A Role for Virtual Reality in Planning Endovascular Procedures

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ABSTRACT

Current imaging technologies are capable of acquiring volumetric data, but they are limited by the flat 2-dimensional representation of complex 3-dimensional data. This pictorial report illustrates the potential role of interactive virtual reality (VR) that enables physicians to visualize and interact with image data as if they were real physical objects. Increasing availability of tools that make the VR environment a possibility could potentially be valuable in the interventional radiology suite.

ABBREVIATIONS

3D = 3-dimensional, 2D = 2-dimensional, VR = virtual reality

Interactive virtual reality (VR) represents the next generation of alternate imaging technology. By allowing the operator to manipulate routine 2-dimensional (2D) images in an open 3-dimensional (3D) space as if it were a real physical object VR allows the operator to visualize and interact with patients' organs and tissues (1–5). Although current technologies allow for 3D volume rendering, these volumetric images are still displayed on a flat 2D screen, precluding the holographic experience. The present pictorial report illustrates the potential role of VR in preprocedural and intraprocedural planning for endovascular procedures commonly performed in interventional radiology (IR). Briefly, VR display systems provide stereoscopic depth and maneuverability of reconstructed images on a dedicated workstation aided by 3D glasses and a freehand stylus (Fig 1). Herein, digitized images from conventional computerized tomography (CT) and cone-beam CT were retrospectively reconstructed in True 3D (Echopixel, Mountain View, California), a VR medical visualization software. Institutional Review Board approval was obtained.

ILLUSTRATIVE CASES

Figure 2 demonstrates CT angiography and VR images of a complex splenic artery aneurysm. The subject is a 58-year-old woman with a history of biliary cirrhosis and portal hypertension who was referred to IR for transarterial embolization of the splenic artery aneurysm. Contrast-enhanced CT angiography images displayed in the coronal plane demonstrate 2 tandem splenic artery aneurysms, the largest measuring 3 cm in diameter (Fig 2a). VR images reconstructed from preoperative CT angiography illustrate both aneurysms (Figs 2b, c), each with a single afferent artery and 2 efferent arteries (Fig 2c). The complex spatial relationship between afferent and efferent arteries relative to the aneurysms are well demonstrated in Fig 2c and in Video 1 (available online at *www.jvir.org*).

Figure 3 demonstrates coronal contrast-enhanced cone-beam CT and VR images of a 3-cm hepatocellular carcinoma in Couinaud segment IVb/V of the liver in a 71-year-old man with a history of alcoholic cirrhosis and portal hypertension. Planar cone-beam CT image (Fig 3a) and the maximum-intensity projection images (not shown) demonstrate multiple arteries supplying the tumor (branches from segments V and IVb, and the cystic arteries). Although each artery can be individually identified

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Figure 1. A general view of the workstation setup and user interface, demonstrating the use of 3D glasses and freehand stylus to maneuver reconstructed images.

on the cone-beam CT images, the 2D display of volumetric data requires the operator to meticulously page through different planes and mentally integrate the multiple 2D slices to cognitively extract the 3D relationship between arteries and the tumor. In contrast, VR reconstruction of the cone-beam CT images (**Fig 3b**), shows the 3 arteries distinctly.

DISCUSSION

These cases demonstrate VR's ability to provide true 3D viewing and maneuverability. Tortuous vascular anatomy that can be difficult to elucidate on 2D imaging (6) and can reduce operator confidence. Visceral artery aneurysms, such as those arising from the splenic artery, can be challenging owing to the multiple afferent and/or efferent arteries feeding the aneurysm and a tortuous parent artery (6) (**Fig 3a**). Similarly, identifying a segmental or subsegmental branch of an artery for subselective catheterization can be difficult owing to overlapping branches, as often seen in patients with cirrhosis. Though not illustrated here, depth perception would also facilitate percutaneous procedures such as those in the chest, mediastinum, liver, and pelvis. Although currently available technology, such as cone-beam CT and reconstruction software, can generate 3D renderings, they are limited by their 2D viewing platform (6). True 3D display, on the other hand, allows the operator to visualize and interact with the tissues as if they were a real physical object. The advantage lies in arming the operator with a deeper and intuitive understanding of spatial relationships, such as that between a complex aneurysm, its neck, and its afferent/efferent arteries. Because preoperative planning is the first and possibly the most critical step toward technical success of surgical procedures (4,7,8), the additive value of VR may prove very useful. A stereoscopic understanding of the aneurysm and its branches, would help to determine the approach: exclusion by placing a stent-graft across the aneurysm and/or embolization of the contributing arteries. Further, data suggest that vessel diameter and length measurements with the use of True 3D are more precise, especially for tortuous arteries, than current technology, thus allowing for appropriate device sizing and selection (9). Although presently unproven for IR procedures, one could theorize that by manipulating the images preoperatively in a virtual space, the operator gains familiarity with the anatomy, akin to that conferred by VR for neurosurgical planning (4), potentially expediting catheterization and thus minimizing the radiation and iodinated contrast dose.

