Technical Note

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Holographically-Guided Endovascular Aneurysm Repair

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Abstract

Purpose: To demonstrate the feasibility of augmented reality visualization in planning and navigating endovascular aortic repair. **Technique:** A 77-year-old patient with abdominal aortic aneurysm was treated with endovascular repair. An augmented reality head-mounted display was used during the procedure. The aneurysm and bones were projected as 3-dimensional holograms. The operator controlled the device with gestures and voice commands (movement, rotation, cutting through, and zooming). Moreover, the hologram was placed in front of the angiography monitor and manually registered with fluoroscopy. **Conclusion:** Augmented reality with holographic rendering is feasible and helpful during endovascular aortic repair. Its routine use could possibly lead to shorter operating time, reduced contrast volume, and lower radiation dose; however, larger studies are required to obtain statistically significant results on the outcomes.

Keywords

three-dimensional imaging, abdominal aortic aneurysm, augmented reality, computed tomography angiography, endovascular aneurysm repair, hologram, image fusion, mixed reality

Introduction

Endovascular aneurysm repair (EVAR) is a gold standard in aortic aneurysm treatment because of its low early mortality.[1] However, this procedure can still be challenging in the case of complex vascular anatomy. Aneurysm neck angulations, vessel tortuosity, acute branch takeoff angles, and other vascular irregularities can complicate the procedure, contributing to increased operating time, radiation dose, and contrast volume.

Vascular structures are located in 3-dimensional (3D) reality with specific spatial relationships between them, but the geometry is lost during projection of 3D anatomy on a 2-dimensional (2D) angiography monitor, meaning a large amount of useful information is unavailable. Preoperative computed tomography angiography (CTA) can provide additional valuable data, and 3D volume renderings can be printed or displayed on a computer screen, although the same aforementioned spatial limitation applies. Another available method is the use of image fusion, which is associated with less exposure to radiation for both patient and operator[2] due to the need for fewer digital subtraction angiograms (DSA). This system is sometimes called a 3D roadmap; however, this in fact overlays 3D images on a flat screen. Therefore, there is a strong need for new technologies that will be able to project a patient's anatomy with preservation of 3D relationships between structures.

Currently, a few visualization methods have been proposed to represent medical data in 3 dimensions, such as 3D printing, virtual reality (VR), and augmented reality (AR). VR creates a virtual, simulated environment and due to obscuring, the real time view is not appropriate in operating rooms. Contrarily, AR is a combination of a computer-generated world and the real environment. Various formats of computerized data can be projected in a user's visual field, allowing the user to see through the display. This kind of technology often uses a wearable optical head-mounted display (OHMD) or "smart" glasses. A surgeon can focus on the operating field instead of on planning sketches, images from volume rendering reconstructions, or computer screens. These clear advantages make AR a promising technology that has been implemented in various medical fields, including cardiology,[3] neurosurgery,[4] and urology.[5] For instance, Opolski et al[3] used smart glasses to display projections of preintervention CTA datasets during percutaneous

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coronary interventions in a catheterization laboratory. A more recent upgrade to the design of the OHMD added see-through high-definition holographic lenses that enabled display of 3D holograms. Sometimes this technology is called mixed reality because of enhanced interaction between the real and computer-generated worlds.

Currently, there is a lack of scientific data regarding the use of AR in the vascular surgery setting. Therefore, the aim of this study was to test the application of AR with holographic display and its feasibility during EVAR.

Technique

A 77-year-old patient with a 55-mm abdominal aortic aneurysm (AAA) qualified for elective EVAR and gave informed consent for the procedure. The preoperative CTA, which was used to create holographic data, was acquired with a SOMATOM Definition AS scanner (Siemens Healthcare GmbH, Erlangen, Germany) at a 0.75-mm slice thickness. A vascular surgeon who was experienced in CTA evaluation for EVAR planning loaded the DICOM (Digital Imaging and Communications in Medicine) files in the open source 3D Slicer software (version 4.10.0; https://www.slicer.org/),[6] where the data were cropped and the voxels converted for isotropic spacing. Then, he performed semiautomatic segmentation, with careful inspection of chosen regions containing the relevant anatomy of the aorta with AAA, aneurysm thrombus, and bones of both the lumbar spine and coccyx. In Blender 3D modeling software (Blender Foundation, Amsterdam, the Netherlands; https://www.blender.org/), small distal arterial branches (unnecessary for EVAR navigation) were cut off. Preprocessing time was under 15 minutes: ~10 minutes for segmentation and 5 for modeling. The exported model mesh was subsequently loaded in CarnaLife Holo software (MedApp, Kraków, Poland), which was able to project both surface and volume rendering data in 3D holographic form.

