Case report

Near-anatomical correction using a CT-guided technique of a forearm malunion in a 15-year-old girl: A case report including surgical technique

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Background: In this case report, we describe a left-arm both-bone forearm fracture in a 15-year-old girl who fell off a swing. Conservative treatment with an above-elbow cast failed, resulting in a malunion with functional impairment. The pro- and supination were 90°/0°, respectively. The patient complained of difficulties performing daily activities. For this pediatric case, a corrective osteotomy was proposed using a CT-guided technique aiming for maximum anatomical and functional outcome. It was the first time this technique was used in our hospital.

Methods: A corrective osteotomy of the patient’s left arm was performed using 3D printed templates to guide the osteotomy orientation. These templates were produced using specialized software in which CT images of her malunited left forearm were overlaid with the mirrored images of her healthy right forearm.

Results: The postoperative CT-scan showed a near-anatomical reduction with close to 1° correction in all three planes, as compared to the preoperative planning. Three months after surgery, the patient had regained full function of her left forearm.

Conclusion: Although this was the first time this technique was used in our hospital, it resulted in excellent anatomical and functional outcomes making it a safe, reliable and precise treatment option that may be useful for even more complex corrections.

Level of evidence: Level V.

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1. Introduction

Fractures of the forearm are amongst the most common fractures in children, accounting for 3.4 to 13% of all pediatric fractures [1]. In most cases, a forearm fracture results from a fall on an outstretched arm [2,3].

In general, forearm fractures in the distal third can be treated with below-elbow cast and fractures in the proximal third with above-elbow cast. Literature on mid-shaft fractures in children is scarce [4].

Conservative and operative treatments should both strive for anatomical reduction [5]. Seventy percent of the surgeries in forearm fractures, however, are performed for malunion and subsequent dysfunction following conservative treatments. Depending on fracture location, fracture type and treatment, malalignment has been reported in 7–91% of the patients [6,7]. Whenever a malunion results in functional impairment, a corrective osteotomy should be considered to restore full functionality. Using a conventional radiograph, malunions, which mostly consist of multiplanar deformities, are difficult to assess. Computed tomographic (CT)-scans, which gives accurate 2- and 3-D reconstructions, are more useful [8,9].

With the latest advancements in technology, a novel technique has been developed using patient-specific computer simulated 3D plastic templates and real-sized plastic bones. This technique effectively removes, for a great part, the challenging peroperative 3D orientation [8–11].

Literature, particularly on pediatric cases using this promising technique, is scarce [8,9].

Here, we present a case-report in which we corrected a severe malunited and dysfunctional forearm with near-anatomical correction using patient-specific guides.
2. Patient case and history

A 15-year-old right-handed girl presented on the emergency department (ED) a tour hospital. She fell off a swing and landed on her left outstretched arm. Radiographs showed a diaphyseal both-bone fracture of her left forearm with acceptable alignment after closed reduction (Fig. 1). She was treated conservatively with an above-elbow cast. At one-week follow-up, the alignment remained unchanged. After six weeks, the cast was removed and a radiograph showed delayed healing and malalignment (Fig. 2). Clinically her supination was reduced to 10 degrees while normal pronation was maintained (Fig. 3). Despite extensive physiotherapeutic treatments up to 7 months post-trauma, supination did not improve and the patient reported difficulties with daily tasks. A corrective osteotomy using patient-specific guides (Materialise NV, Leuven, Belgium) was therefore proposed.

3. Preoperative planning and operative technique

This case report was done in accordance with the Declaration of Helsinki. Written informed consent was obtained from the patient and both of her parents.

CT scans of the left and right forearm were made. Specialized software was used to create a mirrored overlay of the right-sided images creating an ideal presentation for the left forearm correction (Fig. 4).

For the radius, this resulted in a small closing wedge osteotomy of 3.2 mm, correct the radius in 3 planes. The plate consisted of 6 drill holes of which 4 were located distal of the osteotomy. Two holes were located proximally to the osteotomy due to the proximity of the radial tuberosity. The osteotomy was guided by one single 3D-printed plastic template. For the ulna, the preoperative planning resulted in a 20 degrees oblique osteotomy. The distal part of the ulna was slightly supinated, as planned, and fixed in place using a plate with 6 screw holes. The osteotomy was guided by two separate templates: one to guide the drill holes and one to guide the osteotomy (Fig. 5). Additionally, real-sized plastic bones of the preoperative as well as the postoperative situation were supplied in order to enhance orientation during the surgery.

In brief, with the patient in supine position the radius was approached through a volar (Henry) approach [12]. Using the real-sized bones as reference, the position of the radius template could be determined and was fixed using 4 Kirschner wires (Fig. 6). After
Fig. 4. Preoperative planning of the radius and ulna. The mirrored CT-scan of the healthy right forearm was used to create an overlay (pink) representing the ideal outcome for a corrective osteotomy.
fixation of the template, the closing wedge rotational osteotomy was performed (Fig. 7).

