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Case Report

Three-dimensional preoperative planning for adult acute plastic bowing of the ulna

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A R T I C L E I N F O

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A B S T R A C T

Case: We report a case of adult acute plastic deformity of the ulna. Ulnar osteotomy was planned using 3-dimensional (3D) surface data from both injured and intact sides using surface registration technique. Opening wedge osteotomy was planned to correct the position of the ulnar fovea with respect to the proximal ulna. The position of the plate and direction of the screws were decided preoperatively. The operation was performed with reference to a 3D-printed, reduced model. The preoperatively limited pronation and supination of the patient were significantly improved as of 2 years postoperatively. Our preoperative method has several advantages. The risk of nonunion is low because the hinge-side bone cortex remains intact. The surgical procedure is simple, because plate position and direction of drilling are both decided preoperatively. In addition, correction of alignment can be achieved gradually by inserting screws through the plate and checking the range of motion of the forearm.

Conclusion: Our 3D preoperative simulation aimed to correct the rotational axis of the forearm. The surgical procedure was greatly facilitated using the 3D-printed, reduced model for reference.

Introduction

Acute plastic bowing is typical among children, but few adult cases have been reported [1]. Early closed reduction is often difficult because of the high-energy nature of the causative injury and low bone plasticity [2]. We report herein a case of adult acute plastic bowing treated with the assistance of 3-dimensional (3D) preoperative printed model.

Case report

A 37-year-old Asian man sustained a roller injury to the left arm and was transported to our institution. On presentation, the left arm was markedly deformed (Fig. 1A) and he complained of severe pain in the left forearm. Plain radiography showed fractures of the radius in the distal and middle thirds of the shaft and acute plastic bowing of the ulna (Fig. 1B). We diagnosed acute compartment syndrome from the symptoms, fractures of the radius and acute plastic bowing of the ulna. Emergent fasciotomy was performed for the acute compartment syndrome, and an external fixator was applied. Two weeks after the first operation, the fasciotomy was closed. Three weeks after the first operation, osteosynthesis for the radial fracture was performed using a long locking plate (Fig. 1C). Six weeks after the injury, supination and pronation were 0° and 20° from anatomic neutral, respectively. We considered that residual deformity of the ulna was limiting the range of motion, and therefore scheduled osteotomy of the ulna based on preoperative 3D

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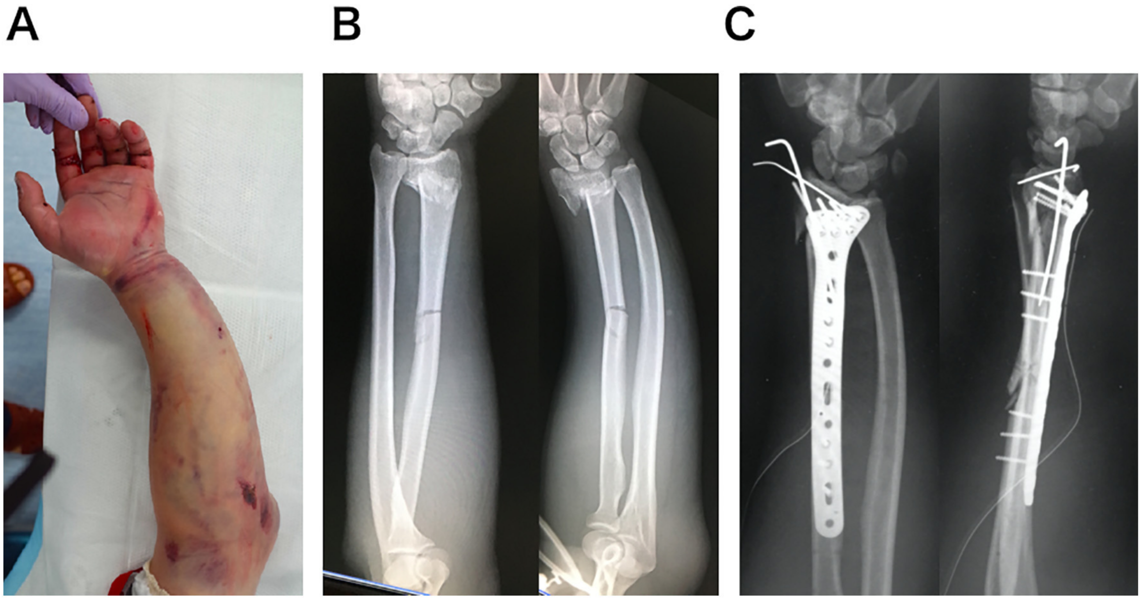

