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Minimally invasive hallux valgus surgery using 3D printed patient specific instrumentation

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Abstract

In this technical report study, we describe technique for performing the osteotomy and screw passage in minimally invasive fourth-generation hallux valgus surgery with transverse and akin extra-articular metaphyseal osteotomy (META) using a 3D-printed patient-specific surgical instrumentation guide. In an effort to minimize the learning curve and address the variability associated with technical corrections and screw placement, we have initiated the creation of personalized patient-specific instrumentation guides using 3D printing. Our hypothesis is that this approach will enhance safety, precision, decrease surgical time, and reduce exposure to radiation.

Level of Evidence: Level V, expert opinion.

Keywords Hallux valgus · Minimally invasive · Percutaneous surgery · 3D printing

Introduction

The utilisation of 3D printing, also known as Additive Manufacturing, in Orthopaedic procedures has gained prominence in recent years [1]. This technology has found various applications within the field of Orthopaedics, one of which is the creation of patient specific surgical guides custom built to individual patients [2].

These guides help surgeons to incorporate individual patient's unique anatomical characteristics when planning the components of a surgical procedure (such as osteotomies or implant positioning) and translate these pre-planned steps to the actual surgery. Within the context of foot and ankle surgery, the use and efficacy of 3D-printed, patient-specific guides have been previously reported in procedures such as total ankle arthroplasty, ankle arthrodesis, and corrective osteotomies [3].

Recent developments in image processing enable the clinical use of 3D printing, providing surgeons with anatomically correct models for surgical planning by translating computed tomography (CT) data into 3D representations. This aids surgical training and may reduce re-operation rates [4].

We hypothesise that such technological advances would be of benefit when planning corrective osteotomies for hallux valgus surgery, a common yet frequently challenging

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deformity for foot and ankle surgeons, even acknowledging the existence of various guides already present in the market.

Recent research on minimally invasive approaches for correcting hallux valgus (HV) through distal osteotomies has revealed significant challenges for new surgeons, including prolonged surgical duration and heightened radiation exposure when compared to traditional open surgery [5–7].

In an attempt to reduce this learning curve and the variability of technical correction and screw placement we have begun the development of customised patient specific instrumentation guides utilising 3D printing. We hypothesise that this will provide greater safety, precision, reduced surgical time and exposure to radiation.

We present the technique for performing the osteotomy and screw passage in the fourth-generation minimally invasive hallux valgus surgery with metaphyseal extra-articular transverse and akin osteotomy (META) using a 3D printed patient specific instrumentation surgical guide after preoperative planning based on 3D CT reconstruction.

Surgical technique

3D planning

A 3D model of the foot (Fig. 1) is reconstructed using CT scans of the foot, formatted in Digital Imaging and Communications in Medicine (DICOM). This reconstruction process is executed with the 3D Slicer software (open-source). Initially, the model incorporates the surface of the skin.

Subsequently, the 3D model is exported as a stereolithography (STL) file to Fusion 3D software (Autodesk, San Rafael, CA, USA) a computer assisted design (CAD) software where the optimal osteotomy and deformity correction is planned (Fig. 2).

Based on the planned osteotomy, deformity correction, and screw placement, two independent guides are designed. The surgical guides are manufactured using biocompatible resin and an SLA 3D Printer (Creality, Shenzhen, China). The first guide (Guide 1) conforms to the patient's skin surface, aiding in osteotomy site identification (Fig. 3). The second guide (Guide 2) is designed based on the planned screw positions, facilitating the passage of guide wires for the chamfered screws (Fig. 4).

In addition to the guides, a 3D model of the foot's bone surface is printed for educational purposes and to assist the surgical team in orientation. These guides can be sterilised through autoclaving and can be brought into the operating room alongside other surgical equipment.