EVAR to implant an Endurant II stent-graft (Medtronic, Minneapolis, MN, USA) was performed in the operating theatre using Ziehm Vision RFD angiography equipment (Ziehm Imaging GmbH, Nurnberg, Germany) for fluoroscopy and DSA. The femoral arteries were exposed. The operator put on Microsoft HoloLens glasses (Microsoft Corporation, Redmond, WA, USA; Figure 1A). Three-dimensional models of the AAA with its thrombus and adjacent bones were visualized (Figure 1B). The hologram could be positioned in any part of the operating room; the operator chose a place not interfering with the operating field and other screens. The virtual model behaved like a physical object located in the room, always presenting itself when the user looks in that specific direction and showing different parts based on the viewing angle. Using gestures and voice commands (Figure 1C), the operator was able to move, rotate, cut through, and zoom the hologram (Figure 1D). Moreover, it was possible to detach thrombus from the aneurysm and separate bones from the arterial system (Figure 1E). Additionally, a 2D image containing the volume rendering reconstruction with arterial diameters and planning notes was displayed next to the hologram.

After the successful procedure, the surgeon reported the hologram useful in navigation and guidance without obscuring vision. The device control was rated as good without a risk of contamination of the operating field. Moreover, the possibility of manual image fusion with fluoroscopic data was explored. For that purpose, the hologram was placed in front of the angiographic monitor and the bones were manually registered between the 2 modalities utilizing scaling and rotation options. After that, the bones hologram was removed from the arterial system, leaving only the latter (Figure 1F). The 3D virtual model transparency was decreased to increase vision clarity of the screen.

Discussion

To our best knowledge, there has been no other study describing the use of holograms with an AR headset during EVAR. The presented method enables a surgeon to have access to 3D CTA data at any time in the operation. Until now, our workflow was to print several images of the volume rendering from different angles. We found that data useful whenever a problem arose due to difficult anatomy (branch takeoff angles, tortuosity, etc). However, such data always were in fact 2D, and we could not reach for views other than those already prepared. The AR approach is far most helpful, being available all the time and enabling rotation in all angles with preservation of structural relationships. Additionally, the 2D image with planning notes also displayed by the Microsoft HoloLens reduced the frequency of operator head rotation, thus inattention. AR systems have the potential to combine many forms of medical data, merging different screens into one shared system to keep the operator's eyes focused on the operating field.

The value of medical datasets presented with novel 3D visualization techniques is expressed by numerous studies reporting the use of 3D printed anatomical models,[7] many of them used for planning, navigation, and guidance during surgery.[8] Disadvantages of physical models is their long manufacturing time and the need for a 3D printer and well-trained, dedicated staff to use it. The cost of the model is increased by consumables. Moreover, an operator usually cannot rotate such a model during surgery without first sterilizing the printed model.[9] AR is free from these disadvantages. Reports regarding endovascular procedures with holographic imaging are scarce, and few are available in a vascular field. Such guidance has been used during pulmonary artery angioplasty and stenting for treatment of chronic thromboembolic pulmonary hypertension.[10] Rymuza et al[11] performed transcatheter valve implantation enhanced by

