Three-dimensional rotational angiography guidance for aneurysm surgery

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Object. The aim of this study was to investigate the feasibility of integrating three-dimensional rotational angiography (3D-RA) data into a surgical navigation system and to assess its accuracy and potential clinical benefit.

Methods. The study cohort consisted of 16 patients with 16 intracranial aneurysms who had been scheduled for routine or emergency surgery. Rotational angiography data were exported using a virtual reality modeling language (VRML) format and imported into the BrainLAB VectorVision2 image-guided surgery equipment. During 3D-RA the position of the head was measured using a special headframe. The authors also determined the accuracy of 3D-RA image guidance and the clinical benefit as judged by the surgeon, including, for example, early identification of branching vessels and the aneurysm.

There was good correspondence between the 3D-RA–based navigation data and the intraoperative vascular anatomy in all cases, with a maximum error of 9° of angulation and 9° of rotation. In eight cases, the surgeon determined that the 3D-RA image guidance facilitated the surgical procedure by predicting the location of the aneurysm or the origin of a branching artery that had been covered by brain tissue and blood clots.

Conclusions. The integration of 3D-RA into surgical navigation systems is feasible, but it currently requires a new perspective-registration technique. The intraoperative 3D view provides useful information about the vascular anatomy and may improve the quality of aneurysm surgery in selected cases.

KEY WORDS • three-dimensional rotational angiography • intracranial aneurysm • image-guided surgery • clip application

The use of surgical navigation systems is becoming an increasingly important part of both planning and performing intracranial surgery. There are numerous clinical reports in which the authors have described image guidance as a useful adjunct to surgery that allows neurosurgical procedures to be less invasive and more effective. Heretofore, advances in image-guided surgery have had little influence on the microsurgical clip application of aneurysms. Few publications in the literature have focused on image guidance via MR or CT angiography and their benefits during the surgical procedure. Nonetheless, especially in aneurysm surgery, data on the continuous 3D topographical orientation around the aneurysm and the spatial relationship between the parent and branching arteries would be of considerable interest to the surgeon. To occlude safely the aneurysm neck and to maintain patency of the parent and branching arteries, it is essential carefully to visualize these structures. Note, however, that the individual vascular anatomy is often complex and, because it may be covered by blood clots or brain tissue, may not be easily visible. Even with the best anatomical knowledge, a surgeon is not always sure about the location of these vessels with respect to the aneurysm. More extensive dissection around the aneurysm is often required to identify these structures, which, unfortunately, increases the risk of premature aneurysm rupture, suboptimal clip application, and neurological sequelae.

Three-dimensional rotational angiography is increasingly used to diagnose intracranial aneurysms and to decide on the optimal treatment modality. It provides high-resolution, quality 3D imaging data that is acquired during the normal diagnostic workup. Image guidance via 3D-RA may be helpful during aneurysm surgery, but the problem of patient registration using the 3D-RA has yet to be resolved. In this feasibility study we report on the following: 1) a newly developed perspective-registration technique that allows one to use 3D-RA volume data in surgical navigation systems; 2) the accuracy of the perspective registration technique; and 3) our preliminary experience of the clinical value of 3D-RA guidance in aneurysm surgery.

Clinical Material and Methods

Clinical Data

This feasibility study involved 16 patients with 16 intra-
cranial aneurysms who were scheduled to undergo routine or emergency surgery. The patients consisted of 13 women and seven men, with ages ranging from 30 to 65 years (mean 51 years). Six patients had ruptured and 10 patients had unruptured intracranial aneurysms. These lesions were located at the ACoA in five cases, posterior communicating artery in four, paraophthalmic ICA in three, and middle cerebral artery in four. Aneurysm surgery was performed as usual, although we utilized the image guidance equipment including pointer and microscope navigation connections. All patients underwent postoperative CT scanning between 24 and 48 hours after surgery and on post surgery Day 14 to distinguish between surgical and vasospastic lesions. Postoperative angiography was performed between Days 7 and 12 in all cases for visualization of neck remnants after applying clips and for potential endovascular treatment of cerebral vasospasm.

