Novel utility of mixed reality technology in fenestrated thoracic endovascular aortic repair surgery: A case report

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Supported by Hubei Natural Science Foundation (2019CFB499) and the National Natural Science Foundation of China (81900432).

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Disclosures: The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

Received for publication Dec 20, 2021; revisions received May 6, 2022; accepted for publication May 9, 2022; available ahead of print May 11, 2022.

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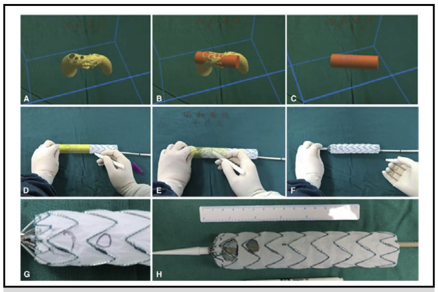
JTCVS Techniques 2022;14:50-2

2666-2507

https://doi.org/10.1016/j.xjtc.2022.05.004



The PMSG procedure of thoracic stent with MR technology.

CENTRAL MESSAGE

We report the first application of mixed reality technology to successfully modify 1 physician-modified fenestrated stent graft during a fenestrated thoracic endovascular aortic repair procedure.

Fenestrated thoracic endovascular aortic repair (f-TEVAR) is commonly performed to prevent severe consequences of thoracic aortic disease with an unfavorable proximal landing zone.[1] In most cases, a physician-modified fenestrated stent graft (PMSG) is suitable to revascularize the branch arteries.[2] However, an inaccurately modified stent may still lead to complications such as an endoleak, a rupture, and/or coverages of branch arteries. Therefore, we report the first application of mixed reality (MR) technology during an f-TEVAR procedure to successfully perform a PMSG. The institutional review board or equivalent ethics committee of the Huazhong University of Science and Technology approved the study protocol and publication of data. The patient(s) provided informed written consent for the publication of the study data. This study was also approved by the institutional review board at Union Hospital July 8, 2020 (No. 2020 [F048]).

CASE PRESENTATION

A 52-year-old man was admitted to the Department of Vascular Surgery, Union Hospital, Wuhan, China, during December 2018 due to complaints of chest pain lasting more than 2 weeks. A cardiac-gated computed tomography angiography (CTA) was performed, which revealed an atherosclerotic thoracic aortic ulcer with thrombosis. CTA showed that the deep ulcer was located in the minor bend of the aortic arch directly opposite the left subclavian artery (LSA) approximately 1 cm away from the left common carotid artery. Preoperative evaluation of aortic stent-covering ulcers will inevitably block the LSA. At the same time, if the left common carotid artery is retained, a short anchoring zone near the ulcer increases the risk of internal leakage. Therefore, the aortic stent should be placed proximal to avoid internal leakage, and the left common carotid artery and LSA covered by the stent should be fenestrated to ensure blood flow. The CTA findings necessitated the revascularization of the left common carotid artery and the LSA. We introduced MR technology to perform an accurate PMSG. Using the original Digital Imaging and Communications in Medicine data of CTA, we rebuilt the stent's 3-dimensional (3D) visualization model from the thoracic aortic artery of the patient. During the PMSG procedure, 3D holographic images of the modified stent were presented in MR glasses (Microsoft HoloLens 2) worn by the operators through image fusion and spatial positioning. The real stent ($28 \times 28 \times 120$ mm) (LifeTec Inc) was fenestrated accurately based on the MR images (Figure 1). A loop of snare was fixed to the hole for additional insurance, and the fenestrated stent was inserted into the patient's aortic artery. The hole perforated on the aortic stent was not radiopaque under digital subtraction angiography,

