



## Utilization of a 3D-printed model for preoperative planning and operative osteotomy of a pediatric cubitus varus deformity



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Cubitus varus is a challenging-to-treat complication following pediatric fractures of the elbow.<sup>2</sup> This is typically thought to occur secondary to malunion of the fracture or uneven growth resulting in varus angulation.<sup>9,10</sup> “Classic” cubitus varus deformity typically consists of varus, extension, and internal rotation, with varying degrees of deformity in any of those planes.<sup>18</sup> The multiplanar nature of this deformity frequently causes cosmetic issues and occasionally compromises function or results in a tardy ulnar nerve palsy.<sup>9</sup> Several types of corrective osteotomies have been described in the literature.<sup>1,4,6,7,11,12,14,16,19,22</sup> Axial imaging, typically with computed tomography, has been used to aid in preoperative planning.<sup>6,13,18,20,21,23,24</sup> However, computed tomography has many limitations compared to magnetic resonance imaging (MRI), especially with regard to the visualization of cartilage and other nonossified tissues in the skeleton of pediatric patients. With the development and increasing prevalence of 3-dimensional (3D) printing, this modality has great advantages for use in planning deformity correction.<sup>1,6,7,11,12,14,16,19,22</sup> This study describes the use of MRI with 3D modeling and printing for the preoperative planning and operative execution of a supracondylar humerus osteotomy for correction of cubitus varus.

### Case report

A 3-year-old right hand–dominant boy with no significant past medical history was seen in the Pediatric Orthopedic Surgery clinic with complaints of right elbow deformity that developed after nonoperative treatment of a right humerus lateral condyle fracture sustained 2 years prior. The patient reported intermittent pain and

used his left hand for most activities during the day. He had met all other developmental milestones for his age and had otherwise been healthy. On physical examination, the patient's right arm had a cubitus varus deformity with a lateral bony prominence (Fig. 1). Carrying angle was 18° of varus on the right upper extremity and 5° of valgus on the left. He had mildly decreased flexion on the right compared to the left, but otherwise had full range of motion. His neurovascular examination was normal. Plain radiographs confirmed a cubitus varus angulation with internal rotation of the capitellum and a bony prominence at the lateral epicondyle (Fig. 2, A and B). Humerus–elbow–wrist angle was 29° of varus on the right and 10° of valgus on the left. The angle between the humeral epicondyles and humeral shaft was 71° of varus on the right and 90° on the left. Tilt angle was 29° on the right and 24° on the left.

The family requested surgical correction of the right elbow deformity, and a right lateral closing wedge supracondylar



**Figure 1** Clinical photograph of the patient's right arm demonstrating cubitus varus deformity with varus carrying angle and internal rotation of the distal humerus.

