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CASE REPORT

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Three cases of posttraumatic wrist problems solved with 3D-printed patient-specific guides

Susan Haandrikman, Femke F. Schröder, Feike de Graaff, Judith olde Heuvel and Anne J. H. Vochteloo

Centre for Orthopaedic Surgery OCON, Hengelo, The Netherlands

ABSTRACT
Symptomatic malunion of the wrist is one of the most common posttraumatic wrist problems. This study demonstrates three patients with complex malunions of the wrist who benefited from a corrective osteotomy using preplanned 3D-printed patient-specific guides, by experiencing improvement in their wrist function, grip strength and a reduction in pain.

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Introduction

One of the most common complications after conservative or surgical treatment of a wrist fracture is a malunion. This manifests itself in causing pain, stiffness, and reduction of grip strength [1,2]. When these symptomatic malunions occur, surgical correction is often necessary. Surgeons generally perform these osteotomies in a freehand fashion. However, the current trend is shifting towards preplanned 3D-printed patient-specific guides (PSGs) to improve the patient's functional outcomes [1,3,4].

Traditionally, the direction and severity of the malunion are measured on plain radiographs. This procedure is sufficient for simple deformities in the coronal or sagittal plane; however, more complex wrist fractures might have deformities in multiple planes [5]. Two-dimensional (2D) images may not provide sufficient insight into the longitudinal axis' rotational deformity [6]. Therefore, preplanning a correction in multiple planes requires a computed tomography (CT) scan of both forearms, of which a 3D model can be made. These provide greater insight into rotational and intra-articular deformities and enable a more accurate evaluation of complex deformities in distal radius fractures [5–7]. Based on the 3D model, patient-specific guides (PSGs) can be created.

Using these PSGs enables surgeons to accurately translate the pre-operative planning into intraoperative results. This improves surgical accuracy, reduces rotational malalignment, and shortens operating and imaging time [8].

Furthermore, this approach improves surgeons' confidence in the performed surgery and enables them to perform complex osteotomies that may not have been possible to undertake 'freehand' [9].

There are limited studies on complex upper limb malunion treatments [10–12], since a corrective osteotomy is more challenging for intra-articular malunions and anatomical deformities that require a multiplane osteotomy [4]. Extensive pre-operative planning is indispensable for these complex cases to ensure a successful post-operative outcome [7,13]. This case report includes three cases with complex symptomatic malunions, all treated with a corrective osteotomy using PSGs.

Materials and methods

Patient cases and history

Case 1: Intra-articular malunion of the radius

A 32-year-old female patient presented with pain and significant functional limitations in wrist movement after conservative treatment for an intra-articular distal

CONTACT Judith olde Heuvel j.oldeheuvel@ocon.nl Centre for Orthopaedic Surgery OCON, Hengelo, The Netherlands.

radius fracture. Conventional radiographs revealed a consolidated intra-articular distal radius fracture with a step-off at the lunate fossa (Figure 1a). Despite hand therapy, functional limitations remained, and an intra-articular corrective osteotomy was performed.

Case 2: Complex extra-articular malunion of the radius

A 29-year-old male patient presented with chronic wrist pain and a crooked wrist two years after a radius fracture was treated conservatively. Physical examination revealed a pronounced misshapen wrist and an unstable distal radioulnar joint (DRUJ). Conventional radiographs indicated a substantial shortening and severe dorsal angulation of the radius with an

Figure 1. Radiographs of the three cases. Consecutively case 1, case 2, case 3 pre-operative and post-operative radiographs of the wrist in anteroposterior (AP) and lateral view. Post-operative scans reveal the situation after 12, 78, and 52 weeks of follow-up respectively for case 1, 2 and 3. Of case 1 an intra-operative image is displayed to show the correction of the lunate fossa.

incongruent DRUJ (Figure 1b). The primary analysis demonstrated that to obtain a congruent DRUJ a radial lengthening was needed, with a calculated gap of 1 cm. There were two options to solve this. First, additional ulnar shortening to achieve bone contact of the radius, with a more rapid healing and recovery. The other option was leaving a bone gap that needs a bone graft and would take more time to heal. After consulting the patient about the pro and cons of both options, a shortening of the ulna and a corrective double osteotomy of the radius was performed. The latter was needed because of the severe malunion of the radius for which a single osteotomy would not have provided sufficient correction.

