Three-Dimensional Corrective Osteotomy for Cubitus Varus Deformity with Use of Custom-Made Surgical Guides

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Based on an original article: *J Bone Joint Surg Am.* 2013 Nov 20;95(22):e173.

Introduction

We present a detailed description of our preoperative planning and surgical technique for three-dimensional (3-D) corrective osteotomy with use of custom-made surgical guides for cubitus varus deformity after supracondylar fracture.

Cubitus varus deformity after supracondylar fracture includes not only varus but also extension and internal rotation deformities of the distal part of the humerus¹⁻³. Three-dimensional corrective osteotomy has been advocated by the authors of several studies to improve cosmetic appearance and to reconstruct the physiological joint motion around the elbow joint⁴⁻⁷. However, the shortcomings of conventional 3-D osteotomies include difficulty in accurately planning and performing the surgery and in providing rigid internal fixation with a relatively small contact area at the osteotomy site after rotational correction. The postoperative loss of correction and a relatively high rate of complications are also of concern⁸.

We developed a computer simulation system that enabled surgeons to precisely evaluate a deformity. It also enabled the simulation of 3-D corrective osteotomy with use of computer models constructed from computed tomography (CT) data⁹ and the design of a custom-made surgical guide to assist in reproducing the preoperative simulation during the actual surgery¹⁰⁻¹². The drawbacks of conventional 3-D osteotomy for cubitus varus deformity can be eliminated by this novel technique.

The technique consists of the following six major steps.

Step 1: Create Computer Bone Models from CT Data

Obtain CT data of both upper extremities and create computer bone models from these data.

- Try to decrease the radiation dose. We used a low-radiation protocol (scan time, 0.5 s; scan pitch, 0.562:1; tube current, 20 to 150 mA; tube voltage, 120 kV) with patients in the prone position, the arms elevated and extended overhead, and the forearm maintained in supination during image acquisition. Forearm supination is preferred but not mandatory. You can make the simulation using the ulna as a reference that is not influenced by the forearm rotational position.
- Create bilateral 3-D surface models of the humerus, radius, and ulna from CT data (Fig. 1) using commercially available software (Bone Viewer; Orthree, Osaka, Japan).

Step 2: Evaluate the 3-D Deformity

Evaluate the deformity in three dimensions by comparing the affected humerus with the mirror image of the contralateral, normal humerus (Fig. 1 and Video 1).

- Superimpose the proximal part of the mirror image of the normal humerus, which is considered the target model, on the corresponding part of the affected humerus (proximal registration) using commercially available software (Bone Simulator; Orthree).
- Apply the same procedure to the distal part of the humerus (distal registration).
- Set the greater tuberosity, humeral head, and humeral shaft as references for the proximal part, and the medial and lateral epicondyles and

distal articular surface for the distal part.

- Use the proximal parts of the forearm bones as references for the distal part when a morphological change is present at the distal part of the humerus.
- The computer software then automatically calculates the 3-D amounts of deformity and correction using the transformation data required for the distal and proximal registration.

Step 3: Plan the 3-D Corrective Osteotomy

Simulate a 3-D corrective osteotomy on the basis of information obtained from the deformity evaluation (Fig. 2 and Video 2).

- Create a plane using the software function.
- Move the plane by dragging it, using a computer mouse, and place it roughly parallel to the distal articular surface and just proximal to the olecranon fossa.
- Name and save the plane as the distal osteotomy plane (DOP).
- Move the DOP by the correction amount described in Step 2, and define it as the proximal osteotomy plane (POP).
- Delete the wedge-shaped segment cut out by the DOP and POP from the affected humerus using the edit function of the software.
- Complete the simulation of 3-D correction by moving the distal segment of the humerus together with the forearm bones by the correction amount.
- Verify that the overall appearance of the extremity has been appropriately corrected on the computer monitor.

Step 4: Operative Setup

Order the custom-made surgical guides that will assist you in reproducing the preoperative simulation during the actual surgery.

- Send the necessary data (computer bone models, DOP, POP, and correction amount) to the third party (Nakashima Medical, Okayama, Japan; <http://www.medical.nakashima.co.jp/en/>) and order the design of the guides.
- Receive and verify the design of the guides by observing them in three dimensions using the computer software (Fig. 3). Ask for design modifications if necessary.
- After confirming the final design of the guides, order their manufacture by Nakashima Medical.
- Receive the surgical guides, and sterilize them to prepare for surgery (Fig. 4).

Step 5: Perform the 3-D Osteotomy Using the Custom-Made Surgical Guides

Perform the osteotomy using the custom-made surgical guides, and achieve anatomical correction using the reduction guides (Figs. 5 and 6; Videos 3 and 4).

- Expose the distal part of the humerus via the lateral approach with the patient in the supine position if he/she has open physes or via the posterior approach with the patient in the lateral decubitus position if he/she has closed physes.
- Place the osteotomy guide onto the posterolateral surface of the distal part of the humerus, where the lateral epicondyle and lateral half of the olecranon fossa serve as good landmarks.
- Verify that all edges of the guide are in exact contact with the bone surface. Then fix it to the bone with Kirschner wires, 1.5 to 2.0 mm in diameter, inserted through the metal sleeves mounted on the guide.
- Perform the osteotomy with a bone saw through the cutting slits on the guide.
- Remove the wedge-shaped bone segment created by the osteotomy.
- Achieve the planned correction by bringing the Kirschner wires into a parallel position, and hold them with a reduction guide.
- Accomplish internal fixation with Kirschner wires or tension-band wiring in patients with open physes or with plates and screws in those with closed physes while the correction is being maintained (Fig. 6).

