual OBPP have also been reported.^{12,35} Hypoplasia and deformities of the scapula and humerus^{6,19} and contracture of the shoulder and elbow are well-known phenomena.^{12-15,31} Typically, internal rotation contracture of the shoulder, flexion contracture of the elbow, and external or internal contracture of the forearm develop gradually in children with residual OBPP. To improve joint function, surgical

intervention and long-term rehabilitation are required.^{20,24,26,38,39}

There have recently been many reports on the use of 2-dimensional (2D) or 3-dimensional (3D) imaging to clarify the pathologic change of the upper extremities and to support the management of OBPP.^{6,9,14,19,28,29} Glenoid retroversion, shoulder subluxation, and humeral head hypoplasia have been well defined. Investigations of elbow morphology have been performed using 2D plain radiographs and limb size differences, and hypoplasia of the trochlea and deformity of the radial head in patients with residual OBPP are now well understood.^{3,4,33,34} Frich et al⁹ reported retroversion of the glenoid fossa in OBPP using 3D bone models, and the reliability of 3D measurements

Table I Patients' demographic and clinical details

Case	Sex	Age (yr)	Affected side	Injury level	Elbow ROM (°)		Past surgical history age at time of operation/operative method
					Flexion	Extension	
1	F	14	R	C5-6	160	-35	No surgery
2	M	17	L	C5-6	160	-45	No surgery
3	M	15	L	C5-6	130	-5	No surgery
4	M	15	R	C5-7	145	-30	0 yr 3 mo/nerve transfer (ICN4, and 5 → MCN· AX, ACC → SS)
5	M	11	R	C5-7	155	-30	2 yr 3 mo/release of subscapularis 5 yr/transfer of latissimus dorsi, corrective osteotomy of glenoid
6	F	11	L	C5-7	175	-40	11 yr/tendon transfer (FCU → ECRL)
7	M	14	L	C5-7	140	-35	1 yr 9 mo/release of subscapularis 5 yr/release of subscapularis, transfer of latissimus dorsi, tendon transfer (FCU → ECRL)
8	F	14	R	C5-7	140	-5	8 yr/tendon transfer (FCU → ECRL)
9	M	9	R	C5-7	150	-5	0 yr 4 mo/transplantation of nerve (C5, C6, C7 → upper trunk)
10	F	5	L	C5-8	160	-20	1 yr 2 mo/release of subscapularis, reduction of radial head
11	F	12	R	C5-8	160	-45	0 yr 6 mo/nerve transfer (ICN4, 5 → MCN)
12	M	14	L	C5-8	155	-20	0 yr 4 mo/transplantation of nerve (C5, C6 → upper trunk) 2 yr 1 mo/nerve transfer (ICN4, 5 → MCN) 3 yr/neurolysis 5 yr/Steindler operation
13	M	8	L	C5-Th1	155	0	0 yr 6 mo/transplantation of nerve (C5, C6, C7 → upper trunk, middle trunk) 5 yr/tendon transfer (FCU → ECRL)
14	M	11	R	C5-T1	150	-15	0 yr 6 mo/nerve transfer (ICN3, 4, 5 → Rad)
15	M	14	R	C5-T1	150	-35	0 yr 3 mo/transplantation of nerve (C5, C6, C7, C8 → upper trunk, middle trunk, C8)
16	M	17	L	C5-T1	140	-20	0 yr 5 mo/nerve transfer (ICN → lateral cord), transplantation of nerve (C7 → SS, middle trunk posterior division) 4 yr/transfer of trapezius, tendon transfer (FCU → ECRL)
17	M	17	L	C5-T1	160	-90	17 yr/extensional osteotomy of humerus, PRC, tendon transfer (FDS4 → EDC, FCU → ECRL)
18	M	5	R	C5-T1	150	-30	2 yr/release of subscapularis
19	F	10	R	C5-T1	150	-35	0 yr 4 mo/transplantation of nerve (C5 → upper trunk posterior division), nerve transfer (ICN → lateral cord, C8), transfer of triceps, reduction of humeroulnar joint
20	F	11	L	C5-T1	160	-40	0 yr 5 mo/transplantation of nerve (C5, C6, C7 → upper and middle trunk)
Average		12.2			152	-29	

