CASE REPORT

3D printing for corrective osteotomy of malunited distal radius fractures: a low-cost workflow

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SUMMARY

After a severe trauma, a 16-year-old female patient sustained multiple injuries, including a distal radius fracture of the left arm. This distal radius fracture eventually developed into a malunion. In this case, we demonstrate our preoperative low-cost workup for three-dimensional (3D) planned and assisted corrective osteotomy of a malunited distal radius fracture using an in-hospital 3D printer.

BACKGROUND

A malunion is still the most common complication of a distal radius fracture, causing functional limitation and pain of the wrist.[1] When surgical treatment of the malunited wrist is required, a corrective osteotomy is typically carried out to restore anatomic configuration of the wrist and improve functional outcome.[2 3] Generally, preoperative planning is done by using plain radiographs and CT scan of the affected radius. However, surgical correction of a symptomatic malunion can be difficult, especially when dealing with multiplane osteotomies.[4] Current advances in three-dimensional (3D) printing technology have proven superior preoperative understanding of the patient's anatomy as well as intraoperative accuracy.[5] 3D surgical planning together with patient-specific 3D anatomic models and custom-made surgical guides have a price; high costs varying from €1500 up to more than €5000 are reported.[6] A recently published systematic review by de Muinck Keizer *et al*[5] demonstrated that 3D planned corrective osteotomy significantly improves both radiographic and functional outcome in patients with a malunited fracture of the distal radius. Unfortunately, not one study in the review provided information about the costs when using this technique, even though the increasing concern about health costs poses an important subject. We would like to give an insight into a low-cost workflow, concerning the preoperative preparation phase of a corrective osteotomy of a malunited distal radius fracture using CT and 3D printing.

CASE PRESENTATION

A 16-year-old female patient was presented to our outpatient clinic with a symptomatic malunion of the left distal radius. Her medical history, 12 weeks prior a polytrauma after a suicide attempt, revealed the following injuries:

- multiple facial fractures,
- an avulsion fracture of L2,
- an intra-articular distal radius fracture of the left hand,
- multiple carpal fractures of the left hand (scaphoid, triquetrum and capitate),
- a calcaneal fracture of the right foot,
- a sacral fracture (both sides) and a left inferior pubic ramus fracture.

The distal radius fracture was first treated with a cast. However, the fracture gradually collapsed resulting in a malunion. Three months post trauma, the patient presented herself at the outpatient clinic with persisting pain in the left wrist and intermittent tingling in the hand, limiting her rehabilitation.

Although some of the pain could have been due to the scaphoid fracture, physical examination of the malunited wrist revealed a limited range of motion in all four axis, a visible malunion and a palpable osseous prominence on the volair side, all signs that could not be related to the scaphoid fracture.

INVESTIGATIONS

At 12 weeks follow-up (figure 1), conventional X-rays of the left wrist demonstrated a consolidated distal radius fracture in malunion, with a clear exostosis on the volar side. Additional CT scan (figure 2) revealed:

- a 4 mm shortening of the radius,
- a 30° dorsal collapse,
- a 10° radial inclination collapse.

The previously mentioned exostosis revealed penetration in the musculus pronator quadratus.

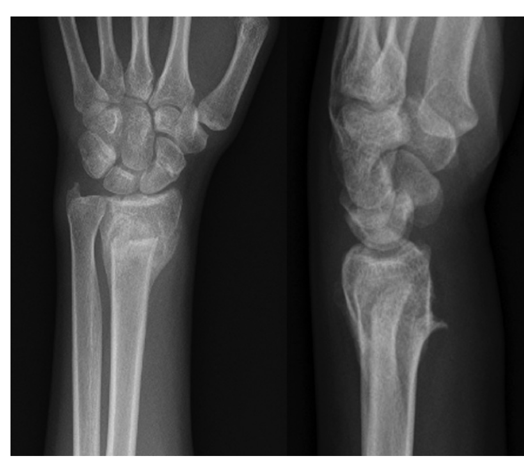

Figure 1 At 12 weeks follow-up, conventional X-rays of the left wrist demonstrated a consolidated distal radius fracture in malunion with a clear exostosis on the volar side.

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Figure 2 Additional CT of the malunited wrist revealed: a 4 mm shorting of the wrist, a 30° dorsal collapse and a 10° radial inclination collapse. The exostosis revealed penetration in the musculus pronator quadratus.

