Case Report

Computer-Assisted 3-Dimensional-Planned Corrective Osteotomy for Symptomatic Fracture Malunion: An Ulna-Only Case Study

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We present a case of an ulna malunion managed with computer-assisted 3-dimensional planned corrective osteotomy in a patient with a history of distal radius fracture treated with open reduction internal fixation and concurrent distal ulna fracture treated conservatively. The distal ulnar diaphyseal deformity was complex and existed in multiple planes, including a clinically significant rotational deformity. Preoperative computed tomography scans were used to plan 3-dimensional guides for the osteotomy, which were subsequently printed and used during surgery. After surgery, our radiologic findings showed a high degree of accuracy and the patient demonstrated pain-free, full range of motion and returned to contact sports 4 months after surgery. This could be a reliable and precise option for complex ulnar diaphyseal malunion corrective surgery.

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Forearm fractures are common and may be managed conservatively or surgically via open reduction internal fixation. 1 Malunion occurs in approximately 15% of forearm fractures and may result in pain, stiffness, instability of the wrist, visible deformity, and early osteoarthritis. 2 Surgery is often indicated to treat symptomatic fracture malunions. 3 However, in complex forearm malunions, surgical restoration of normal anatomy is difficult because of the deformity occurring in multiple planes. 1, 3, 4 Traditionally, plain radiographs have been used to plan for all forearm corrective osteotomies. Although these may be sufficient for simple malunions with predominantly translational deformities, complex forearm malunions involve a significant rotational component. They may have variable postoperative outcomes with plain film guidance alone. 5, 6 In such cases, the recent use of computer-guided 3-dimensional planning models and patient-specific cutting guides has allowed surgeons to offer patients more accurate correction of forearm deformities. 4, 8

The use of computer-guided 3-dimensional planning models is a relatively novel technique in the context of forearm fracture malunions. Of the limited literature comprising case reports, a case series, and a 40-patient randomized controlled trial, most studies reported radius-only osteotomies or ulnar corrective osteotomy in the context of concurrent radius and ulna fracture malunions. 5–9 We present a case using a computer-assisted 3-dimensional planned approach to an ulna-only corrective osteotomy for symptomatic fracture malunion in a patient with a history of a surgically fixed distal radius fracture but malunited conservatively treated distal ulnar fracture, with excellent postoperative outcomes over a 12-month follow-up period. Written informed consent was obtained from the patient for publication of this report and accompanying figures.

We used this technique in a unique setting of a complex distal ulnar diaphyseal malunion with rotational deformity adjacent to a surgically fixed distal radius fracture in an active 17-year-old boy.

Case

A 17-year-old, otherwise healthy, right-handed boy sustained fractures of the left radius and ulna after a direct tackle during a game in the Australian Football League. The initial
injury included a dorsally displaced distal radius fracture and dorsally angulated minimally displaced distal ulna shaft fracture (Fig. 1). The injuries were initially managed by general orthopaedic surgeons, whereby the radius was surgically fixed via open reduction internal fixation, and the ulna was conservatively managed at the initial presentation.

Six weeks after this initial management of both fractures, the patient demonstrated radiologic findings of a well-united distal radius but early signs of malunion of his distal ulnar shaft (Fig. 2). Plain films showed a negative ulnar variance of 2.9 mm and dorsal angulation of the left ulna by 18° (Fig. 2). At the 6-month postoperative review, he had ongoing symptoms of distal radioulnar joint (DRUJ) instability with left wrist stiffness and loss of wrist strength despite undergoing a trial of physiotherapy for 2 months. At this stage, his care was transferred to a specialist hand and wrist surgeon. On clinical review, he demonstrated a positive Ballottement test, positive stress test, positive press test, and a piano key sign on his left wrist, all consistent with DRUJ instability. He had a limited range of active flexion and extension (40° each) and supination and pronation (20° and 10°, respectively) on the left wrist compared with that on the normal right side.