Three-Dimensional Rotational Angiography and Data Export

To diagnose the intracranial aneurysm and to decide on the appropriate treatment modality, all patients underwent 3D-RA (Integris Allura; Philips Medical Systems, Eindhoven, The Netherlands). Our protocol involved performing DS angiography with 3D-RA reconstruction to decide the optimum treatment method for each individual patient and aneurysm. No patient underwent CT or MR angiography as an additional modality.

The DS angiograms were recorded in standard projections (posteroanterior, lateral, and ipsilateral and contralateral oblique). In addition, 100 nonsubtracted angiograms were acquired after the automatic injection of a 17-ml bolus of contrast material (injection time 5.5 seconds, flow 3 ml/second) during a 240° rotation of the angiographic C-arm.

After rotational angiography and utilizing a 3D workstation (Philips Medical Systems), 3D data were reconstructed from the projection images obtained during the rotation by using volume rendering or shaded-surface-display algorithms. The threshold for the 3D data was adjusted to a level showing the maximum extension of arterial vascular structures without displaying the nonvascular surroundings. The shaded surface display of the 3D-RA data was exported as a standard VRML file, which can be opened using standard 3D software.

Neuronavigation Equipment and Algorithm

We used the VectorVision2 neuronavigation system (BrainLAB, Heimstetten, Germany). This image-guided, frameless, armless localization system is based on passive-marker reflection of infrared flashes. It consists of a planning computer with software tools for image transfer, coregistration of multimodal image sets, and surgical planning. An image-guided surgery unit is located in the operating room and consists of a workstation, an infrared camera system (Northern Digital, Waterloo, ON, Canada), and a touch screen display, which can be steriley draped and placed in the operating field. Before skin incision, surgical navigation is performed using a pointer; intraoperatively, microscopic tracking and navigation are performed. More comprehensive reports on the technical details and the use of the VectorVision2 device have been published elsewhere.3,11,12

All surgical procedures were performed with the patient in a state of general anesthesia. The head was immobilized using a Mayfield clamp. A rigid mechanical connection was established between the Mayfield clamp and the reference star. The reference star was positioned outside the surgeon’s working space in a way to maintain visibility for the cameras during the surgical procedure.

Perspective Registration

When using the 3D-RA data without any CT or MR imaging navigation scans, conventional registration techniques cannot be used because the 3D-RA data set contains only a spatially limited area of the vessels of interest and no data that represent surface points of the patient’s anatomy. We have developed a technique that allows one to establish a spatial relationship between the 3D-RA data and the patient’s head by using the angulation and rotation coordinates from the angiography system. The term “angulation” denotes movement of the angiographic C-arm around the patient’s head in a vertical plane (sagittal), whereas the term “rotation” refers to the movement of this arm around the patient’s head in a horizontal plane (axial). The zero positions of the angiographic coordinate system are defined by an AP plane (0° of angulation) and a lateral plane (0° of rotation). Thus, every position of the C-arm can be measured in degrees of angulation and rotation.

Immediately before rotational angiography, a special three-point headframe (Fig. 1) was used to record the position of a patient’s head with respect to the coordinates of the angiographic system. This headframe contains three radiographically visible markers at defined distances—at the left external auditory canal, the nasion, and the right auditory canal—and fits exactly onto these landmarks. These three markers define an arbitrary reference position for the patient’s head, which is later used for adjustment of the 3D-RA data and registration of the patient. To record the head position, the fluoroscope is rotated and angulated to match a view where the three markers of the headframe are in a straight line and have exactly the same distance between them, which requires a fluoroscope position orthogonal to the image shown in Fig. 2 and differs only a few grades from a conventional AP beam projection. This position is usually found within 10 seconds. The position of the fluoroscope in degrees of angulation and rotation is recorded, and a fluoroscopic reference position image is taken without contrast injection and is nonsubtracted. This image is also used to check the accuracy of the reference position and to exclude a major error introduced at this time. The patient’s head is fixed in that position by using stiff cushions, and draping and rotational angiography is then performed. We did not use stereotactic frames or invasive head clamps because doing so would hinder movement of the fluoroscope and would make a routine angiography procedure awkward. Movement can occur at this time, but we believe that performing rotational angiography immediately after obtaining the reference position minimizes possible error. The patient is either awake (in cases of good-grade subarachnoid hemorrhage and of unruptured aneurysms) or intubated and sedated (in cases of poor-grade subarachnoid hemorrhage).