DIFFERENTIAL DIAGNOSIS

Malunited distal radius fracture.

TREATMENT

Realising that a multiplane osteotomy was necessary for the malunited distal radius, a 3D corrective osteotomy was planned. CT scans of the affected and contralateral unaffected radius were made, providing a virtual 3D template how the affected radius should be reconstructed. Both CT scans were imported in Philips Intellispace Portal, an editing program of the radiology department enabling the creation of 3D volume rendering models. Both models were exported as Standard Tessellation Language (STL)-files and imported in Simplify 3D, open source software. The 3D model of the malunited radius was

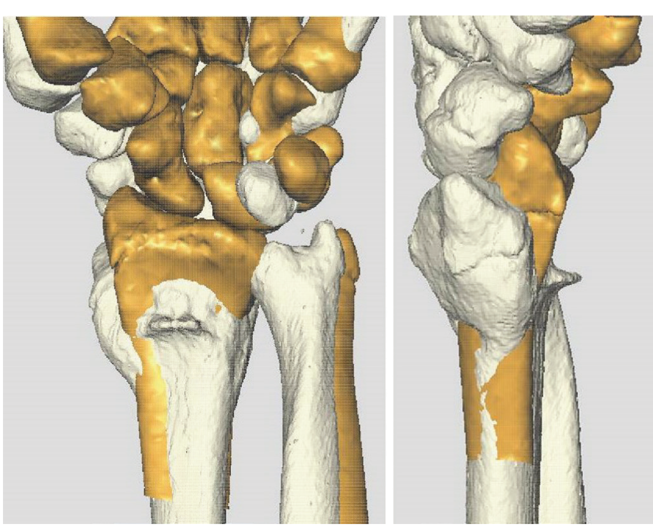

Figure 3 Virtual three-dimensional templates of the affected wrist (white) and the unaffected contralateral wrist (yellow) were created. The scan of the malunited radius was then superimposed on the mirrored unaffected contralateral radius.

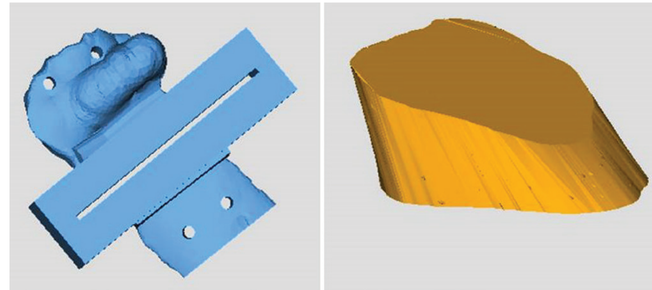

Figure 4 Custom-designed saw guides; a saw guide for the osteotomy and a saw guide for harvesting a corticocancellous wedge from the iliac crest.

superimposed on the mirrored unaffected contralateral radius (figure 3). A virtual osteotomy plane was determined, enabling virtual correction of the malunion. Subsequently, the 3D model was exported as a STL-file and sent online to a 3D laboratory at an academic hospital. The process of creating the STL-file consisted of 30 min. Through a 30 min videoconference call, the treating trauma surgeon together with a 3D medical technician, who is trained in CAD software, designed saw guides based on our virtual osteotomy. The saw guides consisted of a saw guide for the osteotomy and a saw guide for harvesting a corticocancellous wedge from the iliac crest (figure 4). There were no costs involved. The latter saw guide provided a press fit tricortical wedge enabling structural support after the osteotomy. In order to facilitate the correct placement of the osteotomy saw guide, the technician used the exophytic piece of bone on the radius as a landmark and incorporated this shape in the guide. This ensured an exact placement of the guide. The two saw guides were subsequently printed for €10 by a commercial company, specialised in sterile printing. In the meanwhile, for approximately €2 a model of the patient's malunited radius and the surgical guides (figure 5) were printed in-hospital with our own 3D printer, an Ultimaker 3 (Ultimaker, Geldermalsen, the Netherlands).

As mentioned before, the patient also sustained multiple carpal fractures of the left hand (scaphoid, triquetrum and capitate), of which the scaphoid fracture was surgically treated in the same surgical sitting by using a HCS screw.

Figure 5 A model of the patient's malunited radius and the surgical guides were printed inhospital with our own 3D printer providing material to practice the operation and osteotomy.

