Using a novel three-dimensional holographic technology to perform open vascular surgery procedures

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ABSTRACT

Augmented reality technology has been introduced during recent years into everyday clinical practice. Several surgical specialties have begun using such technology for preoperative planning as well as intraoperatively. Regarding vascular surgery, a limited number of reports have described the benefits, mainly for endovascular procedures. We aim to present a novel three-dimensional holographic system we used to perform an open vascular procedure. (J Vasc Surg Cases Innov Tech 2024;10:101440.)

Keywords: Augmented reality; Hologram; Open surgery; Vascular surgery

The integration of augmented reality technology in preoperative planning has allowed physicians to better design surgical procedures.[1] Reconstructing computed tomography (CT) or magnetic resonance imaging (MRI) scans into holographic visualizations can help the surgeon select the optimal path that will be followed during surgery. Additionally, several investigators have described the use of three-dimensional (3D) holograms and augmented reality technology during the performance of different procedures such as liver, hepatobiliary, and other types of surgery.[2-4] However, most studies evaluating the role of such technology have been performed in a preclinical or experimental setting.[5] Additionally, a limited number of studies have evaluated the use of such technology during endovascular procedures but not during open vascular surgery.[6,7] This report aims to present a novel 3D holographic system that was used during an open vascular procedure. We also discuss the associated benefits and future applications.

METHODS

A 72-year-old male patient presented with chronic limb threatening ischemia of the right lower extremity (rest pain, Rutherford classification stage IV). His medical history included current smoking (70 pack-years), arterial hypertension, dyslipidemia, and coronary artery disease. The patient underwent CT angiography, which revealed a coral reef aorta, a heavily calcified occlusion of the right common iliac artery (CIA), a heavily calcified occlusion of the right common femoral artery (CFA; GLASS Global Limb Anatomic Staging System. stage IIB), femoropopliteal occlusion (GLASS grade 3), and below-the-knee arterial disease (GLASS grade 3). Additionally, there was atherosclerosis of the left CIA without significant stenosis, left femoropopliteal occlusion (GLASS grade 3), and below-the-knee arterial disease (GLASS grade 3; Fig 1). The right CFA was not palpable, although the left CFA was palpable. The patient provided written informed consent for the report of his case details and imaging studies.

For the preoperative assessment, we used for the first time the CarnaLife Holo software (commercially available from MedApp SA), which processes DICOM (Digital Imaging and Communications in Medicine) images and can reconstruct detailed anatomic holograms using different imaging methods, including CT, MRI, and ultrasound. These holograms can be visualized using the standard Microsoft Hololens 2 mixed reality goggles. The data can be presented as volumetric, surface, and multiplanar reconstruction visualization. The system also offers a number of features and tools, including scene customization, filtering, scissors to remove unnecessary elements, built-in presets (custom predefined sets of visualization parameters tailored to specific imaging techniques), and the option to create new effects for specific applications. The system allows for full sterilization if necessary before any procedure. It does not use any joystick or other manual device; therefore, the hands are free to operate while using this device. Eye glasses or loupes can also be used by the operator under the goggles. A very short simulation course is needed to be able to use the device during surgery.

Regarding annotation, points of interest can be marked in the medical data that can be easily found in the holographic space. The user can set also markers on specific structures (eg, the pelvis) on the CT reconstruction and

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Funding: This publication was funded by the National and Kapodistrian University of Athens Special Account for Research Grants (Grand no. 16970).

