Augmented Reality in Hallux Valgus Surgery

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KEYWORDS

• Virtual reality • Navigation • Head-up display • Technical progress in surgery

KEY POINTS

- Augmented reality is an emerging technique with huge potential impact in the medical field.
- It might be beneficial to unexperienced surgeons in hallux valgus surgery.
- It has not been established in clinical routine hallux valgus surgery.

INTRODUCTION

Hallux valgus deformity is one of the most frequent foot problems. If pressure of suffering is high, surgical correction can improve the patients' quality of life.[1] Various surgical techniques are available depending on the degree of deformation and the patient's clinical findings. Some investigators recommend a Lapidus procedure with fusion of the first tarsometatarsal joint for patients with hypermobility in the first ray. In cases of severe osteoarthritis in the metatarsophalangeal joint, corrective fusion surgery may be considered to address the deformity by fusing this joint. If fusion is not necessary, most hallux valgus procedures (eg, Chevron, ReveL, and Scarf procedures) achieve hallux valgus correction with an osteotomy of the first metatarsal bone. After the cut is made, the distal metatarsal bone is fixed in a less adducted position.

Although good-to-excellent results are achieved in most patients, recurrent deformity is found in 5% of the patients. Another potential issue is postoperative transfer metatarsalgia, which can occur in 10%[2,3] if elevation or shortening of the first metatarsal occurs. As some shortening of the first ray might be beneficial to correct the deformity, exact planning and execution of the osteotomy is necessary. Improper execution of a distal metatarsal I osteotomy with posterior deviation in the transverse plane can aggravate shortening of the first ray (**Fig. 1**). Even a 10° deviation from the aimed osteotomy perpendicular to the second ray leads to excessive shortening of more than 5 mm if a

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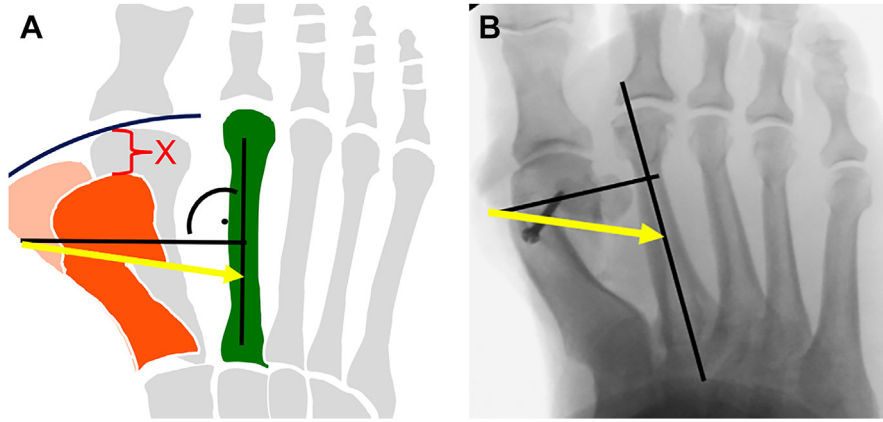

Fig. 1. (*A*) Shortening of first metatarsal (indicated with *red x*) with an inadequate osteotomy plane (*yellow arrow*) pointing posterior and not perpendicular to axis of os second metatarsal bone. (*B*) X-ray to illustrate shortening of os metatarsal I due to wrong orientation of dorsal cutting plane leading to relative lengthening of os metatarsal II.

significant correction is achieved.[4] Therefore, it is particularly important to perform the osteotomy correctly if severe hallux valgus correction is performed.

Besides the extend of deformity, the surgeon's experience is a risk factor for postoperative outcome and correction of the deformity.[5] This is fundamentally important, as cases involving teaching assistant are regularly found in hallux valgus correction.

Augmented Reality in Orthopedic Surgery

Recently, guided osteotomy and 3 dimensional (3D) visualization have gained increasing prominence in orthopedic research and practice. Various approaches are being explored to enhance visualization during surgery, one of which is the use of augmented reality.

