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Leveraging the Apple Ecosystem: Easy Viewing and Sharing of Three-dimensional Perforator Visualizations via iPad/iPhone-based Augmented Reality

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Summary: We introduce a novel technique using augmented reality (AR) on smartphones and tablets, making it possible for surgeons to review perforator anatomy in three dimensions on the go. Autologous breast reconstruction with abdominal flaps remains challenging due to the highly variable anatomy of the deep inferior epigastric artery. Computed tomography angiography has mitigated some but not all challenges. Previously, volume rendering and different headsets were used to enable better three-dimensional (3D) review for surgeons. However, surgeons have been dependent on others to provide 3D imaging data. Leveraging the ubiquity of Apple devices, our approach permits surgeons to review 3D models of deep inferior epigastric artery anatomy segmented from abdominal computed tomography angiography directly on their iPhone/iPad. Segmentation can be performed in common radiology software. The models are converted to the universal scene description zipped format, which allows immediate use on Apple devices without third-party software. They can be easily shared using secure, Health Insurance Portability and Accountability Act–compliant sharing services already provided by most hospitals. Surgeons can simply open the file on their mobile device to explore the images in 3D using "object mode" natively without additional applications or can switch to AR mode to pin the model in their real-world surroundings for intuitive exploration. We believe patient-specific 3D anatomy models are a powerful tool for intuitive understanding and communication of complex perforator anatomy and would be a valuable addition in routine clinical practice and education. Using this one-click solution on existing devices that is simple to implement, we hope to streamline the adoption of AR models by plastic surgeons. *(Plast Reconstr Surg Glob Open 2024; 12:e5940; doi: 10.1097/GOX.0000000000005940; Published online 1 July 2024.)*

INTRODUCING EASY IMMERSIVE PERFORATOR VISUALIZATION ON IPHONE AND IPAD

Autologous breast reconstruction with abdominal free flaps has been demonstrated to result in superior long-term patient-reported outcomes.[1] Facilitated by advances in microsurgical technique, deep inferior epigastric perforator (DIEP) and muscle-sparing transverse rectus abdominis muscle (MS-TRAM) flaps have become the workhorse flaps for autologous breast reconstruction.

Yet, due to the variable arborization pattern and intramuscular course of the deep inferior epigastric artery (DIEA), DIEP flap harvest remains complex. Today, plastic surgeons routinely use preoperative imaging to gain an understanding of the intricate vascular anatomy. Computed tomography angiography has been the dominant preoperative imaging modality due to fast acquisition times, high arterial details, and secondary benefits (eg, cost-effectiveness, reduction in operating time).[2]

However, even though the two-dimensional slice images themselves are highly accurate, surgeons cannot take full advantage of comprehensive imaging without

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Received for publication December 28, 2023; accepted May 10, 2024.

DOI: 10.1097/GOX.0000000000005940

Disclosure statements are at the end of this article, following the correspondence information.

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having an easy means of 3D reconstruction of imaging data, which allows for a more intuitive understanding of the intricate course and topography of perforating vessels.

Previous techniques to increase intuitiveness not only necessitated expensive equipment (eg, headsets or volume rendering software), but also needed surgeons to come to a specific location at a specific time to work with these visualizations. Surgeons cannot independently use these visualizations (eg, "on the go"), as they are dependent on radiologists and technicians. Hence, having the ability to independently review perforator anatomy in 3D would be quite valuable to surgeons. We propose leveraging the ubiquity of mobile devices, (ie, smartphones and tablets) for this purpose.

Augmented reality (AR), the superimposition of virtual data within one's real-world environment, provides an ideal solution. AR capabilities are already integrated in every iPhone and iPad. A 2014 survey found an overwhelming dominance of iPhone market share among US physicians, at 85%.[3] Today, iPads are already commonly used in plastic surgery training.[4,5]

The ubiquity of these devices provides an opportunity to translate AR to everyday use. Both devices allow users to inspect AR anatomical models in their physical surroundings. Medical students studying clinical anatomy already actively use this approach with fully interactive and dissectible 3D anatomy models in AR.[6] A feasibility study in mini pigs demonstrated the utility of using iPad AR for perforator mapping.[7]

However, AR on smartphones and tablets has not yet been used to enable surgeons to easily explore 3D patient models for preoperative planning in more than singular cases.