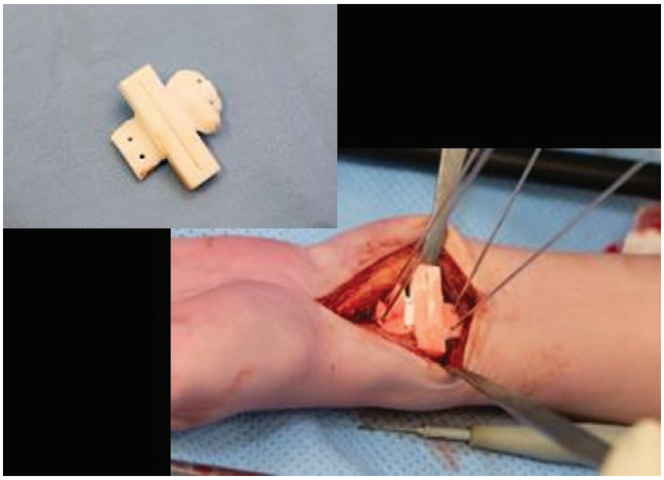

Figure 6 Intraoperative view of the surgical approach showing that the custom-designed synthetic saw guide was easily put into position, just proximal of the distal radius. The guide was temporarily fixed with 4 k-wires and the osteotomy was performed.

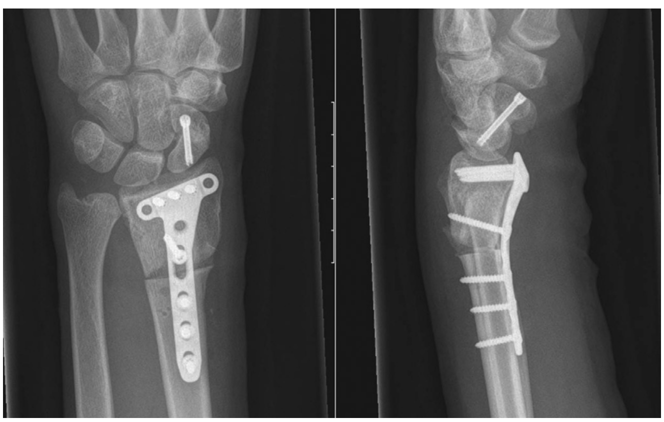

Figure 7 Early postoperative X-rays of the patient's left wrist after reconstruction with an opening-wedge osteotomy and fixation with a 2.4 T plate confirmed near anatomical reconstruction.

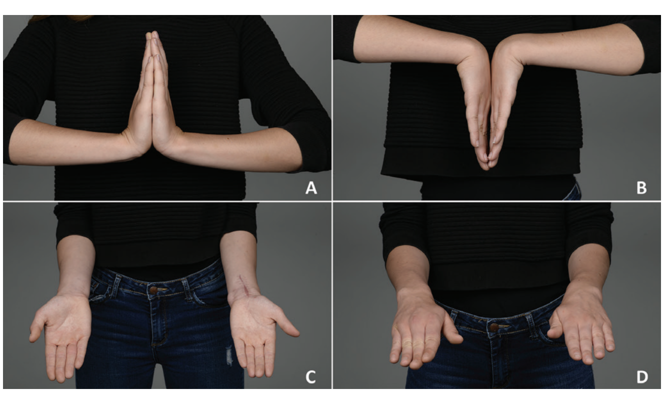

Figure 8 The patient is showing full range of motion and maximum strength at 3 months follow-up: (A) dorsal extension, (B) plantar flexion, (C) supination and (D) pronation.

OUTCOME AND FOLLOW-UP

The operative procedure was initiated as any distal radius operation. A volar henry approach was performed. After exposure of the malunion, the custom-designed synthetic saw guide had a perfect fit on the exophytic bone. The guide was temporarily fixed with 4 k-wires and the osteotomy was performed (figure 6). Subsequently, the iliac crest was explored and fitted with the saw guide for obtaining the graft. Using this guide, a mathematical accurate wedge was obtained to fill the defect. The distal radius was stabilised with the wedge in place using a 2.4 LCP volar T plate (article number: S442.492; Depuy Synthes). The malunion was reduced to near anatomical position. Postoperative X-rays confirmed near anatomical reconstruction (figure 7). The total length of the procedure was 1 hour. Postoperative treatment involved non-weight bearing exercise with physiotherapy. Follow-up at 3 months showed an anatomical position with a consolidated osteotomy. Physical examination at 3 months follow-up revealed full range of motion (dorsal extension 0–80, palmar flexion 0–80, supination 0–90 and pronation 0–90) without experiencing any pain (figure 8A–D).

