COMPUTER-ASSISTED NAVIGATION FOR THE TREATMENT OF BRAIN ANEURYSMS

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ABSTRACT

Endovascular therapy provides a minimally invasive solution for the treatment of brain aneurysms. Interventional neuroradiologists navigate microcathers, platinum coils and stents from the femoral artery to treat the pathological target vessel under fluoroscopic guidance. The procedure involves a clinically significant radiation dose to the patient and the clinical team. We have developed a multi-modality navigation platform providing real-time visualization of the position of endovascular tools without radiation exposure. The system integrates magnetic tracking of surgical devices, and 3D visualization of their position inside a reconstructed model of the vasculature. Preliminary phantom tests have demonstrated an accuracy of 3.8 mm. By merging imaging and localization data, this prototype can provide 3D real-time navigation in brain arteries.

1. INTRODUCTION

Endovascular techniques provide innovative solutions for many cerebrovascular diseases. The benefits for the patient include a shorter period of recovery as well as a diminution of complications as compared with the results of surgery [1]. Navigation in the cerebral vasculature requires two major components: the visualization of anatomical structures, and the real-time localization of the endovascular elements. Traditionally, visualization of vascular structures is provided by digital subtraction angiography, and real-time tracking of the tools is performed through an image intensifier fluorescent screen coupled with a video camera. Therefore X-Ray imaging is used for both visualization and guidance, which involves the radiation exposure of both the physician and the patient, and yet lacks the ability to visualize soft tissue. Thus, the benefits of the current procedure may not outweigh the radiation risk [2]. Pre-operative Computed Tomography Angiography (CTA) and Magnetic Resonance Angiography (MRA) provide valuable morphological information on intracranial aneurysms. However, CT guidance procedures require higher exposure techniques than conventional fluoroscopy [3], and the long conductive guide wires used for endovascular therapy are at risk of heating during MR guidance procedures [4]. Our objective is to achieve real-time tracking and three-dimensional visualization of endovascular components in brain arteries, without radiation exposure. This article presents preliminary results of a magnetic navigation system for endovascular therapy.

2. MATERIALS AND METHODS

Our multi-modality navigation system relies on the separation of the visualization of the patient's anatomy, and the localization of endovascular tools. For visualization of the vasculature, we reconstruct a 3D model of the brain vasculature from a pre-operative CTA dataset included in the surgical planning. The dataset consists of a volume of 235 slices acquired on a multidetector CT scanner (Somatom Sensation 16-slice CT scanner, Siemens), with a slice thickness of 2 mm and a reconstruction interval of 1.5 mm. We use an implementation of the Level-Sets algorithm for contour detection to segment the brain arteries [5]. A 3D model of the vasculature is then reconstructed using the Marching Cubes algorithm [6].

For localization of the surgical tools, we use a magnetic tracking system (Aurora Magnetic Localizer, Northern Digital Inc., Ontario, Canada) composed of a magnetic field generator and miniaturized 0.8 mm x 8 mm 5 Degrees of Freedom sensors embedded inside an endovascular guide. Sensor interface units compute the position and orientation of the sensors with a mean accuracy of 0.8 mm and 0.3º, within a 500 mm x 500 mm x 500 mm measurement volume around the patient's head.

Our navigation platform runs on a standard laptop (IBM Think Pad T42p PC, 1 GB RAM, 60 GB Hard Drive). The system was developed within the 3DSlicer framework, an open-source environment for medical image processing and visualization [7]. We developed the communication interface between the computer and the magnetic localization system using the OpenTracker libraries [8].

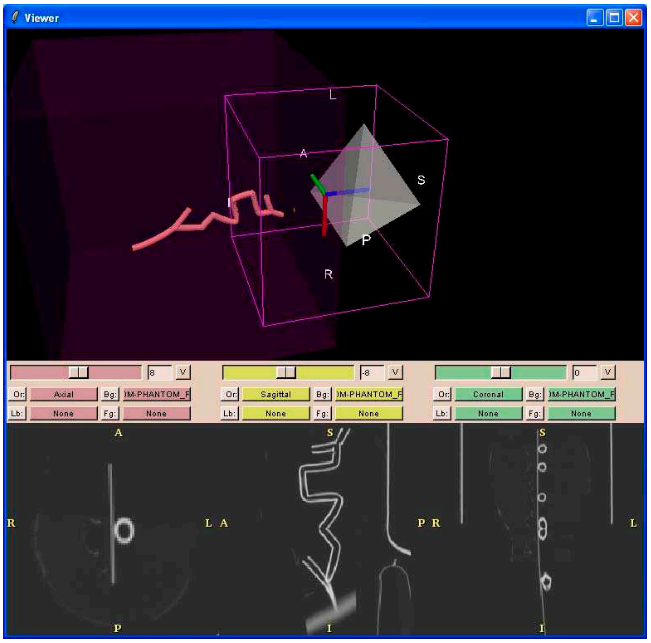

Figure 1. Graphical User Interface of the computer assisted navigation system. The lower part of the interface displays the anatomical slices of the phantom CT dataset. The upper part of the interface shows the 3D model of the phantom vasculature registered within the reference system of the Aurora magnetic tracker, modeled as a pyramid in the scene.