Our technique uses standard radiology software to create 3D abdominal models. Segmentations of the skin, the rectus abdominis muscle, and the DIEA vascular tree are created as we have described in the context of 3D-printing.[8] Using free tools, these segmentations are then converted (Apple RealityConverter), colorized (Apple Xcode), composited in a 3D-scence (Apple RealityComposer), and exported in a universal scene description zipped (USDZ) file.

Originally pioneered by Pixar for movie production, USDZ became the standard 3D AR file format for Apple and is deeply embedded in the operating system throughout devices. This has the major advantage that no additional software is necessary on Apple devices so that surgeons can immediately use these files without any IT overhead. They can be sent through encrypted channels as email attachments, via hospital messenger apps, or shared via cloud solutions (eg, Box or OneDrive). Most hospital systems already have one of these solutions in place for HIPAA-compliant file sharing. In combination, file sharing and direct usage of 3D patient models enables location-independent and remote review by the surgeon at any time on a device they already own.

Having received the file, the patient model is immediately visualized in either object mode (for inspection) or AR mode, where it can be placed on any nearby flat surface (analogous to the operating table). In AR, the model stays locked in place and can be explored by moving around it, similar to inspecting a patient's abdomen. The opaque red arteries and perforators shine through translucent blue muscle (rectus abdominis) and translucent gray skin, allowing perforator exits at the fascia level to be clearly distinguished by a more intense red color. To further increase arterial detail, the surgeon can click on the skin to remove it. Clicking the remaining blue muscle brings the skin back.

We demonstrate the entire on-the-go surgeon workflow on an iPhone. [**See Video 1 (online),** which shows a demonstration of the workflow on an iPhone.] Additionally, Figure 1 gives an overview of three cases side by side on an iPad, and object mode inspection and AR mode exploration are also demonstrated interactively. [**See Video 2 (online),** which shows an interactive demonstration of the three cases from Figure 1.] In total, we tested this technique on 10 cases from one surgeon's breast reconstruction practice and demonstrated consistency in the ability to review and utilize the images.

Takeaways

Question: Preoperative computed tomography angiography is frequently obtained in preparation for microsurgical breast reconstruction. Yet, interpretation of two-dimensional data and three-dimensional (3D) conversion can pose challenges.

Findings: Standard radiology software was used to create 3D abdominal models via segmentations of the skin, rectus abdominis muscle, and deep inferior epigastric artery vascular tree. Using free tools, these segmentations were converted and exported in a universal scene description zipped file, thus, permitting review on Apple devices without IT overhead.

Meaning: Leveraging the ubiquity of Apple devices, our approach permits surgeons to review 3D models of deep inferior epigastric artery anatomy segmented from abdominal computed tomography angiography directly on their iPhone/iPad.

DISCUSSION

Our 3D AR models allow surgeons to intuitively explore the patient's perforator anatomy and topography. AR models make use of software that is free and can immediately be visualized on mobile devices. In contrast, 3D-printing is more expensive and time-consuming, taking hours to days for the surgeon to receive the models. Furthermore, in addition to being able to review the AR models on the go, they could be used intraoperatively by using sterile device covers.[9]

By leveraging Apple's technology, we not only eliminated technical overhead for the surgeon, but also enabled independent, remote review of more intuitive 3D visualization data compared with the original two-dimensional image slices. Three-dimensional models on advanced holographic mixed reality headsets are currently actively investigated for preoperative planning in plastic surgery.[10] Although they have significant advantages, such as more accurate display and better ergonomics, conceptually they