Surgical procedure

1. The patient is placed in the supine position, under spinal anaesthesia, and no tourniquet is used.

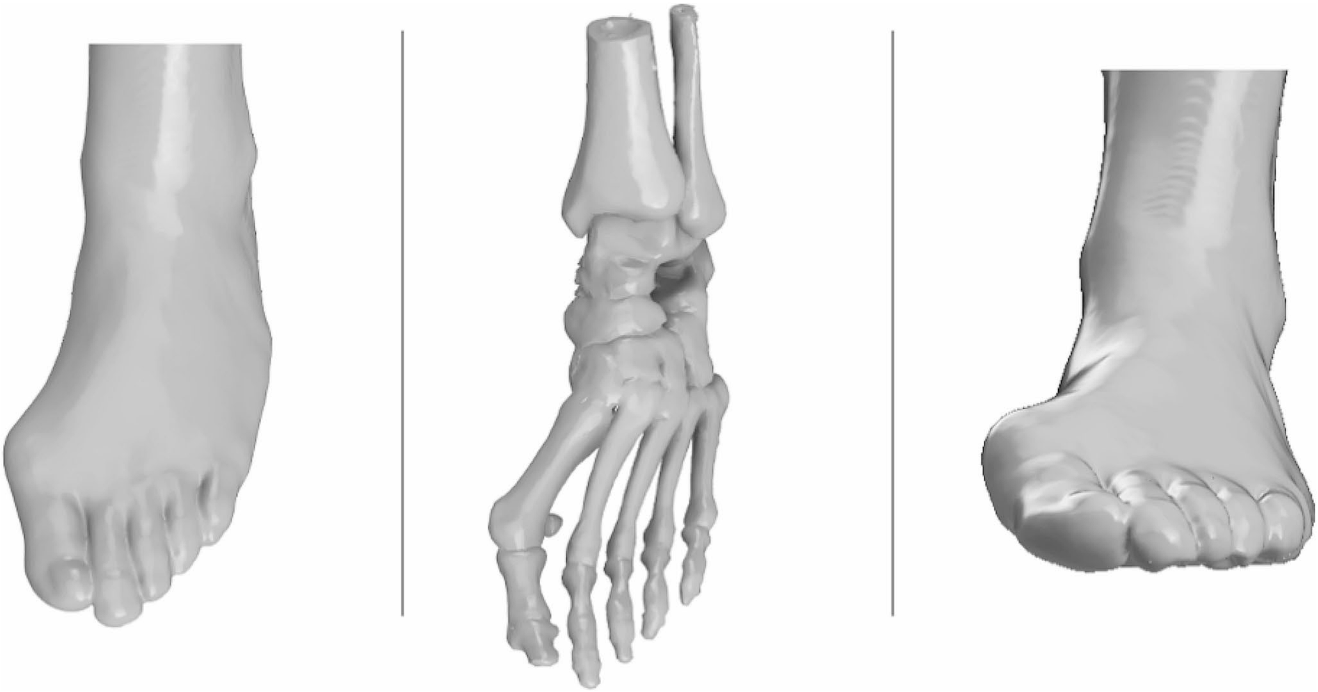

Fig. 1 A 3D model of the foot reconstructed using CT scans of the foot

Fig. 2 Osteotomy planning based on the 3D model of the foot and prediction of translation in the distal fragment