The decision was made to proceed with corrective ulnar osteotomy. This was challenging because it required lengthening and derotation of the ulnar deformity. Therefore, 3-dimensional planning guides were used.

Preoperative planning

Computed tomography (CT) scans of the bilateral forearms were performed before surgery. These scans were used by Materialise NV to calculate the desired lengthening and derotation of the left ulna in comparison with the normal right side. Next, 3-dimensional models of the patient’s ulna pre- and postsurgical correction as well as patient-specific drilling and cutting guides for the osteotomy and subsequent plate-fixation were designed by Materialise NV. The customized models and guides were later manufactured by Anatomics Pty Ltd (Fig. 3) with a total cost of USD 1,190 (excluding design costs). The time for manufacture was 2 weeks. However, the time from obtaining the CT scans and designing the guides to manufacturing and delivering them was approximately 3 months.

Surgical technique

Under general anesthesia, prophylactic antibiotics, and tourniquet, an incision was made along the ulnar border between flexor and extensor carpi ulnaris muscles, exposing the ulna bone. The 3-dimensional printed customized drilling guide was placed first along the medial border of the ulna, 12.8 mm from the distal articular surface, and fixed using K-wires (Figs. 3A, 4A). Drilling was then performed using this guide for later screw placements. Next, the drilling guide was removed, and the osteotomy guide was placed and fixed with K-wires (Figs. 3B, 4B). A single-cut transverse osteotomy was performed using the fixed guide. After the osteotomy, using the strategic position of the drill holes, a distal ulnar plate was fixed (5 screws) in a position allowing for specific
Figure 3. Modes of the A drilling and guide-wire guide, B cutting/osteotomy guide, C drilling guide again where red circles represent guide-wire holes and green circles represent proximal and distal drill holes. D The plate positioning after the osteotomy and desired lengthening and derotation.

Figure 4. Ulnar osteotomy drill and cutting guides and plate-fixation in vivo. A Ulnar osteotomy drill guide is fixed in place with K-wires. B Removal of the drill guide and placement of the osteotomy guide. C Ulnar plate placement after osteotomy and desired lengthening and derotation of the ulna.

Figure 5. Eight weeks after 3-dimensional guided ulnar osteotomy showing almost full range of active A pronation and B supination.
lengthening and derotation of the ulna (Figs. 3D, 4C). A demineralized bone graft was packed in the osteotomy gap to aid healing. Intraoperative left DRUJ stability was confirmed with stress testing and fluoroscopy. Soft tissue closure was completed, and a below-elbow cast was applied. The patient was placed in a below-elbow cast for 6 weeks, followed by an ulnar gutter splint for 2 weeks.

Postoperative outcomes

Clinical and functional outcomes

Clinically, at 8 weeks after surgery, the patient had improved left wrist flexion/extension to 70°/70° and supination/pronation to 70°/86° compared with 75°/75° (flexion/extension) and 90°/80° (supination/pronation) on the contralateral uninjured side (Fig. 5). At 4 months, he achieved pain-free full range of active motion of his left wrist and had returned to contact sports. At his 12-month follow-up, he continued to play in the Australian Football League, opening/closing doorknobs without difficulty, and using tools and utensils without stiffness. He completed the Disabilities of the Arm, Shoulder, and Hand questionnaire at the 12-month postsurgery mark, reporting a score of 1 for each question, including the additional work and sports modules, which yielded a total Disabilities of the Arm, Shoulder, and Hand score of 0.

Radiographic outcomes

Before the ulnar osteotomy, his plain radiographs showed a united, aligned distal radius fracture but a malunited ulnar shaft fracture with 18° dorsal angulation and a significant negative ulnar variance of 2.9 mm (Figs. 1, 6D). Six weeks after the ulnar osteotomy, his plain radiographs showed an almost neutral ulnar variance (slightly positive of 0.1 mm) with no dorsal angulation and evidence of union on this early imaging (Fig. 8). Twelve months after the ulnar osteotomy, our patient showed complete radiological union at the osteotomy site (Fig. 9).

