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Breast

Improving Visualization of Intramuscular Perforator Course: Augmented Reality Headsets for DIEP Flap Breast Reconstruction

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Background: Augmented reality (AR) technology, exemplified by devices such as the Microsoft HoloLens 2, has gained interest for its potential applications in preoperative guidance. This study explores the use of AR technology for perforator identification during deep inferior epigastric artery perforator (DIEP) flap breast reconstruction.

Methods: A case series of five patients where an AR device was used to identify perforators during DIEP flap breast reconstruction is presented. The device was utilized to recognize preoperative perforators and map their extra- and intramuscular routes. Sound and/or color Doppler confirmation was used to verify the findings.

Results: In all five cases, the AR device successfully identified preoperative perforators and delineated their extra- and intramuscular routes. AR technology in perioperative visualization of vasculature offers the potential to enhance surgical precision and reduce operative times. By providing an augmented three-dimensional overlay of patients' vascular structures, AR can facilitate a more comprehensive understanding of individual anatomy, ultimately improving surgical outcomes.

Conclusions: AR technology shows promise in enhancing perforator identification efficiency and deepening understanding of perforator trajectories during preoperative planning. Nonetheless, additional research is needed to establish whether the advantages of AR technology warrant its widespread adoption for perforator identification. *(Plast Reconstr Surg Glob Open 2023; 11:e5282; doi: 10.1097/GOX.0000000000005282; Published online 21 September 2023.)*

INTRODUCTION

Deep inferior epigastric artery perforator (DIEP) flap breast reconstruction is a widely accepted autologous tissue transfer technique that involves the identification and dissection of perforating vessels from the abdominal wall.[1] Despite its advantages in terms of aesthetic outcomes and patient satisfaction, DIEP flap reconstruction can be technically challenging, with a steep learning curve for identifying and dissecting the appropriate perforators.[2] Accurate identification of perforators is crucial for the success of the procedure, as it directly impacts flap viability and postoperative recovery.[3]

In recent years, advancements in augmented reality (AR) technology have garnered attention for their potential in enhancing various surgical procedures, including DIEP flap reconstruction.[4,5] AR headsets, such as the Microsoft HoloLens 2, enable the overlay of virtual anatomical information onto the real-world surgical field, thereby assisting surgeons in visualizing critical structures and navigating complex anatomy (Fig. 1). Preliminary studies have demonstrated the feasibility and potential benefits of AR technology in improving surgical accuracy, reducing operative times, and decreasing complications.[6–8] Furthermore, the integration of AR in surgical education may enable surgical trainees and surgeons to acquire a deeper comprehension of complex vascular anatomy and develop critical skills in a more immersive and interactive learning environment.

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Fig. 1. Surgeon wearing AR headsets in preoperative preparation.

Takeaways

Question: Can the HoloLens 2 technology improve the visualization of the intramuscular perforator course in DIEP flap breast reconstruction?

Findings: The HoloLens 2 AR technology successfully identified preoperative perforators and their routes in five cases, suggesting potential for enhanced surgical precision, reduced operative times, and improved outcomes in DIEP flap breast reconstruction.

Meaning: HoloLens 2 AR technology potentially improves perforator identification efficiency and fosters a more profound understanding of perforator trajectories in preoperative planning

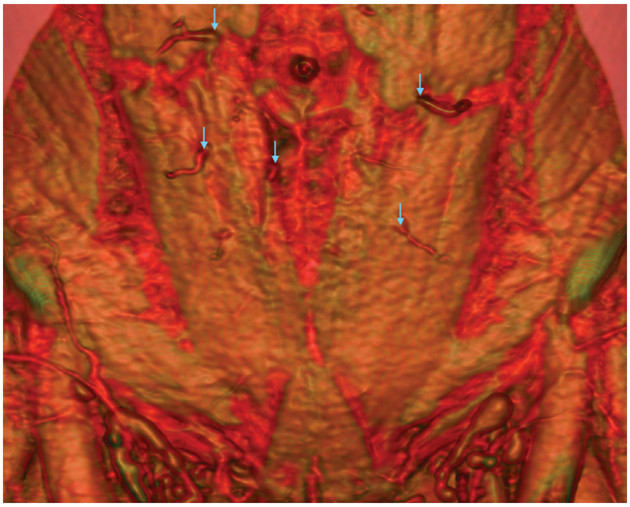

Fig. 2. Stereotactic mapping of the CTA illustrating current best practices in perforator identification.