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2468-4287

https://doi.org/10.1016/j.jvscit.2024.101440

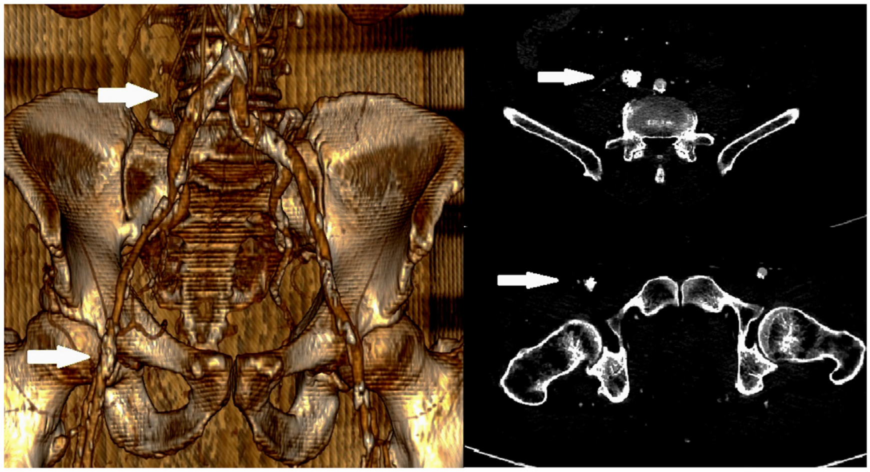

Fig 1. Computed tomography (CT) images showing heavily calcified obstruction of the right common iliac artery and right common femoral artery (CFA; *arrows*).

then virtually mark the corresponding points on the patient, such that the holographic image will be placed and visualized exactly on the patient's body. This will allow the surgeon to use the hologram intraoperatively, not only to reassess the images, but also to cut down and dissect tissues while visualizing the exact anatomy and all surrounding tissues. The software also includes a "cut smart" feature for making any plane in the hologram visible using head movements, a representation of measurements in holographic space. This approach makes it possible to highlight the next steps of the procedure and annotate in real time.

RESULTS

Based on the preoperative assessment, it was decided to perform a femoral–deep femoral artery bypass. Due to coral reef aorta, aortic surgery was excluded. A hybrid procedure was also excluded, because femoral endarterectomy and ipsilateral stenting would be difficult due to the heavy and extensive calcification of the right CIA and CFA.

As seen in Fig 2, the hologram was easily assessed before starting the procedure. Additionally, the hologram was placed on the exact position on the body of the patient (Fig 3; Supplementary Video). This allowed the surgeon to determine the correct location for the incision, especially on the right side where the CFA was not palpable (Fig 4, *A*). The dissection was performed while visualizing the hologram, and the exact location of the femoral bifurcation was identified (Fig 4, *B*). At the same time, visualizing the hologram, the vascular surgeon could see exactly all the structures that were around and below the point of operation, the location of the calcification in the arteries, and the location of branches that should be preserved or could be sacrificed. Due to calcifications in the arteries of the patient, it was decided, with the help of the hologram, exactly where

Fig 2. Visualization of the hologram. Computed tomography (CT) reconstruction (**Right**) and holographic task keyboard (**Left**).

Fig 3. Placement of the hologram exactly on the patient lying on the operating table.

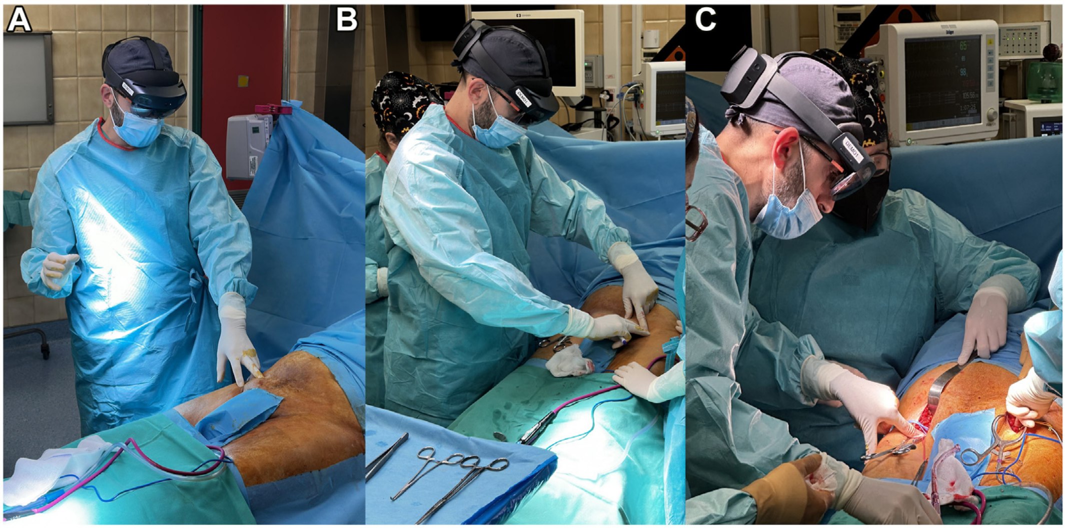

Fig 4. A, Using the device to localize the femoral bifurcation and determine the correct location of the incision. **B,C,** Using the device to make the incisions and dissect the tissues.