ROM, range of motion; ICN, intercostal nerve; MCN, musculocutaneous nerve; AX, axillary nerve; ACC, accessory nerve; SS, suprascapular nerve; FCU, flexor carpi ulnaris; ECRL, extensor carpi radialis longus; Rad, radial nerve; PRC, proximal row carpectomy; FDS, flexor digitorum superficialis; EDC, extensor digitorum communis.

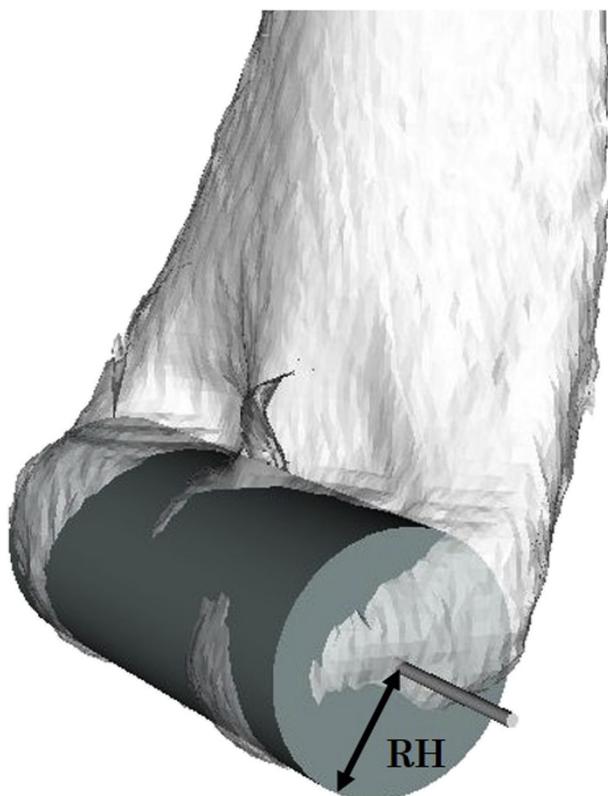


Figure 1 The optimum cylinder fitting to the trochlea and capitellum with the motion axis as the central axis to obtain the radius of the distal humerus (RH).

was superior to that of the 2D method. Therefore, this investigation aimed to quantitatively evaluate the 3D morphologic changes of the elbow joint by focusing on the distal humerus with flexion contracture in upper OBPP. We tested the hypothesis that the shape of the distal humerus with flexion contracture in upper OBPP is hypoplastic in the trochlea, capitellum, and olecranon fossa.

Materials and methods

This is a retrospective case-control study of the 3D morphologic changes in the elbow with flexion contracture in upper OBPP. There were 20 patients (20 upper extremities) with elbow flexion contracture and residual OBPP who participated in the investigation. The patients included 13 boys and 7 girls with an average age of 12.2 years (range, 5-17 years) at the time of examination. No patient had bilateral involvement. The left upper extremity was involved in 10 patients, and the right upper extremity was involved in 10 patients.

According to a diagnosis based on clinical findings, the upper roots (C5-6) were injured in 3 patients, the C5-7 roots in 6 patients, and the C5-8 roots in 3 patients; global lesions (C5-T1) were found in 8 patients. Among the patients studied, 3 patients were treated with conservative therapy, and 17 patients underwent operative intervention for palsy of the upper extremities. Six patients were treated with nerve transfer or nerve transplantation

