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A novel patient specific guide design to correct a complex multiplanar foot deformity.

Steven Lankheet [1-4], Femke Schröder [1-3], Kilian Kappert [4], Wouter Ten Cate [4], Edsko Hekman [3], Malte Asseln [3], Maaike Koenrades[3] and Elgun Zeegers [2].
[1] Medical 3D lab, Medical Spectrum Twente, Enschede, The Netherlands
[2] Department of Orthopedic Surgery, Medical Spectrum Twente, Enschede, The Netherlands
[3] Department of Biomechanical Engineering, University of Twente, Enschede, The Netherlands
[4] Department of Vascular surgery, Ziekenhuis Groep Twente, Hengelo, The Netherlands
Stevenlankheet@mst.nl

Abstract

Surgical intervention is often indicated for complex multiplanar foot deformities (CMFDs). Addressing the 3D nature of these deformities proves challenging for achieving optimal foot alignment and reoperations are often necessary. Virtual surgical planning (VSP) can aid in the understanding of the multiplanar deformity and determine the osteotomies needed for correction. This study introduces a patient-specific guide (PSG) applied to a CMFD patient undergoing midfoot closing wedge osteotomy. The PSG design allowed for accurate reconstruction of the angular deformity, while allowing for intra-operative translational adjustments. Further improvement of the PSG design was proposed to ensure an even better fit in future applications.

1 Introduction

Complex multiplanar foot deformity (CMFD) in neurologic, neuropathic, or idiopathic cases is a foot deformity characterized by multiple angular, rotational and/or translational components, affecting both the bones and the soft tissue [1]. Surgical correction of these complex foot deformities aims for a balanced, plantigrade foot, minimising ulceration risk, and enabling mobility through (bespoke) footwear [2], [3].

While corrective osteotomies are traditionally performed without perioperative guidance [4], [5], [6], the challenge persists in achieving precise correction. Virtual surgical planning (VSP) offers assistance, yet the risk of over- or under-correction remains without additional guidance. Patient specific guides (PSGs) are widely employed in other orthopaedic fields to improve the accuracy [7] [8]. Only a few case studies have reported on the use of PSG in corrective foot surgery [9], this may be due to the nature of the deformities. While the angular component can be planned in detail, the translational component is dependent on intraoperative factors and lacks reference values, complicating the use of a PSG.

This paper presents a case study of CMFD for which a midfoot closing wedge osteotomy is indicated and a PSG is used intraoperatively. The novel guide design allows for intraoperative adjustments while retaining the planned angular correction.

2 Methods

The patient, a 33-year-old male with congenital cerebellar hypoplasia, was scheduled for corrective foot surgery. Following standard clinical procedures for patients with CMFD, a preoperative CT scan of the foot in the maximum achievable neutral position was acquired. A VSP was constructed followed by the PSG design. First a Jones tendon transfer involving all five rays was performed. Two months later, the patient underwent a triple arthrodesis. Ethical approval for the evaluation study and informed consent were obtained. Since both feet were affected, the non-weightbearing reference angles described by Broos et al. were used to plan the correction [4].

The creation of the PSG involved three streps as illustrated in Figure 1. First, a guide base was created by extruding the bone surface at the seating locations. Second, a cutting guidance block was created adjacent to the planned osteotomy plane. Third, pillars were added with horizontal holes through which k-wires were placed intraoperatively, which align the proximal and distal guide part. Additionally, two fixation points were added to each guide base. The guide parts were 3D printed with powder bed fusion in Nylon 12 (Oceanz, Ede, The Netherlands).

Complex foot surgery was performed under general anaesthesia, a lateral incision was made from the lateral malleolus to the base of the space between the fourth and fifth metatarsal. A k-wire was inserted through both the talus and calcaneus to fixate these together during surgery. The PSG bases were fitted onto the bone and fixated with k-wires, and their location was confirmed via fluoroscopy. The PSG guided the proximal cut. The distal side of the talonavicular and calcaneocuboid joint was resected using the sagittal saw. The wedge was removed and the bones were repositioned using the PSG. The subsequent steps of the triple arthrodesis are performed and fixated using osteosynthesis material. The incision was closed and a cast was applied. As part of standard clinical care, a post op CT was obtained and the surgery performance was evaluated based on the VSP.