Case 3: Posttraumatic deformity of the ulna

A 39-year-old female patient was referred with persistent ulnar-sided wrist pain caused by a prior posttraumatic deformation of the distal ulna, due to growth arrest after a physical injury when the patient was 5 years old. Conventional radiographs revealed a short ulna and a relatively steep radius (see Figure 1c). A corrective osteotomy of the radius was performed to obtain a better anatomical position of the radius and ulna in DRUJ, without correcting the ulnar head.

Pre-operative planning and guide design

For all patients, anteroposterior and lateral X-ray images of the wrist, and bilateral CT scans (Siemens Somatom Definition, slice thickness of 0.6 mm) of the forearm were acquired pre-operatively. Radial inclination, radial height, ulnar variance, and volar tilt were measured on pre-operative X-ray images. The CT scans were analyzed by Materialise (Leuven, Belgium) to create 3D models of the radius and ulna for case 2. The costs for the production and design of the PSGs through Materialise are estimated around 2500 euros. The 3D model of the uninjured forearm was mirrored over the injured side, revealing the location and degree of deformity and defining the osteotomy plane (Figure 2).

The 3D models were used to plan the correction, by simulating the osteotomy and correcting it to match the uninjured side. The plate and screw positions were preplanned on the corrected model to indicate the most appropriate fixation. This was then engineered reversely by returning the PSGs to the initial pre-correction position and using them to design the cutting and drilling guides. The guides are designed to fit the bone structure perfectly and uniformly fit the planned osteotomy location, facilitating intraoperative positioning and re-creation of the simulated osteotomy (Figure 3).

The patient-specific osteotomy templates with guiding holes and osteotomy slits were printed using selective laser sintering, a 3D printing process. The 3D models were printed using medically certified polyamide powder and were sterilized in-house according to standard clinical guidelines.

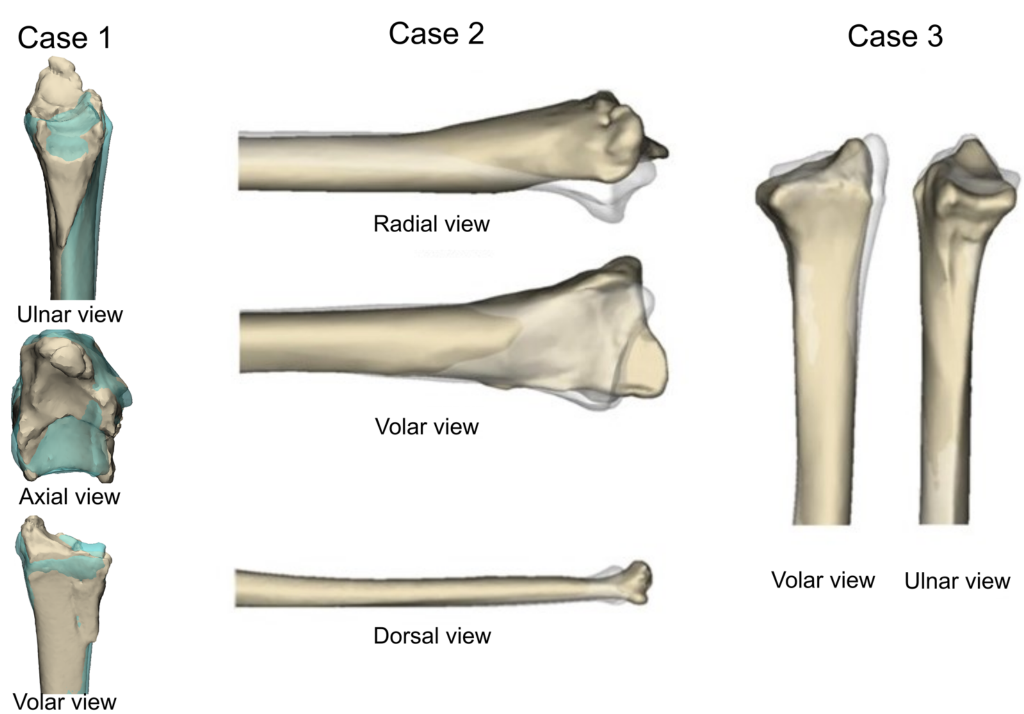

Figure 2. Mirroring the uninjured forearm (transparent blue or grey) over the injured side (beige).