only, 2 patients were treated with tendon transfer only, 1 patient underwent both nerve and tendon transfers, and 1 patient underwent nerve transplantation and tendon transfer. The following were performed for the 7 remaining patients: subscapularis release; subscapularis release with open reduction of the radial head; subscapularis release and tendon transfer; subscapularis release and corrective osteotomy of the glenoid and tendon transfer; extensional osteotomy of the humerus, tendon transfer, and proximal row carpectomy; nerve transfer, nerve transplantation, tendon transfer, and open reduction of the humeroulnar joint; and nerve transfer, nerve transplantation, and Steindler operation. The average elbow passive flexion and extension range of motion on the affected side was $152^{\circ} \pm 10^{\circ}$ and $-29^{\circ} \pm 20^{\circ}$, respectively. [Table I](#) shows the details of the patients.

Computed tomography (CT) imaging (1.0-mm thickness with contiguous slices, with pixels of 0.557×0.557 mm) with a low-radiation setting (scan pitch, 0.562:1; speed, 5.62 mm/rot, 30 mA, 120 kV) was performed on both upper extremities from the shoulder to the wrist, with the elbow maximally extended using an Aquilion One (Toshiba Medical Systems, Tochigi, Japan). Data were saved in Digital Imaging and Communications in Medicine format and entered into a workstation (Dell Precision Workstation T1650; Dell Inc., Round Rock, TX, USA). We constructed 3D surface models on the basis of 3D surface generation²² by using a commercially available software program (Bone Viewer; Orthree, Osaka, Japan). The accuracy of the 3D models of the bones constructed from the CT data has been described previously.²⁵

To assess the morphology of the distal humerus, we compared the 3D computer bone model of the affected humerus with that of a normal contralateral humerus. To quantify the change in the morphology of the trochlea and capitellum, the approximate radius of the distal humerus (RH) in the lateral view was measured. First, the elbow motion axis was verified to pass through the humeral attachment sites of the anterior oblique ligament of the medial collateral ligament and the lateral ulnar collateral ligament according to the anatomic landmarks. The optimum cylinder fitting to the trochlea and capitellum with the motion axis as the central axis was calculated to obtain RH by using an iterative closest point registration algorithm ([Fig. 1](#)).^{2,5}

Changes to the olecranon fossa were evaluated by measuring the shortest distance between the olecranon and coronoid fossa (OCD).³² The longitudinal plane of the elbow (Plane OF) was determined at the deepest point of the olecranon fossa perpendicular to the elbow motion axis ([Fig. 2, A](#)). OCD could be defined as the shortest distance between the depressed area of the olecranon and coronoid fossa on Plane OF ([Fig. 2, B](#)). The size of the olecranon fossa (OFS) was evaluated by its sagittal area. OFS was defined as the surrounding area with the contour of the olecranon fossa and the tangential line passing through the proximal and distal borders of the olecranon fossa on Plane OF ([Fig. 3](#)). RH was calculated for 9 of the 20 cases (patients older than 13 years) with sufficient ossification of the distal radius for evaluation of its shape. OCD and OFS were calculated for all 20 cases.

Statistical analysis

A priori power analysis was performed before the beginning of data collection and revealed that a sample size of 20 cases would provide a power of 90%, which would be sufficient to detect a 2-mm difference in OCD and RH and a difference of 10 mm² in