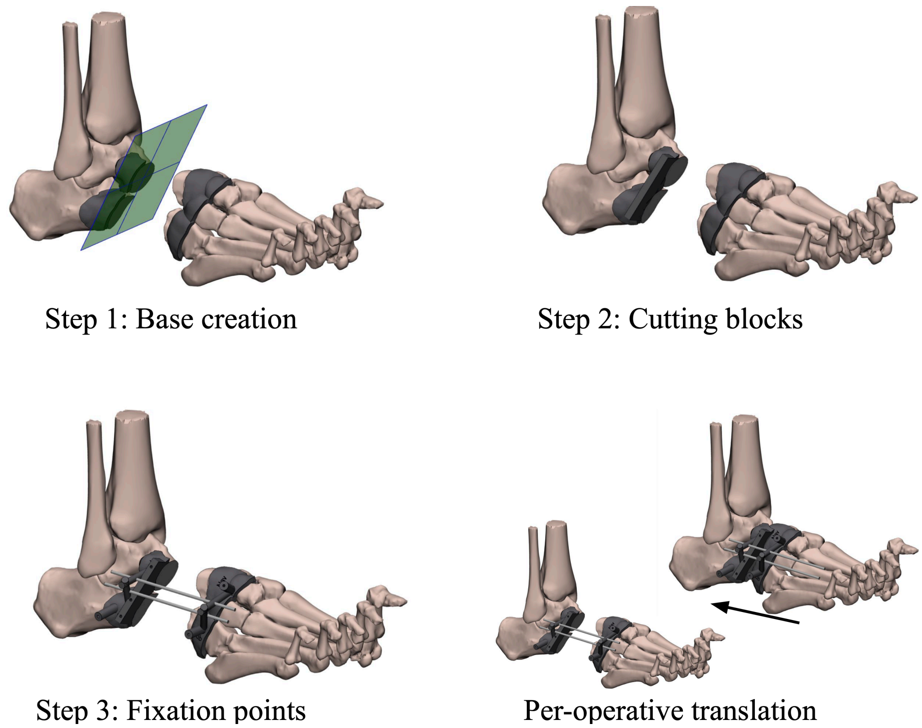
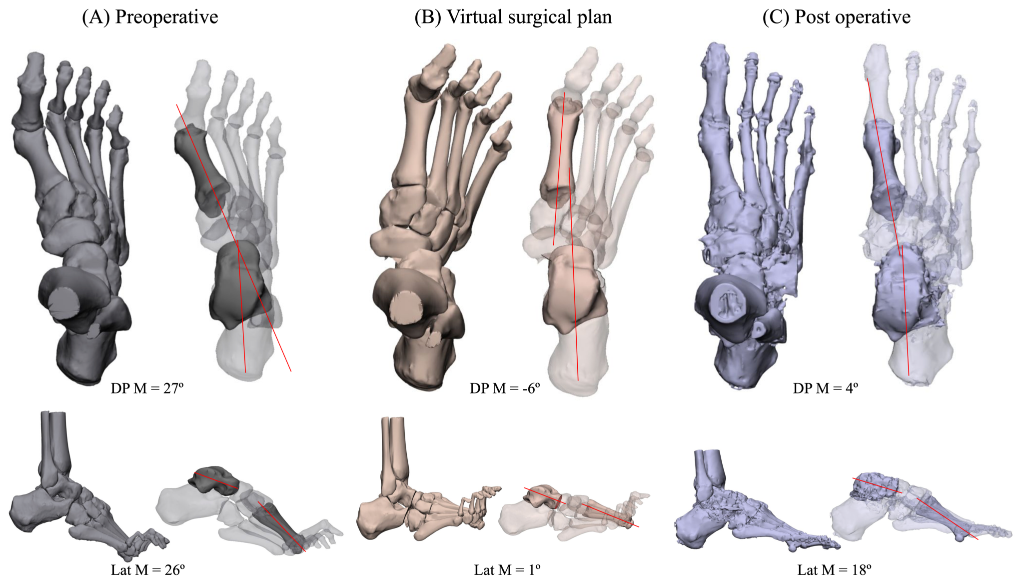


Figure 1: Illustrating the development process of the patient-specific guide (in black). The foot is aligned as part of the virtual surgical plan and the cutting plane (in green) is defined. The guide bases are created (Step 1). The cutting block is added (Step 2) and subsequently the pillars (added in step 3) for the k-wires (in gray) to allow for intraoperative translational positioning (Step 4).

3 Results

Corrective foot surgery was performed successfully without complications. The VSP assisted the surgeon in understanding the deformity and necessary corrections. During surgery the PSG was used to guide the positioning of the triple arthrodesis. The fit was sufficient, albeit marginal for the distal reposition part. The foot alignment was improved, as visualised in figure 2. Clinical status improved from a deteriorating walking pattern with pain to an improved and stable gait with absence of pain. The Meary's angles were improved, though the achieved correction deviated partially from the planned position.

Figure 2: The 3D models of the preoperative foot (A), virtual surgical plan (B) and postoperative result (C) in the dorsoplantar view (top) and lateral view (bottom). Each foot is shown twice to visualise the dorsoplantar Meary's angle (DP M) and the lateral Meary's angly (Lat M).