Figure 9 Anteroposterior and lateral X-ray views of the wrist 6 months after opening-wedge osteotomy and plate fixation showing anatomical position with callus forming.

Conventional X-rays of the wrist 6 months after opening-wedge osteotomy and plate fixation still showed an anatomical position with callus forming (figure 9). One year postoperative the patient completed the Disabilities of the Arm, Shoulder and Hand (DASH) outcome questionnaire. The DASH disability and symptom score was 30. For the Work and Sports modules the patient scored a 37.5 and a 31.25, respectively.

DISCUSSION

Since the first introduction of the 3D printing process in 1986 by Charles Hull,[7] a lot has changed. In the medical setting, 3D printing provides the freedom to produce custom-designed and custom-built products, such as implants, prosthetic moulds, tissue and organ fabricants and equipments.[8] 3D planned surgery seems a promising technique. The treatment of complex malunited distal radius fractures requires precise preoperative planning and an accurate operative technique. 3D printing is able to provide this accurateness by virtually precisely reproducing the patient's surgical anatomy thereby making it possible to manufacture custom-designed surgical guides.[9] However, although in theory the application of medical 3D printing is endless, there are still obstacles that hinders its full usage. One of the biggest obstacles is the high commercial cost, which makes it doubtful for many institutions whether 3D printing is feasible. Despite the price reduction of 3D printers through the years, the high availability and simplicity of planning, hospitals are still not routinely implementing 3D printing. Furthermore, when 3D printing is used, it often is outsourced.[10 11] Subcontracting the 3D process to commercial companies creates unnecessarily high costs varying from €1500 up to more than €5000 depending on the complexity of the reconstructions.[6] Compared with other studies, we have established a low-cost workflow that allows the creation and design of complex anatomic models using free open-source software and in-hospital software combined with our own in-house 3D printer. Our Ultimaker 3 costed €3626. The investment of the 3D printer refund itself in less than 10 3D planned operations according to the manufacturing costs of the study by Wilde and colleagues.[6]

The in-house printed saw guides and anatomical models costed less than €50. The surgical guides, suitable for the operation were €10 and the consultation of the academic 3D lab specialist was for free. Moreover, when not subcontracting the 3D process to commercial companies, like mentioned before, the surgeon is able to rehearse his own operation and thereby learning everything necessary for executing the operation. Suggestions were made that planning might be more accurate when performed by the surgeon than when outsourced.[12]

In our case, the surgeon prepared all steps himself except for making the STL-files of the saw guide. This was done in collaboration with an academic 3D technician who was given the technical instructions needed. By stimulating collaboration with academic 3D labs learning situations can be created. On the one hand, the surgeon can use the knowledge and expertise of the 3D technician and on the other hand the academic 3D labs can increase their experience of preparing more complex surgery. Other benefits of a basic in-hospital 3D printing lab are that the patient's DICOM files do not have to be sent away by mail thereby protecting the patient's privacy and that 3D printing will be accessible 24/7 instead of only during office hours, which is the case when managed by other parties. A beneficial effect of surgical guides in terms of time management was seen by Honigmann *et al*[10] showing a reduction in operation time by 30 min when using any guides. In our case, the total operation time was 60 min with an additional 60 min required for preoperative planning and design. We conclude that our low-cost workflow for 3D printing in corrective osteotomy of a malunited distal radius fracture is beneficial in terms of costs and enhancing preoperative planning. With the purchase of your own 3D printer, open-source software and in-hospital software and collaboration with the academic institutions new learning situations are created and the surgeons can prepare their own operation.

Patient's perspective

The first author requested several times for the patient's perspective; however, the patient does not want to look back on the traumatic experience. This is her official reply: 'I do not like to look back on what happened. I have to live and deal with it for the rest of my life! I had a lot of help in the past couple of months. This helped me to stay on the right path and learn from it. My life's motto has always been: live day by day and enjoy life to the fullest'.

Learning points

- By not outsourcing preoperative workouts to expensive commercial companies, drastic price reduction is feasible.
- With the purchase of your own three-dimensional (3D) printer, free open-source software and in-hospital software and collaboration with academic hospitals, you can easily prepare your own operation.
- We would not recommend the use of 3D printing models if the extent of the deformity could be accurately assessed from standard X-ray films or CT scans.

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