Augmented reality involves enhancing the real environment with virtual features. It has become increasingly integrated into our daily lives, such as through head-up displays in cars or planes.

In orthopedic surgery, augmented reality can take the form of head-up displays mounted on the surgeon's head or screens. This technology can provide important patient or surgical information that is superimposed onto reality. The head-up display usually uses see-through holographic lenses. These lenses allow to project information onto these lenses into the facial field of the surgeon superimposed to the reality. This allows surgeons to view helpful information directly within their field of vision without turning away from the operating field. The easy availability of useful information reduces the effort to bring this information to mind. Therefore, the so-called extrinsic cognitive load of the surgeon is reduced.[6]

Furthermore, using head-up displays for augmented reality enables superimposing 3D models directly on the patient's body to guide surgical steps—potentially improving accuracy and visualizing hidden anatomic structures such as neurovascular bundles. However, while this technique offers potential benefits, its reliance on accurate guidance makes it susceptible to misleading instructions.

Proof-of-Concept of Augmented Reality in HalluxValgus Surgery

A proof-of-concept study was conducted in our hospital to investigate the benefits of augmented reality in hallux valgus surgery. The study utilized a 3D-printed model of

the forefoot based on CT scans (Fig. 2). In order to replicate an authentic surgical scenario, the soft tissue of the foot was remodeled. Two surgeons with different levels of experience performed a typical distal osteotomy of the first metatarsal to correct hallux valgus. To investigate the benefit of augmented reality on the accuracy of the osteotomy, each surgeon carried out this procedure 15 times freehand and 15 times with a head-up display depicting the exact osteotomy (Fig. 3). Subsequently, the deviation of the osteotomy angle in the transverse plane was analyzed. The results indicated that using augmented reality tended to result in more accurate osteotomies for less experienced surgeons, while it did not significantly improve performance for experienced surgeons.

DISCUSSION

Augmented reality has been hailed as a game changer in the field of surgical navigation, with the potential to significantly enhance surgeons' performance by overlaying crucial information directly onto the operating field. This includes providing guidance for performing osteotomies and aligning bones or implants during orthopedic surgery, thus improving accuracy and precision. Additionally, it allows visualization of vulnerable structures to prevent its damage.

Several in vitro and preclinical studies have been conducted to explore its benefits of augmented reality with promising results, for example, in pedicle screw placement,[7–9] joint arthroplasty,[10,11] and tumor resection.[12] In 2021, the first successful spine surgery using augmented reality was performed.[13] Surgeons utilized a head-up display to navigate the placement of pedicle screws in lumbar fusion procedures.

Besides its big advantages, augmented reality could not generally replace conventional or fluoroscopic-guided surgery in clinical practice so far. One reason is that the efficacy of navigation depends on its accuracy and precision of the navigation itself. Augmented reality presents challenges related to accurately overlaying virtual models or guidance onto reality. First technical implementations involve manual matching which carries inherent inaccuracies, newer approaches show promising results through improved automatic or semiautomatic registration of virtual models onto reality.[14] As augmented reality may guide surgical steps but does not provide mechanical guidance through a sleeve or other mechanical device, another potential source of error lies in surgeon's ability to follow this virtual but not mechanic guidance. New techniques that automatically detect incorrect execution of the surgeon might improve the execution of the guided steps in augmented reality.

When it comes specifically to hallux valgus surgery, good-to-excellent outcomes are generally achieved rendering lower requirement for additional navigational support compared to other areas. Hallux valgus surgery might therefore not be the major area

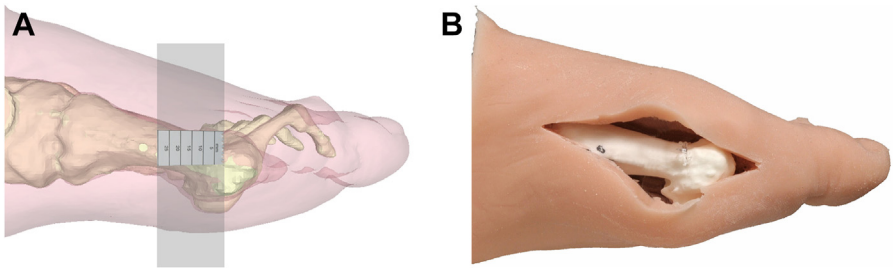

Fig. 2. (*A*) 3D model of the foot and planed osteotomy (virtual model). (*B*) Used model (real model).

