Patient-Specific Digital Modeling and 3D Printing for Preoperative Planning in a Pediatric Distal Radius Osteotomy: A Case Report

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ABSTRACT

INTRODUCTION: This case report describes the utilization of patient-specific 3D modeling for the care of a 13-year-old patient with a distal radius malunion and partial growth arrest.

METHODS: Patient-specific 3D models of the patient's wrist were created using computed tomography scans. Digital modeling software was used to determine the appropriate orientation of the osteotomy, size and shape of bone graft, and final wrist alignment. The 3D models were used to rehearse the osteotomy preoperatively. Intraoperatively, bone graft was harvested to the planned specifications and the osteotomy was successfully performed followed by stabilization.

RESULTS: Radiographs demonstrated appropriate correction of radial length, alignment, and rotation matching the preoperative 3D model. At final follow-up, the patient demonstrated union of the osteotomy and full recovery with excellent function.

DISCUSSION: Patient-specific 3D modeling and printing provide valuable tools for planning complex surgical cases. Further research is warranted to assess the broader applications of this technology in orthopedic surgery.

KEYWORDS: 3D printing; distal radius; malunion

INTRODUCTION

Distal radius fractures are among the most common pediatric injuries.[1] Most of these fractures can be managed conservatively with closed reduction and casting. However, some cases may be complicated by physeal growth arrest, which can result in progressive angular deformity of the distal radius, altered wrist biomechanics, and poor functional outcomes.[1] Surgical intervention is often necessary to correct these complications and precise preoperative planning is crucial to achieving a successful correction.

Recent advances in medical imaging and additive manufacturing have enabled the integration of patient-specific digital modeling and 3D printing into orthopedic surgery. These techniques enable the creation of patient-specific anatomical models allowing for improved visualization, enhanced surgical planning, and the opportunity to rehearse complex procedures preoperatively.[2-4] Additionally, the use of 3D-printed osteotomy guides and graft templates can enhance the accuracy of bone cuts and graft placement during surgery.[5,6]

In this case report we present the successful application of patient-specific digital modeling and 3D printing in the preoperative planning and surgical management of a 13-year-old girl with a distal radius malunion and partial physeal arrest due to prior fracture.

CASE SUMMARY

A 10-year-old girl presented to the emergency department with left wrist pain after falling while playing soccer. Imaging revealed a Salter-Harris type II distal radius fracture with volar displacement and an ulnar neck buckle fracture. She underwent conscious sedation with closed reduction and was made non-weight bearing in a long arm cast. Upon subsequent follow-up, imaging revealed recurrent volar angulation of the fracture. She was taken to the operating room for closed reduction and percutaneous pinning of the distal radius. The pins were removed at six weeks, and she went on to heal the fracture with roughly 15 degrees of dorsal angulation. At two years post-injury, she was noted to have worsening dorsal angulation (27°) and positive ulnar variance (6 mm) due to partial arrest of the distal radial physis [**Figure 1**]. Given the significant deformity and worsening symptoms, surgical correction via distal radius osteotomy with iliac crest autograft and distal radial/ulnar epiphysiodesis was planned.

Figure 1. Preoperative left wrist radiographs demonstrating malunion and partial physeal arrest.

The patient underwent a non-contrast CT scan of the left wrist for preoperative planning. The Digital Imaging and Communications in Medicine (DICOM) data from the patient's CT scan were imported into Aquarius iNtuition 3D workstation (TeraRecon Inc., San Mateo, CA). Using the software, the bony structures of the wrist were carefully isolated and distinguished from the surrounding soft tissue based on their radiodensity values. Next, the segmented structures were converted into a 3D digital model where they could be further refined and adjusted to ensure anatomical accuracy. Once the digital model was finalized, it was exported as a Standard Tessellation Language (STL) file [**Figure 2**].

The STL file was imported into Blender, an open-source 3D modeling application, where the deformity could be visualized and measured in three dimensions.[7] An osteotomy plane was defined that would allow for correction of the length, alignment, and rotation of the distal fragment to reasonable parameters (neutral ulnar variance, 10 degrees radial inclination, 5 degrees volar tilt). To ensure reproducibility in the operating room, the osteotomy was oriented parallel to the joint surface. Then, the distal fragment was separated and moved to its desired final position in Blender. Finally, a volumetric body was created from the resultant osteotomy gap; this represents the ideal size and shape of a structural bone graft that would be needed to maintain the correction [**Figure 3**].