Presently, VR is limited by ergonomics and technology that require the operator to view images on a separate workstation with the use of 3D glasses. The next obvious step would be a 3D glasses–free workflow and/or an immersive augmented reality (AR) environment, one that allows the operator to readily merge available virtual data with the actual surgical environment and vice versa. Thus, in the context of procedural guidance, VR and AR systems represent the next natural evolution of currently available technologies that allow 3D renderings. Although intraoperative cone-beam CT acquires volumetric data for multiplanar and maximum intensity projection reconstruction, it is limited by the 2D display on a separate workstation and presently cannot be integrated with the live environment, ie, fluoroscopy. As illustrated in **Figure 3**, VR (and AR) systems complement currently available intraoperative cone-beam CT. The ability to visualize and manipulate tissues as a physical object allows the operator to define and trace the spatial anatomy and relationship of all the arteries supplying a single tumor, a current challenge for cone-beam CT owing to the 2D display of the acquired 3D data. Furthermore, VR's holographic display facilitates a deeper spatial appreciation of vessel arborization in relation to the tumor. Finally, the future state of the technology will allow an operator to work in a live immersive environment where real-time virtual data is overlaid on the real procedural field. Such systems already exist for surgical navigation in neurosurgery, bolstering the development of extracranial applications.

The potential application of VR is not limited to just procedural guidance. VR can be combined with 3D printing of implants (5) to ensure accuracy before expending the resources of making the implant. Furthermore, similarly to 3D printing, VR can also be used for trainee education by providing students with an intuitive and interactive view of the patient's anatomy that better simulates what will be seen during the actual procedure (3,10,11).

Although industrial applications of VR are known, it is only in recent years that high-throughput processing of digitized radiologic images have made medical visualization platforms using interactive VR a possibility. As one would expect, VR requires powerful computers and adequate training to get familiarized with visualizing and

