CEREBROVASCULAR

Fusion of Intraoperative Three-Dimensional Rotational Angiography and Flat-Panel Detector Computed Tomography for Cerebrovascular Neuronavigation

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Key words
- Aneurysm
- Angiography
- Arteriovenous fistulas
- Arteriovenous malformations
- Digital subtraction angiography
- Image-guided surgery
- Neuronavigation
- Three-dimensional angiography

Abbreviations and Acronyms
3D-RA: 3-Dimensional rotational angiography
ACA: Anterior cerebral artery
AVF: Arteriovenous fistula
AVM: Arteriovenous malformation
CT: Computed tomography
DSA: Digital subtraction angiography
FD: Flat-panel detector
ICA: Internal carotid artery
INR: Interventional neuroradiology
MRI: Magnetic resonance imaging
NNS: Neuronavigation systems

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■ OBJECTIVE: **We introduce a technique that uses intraoperative flat-panel detector computed tomography (FD-CT) and three-dimensional rotational angiography (3D-RA) acquired in the hybrid operative suite to provide full neuronavigation capabilities during cerebrovascular surgery without the use of preoperative imaging studies.**

■ METHODS: **An Artis Zeego FD system (Siemens AG, Forchheim, Germany), mounted on a robotic C-arm was used during the clipping of an aneurysm to acquire intraoperative FD-CT and 3D-RA images. These images were then fused via the use of BrainLab iPlan 3.0 software and sent to a Vector Vision Sky neuronavigation system (NNS; BrainLAB, Heimstetten, Germany) to provide intraoperative image guidance.**

■ RESULTS: **The use of intraoperative FD-CT and 3D-RA with a NNS allowed for accurate visualization of the vascular anatomy and localization of pathology. In a case of a patient harboring two aneurysms, one that was surgically clipped and a second that was treated endovascularly, the 3D-RA clearly showed neck remnants at both aneurysms. Use of the NNS assisted in further clip placement for obliteration of these neck remnants.**

■ CONCLUSIONS: **Hybrid operating suites equipped with FD-CT, 3D-RA, and NNS capabilities can be used to provide intraoperative 3D image guidance during cerebrovascular surgery with excellent accuracy and without the need for preoperative angiography. Furthermore, this technique required less than 15 minutes for image acquisition and utilizes digitally subtracted angiographic images that are superior to conventional CT or MRI for the imaging of cerebrovascular pathology.**

INTRODUCTION

Intraoperative localization during neurosurgical procedures has dramatically improved since the development of neuronavigation systems (NNS). These systems aid in the localization of tumors, complex skull-base approaches, basal ganglia structures for deep brainstem stimulation, and some vascular lesions. In the majority of institutions, preoperative computed tomography (CT) and magnetic resonance imaging (MRI) data sets, obtained before the procedure, are used and referenced to patient position at the time of surgery. Intraoperative CT and MRI augment NNS by providing updated intraoperative data that can validate stereotactic biopsy paths, correct for intraoperative brain shift, confirm the degree of resection, and provide early detection of procedure-related hematoma or infarct. Despite these advances in NNS technology, the application of these technologies in the field of cerebrovascular neurosurgery is limited because of limitations in spatial resolution and susceptibility of these imaging modalities to artifact such as head frames, fixation pins, surgical aneurysm clips, and previously deployed embolic materials.

Many of these limitations in cerebrovascular imaging can be overcome by the use of digital subtraction angiography (DSA). Furthermore, the development of C-arm mounted, flat-panel detectors (FDs) has enhanced the quality of DSA imaging and allowed for the development of high-resolution computed three-dimensional rotational angiography (3D-RA) (4). Until recently, however, DSA equipment and operative room design precluded its widespread use in the operative setting. With the creation of the hybrid cerebrovascular operating suite, the angiographic imaging capabilities of the interventional neuroradiology (INR) suite can now be used in the neurosurgical operating theater (9, 14). We present an illustrative case of the next step in the integration of cerebrovascular imaging and neuronavigation in which an intraoperatively acquired 3D-RA and a flat-panel detector-CT (FD-CT) are fused and incorporated into a NNS for real-time 3D navigation during intracranial aneurysm surgery.

Figure 1. Hybrid operative suite demonstrating image acquisition with robotic C-arm mounted Artis Zeego FD system (Siemens AG) performed after surgical clipping of the ophthalmic-segment ICA aneurysm. Operative field is covered with a sterile Telfa (Covidien), surgical towels, and a sterile plastic drape to prevent contamination.