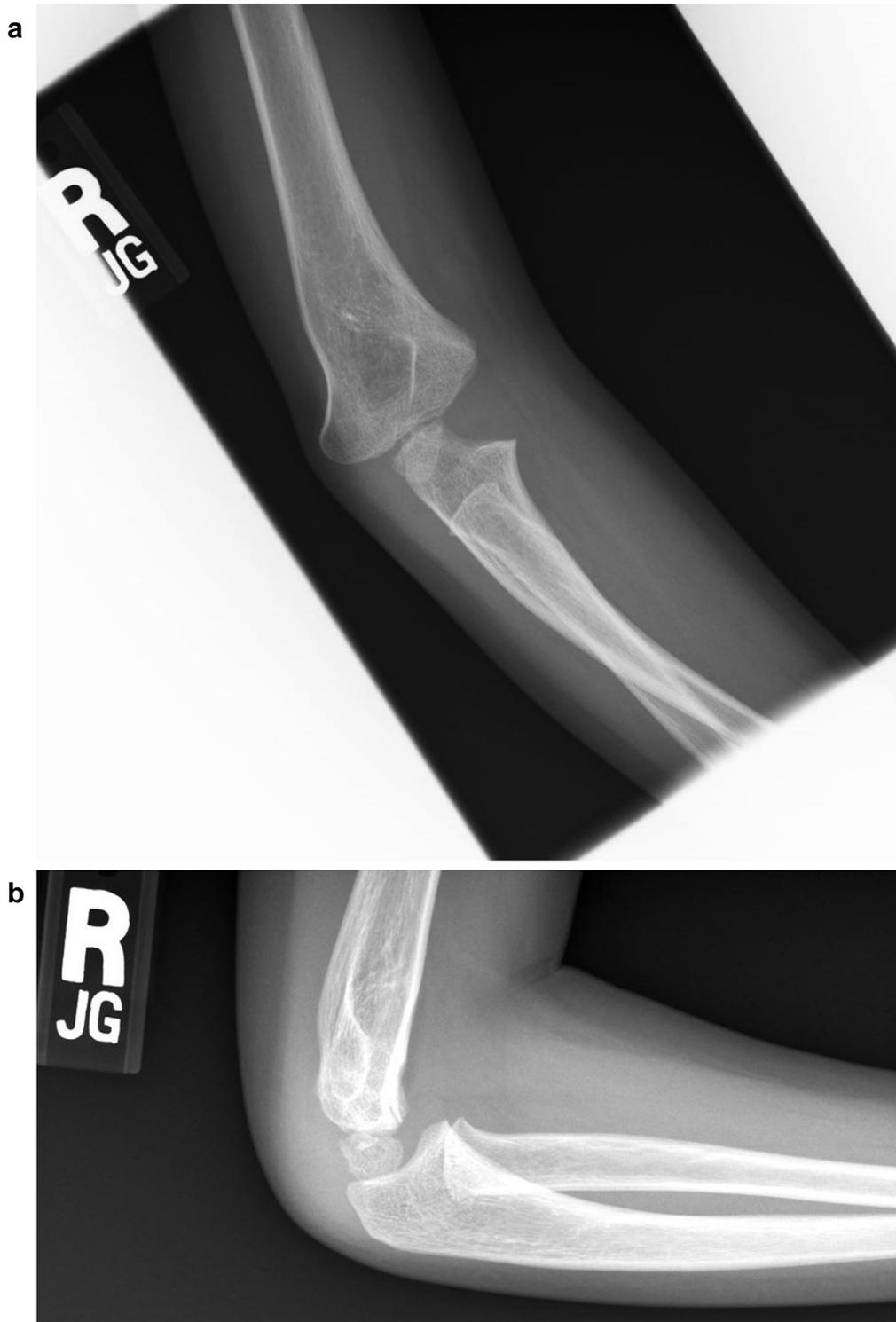
The Western Michigan University Homer Stryker M.D. School of Medicine Institutional Review Board has determined case reports to be exempt from review. The patient's parents consented to publication of this case report.

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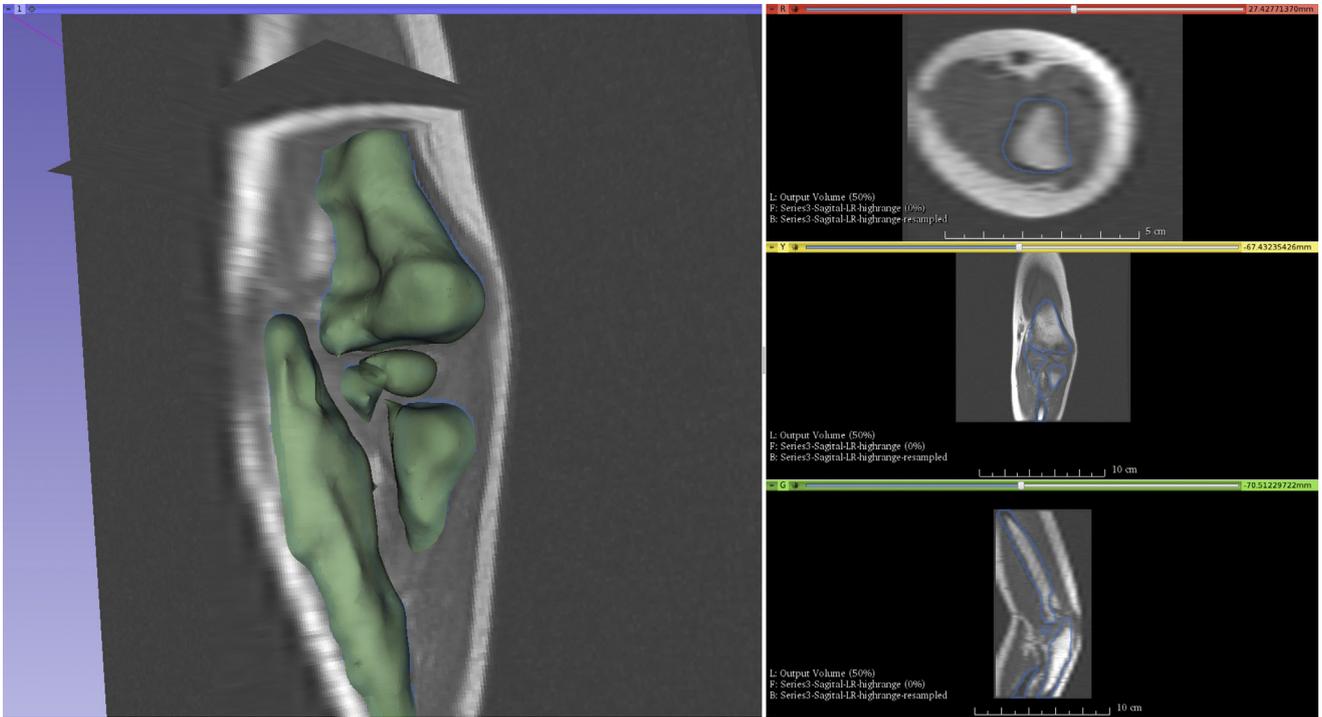
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**Figure 2** Anteroposterior (a) and lateral (b) radiographs of the right elbow demonstrating cubitus varus deformity.