Although traditional imaging modalities such as computed tomographic angiography (CTA) and magnetic resonance angiography have been instrumental in identifying the location and subcutaneous course of perforators,[9] they fall short in providing an augmented visualization of the intra- and submuscular courses of the deep inferior epigastric artery (DIEA) in relation to superficial perforators. Initially, templates were utilized to enhance the accuracy of mapping, but the visualization of the deeper structure remained a challenge. Subsequently, stereotactic guidance was developed to further refine the mapping process (Fig. 2).[10]

To address these limitations, this study employs the use of AR headsets for perforator identification in DIEP flap reconstruction to improve an overlay-augmented three-dimensional mapping of perforators.[9] By providing an augmented three-dimensional visualization of perforator anatomy, AR headsets may improve the efficiency and precision of perforator identification, ultimately leading to better clinical outcomes and reduced operative times.[11] Despite the promising preliminary results,[12] the implementation of AR technology in DIEP flap reconstruction is still in its infancy, with limited high-level evidence to support its widespread adoption. We hypothesized that AR technology would improve the efficiency of perforator identification and used DIEP flap breast reconstruction to test this hypothesis.

METHODS

Study Design and Ethics Approval

This study is a case series of patients who underwent DIEP flap breast reconstruction using AR headsets for perforator identification. Informed consent was obtained from all individual participants included in the study.

Participants and Inclusion Criteria

A total of five women underwent unilateral secondary breast reconstruction using DIEP flaps between August 2022 and April 2023. The procedures were conducted by four distinct surgical teams at two institutions in Denmark (Aarhus University Hospital and Odense University Hospital) and one in Australia (Peninsula Private Hospital, Melbourne) institutes. Informed consent was obtained from all included participants before surgery. The inclusion criteria for the study were women 18 years of age or older, requiring unilateral or bilateral

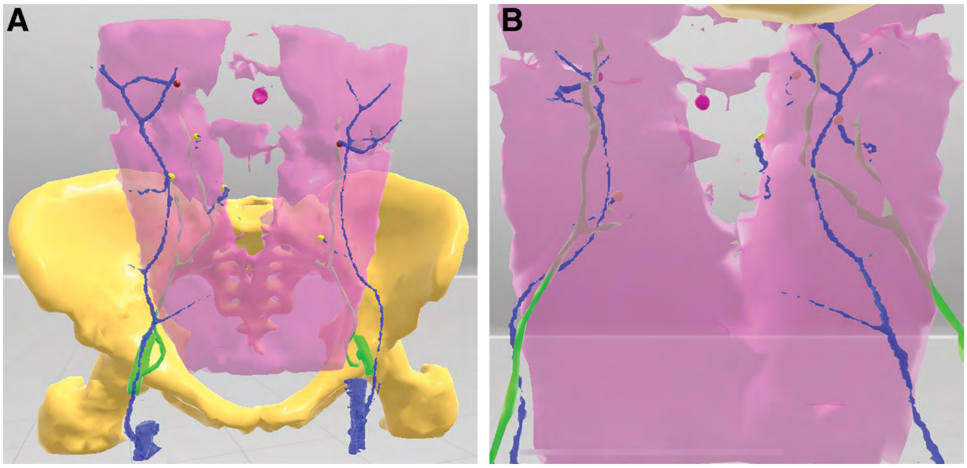

Fig. 3. Patient data segmented in Mimics Innovation Suite and visualized in the Synergy app. A, blue: superficial inferior epigastric vein; green: DIEA-perforator paths; gray: DIEA-perforator intramuscular courses; red dots: optimal DIEA-perforator fascia penetration points (based on size and trackability through muscle); yellow dots: less optimal DIEA-perforator fascia penetration points. The rectus muscle is shown as transparent, and the skin layer has been removed. B, The same patient, but the view is from within the pelvis, displaying the posterior side of the rectus muscle.

breast reconstruction following mastectomy, and suitable for DIEP flap reconstruction based on preoperative imaging findings. Patients with contraindications for DIEP flap surgery or those who declined to participate in the study were excluded.