Step 6: Postoperative Care

Apply a removable splint and have the patient start active and passive range-of-motion exercise after the splinting period has been completed.

- Apply a removable long arm splint with the elbow in 90° of flexion. This is worn for one to two weeks by patients treated with plate fixation and for three to four weeks by those treated with Kirschner wire fixation.
- Have the patient start active and passive range-of-motion exercise after the splinting period has been completed.

Results

In our series of thirty patients¹³, the mean humerus-elbow-wrist angle¹⁴ and tilting angle⁴ of the affected side were 18° (varus) and 25°, respectively, before surgery, which significantly improved to 6° (valgus) and 38°, respectively, after surgery. Hyperextension of the elbow

and internal rotation of the shoulder were normalized in all patients. Early plate breakage was observed in one patient. After revision surgery, bone union was achieved without loss of correction. Recurrence of mild varus deformity was observed in another patient. According to the rating described by Hahn et al.¹⁵, twenty-seven patients had an excellent result, three had a good result, and none had a poor result.

What to Watch For

Indications

- Cubitus varus deformity after malunited supracondylar fracture of the humerus with an unsightly appearance and/or restricted elbow flexion (excessive elbow extension).

Contraindications

- Marked osteoarthritic change of the elbow joint on radiographs.

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Pitfalls and Challenges

- Decrease the rotational correction, leaving a residual rotational deformity of $<15^\circ$, for cases with gross internal rotation deformity when planning the 3-D corrective osteotomy (Step 3). Complete rotational correction may decrease the contact area at the osteotomy site to an extent where bone union would be of concern in some cases.

Clinical Comments

- Should rotational deformity be corrected?
- What is the most appropriate age for corrective osteotomy for cubitus varus deformity?

NOTE: The authors thank Mr. Ryoji Nakao for developing computer software and Ms. Sumika Ikemoto for assistance with the simulation. They also thank Prof. Kazuomi Sugamoto and Prof. Hisao Moritomo for their clinical commitment.

Disclosure: None of the authors received payments or services, either directly or indirectly (i.e., via his or her institution), from a third party in support of any aspect of this work. One or more of the authors, or his or her institution, has had a financial relationship, in the thirty-six months prior to submission of this work, with an entity in the biomedical arena that could be perceived to influence or have the potential to influence what is written in this work. In addition, one or more of the authors has a patent or patents, planned, pending, or issued, that is broadly relevant to the work. Also, one or more of the authors has had another relationship, or has engaged in another activity, that could be perceived to influence or have the potential to influence what is written in this work. The complete **Disclosures of Potential Conflicts of Interest** submitted by authors are always provided with the online version of the article.

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Figures

Fig. 1

The proximal part of the affected humerus was superimposed onto the mirror image of the contralateral, normal humerus (proximal registration). The same procedure was then applied to the distal part (distal registration). P and D are the transformation matrices required for proximal and distal registration, respectively. The computer software automatically calculates the 3-D amounts of deformity (M) and correction (C) using these transformation data. The deformities in this case were 21° of varus, 13° of extension, and 11° of internal rotation.

Fig. 2

The distal osteotomy plane (DOP) was set roughly parallel to the distal articular surface and just proximal to the olecranon fossa. The DOP was then moved by the correction amount described in Step 2 and was defined as the proximal osteotomy plane (POP) (**Fig. 2-A**). The wedge-shaped segment (pink area in **Fig. 2-B**) cut out between the DOP and POP was removed from the affected humerus (**Fig. 2-C**), and 3-D correction was simulated (blue curved arrow in **Fig. 2-C**, and **Fig. 2-D**).

Fig. 3

A diagram of the operative procedure. The osteotomy guide was placed on the posterolateral side of the distal part of the humerus (**Fig. 3-A**, asterisk). The pink segment cut by the osteotomies through the slits on the guide was removed, two sets of Kirschner wires were brought into a parallel position, and the planned correction was achieved (**Figs. 3-B, 3-C**, and **3-D**). The correction was maintained by holding the Kirschner wires parallel with a reduction guide (**Fig. 3-E**, double asterisk).

Fig. 4

A custom-made osteotomy guide (**Fig. 4-A**, arrowhead) and a reduction guide (**Fig. 4-B**, double arrowheads) were manufactured with use of rapid-prototyping technology. In this figure, they were placed on the full-sized bone models. Metal sleeves (arrow) and slits (asterisk) were mounted on the guides.

Fig. 5

In this adult case, a posterior approach with the patient in the lateral decubitus position was employed. The osteotomy guide was placed onto the posterolateral surface of the distal part of the humerus and fixed with Kirschner wires through metal sleeves mounted on the guide (**Fig. 5-A**). Osteotomy was performed with a bone saw through the slits on the guide (**Fig. 5-B**). The guide was then removed, leaving the Kirschner wires in place, followed by resection of the wedge-shaped section of bone created by the osteotomy. Removal of the metal sleeves leaves enough space between the Kirschner

wires and the guide. The space in between and the flexibility of the Kirschner wires enable the removal of the guide without breaking it (**Fig. 5-C**). The planned correction was achieved by bringing the Kirschner wires parallel with each other and then holding the wires in position with a reduction guide (**Fig. 5-D**). While the correction was being maintained, plates and screws were applied to the medial side (**Fig. 5-E**). Finally, internal fixation was accomplished by applying a plate to the lateral side (**Fig. 5-F**) after the reduction guide and Kirschner wires were removed.

Fig. 6

Preoperative (**Fig. 6-A**) and postoperative (**Fig. 6-B**) radiographs of the elbow.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6