humerus osteotomy with right elbow arthrogram was recommended. During preoperative planning, MRI of the right elbow without contrast was obtained for better visualization of the deformity, including the cartilaginous portions of the epiphysis and alignment of the articular surfaces. Segmentation was completed using 3D Slicer (version 4.5, <https://www.slicer.org/>, accessed August 2018) to convert the images to a 3D surface representation of the bony/cartilaginous anatomy of the distal humerus (Figs. 3

and 4). The surfaces were used to 3D-print physical representations of the deformity. Corrective osteotomy was planned using Boolean operations and surface transformations (ie, virtual corrective osteotomy) on the computer model (Fig. 5) using FreeCAD (version 0.16, <https://www.freecadweb.org/>, accessed September 2018). Subsequently, 2 simulated physical corrections were performed in the lab using 3D-printed models (Fig. 6). This allowed formulation of a precise operative osteotomy plan.

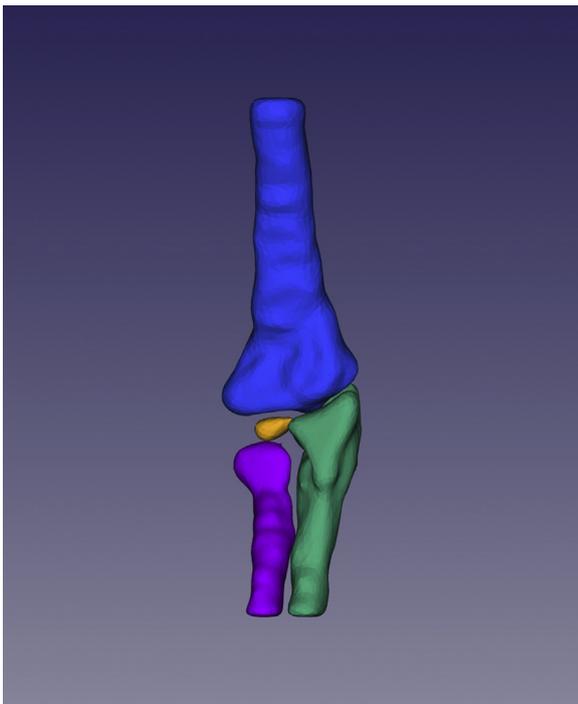


**Figure 3** Segmentation of the magnetic resonance images.

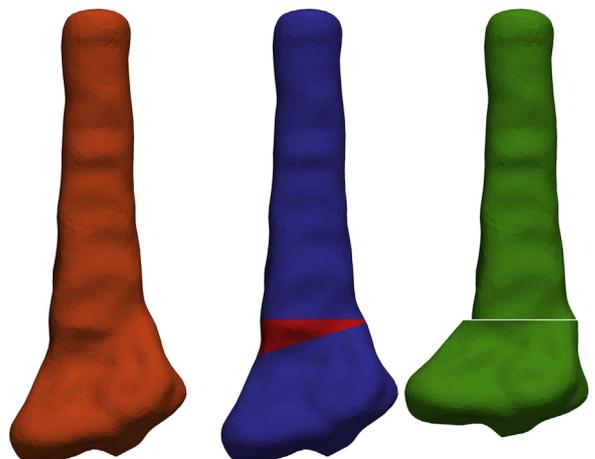
Under general anesthesia, range-of-motion examination was performed using a goniometer. The carrying angle for the right upper extremity was 18° of varus compared to 5° of valgus on the left. Right elbow flexion was 130° compared to 150° on the left. Both right and left elbow had approximately 20° of hyperextension. The right shoulder lacked 20° of external rotation compared to the

left. The surgical procedure was performed with the patient positioned supine with the right upper extremity supported on a hand table. The right upper extremity was prepped and draped, and C-arm fluoroscopy was used to remeasure the humeral-elbow-wrist angle. Two lateral-entry Kirschner (K)-wires were placed through the skin into the capitellum and advanced into the distal humerus. Articular alignment was confirmed with arthrography. The right upper extremity was exsanguinated with an Esmarch bandage, which was then left in place as a tourniquet. The Esmarch bandage was used because of the small size of the patient's arm as the smallest pneumatic tourniquet available at our institution would have partially covered the desired incision and surgical site. The tourniquet was removed after 98 minutes. Hemostasis was maintained and perfusion was confirmed.

The distal humerus was exposed subperiosteally through the interval between the brachioradialis and triceps. A K-wire was



**Figure 4** Computer model produced from segmentation of the magnetic resonance image to create a 3D surface representation of the patient's elbow.