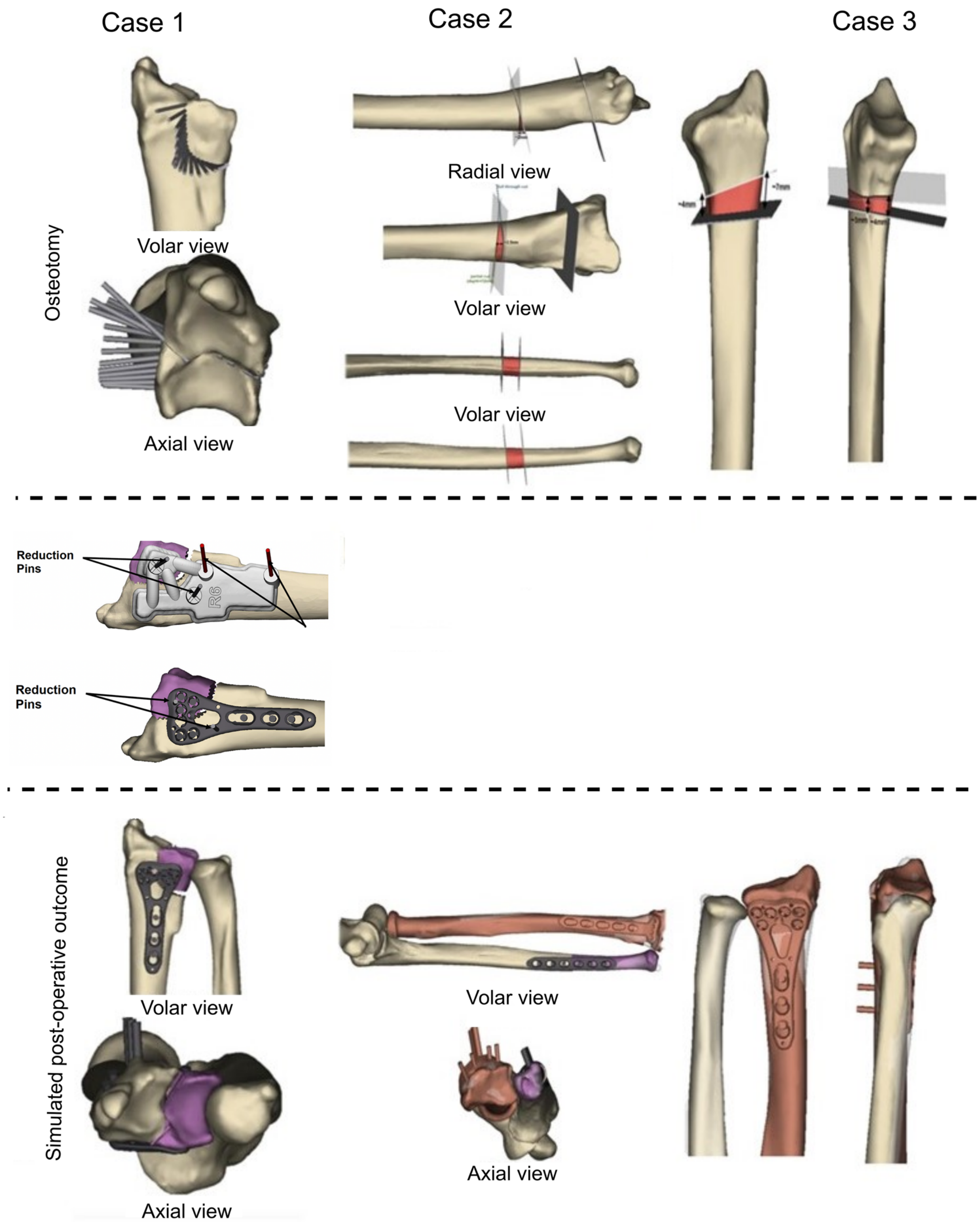

Figure 3. Results of computer-assisted planning for each patient. The top row illustrates the pre-operative planning for the correct site of the osteotomy and the degree of the necessary correction. Middle row, for case 1, the procedure of placing the reduction pins (K-wires) to ensure correct position of the distal fragment in relation to the proximal radius and plate position is displayed. The bottom row presents a virtual model after the simulated osteotomy and the plates and screws placement.