Fig. 1. A) The left forearm of the patient is clearly deformed.
B) Radiography shows fractures at the distal and middle radius, and plastic bowing of the ulna.
C) Osteosynthesis for the radial fracture was performed 3 weeks after the injury. The radial fractures are fixed with a locking plate and wires. The ulna shows remnant plastic bowing deformity.

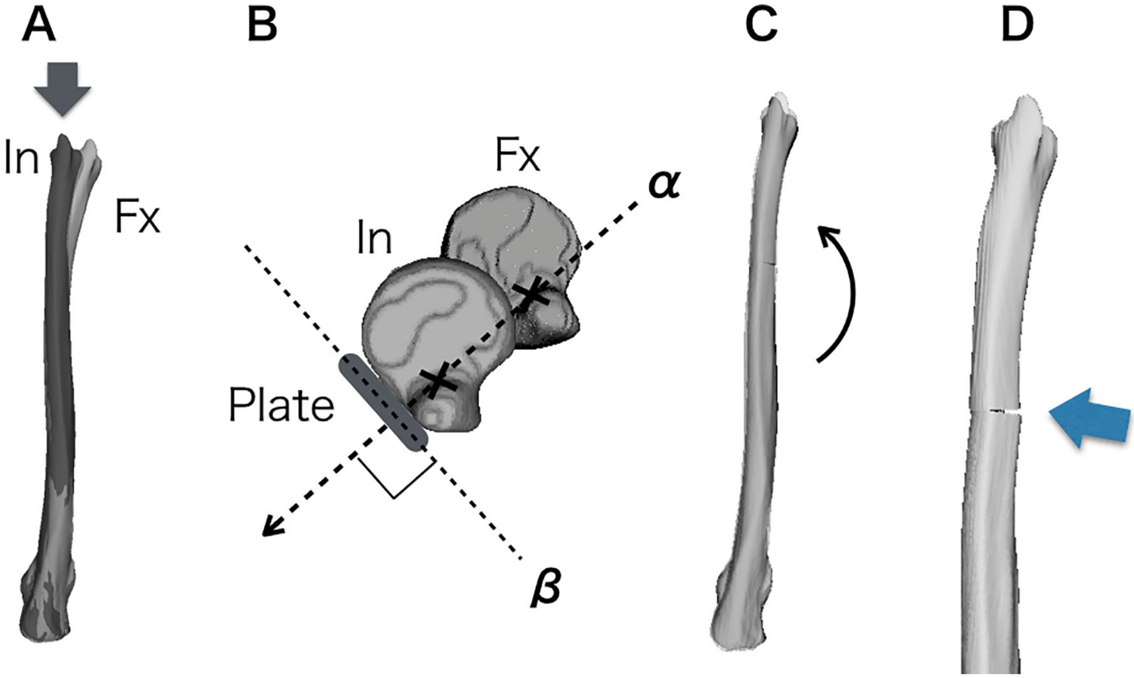

Fig. 2. A) Preoperative planning of the ulnar osteotomy. Surface data for bilateral ulnas are reconstructed. The intact side is flipped horizontally as a mirrored intact model. The proximal quarter of the ulnar surface is matched to the intact side by surface registration using the iterative closest point algorithm.
B) The position of the plate and correction direction of the ulna are decided in the view from the distal side of the ulna. The line between the ulnar fovea in the mirrored intact and fractured sides provides the correction direction (α). Screw direction should be parallel to this direction. The position of the plate should be perpendicular to this direction and fitted to the ulnar shaft.
C) The osteotomy site is set almost at the end of the surface overlapping area by considering the operation approach. The surface distal to the osteotomy plane is rotated to match the fovea on the fracture side to that on the intact side.
D) The surface data are connected to be printed. The partial bone cortex on the plate side is planned to be left intact as a hinge for osteotomy.