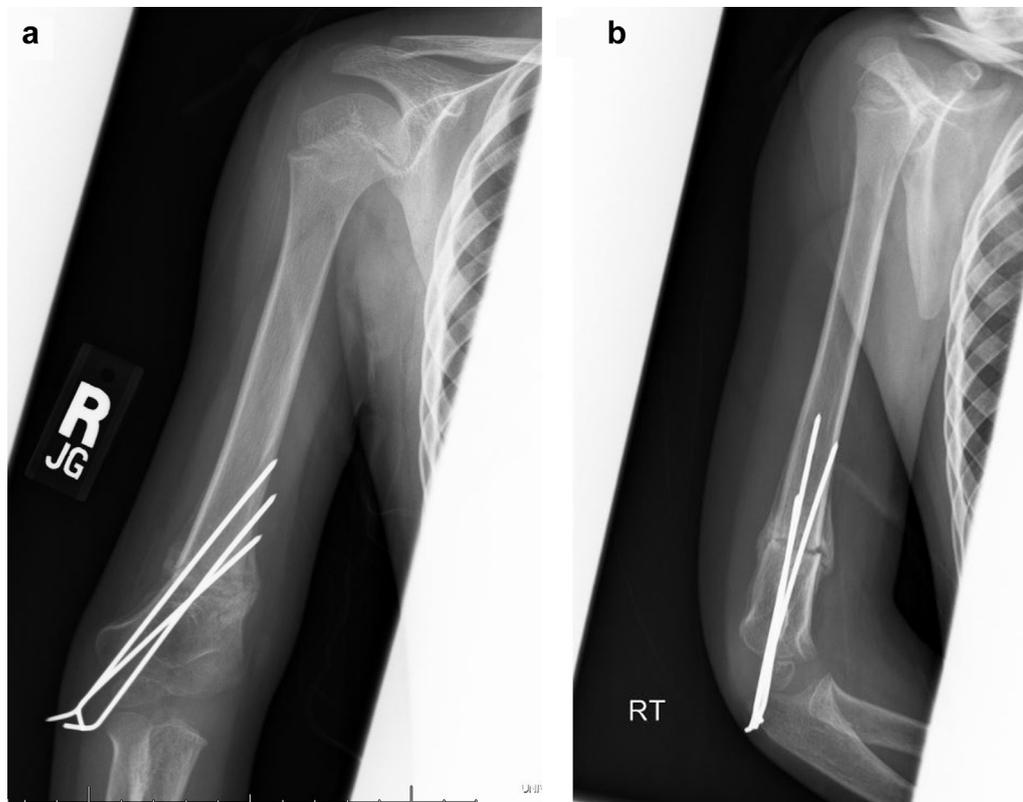


**Figure 5** Virtual corrective osteotomy planned using computer model.



**Figure 6** 3D-printed model with planned cut from the computer model executed in the lab.

inserted parallel to the joint line as confirmed by arthrogram and preoperative planning to use as a reference. The osteotomy was started perpendicular to the shaft of the humerus on lateral view and parallel to the articular surface on anteroposterior view. In accordance with preoperative planning using both the computer model and 3D-printed model to create the appropriate-sized wedge for the desired coronal angular correction, 6 mm was measured proximally along the lateral cortex and a second K-wire was placed to confirm the trajectory, with the planned cuts converging at the medial cortex. Fluoroscopy was used to confirm the desired trajectory and angulation in multiple planes. A saw was used to begin the osteotomy, and the wedge of bone was removed using an osteotome. The planning K-wires were removed and the osteotomy was closed with a slight amount of external rotation to match that planned with the use of the 3D-printed model preoperatively. With the osteotomy reduced, the previously placed distal capitellar K-wires were advanced across into the proximal humerus to provide fixation of the osteotomy. Alignment was confirmed with C-arm fluoroscopy, and the angle between the joint line and the diaphysis was found to be approximately 90°. The range of motion of rotation of the shoulder now matched the contralateral