METHODS

The operative procedure and acquisition of all image data sets were performed in our cerebrovascular hybrid operative suite, which consists of an Artis Zeego system, a ceiling-mounted Vector Vision Sky neuronavigation system, and an OPMI Pentero microscope (Zeiss, Oberkochen, Germany). The Artis Zeego system is an FD system, mounted on a robotic C-arm, which may be maneuvered in and out of the operative field. The Artis Zeego system is therefore designed to provide ample clearance for the surgical team during the open neurosurgical portions of the case but easily positioned over the field of interest during acquisition of FD-CT or angiographic images (**Figure 1**).

The Artis Zeego system acquires FD-CT (DynaCT) images by rotating around the patient 200 degrees and obtaining an array of equally spaced two-dimensional x-ray projection images. For acquisition of a 3D rotational angiogram, the system initially acquires a mask spin (133 frames over 5 seconds) followed by the fill spin (133 frames over 5 seconds) during contrast injection. The images are sent to the Syngo X workplace station (Siemens AG, Forchheim, Germany) to create the Native Mask (bony anatomy) DynaCT, Fill DynaCT (bony and vascular anatomy), and Subtracted DynaCT (subtracted vascular anatomy) images. DynaCT image data sets can then be reconstructed as a 3D image on the Syngo X workplace and exported to the NNS as DICOM (i.e., digital imaging and communications in medicine) images.

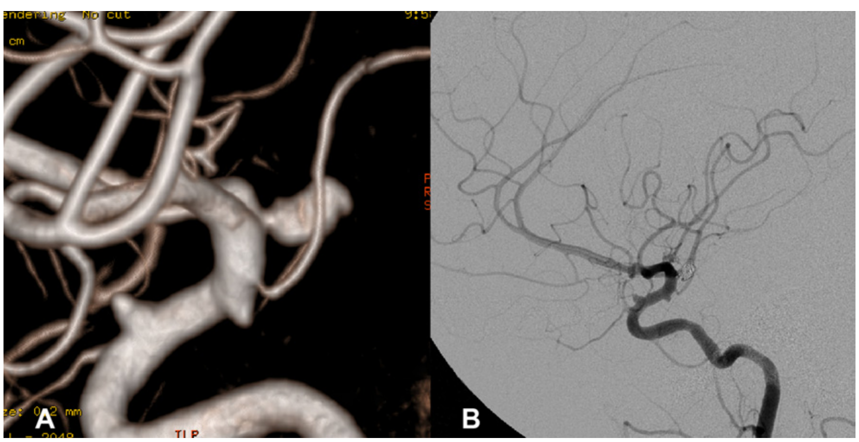

Figure 2. (**A**) Angiogram demonstrating 6.4-mm × 3.0-mm × 3.0-mm aneurysm of the left A1 anterior cerebral artery (ACA)/supraclinoid internal carotid artery (ICA) junction and a 2-mm wide-based aneurysm of the left ophthalmic-segment ICA. (**B**) Angiogram of left A1 ACA/supraclinoid ICA junction aneurysm. A small portion of the aneurysm neck could not be completely occluded because of an unstable microcatheter position.

In this case, a 52 year-old female patient presented with a Hunt-Hess grade 4/Fisher scale 4 subarachnoid hemorrhage. CT angiogram performed at admission demonstrated a posterior directed 6.4-mm × 3.0-mm × 3.0-mm aneurysm at the left A1 anterior cerebral artery (ACA)/supraclinoid internal carotid artery (ICA) junction and a 2-mm wide-based aneurysm of the left ophthalmic-segment ICA (**Figure 2A**). The patient underwent initial endovascular coil embolization of the larger left A1 ACA/supraclinoid ICA junction aneurysm. A small portion of the aneurysm neck could not be completely occluded because of an unstable microcatheter position (**Figure 2B**). Both aneurysms including the neck remnant of the endovascularly coiled aneurysm and the second aneurysm were then clipped in the cerebrovascular operative suite after the cerebral vasospasm period.

The standard protocol for cerebrovascular cases performed in our cerebrovascular hybrid operative suite include (i) initial placement of a femoral artery sheath after induction of general anesthesia, (ii) "test" 3D spin to confirm optimal head position in respect to the Artis Zeego system, (iii) open surgical treatment of targeted vascular lesion, (iv) confirmation of treatment with 2D angiography and 3D-RA, (v) readjustment of surgical clips or further resection as needed, and then finally (vi) completion and closure of the craniotomy.

In this instance, the patient underwent an initial DynaCT with CT-compatible scalp fiducials after patient positioning in the operative suite. The acquired DynaCT date set was then uploaded to the Vector Vision Sky NNS as standard DICOM images. The images were registered to the patient by use of