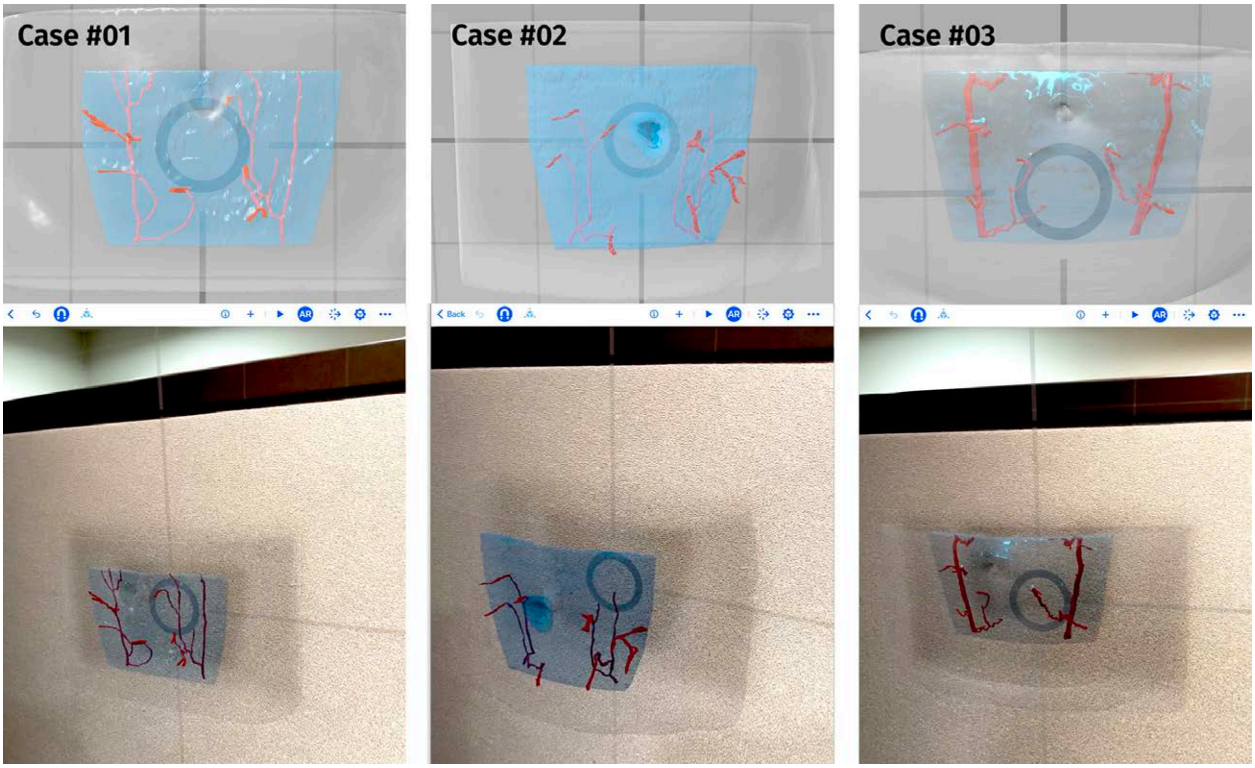

Fig. 1. Side-by-side comparison of three DIEP flap cases. Top: 3D models in object mode. Bottom: 3D models in AR mode mapped to a cubicle wall. Rectus abdominis muscle is shown in translucent blue; DIEA vascular tree in red.

are very similar and superimpose 3D models in real-world surroundings. With the advent of Apple Vision Pro, our 3D models and this simple workflow will be usable on high-resolution AR glasses directly.

We are convinced that patient-specific 3D anatomy models are a powerful tool for intuitive understanding and communication of complex anatomy among peers in plastic surgery, from preoperative planning to resident education. By essentially enabling a free one-click solution on existing devices, we hope to streamline the adoption of AR models by plastic surgeons and further stimulate research in this direction.

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DISCLOSURES

Necker is a part-time research student at Siemens Healthineers (Erlangen, Germany). Dr. Leuze is a co-founder and owner of Nakamir Inc (Menlo Park, Calif.). Dr. Momeni is a consultant for AxoGen, Gore, RTI, and Sientra. All the other authors have no financial interest to declare in relation to the content of this article. This study was supported by BaCaTeC—Bavaria California Technology Center, Erlangen, Germany (an institution fostering collaborations between Bavaria and California funded by the Bavarian State Ministry for Science and Art).

ACKNOWLEDGMENT

The present work was performed in fulfillment of the requirements for obtaining the degree "Dr. Med." for Fabian Necker.

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