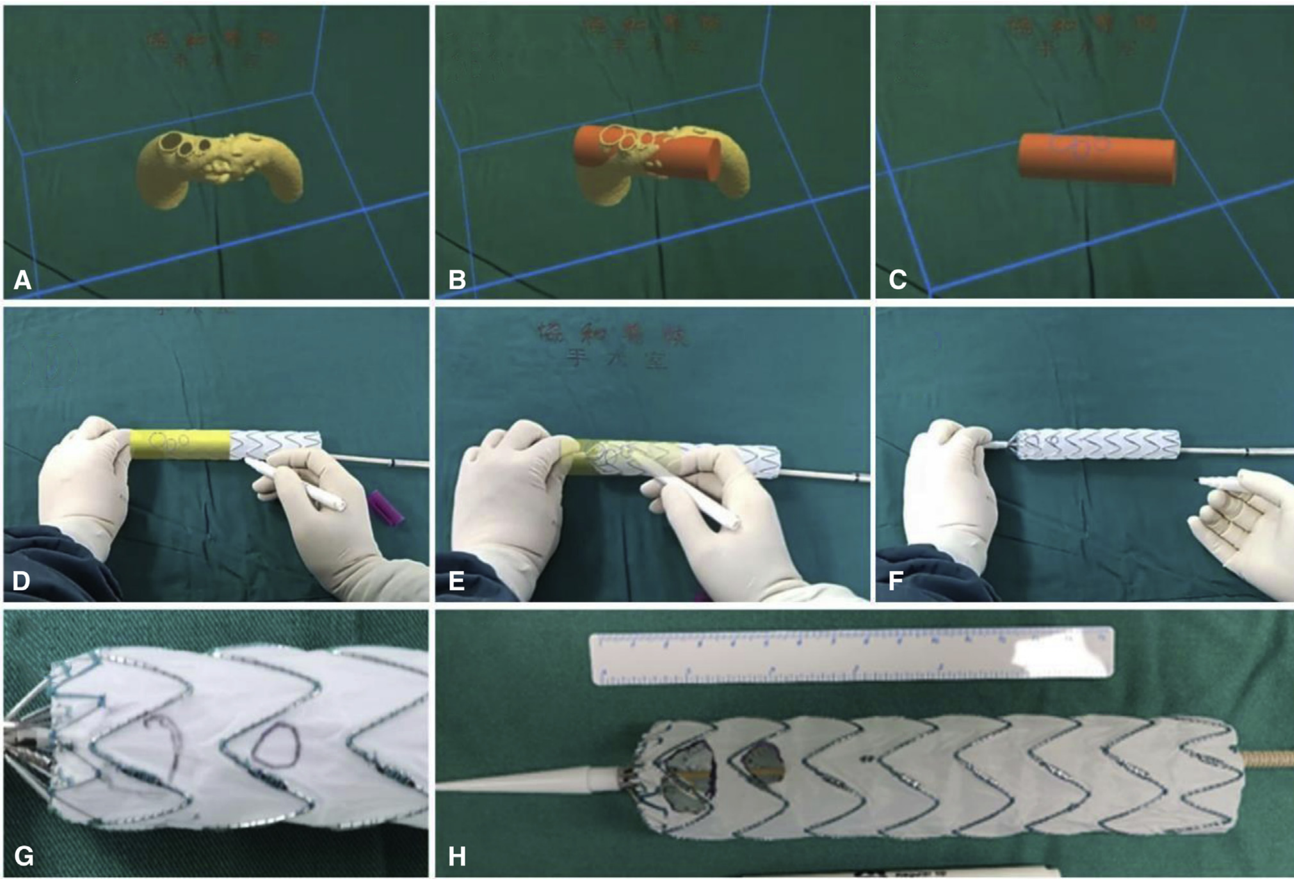


FIGURE 1. The physician-modified fenestrated stent graft procedure of thoracic stent with mixed reality technology. A, The 3-dimensional (*3D*) visualization model of the thoracic aortic artery. B, Generated model of the stent, according to the model of the artery. C, The 3D visualization model of the stent. D through G, Accurately mark the positions planned to fenestrate based on the 3D visualization model of the stent. H, The fenestrated stent graft (28 × 28 × 120 mm) (LifeTec Inc).

which was not conducive during the surgery for intraoperative positioning and branch stent placement; therefore, the radiopaque spring coil was fixed on the hole to facilitate subsequent intraoperative alignment and branch stent placement. A branch stent needs to be inserted into the hole of the aortic stent to ensure blood flow of LSA and stabilize the aortic stent. Left common carotid artery fenestration was satisfactory, and no branch stent was inserted. Repeated digital subtraction angiography images revealed that the ulcer was isolated and the LSA was revascularized. Type 1 endoleak was not detected (Figure 2). After surgery, the patient was treated with aspirin (100 mg orally, once a day) and antibiotics. One week later, the patient underwent another CTA to evaluate the postoperative status of TEVAR, which revealed a revascularized LSA and no signs of endoleak. Another CTA was performed at the 3-month follow-up, which reported the same findings. The patient was followed-up by telephone 1 and 2 years after the operation. The patient had no discomfort, and the pulse of the left upper limb artery was palpable.

DISCUSSION

Augmented reality (AR), virtual reality (VR), and MR are digital imaging technologies that have emerged in recent years, and there are huge differences among them. AR is a VR technology that can only create a completely virtual scene and cannot be projected onto the real world. Based on AR, VR can project created virtual scenes or things into the real world; however, it cannot interact with the real world. MR can not only create virtual scenes or things in the real world but also mediate the interaction between virtual things and the real world, as well as the interaction among multiple people. Because of this interaction, MR is used in many fields. MR is a new digital holographic imaging technology that allows users to perceive both the physical environment and digital elements (virtual objects) presented through the displays. MR systems give users the illusion that digital objects coexist in the same space as physical objects. This technology has existed for some time now and has been applied in fields such as manufacturing, architecture, military, visual media, and

FIGURE 2. Digital subtraction angiography images (A) before and (B) after thoracic endovascular aortic repair.

medicine.[3] f-TEVAR is a technique wherein the physician builds a "window" in the stent graft at the position corresponding to the vital branch vessels. MR technology can provide 1:1 3D holographic images of modified stents based on the original data from CTA, which guarantees an accurate and direct fenestration of the stent. Compared with the traditional stent-fenestration method, MR provides more information on the diameter, angle, and position of the target vessel. This avoids coverage of the vessel and lowers the probability of endoleaks. Compared to other digital techniques such as VR, AR, and 3D printing techniques, MR provides more accurate measurements and real-time interactions during surgery, along with less financial pressure on the patient. However, the application of MR requires high-resolution CTA/MR data and expensive computer programs and equipment, limiting its potentially wide usage. Precision medicine, which is the current direction of medical development, requires digital, remote, precise, and personalized treatment of diseases. MR technology allows for personalized and accurate evaluations, precise treatment plans, and shorter operation times. In the present case, a complex aortic ulcer was successfully treated with f-TEVAR assisted by MR technology, which is among the most promising digital techniques in modern medicine.

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