SCIENTIFIC ARTICLE

Corrective Osteotomy for Malunited Diaphyseal Forearm Fractures Using Preoperative 3-Dimensional Planning and Patient-Specific Surgical Guides and Implants

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Purpose Three-dimensional planning based on computed tomography images of the malunited and the mirrored contralateral forearm allows preoperative simulations of corrective osteotomies, the fabrication of patient-specific osteotomy guides, and custom-made 3-dimensional printed titanium plates. This study aims to assess the precision and clinical outcome of this technique.

Methods This was a prospective pilot study with 5 consecutive patients. The mean age at initial injury was 11 years (range, 4−16 years), and the mean interval from the time of injury to the time of corrective surgery was 32 months (range, 7−107 months). Patient-specific osteotomy guides and custom-made plates were used for multiplanar corrective osteotomies of both forearm bones at the distal level in 1 patient and at the middle-third level in 4 patients. Patients were assessed before and after surgery after a mean follow-up of 42 months (range, 29−51 months).

Results The mean planned angular corrections of the ulna and radius before surgery were 9.9° and 10.0°, respectively. The mean postoperative corrections obtained were 10.1° and 10.8° with corresponding mean errors in correction of 1.8° (range, 0.3°−5.2°) for the ulna and 1.4° (range, 0.2°−3.3°) for the radius. Forearm supination improved significantly from 47° (range, 25°−75°) before surgery to 89° (range, 85°−90°) at final review. Forearm pronation improved from 68° (range, 45°−84°) to 87° (range, 82°−90°). In addition, there was a statistically significant improvement in pain and grip strength.

Conclusions This study demonstrates that 3-dimensional planned patient-specific guides and implants allow the surgeon to perform precise corrective osteotomies of complex multiplanar forearm deformities with satisfactory preliminary results. *(J Hand Surg Am. 2017;■(■):1.e1-e12.*

Type of study/level of evidence Therapeutic V.

Key words Forearm, malunion, osteotomy, 3-dimensional planning, patient-specific guides and plates.

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PEDIATRIC FOREARM FRACTURES are routinely managed by closed methods with success in a large proportion of cases. Owing to potential remodeling during skeletal growth, fracture healing in a less than anatomical position is still compatible with unimpaired function.[1] However, forearm malunions with angular deformity, displacement, and malrotation may result in functional impairment, pain, instability, and poor cosmetic appearance.[2] Malunion rates between 15% and 35% have been reported following pediatric forearm fractures.[3,4] Malunion with restriction of forearm rotation to less than 50% to 60% of normal is associated with considerable functional impairment and surgical intervention is recommended.[2,5] To avoid long-term problems, the timing of corrective surgery is important, in relation to both skeletal maturity and time since the initial fracture.[6] Corrective osteotomies performed in children younger than 10 years of age have demonstrated greater improvements in range of motion than those in older children.[2,7] Increased range of motion and fewer complications have been reported with forearm corrective osteotomies performed within 12 months of the initial injury.[8]

Reconstructive surgery for malunited forearm fractures can be technically demanding. Precise forearm reconstruction may require simultaneous multiplanar correction of angulation and axial alignment, with restoration of ulnar variance and radioulnar joint congruity and stability, to obtain a pain-free, stable, and functional radioulnar joint. Conventional preoperative planning with 2-dimensional plain radiographs or cross-sectional imaging may not provide adequate information to fully appreciate the complexity of the 3-dimensional deformity, particularly with regards to rotational malalignment.[9–11] Recent advances in computer technology allow accurate 3-dimensional deformity evaluation based on computed tomography (CT) data, and rapid prototyping technology allows development of patient-specific guides and implants.[6,11–13]

To establish a reliable surgical treatment for malunited forearm fractures, a 3-dimensional computer simulation system was used to compare the CT images of the malunited and mirrored contralateral forearm. The system allowed the reproduction of preoperative simulations during the surgical procedure with patient-specific osteotomy guides and custom-made implants, where standard implants failed to match the surface contours of the osteotomized bones during the planning simulation. This study hypothesizes that preoperative 3-dimensional planning combined with patient-specific guides and plates can correct angular deformities of the forearm bones to within 5° of the contralateral side.

MATERIALS AND METHODS

Patients

From December 2011 to May 2013, 5 skeletally immature patients with diaphyseal forearm malunions (4 at the middle-third level, 1 at the distal level) presented as tertiary referrals and were enrolled in this prospective study (Table 1). The inclusion criteria were skeletally immature patients with decreased forearm rotation secondary to osseous deformity of the diaphysis of both forearm bones and incongruence between standard plate constructs and the anatomical contour of the corrected radius and ulna on the preoperative computer simulation. Exclusion criteria included medical comorbidities that could interfere with study participation, any involvement of adjacent joints, previous injury to the contralateral forearm, and cases in which standard fixation plates could be used. Initially, 4 patients had been managed with closed reduction and cast immobilization; 1 patient was treated with closed reduction and intramedullary nailing. Prior to deciding on surgical forearm correction, sequential orthogonal radiographs were performed to confirm the presence of osseous union and that no further remodeling had occurred (Fig. 1). Corrective surgery was indicated for loss of forearm rotation in 1 patient, and loss of forearm rotation with wrist or forearm pain in 4 patients. All patients underwent corrective osteotomy of both the radius and the ulna using preoperative 3-dimensional planning and custom-made patient-specific osteotomy guides and plate constructs (Fig. 2; Video A; available on the *Journal*'s Web site at www.jhandsurg.org). All patients and their parents gave informed consent before surgery and institutional review board approval was provided for this study.

The study included 3 male and 2 female patients with a mean age of 11 years (range, 4–16 years) at the time of initial injury (Table 1). At the time of corrective surgery, the mean age was 13 years (range, 7–17 years). The median interval from the time of injury to the time of corrective surgery was 16 months (range, 7–107 months). None of the patients were lost to follow-up or excluded from the study after initial enrollment.

Preoperative planning

The affected and contralateral forearms had CT imaging (Somatom Sensation 64 CT scanner: slice thickness, 0.6 mm; slice increment, 0.6 mm; image