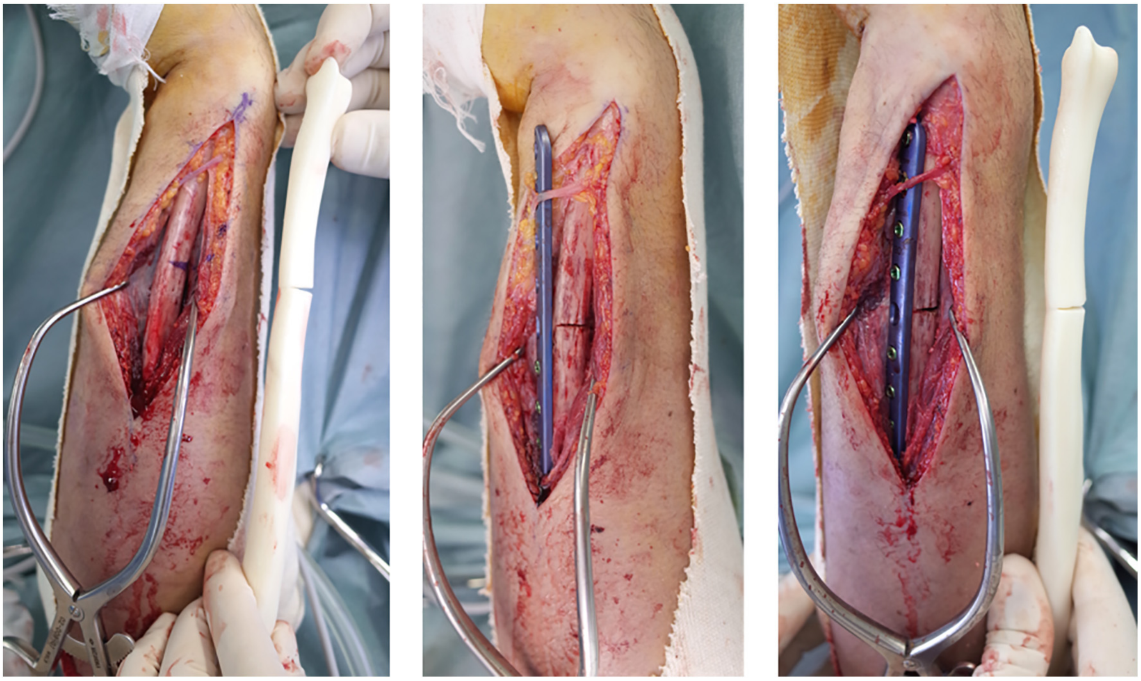

Fig. 3. The operation is performed with reference to the 3D-printed osteotomy model. The 3D printed model shows the osteotomy direction and position. The osteotomy line is decided and partial osteotomy is performed. The straight plate is placed in the simulated position and fixed using the proximal holes. Correction is achieved by inserting distal cortex screws with confirmation of the alignment and range of motion.

planning.