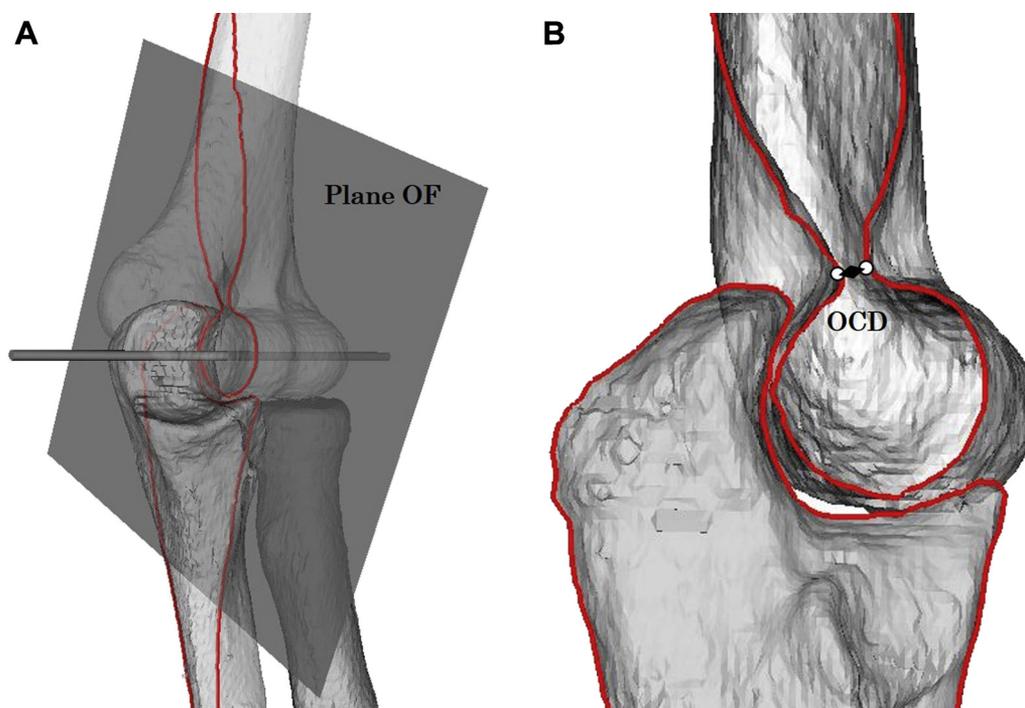


Figure 2 (A) The longitudinal plane of the elbow (*Plane OF*) was determined at the deepest point of the olecranon fossa perpendicular to the elbow motion axis. (B) The shortest distance between the depressed area of the olecranon and coronoid fossa (*OCD*) on *Plane OF*.

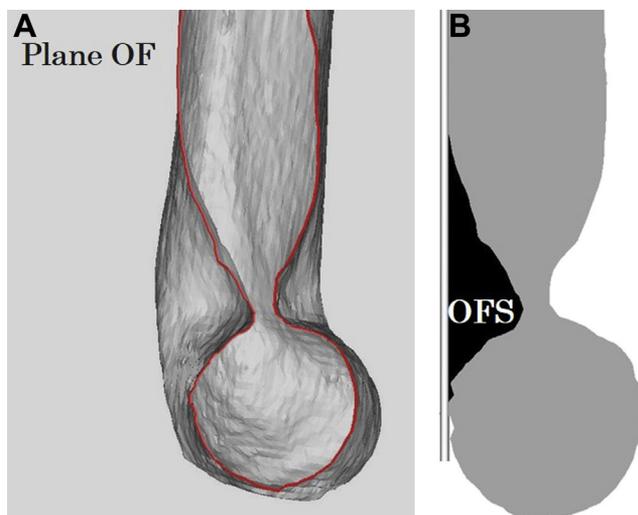


Figure 3 (A) Sagittal section of the distal humerus on longitudinal plane of the elbow (*Plane OF*). (B) The size of the olecranon fossa (*OFS*) was defined as the surrounding area with the contour of the olecranon fossa and the tangential line passing through the proximal and distal borders of the olecranon fossa on *Plane OF*.

OFS at the 0.05 confidence level. Data are expressed as means and standard error of the mean. One-way analysis of variance was performed to determine the significant differences across groups. The differences in values between the affected and normal sides were analyzed using the Wilcoxon signed rank test. Significance was established at $P < .05$.