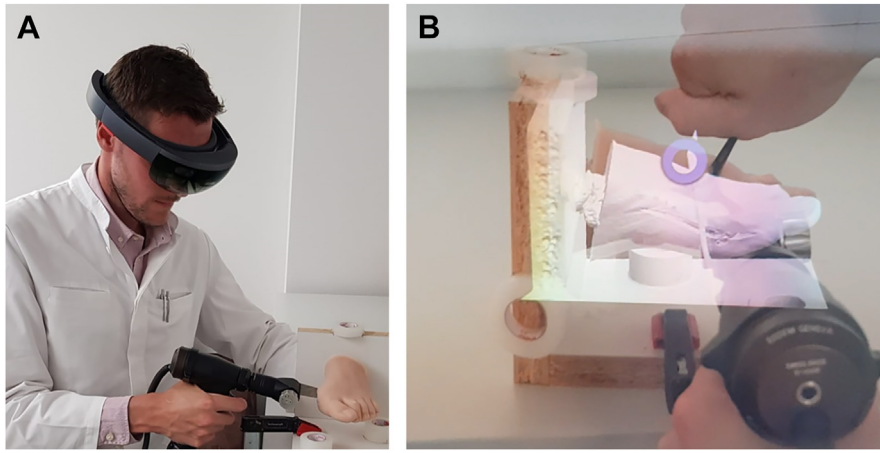

Fig. 3. (*A*) Experimental setup with surgeon performing hallux valgus corrective osteotomy wearing the holographic lenses. (*B*) View through a head-up display showing the superimposed model (augmented reality). Inaccuracy of the virtual to the real model is mainly due to the photo shooting technique.

of navigated surgery or augmented reality research in particular. However, patient dissatisfaction due to improper osteotomy performance cannot be entirely dismissed notably when major corrections are involved. In these cases, augmented reality might be beneficial especially for unexperienced surgeons.

Another intriguing application area for augmented reality might be minimally invasive surgery which has recently gained attention within orthopedic and hallux valgus surgery. As minimally invasive techniques do not expose critical anatomic structures, enhanced visualization with augmented reality might be beneficial. Another potential benefit of augmented reality in minimally invasive surgery might be the visualization of the trajectory of the osteotomy. Therefore, the difficulty of registration of the virtual model to the foot has to be overcome. Looking ahead future uses of augmented reality could also include teaching assistance allowing an experienced surgeon overview over the operative field by projecting the view of the unexperienced surgeon on his head-up display. This might simplify the surgeon's collaboration in the future.

Although augmented reality shows promising results and opportunities, the application of the technique has not find entry into the surgeons practice so far. In hallux valgus surgery, augmented reality cannot be recommended at the moment in daily clinical use due to the lack of evidence and the already good-to-excellent results with standard techniques. However, the rapid development of this new technique might find entry to bring the surgical procedure to perfection or train unexperienced surgeons.

SUMMARY

Augmented reality is a promising new technique to enhance visualization and precision in orthopedic surgery. So far, only one study focused on augmented reality in hallux valgus surgery. From this proof-of-concept study, improvement for unexperienced surgeons was put in perspective. However, to the present-day augmented reality has not advanced to displace conventional hallux valgus surgery. With further improvement of augmented reality-guided surgery including automated registration to soft tissue and bone, this technique might receive entry in surgical teaching or improving accuracy of hallux valgus surgery in the future.

CLINICS CARE POINTS

- Improper execution of the osteotomy in hallux valgus surgery might result in excessive shortening of the first ray.
- Augmented reality has not proven its superiority to conventional hallux valgus surgery so far.

DISCLOSURE

The authors have nothing to disclose.

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