Preoperative 3D planning

We planned the osteotomy to correct the rotational axis of the forearm by correcting ulnar alignment under hinged osteotomy at one site. Surface data for the whole ulnas of both forearms were obtained in Standard Triangulated Language (STL) format from CT Digital Imaging and Communications in Medicine (DICOM) data using surface reconstruction software (AVIZO version 9.3.0; MAXNET Japan, Tokyo, Japan), and the intact forearm was inverted horizontally to create a mirror image of the intact side (Fig. 3A, B). We considered that bowing deformity was present at the ulnar shaft. The proximal one-quarter of the affected ulnar surface, which includes anatomically characteristic features such as the coronoid process, was matched to the mirrored intact side using a surface registration algorithm (Fig. 2A). We used an iterative closest point algorithm for surface registration to match the two surfaces and minimize distance between the two surfaces (VTK version 6.3.0; Kitware, Clifton Park, NY). The matched surface showed dorsal bowing of the distal ulna. We planned osteotomy to correct the position of the ulnar fovea by deciding the plate position and screw direction (Fig. 2B). The osteotomy site was set almost at the end of the surface overlapping area by considering the operational approach (Fig. 2C, D). The ulnar cortex of the plate position was planned to be left intact as a hinge for the osteotomy. The remaining proximal surface and rotated distal surface were connected and 3D-printed (*Uprint*; Marubeni, Tokyo, Japan).

Surgical procedure (Fig. 3)

The limited range of motion remained unchanged with testing of passive range of motion under general anesthesia. A straight incision was applied to the ulnar shaft. The ulnar shaft was approached from the line between the flexor carpi ulnaris and extensor carpi ulnaris muscles. We determined the osteotomy line with reference to the 3D-printed model. Almost two-thirds of the cortex was cut using an osteotome of 0.4 mm thickness. A proximal hole was drilled with the drill bit directed parallel to the direction of ulnar fovea correction. The conventional titanium straight plate was then applied and the first screw length was decided. Other proximal holes were drilled and fixed using cortex screws. Next, the distal holes were drilled and non-locking cortex screws were inserted from the osteotomy site to distal to open the osteotomy site, and the planned gap was gradually achieved at the osteotomy site. Supination was improved after the osteotomy procedure. We could achieve the same alignment and confirmed improvement of the range of motion, and postoperative radiography showed ulnar reduction on the lateral view (Fig. 4A). No bone grafting was performed.

Bone union of the whole cortex was achieved (Fig. 4B) and range of motion remained improved as of 2 years postoperatively. Supination and pronation were measured at 80° and 50°, respectively (Fig. 4C).