The computer-assisted intervention is composed of two phases. At the beginning of the procedure, the clinician acquires the position of fiducials on the patient's head using a calibrated magnetic pointer, and selects the corresponding points on the CT slices. A paired-point registration replaces the CTA model in the intra-operative reference system of the magnetic tracker. During the procedure, the system updates in real-time the position of the magnetically-tracked endovascular guide within the 3D model of the vasculature. The clinician uses the display of the navigation platform to guide the endovascular devices to the target vessel.

We evaluated the accuracy of the navigation on a phantom experiment. We built a phantom of the head composed of a Styrofoam skull and a model of the cerebral vasculature. Four ECG electrodes were used as non-invasive fiducials, and seven control points were positioned along the vascular path. A CTA dataset of the phantom was acquired on a multidetector CT scanner (Somatom Sensation 16-slice CT scanner, Siemens). A trained neuroradiologist used a 7F endovascular guidewire (Boston Scientific, Natick, MA), equipped with a miniaturized magnetic sensor, to navigate inside the phantom arteries. The movements of the guidewire inside the vasculature were then displayed within the 3D scene. Figure 1 shows the interface of the navigation system with phantom data.

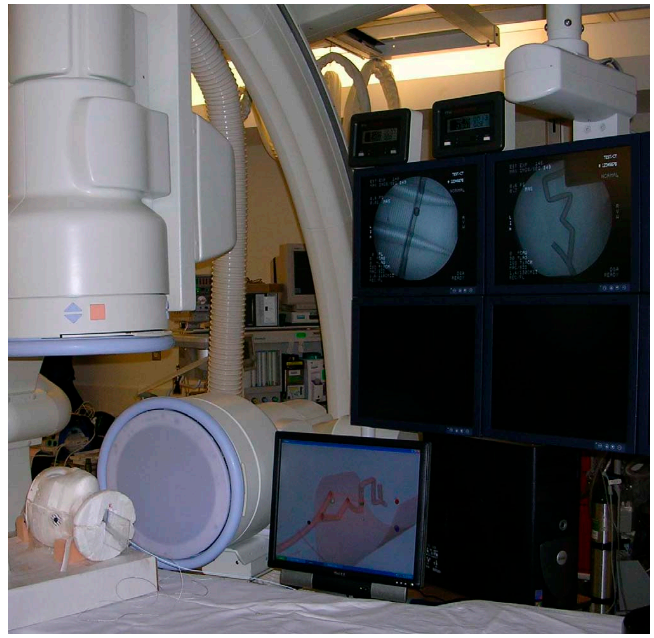

Figure 2. Computer-assisted navigation in the operating room.

We defined a validation protocol for the computer-assisted endovascular procedure to compare the position of the guidewire, as indicated by the system, with its real position inside the phantom [9]. Seven pre-defined control points had been added along the vasculature. The control points were composed of thin 2 mm diameter plastic hollow tubes inserted through the wall of the vessels of the phantom. We used the navigation system as a guidance tool to reach the distal extremity of each one of the tubes along the cerebrovascular path. We performed the endovascular procedure in the environment of the operating room (Figure 2). A trained neuroradiologist navigated the guide by controlling its progression within the 3D display of the system. The accuracy was defined as the distance between the actual location of the guide, and its expected position measured for each control point in CT data. X-Ray images of the guide validated the results of the navigation.

3. RESULTS

The augmented reality based navigation system achieved real-time co-registration of the location of a guidewire inside a 3D reconstruction of the patient vasculature, without the use of fluoroscopy. Preliminary results using the Aurora magnetic tracking system gave a mean accuracy of 3.8 mm and a maximal error on the distance of 4.4 mm. Figure 3 shows the endovascular navigation of the magnetically tracked guidewire to the pre-defined targets.

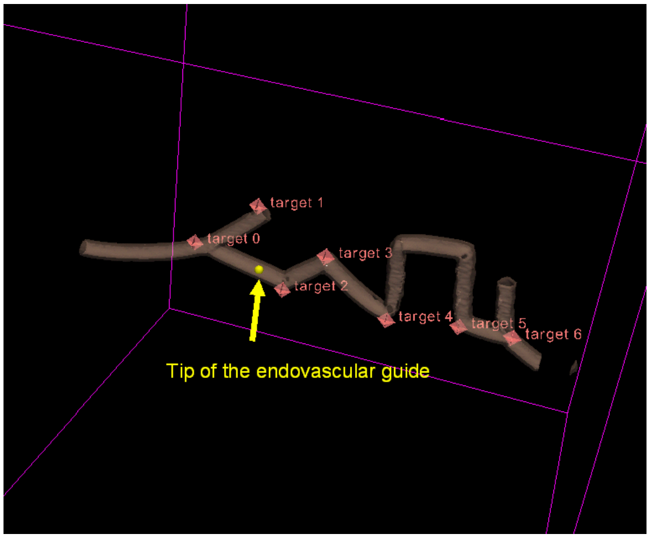

Figure 3. Endovascular navigation to pre-defined targets. The system displays the position of the tip of the guidewire within the 3D model of the phantom vasculature.

4. CONCLUSION

We have developed a new navigation system for the endovascular treatment of brain aneurysms. This augmented reality system is based on the fusion of magnetic tracking data with a 3D reconstruction of the anatomy from pre-operative imaging. The prototype provides real-time 3D visualization of the position of endovascular components in cerebral arteries with clinically relevant accuracy, and thus can reduce the use of fluoroscopy during neuroradiological interventions. Pre-clinical evaluation of the computer assisted procedure is underway.

5. REFERENCES

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