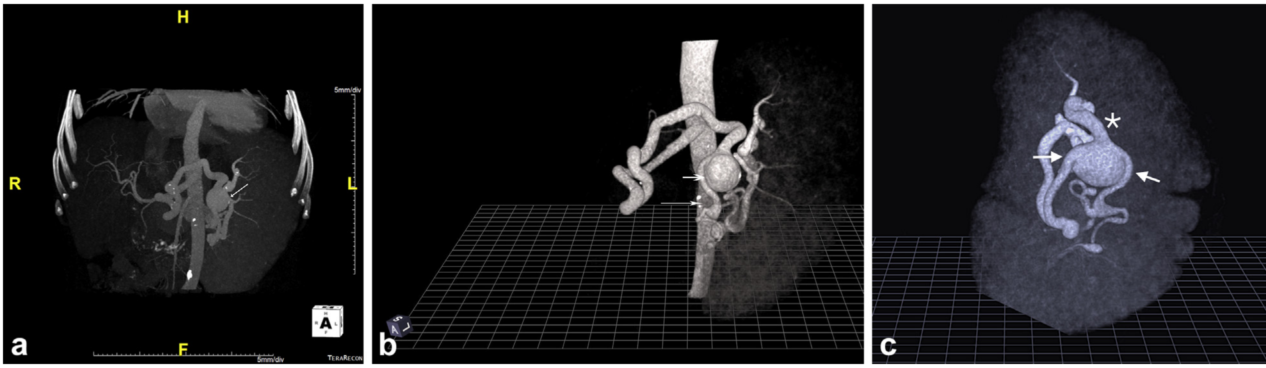

Figure 2. A 58-year old woman with 2 tandem, splenic artery aneurysms. **(a)** Contrast-enhanced CT angiography image in the coronal plane demonstrates the larger, 3 cm, aneurysm arising from the mid-distal splenic artery (arrow). **(b)** Reconstructed VR image in a slight left anterior oblique view demonstrates 2 complex aneurysms (larger 3-cm aneurysm, short arrow; smaller aneurysm, long arrow). **(c)** Lateral view of the same aneurysms demonstrates the spatial relationship between the single afferent artery (asterisk) and the exiting 2 efferent arteries (arrows). The efferent artery of the 3-cm aneurysm is the afferent artery for the smaller, second aneurysm.

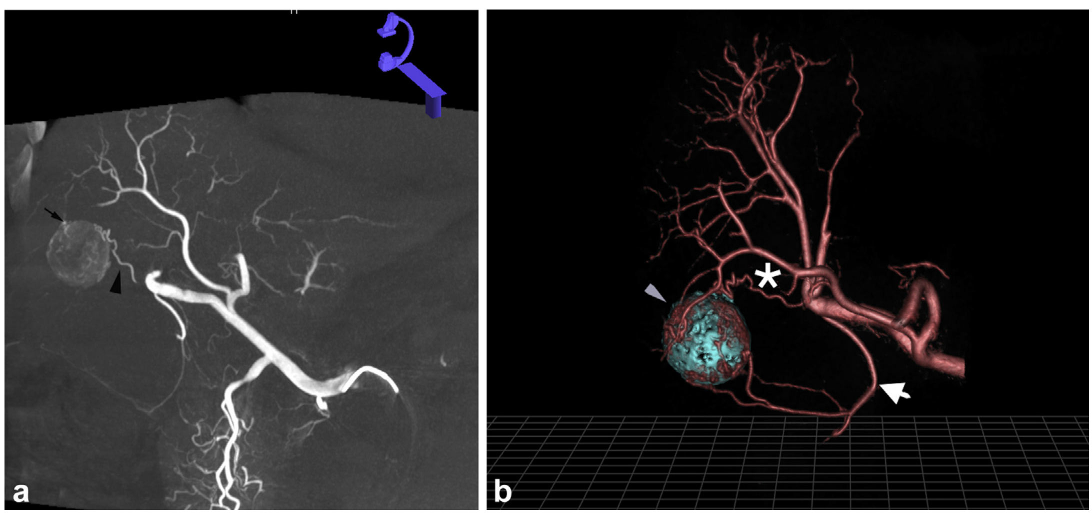

Figure 3. A 71-year old male with alcohol-induced cirrhosis and a 3-cm hepatocellular carcinoma in Couinaud segment IVb/V. **(a)** Coronal contrast-enhanced cone-beam CT image demonstrates supply from the segment IVb artery (arrow) and an accessory segment V artery (arrowhead). **(b)** Reconstructed VR image demonstrates 3 distinct arteries supplying the tumor: segment IV (arrowhead), accessory segment V (asterisk), and a parasitized branch of the cystic artery (arrow).

manipulating tissue and organs in an open 3D space. One limitation of the VR environment is its dependence on the quality of the original imaging dataset which is susceptible to artifacts secondary to motion and beam hardening. Furthermore, minute structures may be too small to resolve on the 3D reconstruction. Similarly to cone-beam CT, VR is constrained by its lack of temporal resolution and limited in-plane resolution (1). Finally, VR presently cannot compensate for intraoperative soft-tissue mobility and deformation (4). Nevertheless, virtual and augmented reality complements and advances the current imaging technologies by allowing the interventional radiologist to visualize the anatomic area of interest in a 3D space, rotate it, manipulate it, and segment it like a physical object, thus providing true spatial orientation. The availability of the VR environment, and the AR environment in the near future, has the potential to help IR truly exploit volumetric data that is presently buried in 2D display systems.

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