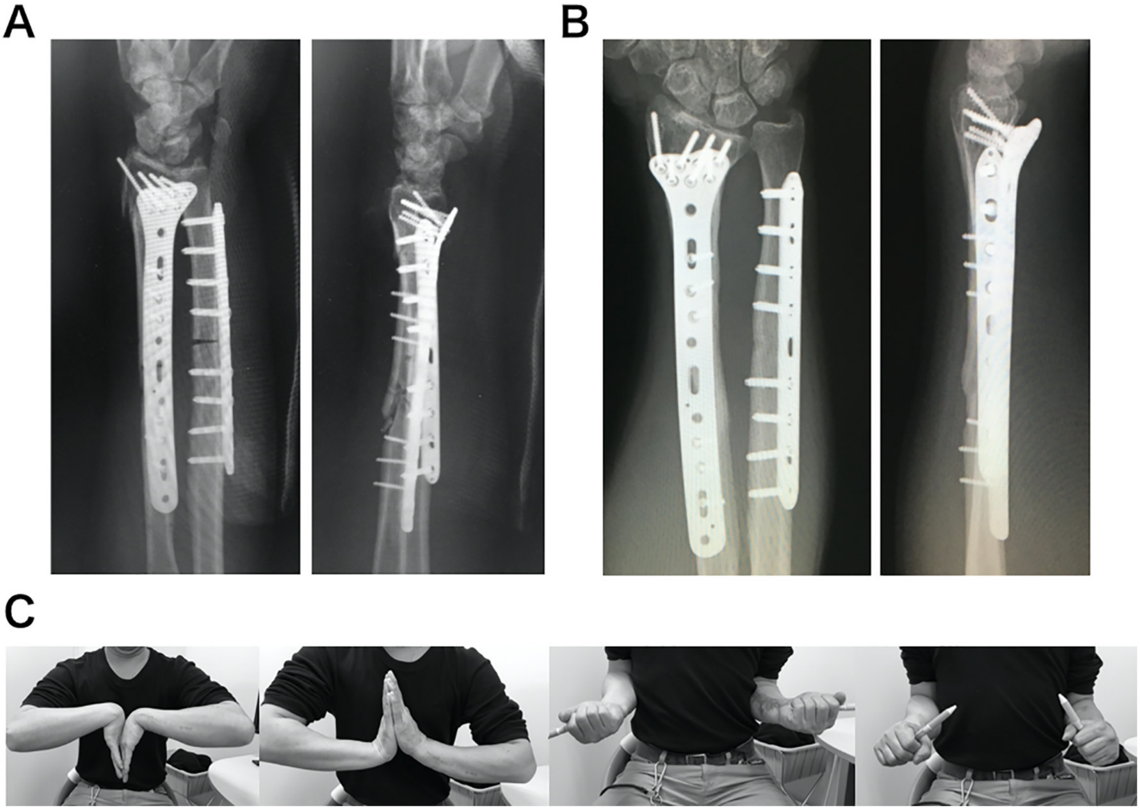

Fig. 4. A) The postoperative radiography shows that correction of alignment has been achieved.
B) Images at 1 year postoperatively. Bone union has been achieved.
C) Images at 2 years postoperatively. Range of motion remains improved.

Discussion

Adult ulnar plastic bowing is a rare injury compared to those among children. Several reports have been described, with most cases representing direct injuries such as industrial accidents [3], although some reports have described indirect injuries [4,5]. Although some studies have reported early closed reduction for bowing deformity [6] some have required osteotomy despite attempts at closed reduction [2].

Biomechanical studies have revealed that the mean forearm rotation axis coincided with the ulnar fovea and center of the radial head [7]. The main purpose of the ulnar osteotomy is positioning of the ulnar fovea in the forearm during the whole range of pronation and supination. Murase reported excellent results from 3D planned osteotomy for a patient with forearm deformity [8]. That method required complete osteotomy and a specially ordered osteotomy guide in most cases. Our method aimed to correct the rotational axis of the forearm by hinged osteotomy. This method offers several advantages. First, the risk of nonunion is low because the hinge-side bone cortex remains intact. Nonunion or re-fracture after implant removal of the ulnar after osteotomy are common complications, although the osteotomy site is usually the ulnar shaft because of the position of the deformity and for easy accessibility. Second, the surgical procedure is simple. Once the plane of the angular deformity is identified in 3D preoperative planning, plate position and direction of drilling are both decided preoperatively (Fig. 2B). The operator can easily decide the position and direction of the first screw and place the implant with reference to the 3D printed model. Correction of alignment can be achieved gradually by inserting non-locking screws through the plate and checking the range of motion of the forearm. Once the correction is achieved and improvement of the range of motion is confirmed, locking screws can be used in the distal holes to fix the correction. Currently, 3D printers are readily available for fracture treatments [9,10]. A 3D-printed, reduced model provides a valuable intraoperative reference.

On the other hand, several limitations to our method must be kept in mind. Correction of rotational deformity was impossible. The deformity was caused by a direct blow to the forearm and we hypothesize that gradual hinged correction with checking range of motion of the forearm would prove sufficient for this case. If the rotational deformity of the ulnar styloid is significant in the preoperative planning, more precise correction should be considered. Second, we focused on correcting ulnar alignment based on the hypothesis that the alignment of the radius was normal. In the present case, we assumed that alignment of the radius was largely correct. However, in cases with severe deformity of both radius and ulna, a more complicated 3D osteotomy plan could be another option because reduction of the radius would be insufficient due to severe ulnar deformity. In addition, ulnar length was slightly increased because of opening wedge osteotomy. This change in length may have caused symptoms at the distal radio-ulnar joint.

Conclusion

Our 3D preoperative simulation aimed to correct the rotational axis of the forearm. The surgical procedure was simple and greatly facilitated using a 3D-printed, reduced model for reference.

Declaration of competing interest

The authors declare that they have no conflict of interest.

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