The ulnar malunion deformity also comprised a rotational deformity assessed via CT imaging and 3-dimensional models, Figure 6. Angles for rotational deformity. Green line and IVORY bone represent the left ulna; purple line and red bone represent the mirror image of the normal right ulna, ie, the planned model of the left ulna. Negative values represent supination, and positive values represent pronation. A The proximal angle of deformity of 5° supination, B a 9.5° pronation angle of deformity in the distal segment of the ulna, resulting in an absolute rotational deformity of 14.5°, predominantly pronated. C The postcorrection residual angle of 1.5° supination in the proximal ulna. D shows 0.5° pronation residual angle in the distal ulna, resulting in an absolute residual rotational deformity of 2°, predominantly supinated. The apparent angles of deformity (ie, visible deformity) can also be derived from these images as 4.5° pronation before surgery and only 0.5° residual supination after surgery.
Figure 7. Residual angles comparing 3-dimensional/computer-planned versus postoperative alignments. The lines of best fit were calculated for each bone alignment, both 3-dimensional planned (purple) and postoperative (green) lines of best fit along all 3 (along the 3-dimensional planes) anatomical planes, A coronal, B sagittal, and C axial. D The ulnar variance is also demonstrated.
showing an absolute rotation of 14.5°, predominantly a pronation deformity (Figs. 6A, B), or an apparent rotation of 4.5° pronation when seen clinically. The absolute rotational deformity angle was measured by subtracting the distal-most axial angle comprising the deformity and the proximal-most axial angle comprising the deformity, as inspired by Filer et al., who used a 5° cut off in either direction as the normal for absolute rotational angles of the distal radius. In our case, we measured the distal angle from the horizon to a line drawn between the ulnar styloid process and a point directly opposite it on the ulnar head/articulating surface to the radius. The proximal angle was measured from the horizon to a line drawn on the ulna between the point farthest from the adjacent radius to the interosseous border of the ulna (Fig. 6). Six weeks after ulnar osteotomy, the corrected absolute rotational deformity was approximately 2° supination (an apparent deformity of 0.5° supination) (Fig. 6).

Using the software Geomagic Freeform, we also calculated residual angles at various 2-dimensional planes, comparing the 3-dimensional model (expected) and surgical correction (outcome) of the left ulna to quantify the precision of this technique. As shown in Figure 7, the residual angle in the coronal and sagittal planes was less than 1° and was 2° in the axial plane. This is consistent with previously reported residual angles for forearm osteotomies using this technique.

The combination of a neutral ulnar variance, <2° residual deformity in 2-dimensional planes, and 2° absolute rotational deformity after surgery demonstrates the accurate and precise surgical correction using 3-dimensional planning technology.

Discussion

To our knowledge, this is the first case report to describe a computer-assisted 3-dimensional guided osteotomy of an ulnar-only diaphyseal fracture malunion. It occurred in the setting of a surgically fixed distal radius fracture and malunited concurrent distal ulna shaft fracture (conservatively managed at initial presentation). Our case illustrates that corrective surgery for a complex fracture malunion could be performed with high precision (closeness of the surgical outcome to the predicted) and accuracy (degree of correction of the deformity) using 3-dimensional planning. Our patient reported a pain-free return to normal activities 4 months after surgery, which persisted at a longer-term 12-month follow-up. Radiologically, we showed near anatomical correction with residual errors matching accurate laboratory-studied cadaveric results and complete union of the ulnar osteotomy. This technique can potentially reduce operative time and intraoperative radiation and significantly reduce observer error. The major limitation of this technique is the cost associated with the 3-dimensional models and cutting guides. It also requires significant preoperative planning and increased time for surgery. Large-scale studies comparing 3-dimensional computer-assisted osteotomy with traditional osteotomy may be helpful.

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