After reconstructing the rotational angiography images and optimizing the image quality, the 3D data were export-
ed as VRML files, which are commonly used 3D file formats comparable with data in the angiographic system that allow viewing from any 0 to 360° angle of rotation and angulation. In the operating room, the VRML file is loaded into the navigational system. The same three-point headframe that was used during angiography is exactly repositioned on the patient's head. The design of the headframe allows for a fit in only one position, which is defined by the nasion and the left and right external auditory canals. The frame has two balls that fit into the external auditory canals and a bow that fits into the nasion. Therefore, the frame can be repositioned with negligible error for the accuracy of the perspective view. The built-in fiducial markers are used to collect three points for the registration procedure. Given that the position of the three-point headframe in relation to the position of the 3D-RA data is known from the fluoroscopic reference position image obtained before rotational angiography procedure, the 3D-RA data file can be registered (Fig. 3).

Data Analysis

We measured the additional time required for 3D-RA guidance data preparation, data export, file transfer, and patient registration. The accuracy of 3D-RA guidance was measured using intraoperative photographs from the surgical field, which were compared with the screenshots taken from the navigation screen of the 3D-RA view from the same period in time. In detail, the 3D-RA model was used after surgery and visually adjusted to match exactly the position of the vessels shown on the intraoperative screenshot obtained from the 3D-RA navigation screen. The degrees of angulation and rotation for the 3D object were noted. Then, the 3D-RA object was turned and moved to match exactly the position of the vessels shown on the intraoperative photograph obtained from the surgical microscope. Again, the degrees of angulation and rotation of the data were noted. The difference between the true intraoperative position and the screenshot of the navigation screen was then given in degrees of angulation and rotation (mean ± standard deviation, range).

Results

Sixteen aneurysms were clipped using intraoperative 3D-RA guidance. The procedure was technically successful in all cases; there was no hardware or software problem and no registration failure. The time required for the fluoroscopic reference position image with the three-point headframe during angiography was less than 1 minute; for data preparation, export, and file transfer, less than 15 minutes; and for registration, less than 3 minutes.

The spatial relationship between the aneurysm and the parent and branching arteries in the 3D-RA–based navigation demonstrated good correspondence with the intraoperative vascular anatomy in all cases. When measuring the difference between the surgeon’s view in the microscope as documented by the intraoperative video and the 3D-RA
view provided by the navigational system as documented on intraoperative screenshots, the error of 3D-RA image guidance was less than 9˚ of angulation (6 ± 1.5˚, range 3–8˚) and 9˚ of rotation (5.3 ± 2.2˚, range 0–8˚) in all cases (Fig. 4).

In eight cases, the surgeon determined that 3D-RA guidance facilitated the surgical procedure by predicting the exact location of the aneurysm or the origin of a branching artery that had been covered by brain tissue and blood clots.

Discussion

Three-dimensional data of the vascular anatomy are of considerable help in identifying and understanding the topographical relationship between an aneurysm and related arteries. These 3D data can be reconstructed from CT angiography, MR angiography, or rotational DS angiography, and often can provide significant information regarding further treatment in a patient.

Neurosurgeons often use the 3D-CT angiography or 3D-RA model before going to the operating room to visualize details not visible on biplanar DS angiograms and to get an impression of what they will encounter when approaching the aneurysm, including the topographical relationship among the aneurysm neck, aneurysm dome, putative rupture site, and the parent and branching vessels. It is therefore difficult to understand why image guidance during aneurysm surgery is used in so few centers.