Surgical procedure

In all cases, a volar flexor carpi radialis approach was used to perform the radius osteotomy [14]. A clear exposition of the malunion side was needed to fit the drilling guide on the radius. First, the patient-specific drilling guides were fitted onto the distal radius at the predetermined location with K-wires and used as guides for predrilling. Second, the guides were positioned on the bone by comparing their position with the guides outlined on the bone models. Third, the drilling guides were replaced by the cutting guides using K-wires to guide the saw blade for the osteotomy. Finally, standard radius plates (VA 2.4 Synthes, DePuy Synthes Trauma, Switzerland) were attached with screws placed into the predrilled holes. In case 2, these steps were repeated on the ulna through a direct approach between the extensor carpi

Table 1. Range of motion, grip strength, patient related wrist-Hand evaluation (PRWHE) and visual analogue score (NRS) of the uninjured and injured sides pre-operative and one year post-operative.

		Dorsi- and plantar flexion (degrees)	Pro- and supination (degrees)	Radial- and ulnar deviation (degrees)	Grip strength (kg)	PRWHE (0–100)	NRS (0–10)
Case 1	Uninjured side	75°–0–55°	85°–0–85°	20°–0–50°	35.5	–	–
	Pre-operative	50°–0–40°	60°–0–25°	0°–0–10°	–	–	2–3
	Post-operative	60°–0–55°	80°–0–75°	10°–0–45°	36	0	0
Case 2	Uninjured side	70°–0–80°	75°–0–80°	35°–0–30°	55	–	–
	Pre-operative	80°–0–45°	60°–0–90°	20°–0–35°	19.3	71	5
	Post-operative	70°–0–70°	60°–0–90°	20°–0–40°	55	0	0
Case 3	Uninjured side	65°–0–90°	85°–0–80°	30°–0–40°	27	–	–
	Pre-operative	52°–0–48°	70°–0–80°	15°–0–30°	3	91	7–10
	Post-operative	58°–0–65°	75°–0–85°	25°–0–45°	7	49	4

PRWHE and grip strength were not documented for case 1 pre-operative.

ulnaris muscle and the flexor carpi ulnaris muscle. Intraoperative fluoroscopy was used to check the position of the osteotomy, distal radioulnar joint, correct plate position, and screw length.

Measurement techniques

The range of motion (ROM) measured with a goniometer and grip strength with a Jamar dynamometer were evaluated pre- and postoperatively at three and 12 months. Additionally, patients completed the Patient Rated Wrist-Hand Evaluation (PRWHE) [15] to assess wrist pain and disability in their daily lives on a scale from 0 to 100, a higher score indicating more pain and functional disability. Lastly, patients were asked to rate their pain using a Numeric Rating Score (NRS) on a scale of 0 to 10, 0 representing no agony and 10 being the most pain.

Clinical and radiographic follow-up examinations were conducted at 2, 6, 12 and 52 weeks post-operative.

Results

All patients demonstrated an overall improvement in ROM after one year with wrist function close to the ROM of the uninjured side (Table 1). Grip strength improved with no difference to the uninjured side in case 1 and 2. For these patients, the PRWHE and NRS scores were also fully restored. In case 3, the grip strength, PRWHE score, and NRS score lagged behind expectations. The patient stated that her recovery went well until two months before the one year post-operative measurement, when she spontaneously developed pain complaints around the ulna. All three patients stated that they experienced improved wrist function, were very happy with the obtained result, and would undergo the procedure again. None of the patients had complications.

In all cases full consolidation of the osteotomy was obtained, based on post-operative radiographic images. Normal values and acceptable limits of deformity of the surgical correction of malunited distal radius fractures are not universally defined [16]. Therefore, we used parameters proposed by de Muinck Keizer et al. [4] All post-operative radiological measurements were within the acceptable limit of deformity, with radial inclination and ulna variance restored within normal values in cases 2 and 3 and radial length in case 2 (Table 2 and Figure 1).

Table 2. Radiographic measurements pre- and post-operative.