side, confirming the amount of external rotation chosen was appropriate. A final percutaneous lateral entry K-wire was placed for additional fixation and the incision was closed appropriately. The patient was placed in a long arm cast in approximately 70° of elbow flexion. He did well postoperatively and was discharged home the next day. Radiographs taken 4 weeks postoperatively are shown in [Figure 7](#). Casting was discontinued 6 weeks following surgery. At 15 months postsurgery, the patient had improved clinical alignment ([Fig. 8](#)) and range of motion equal to the contralateral side. Radiographs demonstrated neutral alignment of the right elbow with normal-appearing physes. At 28 months postsurgery, the patient continued to have symmetric range of



**Figure 7** Anteroposterior (a) and lateral (b) radiographs of the right humerus 4 weeks after surgery demonstrating healing osteotomy with pin fixation in place. The pins were removed without complication at this follow-up visit in the office.



**Figure 8** Clinical photograph taken 15 months postoperatively demonstrating improvement in right upper extremity carrying angle.

motion in both upper extremities and normal neurovascular examination. Radiographs confirmed appropriate alignment and healing (Fig. 9). He was participating in all activities as desired and denied pain.

### Discussion

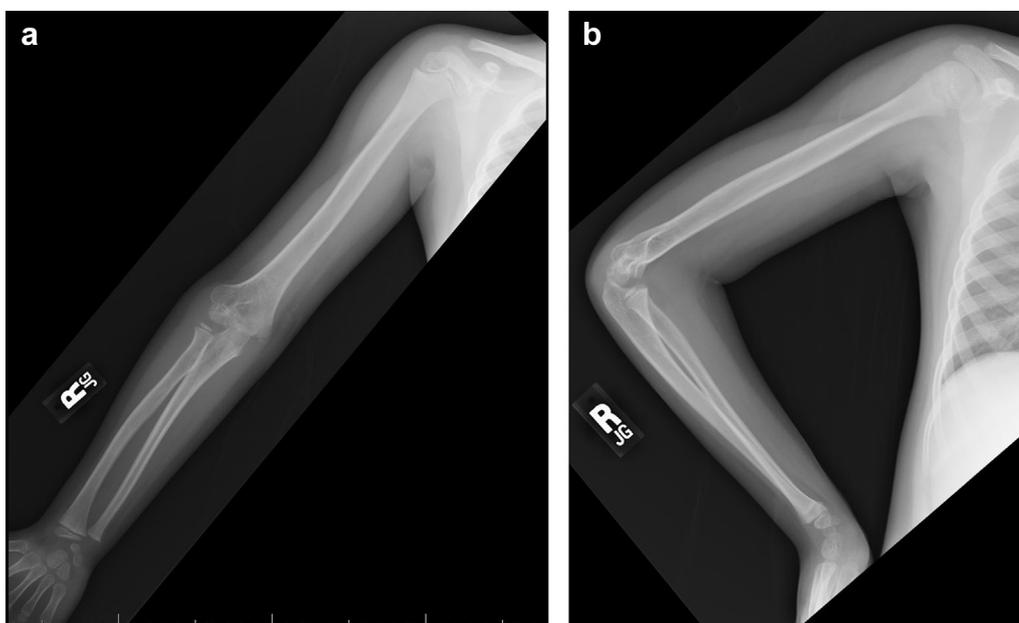
Supracondylar osteotomies are common procedures for the correction of posttraumatic cubitus varus in pediatric patients.<sup>16,19</sup>

