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Corrective osteotomy for hyperextended elbow with limited flexion due to supracondylar fracture malunion

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Background: Extension deformity of the distal humerus after a malunited supracondylar fracture can restrict elbow flexion. Here we report a computer-assisted operative procedure and review the results of clinical cases in which corrective surgery was performed.
Methods: The medical records of the patients who underwent corrective osteotomy for hyperextended elbow malunion of the distal humerus with limited elbow flexion (flexion angle ≤100°) were reviewed retrospectively. Osteotomy was performed using patient-specific instruments designed based on preoperative 3-dimensional computer simulation.
Results: Three patients, a 55-year-old woman and two 12-year-old boys, met the inclusion criteria. The angles of hyperextension of the affected distal humerus were 29°, 29°, and 25°, respectively. The range of flexion/extension of the elbow motion in the first patient improved from 95°/25° preoperatively to 140°/–10° postoperatively, in the second patient from 100°/20° to 145°/5°, and in the third patient from 80°/25° to 140°/10°. Bone union was achieved in all patients. There were no major complications. The corrective operations not only improved elbow flexion but also increased the total range of motion in the elbow by rebuilding the anterior curve of the distal humerus.
Conclusions: Correction of the extension deformity of the distal humerus after a malunited supracondylar fracture is a reasonable option for patients older than 10 years with restricted elbow flexion. Preoperative computer simulation and the use of patient-specific instruments can be a useful alternative that enables accurate deformity correction and improves the total range of motion.
Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Corrective osteotomy; hyperextension; malunion; supracondylar fracture; limited flexion; computer simulation

The Institutional Review Board of Osaka University Hospital, Japan, approved this study.

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Post-traumatic cubitus varus deformity is a common complication of supracondylar fracture of the humerus.[6,11,24,35] In patients with cubitus varus deformity, extension[6] and rotational[6,24] deformity may coexist. A previous 3-dimensional (3D) analysis revealed that only 20% of patients with cubitus varus deformity had varus deformity alone, whereas the

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remaining 80% presented deformities combined with hyperextension or internal rotation, or both.[28]

Correction in varus deformity alone has been widely performed, regardless of coexisting extension deformity.[3,12,21,34] On one hand, Takagi et al[27] reported good results in patients aged <10 years for corrections in the coronal plane alone. On the other hand, Usui et al[32] performed 48 3D corrective osteotomies for cubitus varus deformity, and this corrected 12° of hyperextension on average.

The need to correct hyperextension has been discussed in association with the correction of varus deformity. However, little attention has been paid to corrective osteotomy for the extension deformity of the distal humerus without obvious cubitus varus. Here, we review patients in which the extension deformity of the distal humerus and limited flexion of the elbow joint after malunited supracondylar fracture were successfully treated with flexion osteotomy, which was performed using patient-specific instruments (PSIs) designed based on preoperative 3D computer modeling.[17,20,29,30,33]

Materials and methods

This is a retrospective case series of patients who underwent corrective osteotomy for hyperextended malunion of distal humerus with limited elbow flexion. A retrospective review of the medical records of the patients who met the following criteria was conducted. Between January 2012 and December 2016, 76 corrective osteotomies of the upper extremity were conducted at our hospital. Overall, 20 of these patients underwent corrective osteotomy at the distal humerus. We excluded 6 patients aged <10 years because remodeling occurs in those aged <10 years.[15] The inclusion criteria were hyperextension deformity of the elbow ≥20° before surgery, restricted elbow flexion ≤100° caused by extension deformity of the distal humerus, and ≤10° difference in the carrying angle between the affected elbow and the opposing normal elbow. Three patients met the inclusion criteria. There were no patients with prior infection or follow-up of <2 years. The preoperative angle of hyperextension of the affected distal humerus was evaluated by 3D analysis. The preoperative and postoperative ranges of motion of the elbow were obtained from the medical records.

Preoperative simulation and surgical technique

To analyze the 3D deformity of the distal humerus, computed tomography (CT) scans of bilateral elbows were obtained. The patient was positioned in a way that the elbow was extended and the forearm was supinated. In our previous studies, we reported corrective osteotomy with CT-based computer simulation and PSIs.[17,20,29] BoneViewer software (Orthree, Osaka, Japan) was used to construct 3D bone models from the bilateral CT data of the elbow. Then, 3D deformity was analyzed by superimposing the model of the affected humerus on the mirrored model of the contralateral normal humerus with BoneSimulator software. Closing-wedge osteotomy was planned based on the analysis of the 3D deformity (Fig. 1). After the osteotomy was performed

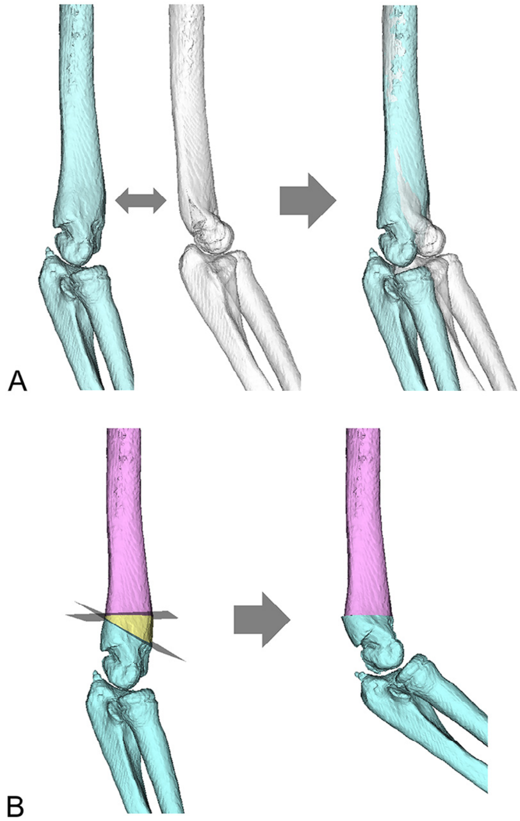

Figure 1 (**A**) Three-dimensional deformity analysis. The malunited elbow (*light blue*) and the mirror image of the intact elbow (*white*) are overlaid. (**B**) Preoperative planning of corrective osteotomy. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

virtually, the axis of elbow flexion was delineated from the center of a sphere fitted to the capitellum trace and a circle fitted to the trochlea trace.[5,8,9,13,16,18,36] The flexion-extension motions of the postcorrection elbow were estimated by rotating the radius and ulna around the presumptive rotational axis of the elbow joint[14,18] (Fig. 2). Thus, any bony prominence that could cause an impingement during elbow flexion was detected on the computer simulation.

PSIs for osteotomy and correction were created using a 3D printer (Eden250 [Objet Geometries, Rehovot, Israel] or FORMIGA P100 [EOS Electro Optical Systems GmbH, Krailling, Germany]) with medical-grade resin. The shape of PSIs for osteotomy was such that they fit exactly to the characteristic dorsal surface of the distal humerus and were equipped with multiple guide holes for Kirschner wire insertion and 2 slotted cutting guides.

In the actual operation, a PSI was placed on the bone surface and fixed with Kirschner wires, followed by osteotomies performed through the slotted cutting guides (Fig. 3, *A-C*). The positions of the Kirschner wires were designed so that the correction would be completed when they became parallel to each other and were through the holes of another guide that maintained the correction (Fig. 3, *D* and *E*). In patients aged <13 years, bony fragments were fixed using the