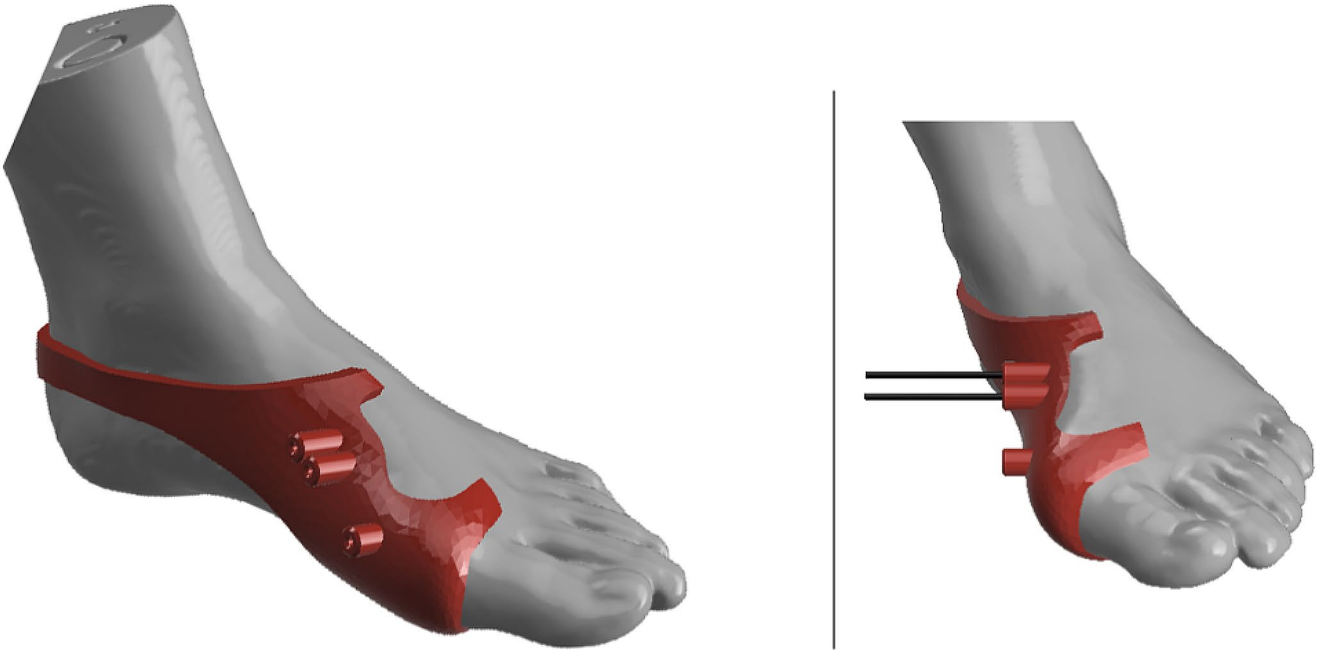

Fig. 3 3D model of Guide 1, for identifying the osteotomy site and positioning for the fixation of Guide 2

2. We place the Guide 1 fixed on the foot and ankle in regions with little fat or soft tissue, which are places with greater stability (Fig. 5). This initial guide will indicate the osteotomy site and the two locations for the passage of the support Kirschner wires for the final guide. It is important to know that the two holes to be made in the initial guide will be made with 2.0 mm Kirschner wires and exactly programmed to enter the middle of the first metatarsal in the lateral view.