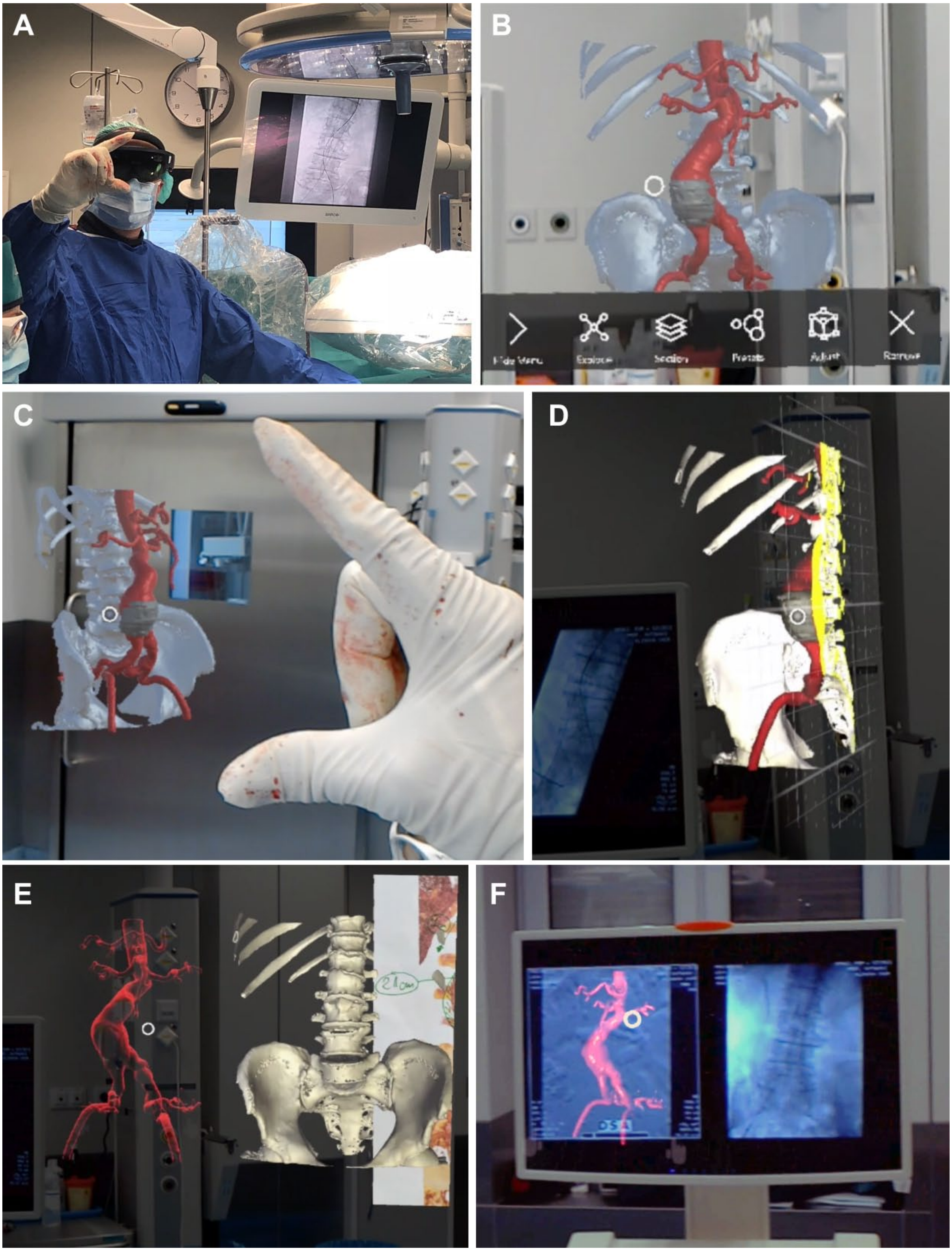

Figure 1. (A) Operator wearing Microsoft Hololens. (B) Three-dimensional abdominal aortic aneurysm and bones. (C) Manipulation of the hologram with gesture. (D) Cutting the hologram. (E) Splitting aneurysm from bones. (F) The hologram is placed in front of the angiographic screen for manual registration.

AR. Both ended successfully. The authors expressed great potential in this new method.

While observational studies are needed to evaluate any effect of AR on operative outcomes, we were able to demonstrate the feasibility of an AR headset during EVAR. The operating physician reported its usefulness without compromising his view and limiting operational skills. No headache, dizziness, or other unpleasant feelings were reported. This was an initial experience, and upcoming studies should involve more sophisticated anatomies during fenestrated or branched EVAR.

The preparation of data for surface rendering in AR was performed in 3D Slicer, though the data can be prepared in any DICOM processing software with segmentation tools. This step should be performed or reviewed by a physician with expertise in CTA assessment to ensure accuracy of the displayed hologram. Segmentation and surface rendering can be omitted, and the DICOM files can be imported directly to software like CarnaLife Holo and processed with volume rendering, which reduces all limitations connected with segmentation for surface rendering. It should be noted that the greatest limitation of 3D model quality is the source imaging, especially slice thickness, which in our opinion should not be greater than 1.25 mm.

The OHMD employed in this case (Microsoft HoloLens) also has several limitations. The battery life is between 2 and 3 hours of working time, meaning it may not be sufficient for long procedures. This can be overcome be using the device only during the most challenging parts of the case. The other drawback is the weight of the headset (579 g), which can cause some fatigue to the operator's neck, though this was not experienced in our case. The binocular vision field is relatively small (30×17.5 grades), such that vast anatomies must be examined by head movements. These limitations will be overcome with the next generations of the OHMDs.

There is a place for software upgrades as well. The future holds promise for advancements in terms of automatic registration and fusion of fluoroscopic data and CT-based holograms. Right now, there are no available solutions that would allow live integration of, for example, a C-arm projection with 3D models. Such combination will potentially synergize advantages further, reducing the contrast and radiation dose and operation time. Though fusion was feasible, manual registration was uncomfortable and time-consuming, so it will not find a place in everyday use. In addition, anatomical markers (eg, vessel ostia) cannot be included as default. If they are to be added, they must be predesigned in modeling software such as Blender. Currently, CarnaLife Holo is unable to report the angle of the hologram as angiographic projections; thus, a surgeon cannot use these data to set a C-arm. This feature is also in development.

Conclusion

Augmented reality with holographic imaging of CTA data is feasible and helpful during EVAR. AR has a potential to improve perioperative outcomes; however, studies are required to assess any statistically significant impact on operating time, contrast volume, and radiation dose.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Jan Witowski, Jakub Kamiński, and Jakub Serafin are employees of MedApp S.A., Kraków, Poland.

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