The digital models were then exported as STL files and imported into Ultimaker Cura, a slicing application for 3D printers, which allows the models to be sliced into layers and converted into machine instructions for 3D printing.[8] The models were printed at 1:1 scale on the author's own fusion deposition modeling desktop printer (Ender-3 V2, Creality©, Shenzhen, China) using polylactic acid (PLA) filament [**Figure 4**]. Prior to the procedure, the models were used to visualize the deformity in three dimensions. A cast saw was used to rehearse the osteotomy on the model to ensure that the desired correction could be achieved with the planned cut. It was also verified that the interposition bone graft piece fit appropriately to maintain correction [**Figure 4**].

During surgery, the patient was positioned supine and underwent general anesthesia. An appropriately-sized iliac crest bone graft was harvested from the ipsilateral iliac crest. The 3D printed bone graft piece was brought into the operating room and used as a visual reference for appropriate graft sizing. The option to place the graft model into a sterile bag on the operative field was available; however, this was deemed unnecessary. A 1 cm incision was then made over the ulnar neck and a standard lateral approach was used to expose the distal ulnar physis. A distal ulna epiphysiodesis was performed with a 2.5mm drill bit. Next, a 3cm longitudinal incision was made over the dorsal aspect of the wrist. The distal radius was approached dorsally between

Figure 2. Preoperative digital model of the left wrist created by segmenting CT scan data.

Figure 3. Preoperative digital model of the left wrist demonstrating planned osteotomy orientation, final orientation of the distal segment after planned correction, and the interposition graft needed to achieve the desired correction.

Figure 4. Preoperative 3D printed model of the left wrist before and after simulated osteotomy with insertion of the 3D printed interposition graft model.

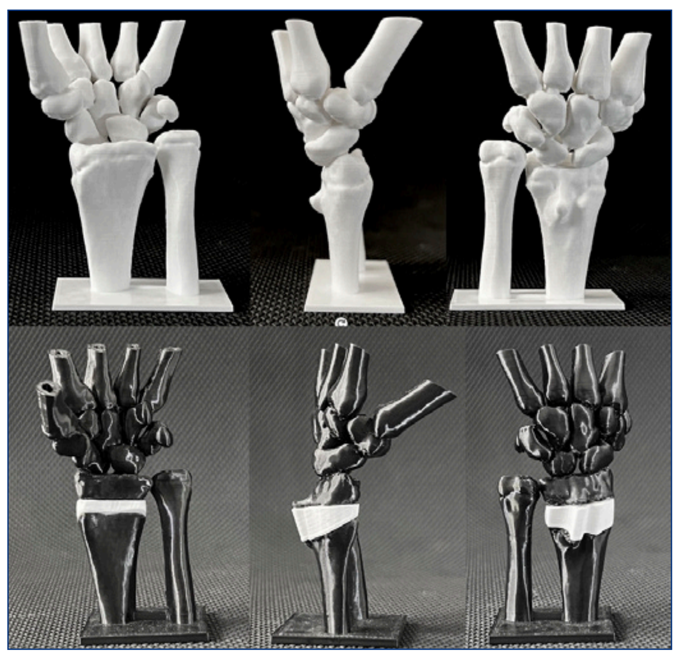


Figure 5. Intraoperative fluoroscopy demonstrating correction of length and alignment of the distal radius after osteotomy and placement of fixation hardware.

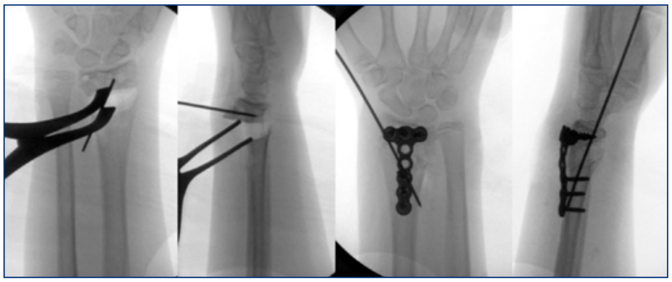
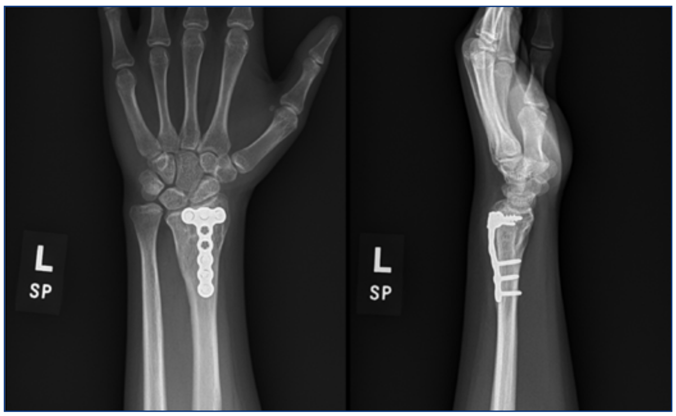