Results

The size of the distal humerus on the affected side was small, and the olecranon fossa was shallow relative to that on the normal side. Moreover, no case had a congenital foramen between the olecranon and coronoid fossa, which corresponds to 0 mm of *OCD*. The average *RH* of the normal side was 9.8 ± 1.8 mm, whereas that of the affected side (8.7 ± 1.5 mm) was significantly smaller ($P = .0169$). The average *OCD* of the normal side was 3.0 ± 2.0 mm, whereas that of the affected side was 5.3 ± 2.5 mm. This result indicates an increase in thickness between the olecranon and coronoid fossa ($P = .0013$). The average *OFS* of the normal side was 79 ± 30 mm², whereas that of the affected side was 39 ± 20 mm², thus indicating hypoplasia of the olecranon fossa ($P < .0001$). The average *RH*, average *OCD*, and average *OFS* of the affected side were, respectively, smaller, greater, and smaller than those of the normal side (Fig. 4).

Discussion

Relationship to the existing literature

The principal finding of this investigation was that the distal humerus of the affected side in long-standing OBPP is underdeveloped and that the olecranon fossa of the elbow characteristically changes to be shallow and hypoplastic.

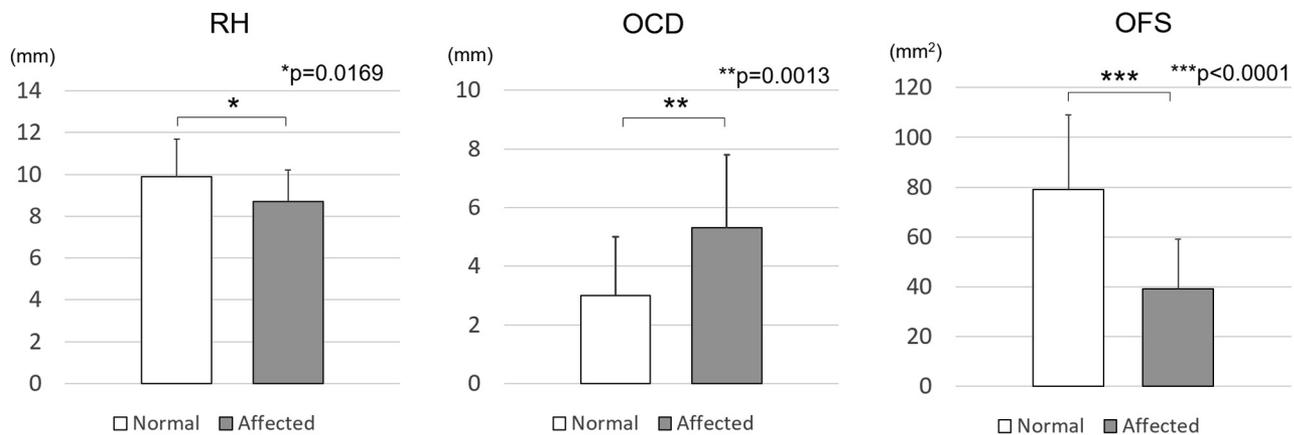


Figure 4 The radius of the distal humerus (*RH*) and the size of the olecranon fossa (*OFS*) were significantly smaller ($P = .0169$ and $P < .0001$) on the affected side than on the normal side. The shortest distance between the depressed area of the olecranon and coronoid fossa (*OCD*) was significantly greater ($P = .0013$) on the affected side than on the normal side.

The study results support our hypothesis that the shape of the distal humerus with flexion contracture in upper OBPP is hypoplastic in the trochlea, capitellum, and olecranon fossa. The skeletal abnormality of the upper extremity after OBPP has been well described,^{4,6,19,34} and peripheral nerve deficits typically result in innervated limb hypoplasia.⁷ McDaid et al²³ reported on limb length differences by using radiographic measurement and demonstrated that the length of the upper limb of the affected side was significantly shorter than that of the normal side. Furthermore, morphologic evaluations of the shoulder joint using magnetic resonance imaging found that the articular surface of the glenoid was retroverted, the size of the humeral head was small, retrotorsion was decreased in hypoplasia,²⁹ and the shoulder joint was posteriorly subluxated.¹⁹ These deformities probably progressed to the internal rotation contracture of the shoulder as a result of an imbalance of the muscles surrounding the shoulder and caused osseous changes and hypoplasia. The flexion contracture of the elbow joint also typically occurs after birth palsy.