4 Discussion

This paper highlights a novel design for a PSG and its intraoperative implementation for a CMFD patient. The PSG guided the planned angular correction while allowing for translational adjustments to ensure a good intraoperative bone contact.

The design differs from a previous study by Dagnegaux et al., who designed a cutting guide with free-handed repositioning [5]. This method does not guarantee accurate reconstruction of the angular correction in all directions. In patients with CMFD, a multiplanar correction is needed, increasing the demand for a repositioning guide.

However, our study acknowledges certain limitations. Firstly, the reconstruction relied on reference angles for non-weight-bearing CT images[4]. This is due to the absence of an unaffected contralateral foot. However, adhering to standardized 2D angles is not always feasible in these complex cases. Secondly, the available space for bone seating was smaller than expected, resulting in suboptimal fit for the distal guide part. Reducing the area could improve the fit; however, there might be an insufficient surface for identifying the correct seating position. Thirdly, the postoperative CT was not obtained with the foot in a neutral position, introducing potential inaccuracies in the analysis. To address this, reference planes were based on the talus position as described by Krakers et al. [10]. Despite these limitations, the current workflow showed that the design was sufficient in achieving an improved foot shape.

5 Conclusion

The presented PSG design was successfully implemented in a clinical case of CMFD. The intervention resulted in an improvement in foot shape, consequently enabling the patient to walk pain-free. Further improvement of the PSG was proposed to ensure an even better fit in future applications.

References

[1] H. Shalaby and H. Hefny, "Correction of complex foot deformities using the V-osteotomy and the Ilizarov technique," *Strategies Trauma Limb Reconstr*, vol. 2, no. 1, pp. 21–30, Apr. 2007, doi: 10.1007/s11751-007-0015-7.

[2] A. Doorgakant and M. B. Davies, "An Approach to Managing Midfoot Charcot Deformities," *Foot Ankle Clin*, vol. 25, no. 2, pp. 319–335, Jun. 2020, doi: 10.1016/j.fcl.2020.02.009.

[3] V. J. Sammarco, "Superconstructs in the Treatment of Charcot Foot Deformity: Plantar Plating, Locked Plating, and Axial Screw Fixation," *Foot Ankle Clin*, vol. 14, no. 3, pp. 393–407, Sep. 2009, doi: 10.1016/j.fcl.2009.04.004.

[4] M. Broos, S. Berardo, J. G. G. Dobbe, M. Maas, G. J. Streekstra, and R. H. H. Wellenberg, "Geometric 3D analyses of the foot and ankle using weight-bearing and non weight-bearing cone-beam CT images: The new standard?," *Eur J Radiol*, vol. 138, p. 109674, May 2021, doi: 10.1016/j.ejrad.2021.109674.

[5] L. Dagneaux and F. Canovas, "3D Printed Patient-Specific Cutting Guide for Anterior Midfoot Tarsectomy," *Foot Ankle Int*, vol. 41, no. 2, pp. 211–215, Feb. 2020, doi: 10.1177/1071100719882723.

[6] S. H. Wirth and N. Espinosa, "The Use of Virtual Planning and Patient-specific Guides to Correct Complex Deformities of the Foot and Ankle," *Foot Ankle Clin*, vol. 25, no. 2, pp. 257–268, Jun. 2020, doi: 10.1016/j.fcl.2020.02.004.

[7] T. Pastor, L. Nagy, P. Fürnstahl, S. Roner, T. Pastor, and A. Schweizer, "Three-Dimensional Planning and Patient-Specific Instrumentation for the Fixation of Distal Radius Fractures," *Medicina (B Aires)*, vol. 58, no. 6, p. 744, May 2022, doi: 10.3390/medicina58060744.

[8] C. Pioger, A. Mabrouk, R. Siboni, C. Jacquet, R. Seil, and M. Ollivier, "Double-level knee osteotomy accurately corrects lower limb deformity and provides satisfactory functional outcomes in bifocal (femur and tibia) valgus malaligned knees," *Knee Surgery, Sports Traumatology, Arthroscopy*, vol. 31, no. 7, pp. 3007–3014, Jul. 2023, doi: 10.1007/s00167-023-07325-y.

[9] D. Popescu and D. Laptoiu, "Rapid prototyping for patient-specific surgical orthopaedics guides: A systematic literature review," *Proc Inst Mech Eng H*, vol. 230, no. 6, pp. 495–515, Jun. 2016, doi: 10.1177/0954411916636919.

[10] S. Krakers, A. Peters, S. Homan, J. olde Heuvel, and G. Tuijthof, "Definition of a Global Coordinate System in the Foot for the Surgical Planning of Forefoot Corrections," *Biomechanics*, vol. 3, no. 4, pp. 523–538, Nov. 2023, doi: 10.3390/biomechanics3040042.