Preoperative Imaging and AR Headset Preparation

Before surgery, all patients underwent a CTA to identify perforator locations and the subcutaneous course of the vessels. Clinical engineers at Aarhus University's 3D-print center segmented the CTAs using Materialise Mimics Innovation Suite (Materialise NV, Belgium) (Fig. 3). Using semiautomated techniques, the engineers identified anatomical structures such as skin, rectus abdominis muscle, and bone structures like the pelvis and xiphoid process. They then made fine-tuning adjustments manually. Importantly, engineers are not needed to be on-site during surgical operation, and therefore, integration of this technology can be achieved by institutions paying for the device or through a license deal on a case-by-case basis. Following segmentation, standard triangular language files were exported to Blender (Blender, The Netherlands) to add color and transparency to the different anatomic structures. The result was then exported as GLB files to the Synergy application (SynergyXR, Denmark) on the AR device. A key feature of this application is its ability to turn on/off different anatomic structures (Fig. 3). The Microsoft HoloLens 2 is a standalone wireless AR headset that offers about 2 hours of operational time per charge, with each charge taking an hour. No supplementary lighting attachments were used with the headset; it functions optimally under standard operating theater lights. For first-time users, the device requires a learning curve of approximately 30 minutes to become familiar with the necessary gestures and movements. To gain full comfort in its use, it typically takes about one to two operative cases. The device is priced at $3500, although this does not include the additional cost of software licenses. The image of a surgeon wearing an AR device can be seen in Figure 1, and an illustrative video of its use can be found in a previous study.[13]

Surgical Technique and AR Headset Integration

In this study, we assessed the accuracy of the perforator identification preoperatively. The primary focus was on the efficacy of the perforator identification using an AR device and its vasculature course and its seamless integration into the existing workflows of experienced plastic surgeons. This case series provides anecdotal evidence showcasing the incorporation of AR technology into surgeons' practice.

Before the surgeons examined the patients, an operator used the AR device to create DIEA-perforator maps on the patients' abdomens (Fig. 4). The suprafascial course, fascia penetration, and intra- and submuscular courses were illustrated (Fig. 3). Fixed anatomical landmarks were utilized to manually align the virtual overlay with the correct position on the abdomen. Surgeons subsequently entered the room and, using handheld sound Doppler (Aarhus and Melbourne) or sound and color Doppler (Odense), identified the perforators according to CTAs.

The surgeries proceeded according to each institution's standard method. In two cases (one in Aarhus and one in Odense), the operator utilized the AR headset during surgery to outline the intramuscular course of the chosen DIEA-perforator toward its exit at the inferior lateral edge of the rectus abdominis muscle.

RESULTS

The AR headset was used in all five cases. Engineers took approximately 60 minutes to convert the CTA for

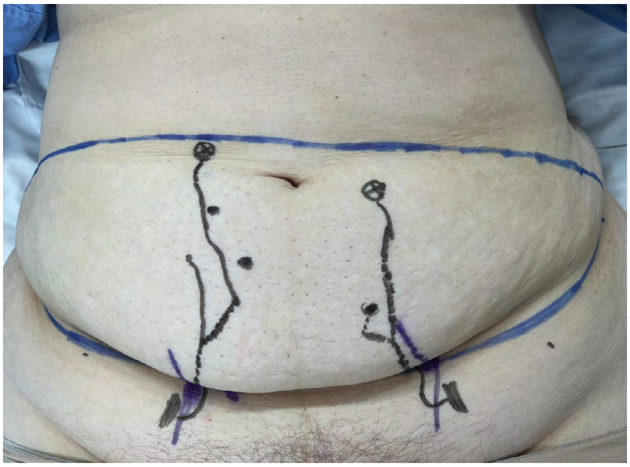

Fig. 4. Perioperative surface markings of the patient in Figure 3.

use with the AR headset. The operator, tasked with manually aligning the virtual overlay on the patient's abdomen, devoted 7–10 minutes to this process. Using the AR headset to draw the perforators' courses on the abdomen required 5–7 minutes (Fig. 3). In four cases, the piercing of the anterior fascia was perfectly aligned, as confirmed by sound Doppler. However, in one case, the perforators' fascia piercing was misaligned by 1 cm when compared to sound and color Doppler. Tracking the intramuscular course of the selected DIEA-perforator perioperatively and drawing on the fascia took approximately 5 minutes, including setup.