In this study, we conducted 3D evaluation of patients who had developed elbow flexion contracture, with a focus on the trochlea, capitellum, and olecranon fossa morphology. We found that the *RH* of the affected side was significantly smaller than that of the normal side, which indicates that the shape of the distal humerus is underdeveloped. The *OCD* of the affected side had increased by 175% compared with that of the normal side, whereas the *OFS* of the affected olecranon fossa had decreased by 50%. The affected olecranon fossa was shallower than that of the normal side, thereby exhibiting hypoplasia. The cause of these hypoplastic changes could be a flexion contracture position wherein the elbow joint develops muscle imbalance and becomes predominantly flexed, similar to that reported in the shoulder joint.^{24,27,30,31} The disappearance of stress placed on the olecranon fossa by the olecranon during infancy would likely result in a shallow recess in the

absence of normal formation of the olecranon fossa and consequently lead to hypoplasia.^{8,18,21,37}

A variety of treatments are prescribed for elbow flexion contracture after birth palsy. It has been reported that a mean 48° flexion contracture improved by 26° through conservative therapy involving rehabilitation and splinting.¹⁵ From a surgical perspective, contracture release has improved a mean 45° preoperative flexion contracture to 17° postoperatively,¹⁰ and the closed gradual arthrodiastasis using a unilateral hinged elbow external fixator has improved a mean preoperative 55° flexion contracture to 8°.³⁶ However, full extension has been achieved in only a very few patients with 10° to 40° of residual restricted extension. Our 3D evaluation revealed that the olecranon fossa is shallow with hypoplasia, thus suggesting that some restriction to extension might have remained because of the impingement of the olecranon to the olecranon fossa despite release of the soft tissue. In considering surgical therapy for elbow flexion contracture after birth palsy, it is necessary to conduct a 3D evaluation of the bone, particularly the morphology of the olecranon fossa, and an evaluation of soft tissue contracture. In cases with a hypoplastic and shallow olecranon fossa, it is essential to consider fossaplasty or surgical fenestration, such as the Outerbridge-Kashiwagi procedure,¹⁷ to achieve full extension of the elbow after the release of soft tissue. In cases of treatment with physical therapy or splint, information that the hypoplastic olecranon might prevent full elbow extension would help therapists, patients, and their families to determine the goal of treatment.

Experimental considerations

The limitations of this investigation include the size and character of the objectives. Although a larger number of participants may have resulted in different findings, the a

priori power analysis and sample size of 20 patients had a statistically high power of >0.9 for OCD and OFS in the post hoc power analysis ($\alpha = .05$). Variations in the treatment strategies, the patient's progress, and the surgical or conservative treatments may also have affected the different growth process of the elbow. However, in most cases with flexion contracture of the elbow, the distal humerus including the olecranon fossa, trochlea, and capitellum was hypoplastic. CT of bilateral elbows was performed in this study to compare the 3D shape of the distal humerus of the affected side with that of the normal side, which highlights radiation exposure in patients. However, our CT protocol reduced radiation exposure to less than one-tenth the radiation exposure with normal conditions.²⁵ This information on the 3D findings of the elbow is essential to assist surgeons and therapists in treating patients with OBPP and flexion contracture of the elbow.

Conclusions

Conservative treatment by use of a splint and surgical treatment involving the release of soft tissue contracture for elbow flexion contracture in patients with OBPP are routinely employed to improve the extensional motion range of the elbow. However, some degree of restriction of elbow extension often remains despite the best efforts of clinicians. The results of this investigation suggest that the hypoplastic olecranon fossa might prevent full extension of the elbow even if contracture release has been performed. It is recommended that the 3D morphology of the olecranon fossa be evaluated with CT to determine the indication for surgery.

Disclaimer

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