		Radial inclination	Radial length	Ulnar variance	Volar tilt
Normal value		21–25°	10–13 mm	neutral +1 mm	11°
Acceptable limit of deformity [8]		>15°	7–15 mm	<3 mm	<20°
Case 1	Pre-operative	35°	18 mm	+3 mm	8°
	Post-operative	32°	15 mm	+2 mm	7°
Case 2	Pre-operative	9°	5 mm	+9 mm	43°
	Post-operative	22°	12 mm	0 mm	4°
Case 3	Pre-operative	35°	13 mm	−3 mm	5°
	Post-operative	23°	9 mm	+1 mm	4°

Discussion

The three presented cases demonstrate that complex wrist malunions benefit from a corrective osteotomy with PSGs. They report an improvement in ROM, grip strength, and satisfaction with the surgical outcome. The radiological parameters were restored within the acceptable limit of deformity.

Malunions after wrist fractures are often complex deformities. Although no large, randomized trials have been conducted, there is growing evidence that 3D technology can improve clinical and radiographic outcomes after corrective surgery for malunions of upper limb fractures [17]. Buijze et al. found that patients who underwent surgery using 3D planning had superior radiographic results compared to those with conventional radiographs who underwent distal radius correction. However, there was a nonsignificant trend towards better patient-reported outcomes (e.g. pain and satisfaction scores) in favor of the 3D planning due to lack of power [13].

A recent systematic review by de Muinck Keizer et al. indicated an improvement in radiographic and functional outcomes after 3D planned corrective osteotomies for a distal radius malunion [4]. Most cases demonstrated an improvement within 5° of the normal values (i.e. volar tilt and radial inclination) and within 2 mm of the planned ulnar variance. Our results were similar, with the radial inclination of case 1 being 8° outside of the normal value but within the acceptable limit of deformity. In our three cases, the average volar tilt was 6° compared to the normal value of volar tilt of 11°. The ulnar variance of all cases fell within 2 mm.

The increase in ROM after surgery is similar to the results of others studies. Schweizer et al. demonstrated an improvement in ROM and grip strength, with four out of six patients no longer suffering from pain after one year [18]. Additionally, case studies with similar complex problems as ours, revealed comparable results with improvements in pain and function and reported improvement in radiographic parameters [11,12,19].

As mentioned in the results, case 3 ROM improvement was noticeably less compared to case 1 and 2, and the patient posted higher NRS and PRWHE scores one year post-operative. The pre-operative grip strength was also very low compared to the healthy side, but did improve. A thorough review of this patient's medical records did not yield an explanation for the sudden onset of pain months after surgery.

Intra-articular corrective osteotomies can often be challenging as the fragment that has to be corrected can be rather small and fixation can therefore be a burden. Our way to dealing with this issue is using two temporary K-wires that are placed in the fragment and in the proximal radius through a specific reduction guide (securing the wanted correction and therewith the exact position and angle of the K-wires).

After removing the guide, the plate is positioned over the K-wires through the special K-wire holes in the plate (distally and proximally), therewith securing the correct position of the distal fragment in relationship to the proximal radius and plate position. Once the plate is in place, screws are put in though the pre-osteotomy drilled holes.

A limitation of this study is that post-operative 2D images might be unable to quantify the precise surgical correction. Post-operative evaluation can be improved by comparing pre-and post-operative CT scans, making it possible to determine the degree of anatomical correction with greater accuracy. To avoid unnecessary radiation, we did not obtain a post-operative CT scan [1,4,9,16].

PSGs enable surgeons to operate on these more complex fractures, which they previously might not have attempted or would have been more challenging to correct due to the lack of precise pre-operative preparations and intraoperative guidance. The accumulation of experience is likely to lead to advances in quality, reliability, and repeatability, ultimately improving treatment with PSGs for individual patients. With increasing use of this technique, larger-scale studies can be conducted to better validate the efficacy and effectiveness of 3D technology even in complex cases.

In conclusion, the three cases presented here confirm that 3D technology aids in understanding of such complex deformities and in restoring normal anatomy with PSG corrective osteotomy and function of the wrist.

Disclosure statement

The authors report there are no competing interests to declare.

Ethical approval

Informed consent was obtained from all individual participants included in the case report.

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