The ulna was approached between the m. flexor carpi ulnaris and m. extensor carpi ulnaris. The template for the drill holes was fixed on the exposed ulna with 4 Kirschner wires (Fig. 8). The second ulnar template was used for the osteotomy (Fig. 9). The distal part of the ulna was slightly supinated to get the drill holes in line. A 6-hole fixation plate was fixed on the ulna with 6 cortical screws (Fig. 10). According to the preoperative planning, the radial plate was bent 7 degrees between the second and third screwhole. The real-size plastic radius was used as reference (Fig. 11). Plate fixation on the proximal part of the radius consisted of one locking screw and one cortical screw (Fig. 12). Once the distal part was rotated to get the drill holes in line, the remaining 4 holes were filled with cortical screws. The plate and screw positions were confirmed using fluoroscopy. After soft-tissue closure, but still under anesthesia, the postoperative pro- and supination were 90/0/90, respectively.

4. Postoperative course

The patient was treated with an above-elbow cast for 2 weeks and received physiotherapy twice per week. The physiotherapist trained her left arm based on pain perception until she regained full functional capacity. Twelve weeks after the corrective osteotomy pro- and supination on the left side were 90/0/90, respectively (Fig. 13), and the patient was able to reengage in her previous daily activities. Conventional radiographs 6 months after surgery showed consolidation (Fig. 14).

Six months after surgery a postoperative CT scan of both arms was performed to analyze ultimate correction. Compared to the planned correction the ulna was corrected in the coronal, sagittal and axial plane with respectively 0.3°, 0.5° and 0.1° accuracy. The radius was corrected with 4.9°, 0.6° and 1.38° accuracy for the coronal, sagittal and axial plane, respectively (Fig. 15).

5. Discussion and conclusion

In this case report, we have presented a highly accurate treatment modality using CT-scan-based and patient-specific 3D plastic templates and real-sized plastic bones for the correction of a forearm malunion.
Closed reduction remains the gold standard for pediatric forearm fractures, but carries the risk of malunion [10,13]. Children may have the benefit of a high remodeling potential but this capacity is dependent on age and may be considered insufficient after the age of 10 to 11-years [14,15]. As the growth plate lies distal, remodeling is also dependent on location. Good outcomes have been described for distal fractures in children up to 15-years of age and for diaphyseal fracture in children up to 10-years old [16]. Children older than 15 years, females in particular, should consequently be treated as adults with open reduction and internal fixation or with the increasingly used, minimally invasive, elastic stable intramedullary nailing [17–19].

The major advantages of this novel technique, the accurate reduction and ease of intraoperative navigation, are self-explanatory. A corrective osteotomy without the use of this technique requires extensive experience and tremendous
multiplanar orientation. In this case, the malunion was corrected close to 1° accurate in all planes. Only the radial deviation in the coronal plane was higher with 4.9°. We attributed this to the fixation plate, which was placed more distally than planned and might have resulted in insufficient correction of the preoperative laterally bowed radius. The absence of bony landmarks on long bones and additional soft-tissue hindrance has possibly impeded the radial plate fixation. Although there is no literature with CT-based accuracy assessment numbers for conventional corrective osteotomies, our accuracy can be considered as exceedingly good. Only laboratory studies on cadaveric material have shown residual errors close to 1° [20].

The surgery was performed by 2 experienced orthopedic surgeons using this technique for the first time. Although literature postulates that high accuracy numbers might not always be strictly necessary for good functional outcomes, the accuracy obtained in our case highlights the suitability of this technique for even more demanding and complex fractures [21,22].

Another advantage is that the optimal osteotomy position can be adjusted to fulfill both mechanical and biological considerations via a preoperative multidisciplinary meeting.

One of the limitations of this technique is the additional cost. This specific case cost 3000 euros more than conventional revision surgery. Radiation might also be a concern when considering this technique as our patient received two CT-scans. The postoperative CT-scan, however, was performed for research purposes only and this technique normally only requires one preoperative CT-scan of both forearms. The radiation dose received for both these exams is between 0.5 and 1.0 mSv, the equivalent of 2–5 months background radiation [23]. Other limitations of this technique include its time-consuming planning, high demanding software and high need for computer skills [24].
**Fig. 15.** Residual error calculations based on the CT-scan 6 months after the corrective osteotomy.
In conclusion, this technique enables surgeons to easily navigate the normally challenging corrective osteotomies with excellent anatomical and functional outcomes, even when used for the first time, and may be useful for even more complex corrections.

Disclosure of interest

The authors declare that they have no competing interest.

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