Figure 6. Postoperative left wrist radiographs at final follow-up demonstrating maintained correction of alignment of the distal radius.



the third and fourth extensor compartments. A large malunited Lister's tubercle was excised with a rongeur. A distal radial epiphysiodesis was performed with a 2.5mm drill bit, which was left in the physis to mark its location and orientation. Using the 3D model as a reference, a sagittal saw was used to osteotomize the distal radial metaphysis along the planned orientation. The distal segment was elevated with a laminar spreader and placed into its final position using the drill bit as a joystick. The iliac crest autograft was placed into position and held in place with a radial styloid pin. After confirming that the distal fragment and iliac crest autograft were in appropriate position with fluoroscopy, an eight-hole 2.7 mm T-plate was placed and fixated with 2.7 mm fully threaded screws. Final intraoperative radiographs demonstrated appropriate restoration of alignment parameters (radial length, volar tilt, and radial inclination) [**Figure 5**]. After irrigation and closure, the patient was placed into a long arm cast and discharged on postoperative day one. Her postoperative follow-up duration was 19 months. Upon final follow-up, she had regained full forearm pronosupination, wrist extension, and radial deviation; however, wrist flexion and ulnar deviation both lacked 10 degrees compared to the contralateral wrist. She had no pain with range of motion or functional use of her wrist. Final follow-up imaging demonstrated union of the osteotomy with maintained alignment of the distal radius; however, unintended overgrowth of the distal ulna physis resulted in 5 mm of positive ulnar variance [**Figure 6**].

DISCUSSION

The management of pediatric forearm and wrist deformity requires careful preoperative planning and precise osteotomy orientation to achieve a desirable correction. This case report demonstrates a workflow for patient-specific 3D modeling and 3D printing that can be used to plan and rehearse pediatric wrist deformity correction or other comparable cases. In this case, preoperatively creating the osteotomy in software allowed for optimization of the orientation in order to achieve the desired correction in a way that would be favorable to the surrounding soft tissue. Rehearsing the osteotomy on the 3D printed model allowed for practice to ensure that the planned osteotomy orientation would be easily reproducible at the time of surgery. Finally, the 3D printed interposition graft model allowed for intraoperative sizing of the patient's iliac crest autograft in order to minimize wasted autograft and to properly shape the graft to produce the desired correction. This graft model was kept off of the sterile field and used as a visual reference during surgery; however, the option exists to place the model in a sterile bag on the field if direct interaction with the model is needed intraoperatively.

The utilization of 3D modeling and 3D printing in orthopedic surgery is expanding and becoming more accessible to surgeons. Several studies have reported on its potential uses, including medical education, surgical training, patient education, surgical planning, instrument guides, and patient-specific implants.[2,6,9-11] In the case of surgical planning, a systematic review by Lee et al included 17 studies involving 889 patients with pelvic and acetabular fractures, 431 of which were randomized to allow the surgical team access to a 3D printed model of the injury for preoperative planning, plate contouring, and screw length estimation.[12] They found that access to the 3D printed model was associated with a significant decrease in surgical duration, blood loss, intraoperative imaging, and postoperative complications, and a significant increase in rates of excellent/good reduction quality. Similarly, a systematic review and meta-analysis by Morgan et al included 17 studies involving 922 patients who underwent orthopedic trauma surgery found that 3D printing for preoperative planning was associated with a significant reduction in operative time, intraoperative blood loss, and fluoroscopy use.[13]

While the benefits of 3D modeling and 3D printing for preoperative planning are evident, the implementation of this technology can involve a financial barrier and/or a technological learning curve. Several publications have outlined specific roadmaps to implementation of this technology.[14,15]

This study adds to the literature by describing a methodology to produce 3D printed models of orthopedic injuries at a low cost.

Furthermore, 3D modeling and 3D printing technology have allowed for creation of custom osteotomy guides. This can significantly improve accuracy and consistency when performing corrective osteotomies.[11] However, this technique can come with significant cost barriers and institutional red tape, as the osteotomy guides must be designed with highly specialized software, and the guide must be fabricated with a material that is suitable for sterilization and intraoperative patient contact. In contrast, this case report demonstrates a much lower-cost and more approachable technique for utilizing 3D modeling and 3D printing for advanced surgical planning in an osteotomy case without the requirement of sterilizability and patient contact.

In conclusion, while distal radius malunion in pediatric patients present formidable challenges, the application of 3D modeling and 3D printing offers an exciting avenue to enhance surgical precision and potentially improve patient outcomes. Our results align with the growing body of literature on this subject. More extensive studies with larger cohorts are warranted to validate these findings and expand upon the broader utility of 3D technologies in orthopedic surgery.

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Disclosures

None

Ethical Statement: Our institution does not require ethical approval for reporting individual case reports.

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