Several explanations may be cerebral angiography’s position as the gold standard in diagnosing an aneurysm and the fact that conventional techniques of image guidance require a set of CT or MR imaging data for navigation. Moreover, the image quality of 3D data reconstructed using the standard software of most navigational systems is often poor. We are aware that in selected centers where CT angiography, rather than catheter angiography, is used as the primary diagnostic tool for aneurysm detection, vascular image guidance can be performed easily with the CT angiography data set. However, our goal was to find a way of allowing the use of 3D-RA data without additional imaging.

Image resolution and quality in 3D-RA are excellent. Increasingly, 3D-RA data are used to decide whether clip application or coil embolization is the optimum treatment method for an aneurysm. The advantage of using these data is that after rotational angiography, the vascular neurosurgeon always has the 3D image guidance data ready for surgery, and there is no need for further CT or MR imaging just for the planned 3D-RA guidance.

Perspective Registration and Navigation

Although the 3D-RA file contains a Cartesian coordinate system, it cannot be registered using a conventional fiducial marker, surface matching, or anatomical landmark registration. Exact 3D positioning via a 3D-RA data set can only be achieved by acquiring additional CT or MR data with cerebral vessels and by matching them with 3D-RA data. Then, navigation can be performed using standard registration methods.
Alternatively, perspective registration allows one to use the 3D-RA data alone for image-guided surgery. The main difference from conventional registration techniques is that a perspective registration does not use points for registration; instead, it utilizes a set of angle coordinates (degrees of rotation and angulation) that are provided with the 3D-RA data. Thus, the 3D model is continuously adjusted on the navigation screen exactly according to the angle allowed by the surgical microscope when using microscopic navigation. This perspectival view provides useful information about individual vascular anatomy, which may be covered by blood clots or brain tissue and may not be easily visible. Early identification of critical structures, such as the branching vessels or a fragile daughter sac, may be helpful and limit the amount of dissection required for clip application (Fig. 5).

Limitations of the Method

Perspective registration does not utilize corresponding points (paired points) of the 3D data and the patient’s anatomy; instead, it makes use of angulation and rotation angles. In contrast to CT or MR angiography data methods, perspective registration does not allow navigation within the data and rather provides the perspective view from outside the data onto the 3D model. Compared with CT or MR angiography, the disadvantage of the 3D-RA method is that it precludes getting the exact position of the aneurysm and measuring distances. However, this disadvantage has very little effect because dissection is performed in a stepwise manner with identification of the parent vessel first in most cases. Thus, it is less important for the surgeon to be guided to the aneurysm by neuronavigation and more important to know the spatial relationship between the aneurysm and the parent or branching vessels.

Another limitation results from the technique of selective angiography during 3D-RA. In contrast to CT angiography in which all major arteries are visible, there may be a major vessel missing despite its relation to the aneurysm given that the contrast agent is injected selectively, that is, into only one side of the ICA. For example, in an ACoA aneurysm, the 3D-RA model contains only the A1 ipsilateral to the contrast injection; the contralateral A1 will be missing in the model. This circumstance will be encountered mainly in ACoA aneurysms and will be rare in lesions in other locations such as the P1/P2 junction or the vertebrobasilar junction.

Possible sources of error that may affect the method’s accuracy may be introduced during angiography when the reference frame is positioned on the patient’s head, while the reference image is being acquired, by head movements, on intraoperative registration when the headframe is repositioned, or during surgery when retractors are used or the brain shifts by gravity or cerebrospinal fluid loss. Note, however, that the maximum error in our cases was always less than 9° of angulation and rotation, which is still highly accurate in terms of providing a useful perspectival view of the patient’s vascular anatomy.

Conclusions

Image-guided aneurysm surgery using 3D-RA data is feasible when using our new perspective-registration technique. An intraoperative 3D-RA view provides useful information about the topographical relationship between the
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aneurysm and the related parent and branching vessels. It may help to focus the dissection, minimize exposure, and improve the quality of aneurysm surgery in selected cases.

Disclosure

BrainLAB and Andreas Raabe, M.D., Ph.D., have developed the method of perspective registration and have filed for a patent.

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References


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