Multiple surgical techniques are described in the literature, and it is difficult to determine if one technique is verifiably superior to the others.<sup>1,4,7,12,14,16,19,22</sup> Regardless, almost all stress the importance of detailed preoperative planning as complications are common and patient satisfaction with cosmetic outcomes remains a concern.<sup>2,3,15</sup>

3D-printed models are a valid way to conduct comprehensive and accurate preoperative planning, especially when performing corrective osteotomy for complex multiplanar deformity.<sup>17</sup> This allows simulation to fine-tune the osteotomy and demonstrates quantitative measurements and anatomic landmarks matching that of the patient's native anatomy to assist in performing the surgical procedure.<sup>5</sup> The impact of this planning method varies. Even when the resulting surgical technique is similar, the location of incisions and the design of the osteotomy are refined to reflect decisions made during practice on the models. Overall, 3D-printed models allow for reduced operating room time and improved clinical outcomes in a majority of patients, with a downside often being increased costs.<sup>8,17</sup> The authors found practicing the correction on the 3D-printed model to be especially useful in planning the rotational portion of the correction, as noting the offset created at the desired rotation of the osteotomy provided another way of confirming appropriate alignment during the procedure.

The potential benefits of in-depth preoperative planning with hands-on practice on a 3D-printed model may be especially seen in surgery for pediatric patients.<sup>5</sup> Surgery becomes more specific and focused, creating a functionally and cosmetically appealing osteotomy while lowering the risk of repeat osteotomy in patients who have such little bone. Accuracy in surgical management is paramount in pediatric patients, as every surgery has long-term implications for the overall health and satisfaction of the child and complications may be devastating.

Relatively little literature is available concerning the use of 3D-printed models for the correction of cubitus varus in children. Multiple examples can be found utilizing 3D-modeling software and 3D-printed surgical guides for preoperative planning and intraoperative assistance, but few go so far as to practice the surgical plan on an anatomically correct model.<sup>13,20,21,23,24</sup> In those



**Figure 9** Anteroposterior (a) and lateral (b) radiographs of the right upper extremity 28 months following surgery demonstrating deformity correction and healing of the osteotomy with preserved physes. There has been appropriate interval growth and appearance of additional ossification centers at the radial head and medial epicondyle.

examples where 3D-printed modeling is used extensively, the patients in question are usually adults.<sup>6,8</sup> In addition, computed tomography is often used to create the 3D model.<sup>8,13,17,20,23,24</sup> However, this results in incomplete visualization of the cartilage portions of the epiphysis in a young child. Because the alignment of the articular surface is critical in achieving a good result, MRI was utilized in this case to build a model including the cartilaginous areas of the distal humerus. MRI has the added benefit of limiting radiation exposure, increasing its utility in pediatric cases.

## Conclusion

The use of 3D printing has been a recent improvement in medicine and has multiple applications. Indications for its use are evolving rapidly. 3D-printed models are a valid way to conduct comprehensive and accurate preoperative planning, especially when performing corrective osteotomy for complex multiplanar deformity. It allows quantitative measurements and anatomic landmarks matching that of the patient's native anatomy to assist in surgical procedure. Further studies will be needed to determine the utility of this new tool in correcting orthopedic deformities in the pediatric population.

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