DISCUSSION

This case series demonstrated the use of AR headsets for perforator identification in DIEP flap reconstruction. Our findings demonstrate that the integration of AR technology into the DIEP reconstruction may enhance the visualization of relevant vascular anatomical structures, which may improve the accuracy of perforator identification and preservation, which in turn has the potential to positively impact patient-centered outcomes. However, this needs to be confirmed in a comparative prospective study. Overall, the AR headset coupled with CTAs correctly identified perforators and their intra- and extramuscular courses. Misalignment in one case was caused by suboptimal triangulation. In this case, the CTA was more than 16 months old, and the patient's weight distribution had changed. This underlines the imperfectness of using a point-in-time CTA as the basis for a virtual overlay. Minor changes in body composition will affect alignment and, thus, targeting of the perforators and their courses.[5] Having identified the misalignment with color Doppler, the overlay was reset to the correct perforator position, whereafter the intramuscular course tracking could be drawn. Although AR technology presents challenges for tracking the intramuscular course of a perforator, especially after flap retraction, it still offers the advantage of enabling a preoperative 3D model of the patient's anatomy, complemented by preoperative patient markings. This suggests that the two modalities potentiate each other. Although color Doppler can visualize the same course, it necessitates a high degree of proficiency in ultrasound, whereas utilizing the AR headset requires virtually no prior expertise. This study was primarily conducted to assess whether the AR devices could provide supplementary insights to surgeons, and to evaluate our alignment strategy for AR. Doppler confirmation was deemed essential for this exploratory study. Currently, most surgeons use Doppler technology in their practice. The question of whether AR will eventually join or even supersede the use of Doppler in surgical applications is a subject for future exploration and research. Last, although CTA is the current gold standard for DIEA preoperative perforators, the authors utilized audible Doppler signals to verify the points where perforators breached the fascia, which requires proficient interpretation for accuracy.[10] These findings indicated a perfect alignment between Doppler readings and the 3D AR visualization of these perforators, demonstrating the potential efficacy of combining these techniques.

This is not the first report to describe the use of AR devices in perforator identification.[13–15] A key challenge to the widespread adoption of this technology is achieving an automatic alignment of the virtual overlay without too much disruption to the standard workflow of surgeons. Quick response markers are a promising approach to solving this[16]; however, the issue of employing a static point-in-time CTA as the basis for alignment remains. Also, the use of AR headsets requires personnel proficient in segmentation. When evaluating its efficiency, the time spent in virtual surgical planning should not be discounted.

Furthermore, AR devices can effectively overcome geographical barriers in healthcare. Its high-definition holographic displays enable doctors to remotely diagnose patients, guide self-administered treatments, and facilitate peer consultations on complex cases. This technology was investigated in rural settings of India for cervical screening and found beneficial in providing advice in remote or rural areas with limited healthcare access.[16] Despite the initial investment for an AR device, its long-term cost-effectiveness becomes evident considering reduced travel expenses, improved patient outcomes, and superior provider training.

Despite these limitations, our case series demonstrates the potential of AR headsets to provide true spatial 3D visualization of all pertinent anatomic structures, an area where this technology is still in its infancy.[17] By wearing AR glasses, surgeons can virtually examine the patient's anatomy before performing the actual procedure, offering a more immersive and realistic experience compared to the two-dimensional images on the computer screen. The integration of AR technology allows for a more comprehensive understanding of the intramuscular and submuscular courses of the DIEA in relation to superficial perforators, facilitating more precise dissection and preservation of these structures. This improved visualization should potentially lead to better flap viability, reduced operative time, and fewer postoperative complications, ultimately enhancing patient outcomes. Furthermore, integrating AR technology to implement a grading system may aid in the assessment of perforator availability and patency for DIEP flaps. This grading system could enhance surgeons' ability to identify and select the optimal perforators for flap construction, streamlining the selection process and safeguarding flap viability, as an example of a crude version of this (Fig. 3A). It is important to note that the successful implementation of AR headsets in DIEP flap reconstruction relies heavily on accurate preoperative imaging and patient-specific 3D modeling. The integration of CTA or magnetic resonance angiography findings is crucial for generating precise 3D models that can be used in conjunction with the AR headsets during surgery. Also, considerations arise when dealing with patients' body fat composition or significant pannus when using AR technology. AR overlays digital information onto the physical world, and substantial shifts in the patient's position or distortion of anatomy due to excessive weight may potentially lead to misalignment in the AR display. Last, AR devices are still expensive. To our knowledge, a cost–benefit analysis has not yet been done, and it remains to be determined if its use has a net positive or negative impact on operative time; therefore, future studies should conduct in-depth cost analysis to clarify these uncertainties.

CONCLUSIONS

In conclusion, the incorporation of AR technology in preoperative planning holds promise for enhancing the accuracy and efficiency of perforator identification and providing surgeons with a more comprehensive understanding of perforator trajectories. Moreover, the application of AR in surgical education and training could revolutionize the way surgeons acquire essential skills and knowledge. However, additional research and development are warranted to evaluate the full scope of benefits offered by AR technology to determine if its potential advantages justify widespread adoption for perforator identification and other surgical applications.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

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