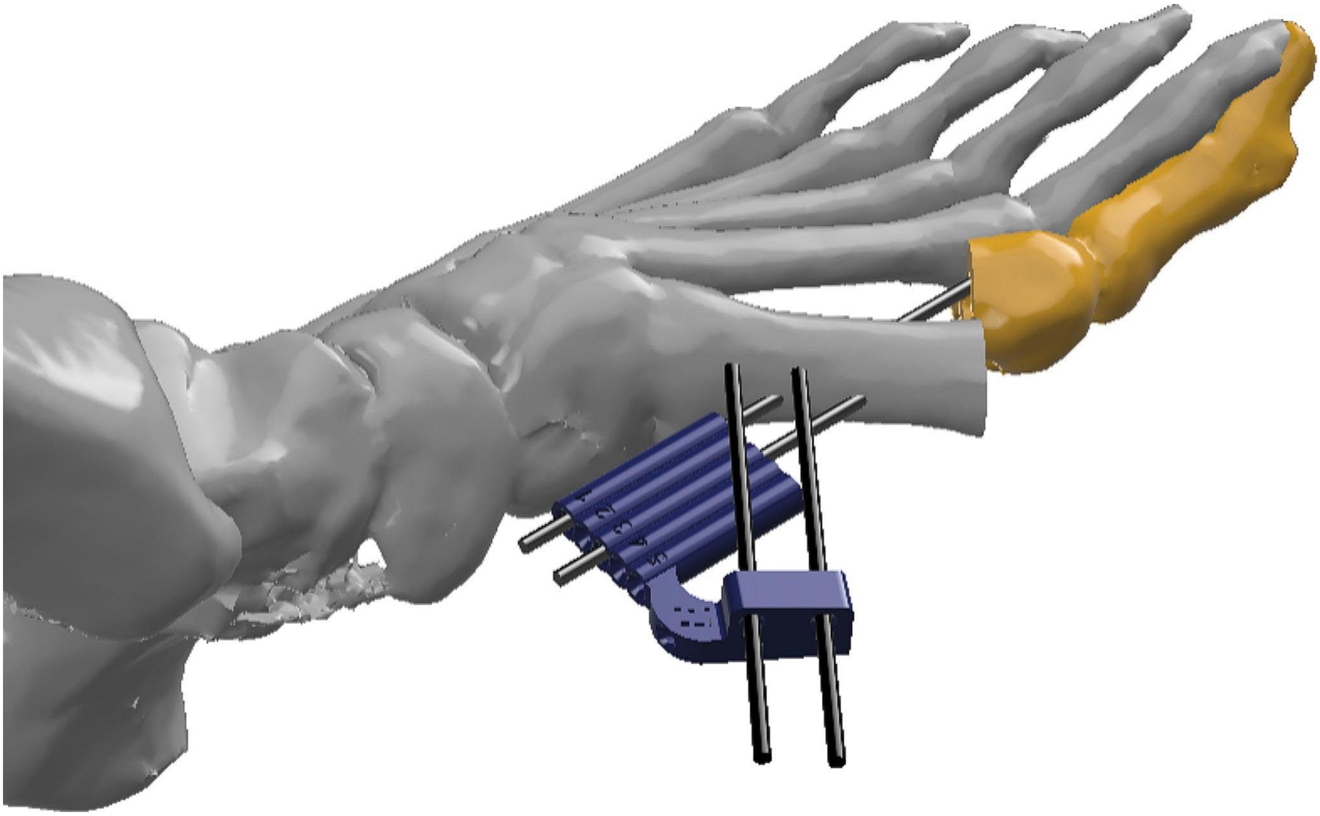

Fig. 4 3D model of Guide 2 to direct the thread guides for the chamfered screws

Fig. 5 Guide 1 positioned in the medial region of the foot and ankle and passage of the two Kirschner wires

3. The Guide 1 is used to pass the two K-wires, which are then retained after its removal. Subsequently, Guide 2 is inserted through these two K-wires. (Fig. 6).

4. The transverse osteotomy was performed as described by Lewis et al., and we place the screw passage guide [8].
5. We displace the metatarsal head with the periosteal detacher or mosquito clamp, always remembering to correct the pronation of the first metatarsal.
6. We thread the 2.0 mm Kirschner wires through Guide 2, then exchange them for the chamfered screws (Fig. 7).
7. Finally, the Akin osteotomy is performed without the help of a guide and without fixation with screws.

It is imperative to adhere to the steps outlined in the utilization of the guide to mitigate potential complications such as improper placement of Kirschner wires and, consequently, screws. Following the prescribed sequence ensures accuracy and precision during the surgical procedure, minimizing the risk of postoperative complications and optimizing patient outcomes.

Discussion

The potential advantages of using a 3D printed patient specific instrumentation guide in the minimally invasive correction of HV are greater precision in the passage of screws, shorter surgical time, less exposure to radiation, safe procedure and reduction in the learning curve.

In recent years, there has been a notable surge in publications advocating minimally invasive techniques for HV correction, often demonstrating comparable outcomes to conventional open techniques [6, 8–10]. However, greater radiation exposure has been proven in minimally invasive techniques when compared to an open HV correction technique [6].

Toepfer et al. analysed his first 50 consecutive minimally invasive Chevron and Akin osteotomy (MICA) surgeries. The results showed that the average surgical time was 46.8 min and the authors concluded that surgical efficiency improved as proficiency developed, with a consistent reduction in surgical time and radiation exposure after 40 procedures [5].

The adoption of personalised surgery with 3D printing guides addresses important concerns, such as the extended learning curve and radiation exposure. This approach not only enhances safety but also minimises surgical time and