the arteriotomy and anastomosis should be performed. The course of the tunnel through which the graft was placed was also defined with the help of the hologram. This approach also helped dissect the femoral bifurcation and, especially, the deep femoral artery (the location of the distal anastomosis) more easily, without damaging any other vascular or neural structures (Fig 4, *C*).

The procedure lasted a total of 143 minutes. No major complications occurred during or early after the procedure. Distal perfusion was significantly improved, and the patient had no rest pain. The patient was discharged after 4 days.

DISCUSSION

The usage of 3D holographic imaging for preoperative assessment and design of vascular surgery procedures has become more popular recently. It has allowed for more precise measurement of all vascular structures, degree of stenosis, amount of calcification and thrombus, and relationships with other significant structures.[8] In addition, due to technological advances, surgeons have used such technology intraoperatively to improve the outcomes of procedures.[9]

The aim of using 3D holographic images during a procedure includes the safer and faster dissection of tissues, avoiding any potential iatrogenic injury. Combining this technology with two-dimensional angiographic images during endovascular repair might help in navigation of endovascular tools, probably with lower radiation and contrast exposure.[5] During open procedures, all vascular segments and adjacent structures or organs can be identified in real time. Precision in dissection and performance of all steps of open vascular surgery, especially procedures for aortic or peripheral artery disease, can be guided using virtual 3D holograms. Such holograms could be a new next-generation, operation-supportive tool in terms of spatial awareness, sharing, and simplicity.[10]

An optimal holographic system should first be able to use data from different types of imaging methods, including CT, MRI, ultrasound, and, even, digital subtraction angiography.[11] This will facilitate the use of such systems, especially for vascular and endovascular procedures. Second, such a system should be a fully on-premise solution that does not require any internet connection to be fully functional. CarnaLife Holo has such features. In contrast, other similar systems are cloud-based, requiring a stable and reliable internet connection to be able to work with all datasets. The CarnaLife Holo software also uses volumetric visualization, enabling the cut smart feature to cut in the visualization from any angle using head movement, change the window and preset, and do many adjustments to the data that are needed from the surgeon's perspective. Other holographic systems use segmented data to show only anatomic structures. This requires intensive steps before loading data into the system, and its diagnostic value is limited to the performance of segmentation steps. CarnaLife Holo enables the surgeon to see the patient's hologram in real size and overlay it on the patient itself. However, other systems do not have the possibility to perform this or do not have the appropriate certification.

Despite these advances, the software has aspects that require further evaluation or improvement. Specific artificial markers need to be developed for placement on the patient during the imaging studies. This would allow placement of the hologram on the patient automatically and more precisely compared with placement by the surgeon. Furthermore, such markers, if left on the patient during surgery, would facilitate the detection of any movement intraoperatively, allowing the position of the hologram to be automatically adjusted. Additionally, such a system could help design the trajectory for biopsy needle insertion or arterial puncture. These applications could facilitate tissue biopsy collection and the catheterization of vessels with extreme precision, limiting radiation exposure and the risk of complications. Finally, although the cost of this software remains high, this could be overcome by the increasing clinical benefits associated with a wider application of this technology in different procedures in the future.

CONCLUSIONS

The novel 3D holographic visualization system CarnaLife Holo could be a very useful tool to assist the vascular surgeon in preoperative planning and intraoperative completion of all the steps of an open procedure, adding precision and reducing all possible risks of complications. Large cohort studies are needed to evaluate all the benefits. Further development could expand the applications of such systems.

DISCLOSURES

None.

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Submitted Dec 12, 2023; accepted Jan 11, 2024.