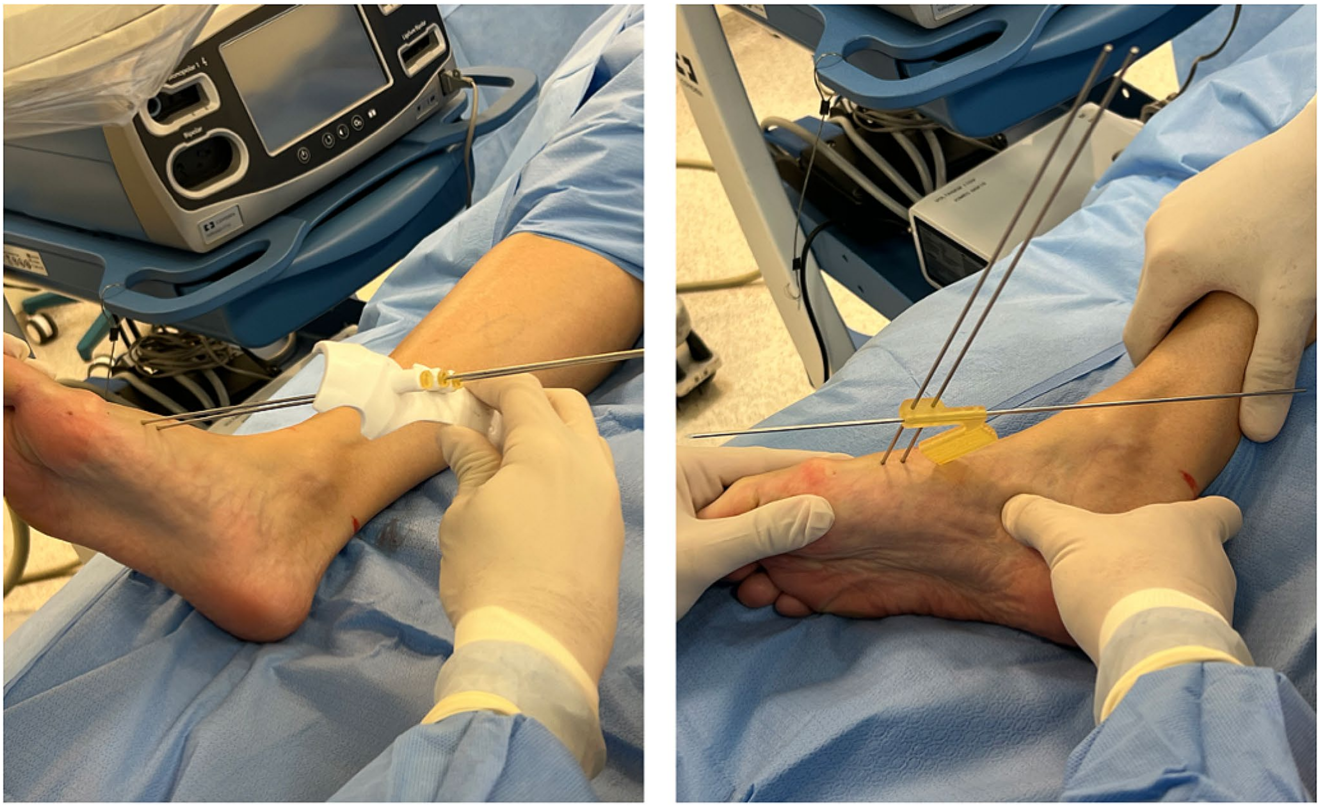

Fig. 6 Guide 1 is removed and Guide 2 is placed with radioscopy checking its central position in the lateral view

Fig. 7 Final radioscopic position of the two chamfered screws and correction achieved

radiation exposure, as the surgeon can pre-plan instrument placement for optimal precision during the procedure.

Unfortunately, there is still an unpredictable variability in the positioning of the metatarsal head after osteotomy, as this is difficult to measure due to existing variables such as instability of the tarsometatarsal joint, degree of rotation and soft tissue tension. Further advances with this technology could include reduction components building in rotational correction based on the head pronation and head medialization based on the intermetatarsal space.

There is a growing body of evidence that 3D printed patient specific instrumentation can positively impact on operative time and reduce radiation exposure. A recent scoping review with a pooled total of 932 participants showed that operating time ($p < 0.001$), blood loss ($p < 0.001$), fluoroscopy times ($p < 0.001$), bone union time ($p < 0.001$), pain ($p = 0.040$), accuracy ($p < 0.001$), and functional scores ($p < 0.001$) were significantly improved with 3D printing compared to the control group with no significant differences in complications [11].

It is important to emphasize that the likely radiation reduction with the use of 3D printing guides will be for the surgeon and not for the patient, as all planning is based on a CT scan of the patient's foot and ankle, which involves radiation exposure and is not essential in all cases when surgical correction of HV is indicated. However, it is worth noting that the radiation dose delivered by modern CT equipment, particularly when focused on extremities, is decreasing steadily over time [12].

This feasibility study does not have data to compare the data present in the literature but we believe that despite generating additional costs such as the need for a CT scan, guide printing, and sterilization, notably, the risk of a repeat surgery due to complications should decrease, especially for those beginning this technique, along with a reduction in procedure time, thus reducing the cost of the operating room.

In summary, the utilisation of novel 3D printed patient specific instrumentation guides in minimally invasive HV correction potentially provides several advantages, including enhanced precision in screw placement, reduced surgical time, decreased radiation exposure, procedural safety, and expedited learning curves.

Nevertheless, prospective studies are imperative to substantiate its applicability within contemporary clinical practice and to establish its economic viability, bearing in mind the intricacies mentioned, such as the disadvantaged, and recognizing that our feasibility study serves as an initial outlook, indicating the necessity for further efforts in the future.

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Data availability Not available.

Declarations

Informed consent Patients signed the image usage agreement for the study.

Competing interests The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. ICMJE forms for all authors are available online.

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