How to perform multi-modality 3D roadmapping in neuro-vascular procedures

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Learning objectives

Pre-procedural image data, such as CT or MR, can provide valuable information during interventional treatment. Fusion of this multi-modal image data into the live fluoroscopy image can aid accurate neuronavigation. In case of angiographic multi-modal data, contrast agent usage can be reduced during the intervention. For AVM treatment, pre-procedural MR can be used to localize arterial feeders and drainage veins of the AVM, hemorrhage, hematoma cavities, and fistula during the intervention. The learning objectives comprise the steps leading to accurate fusion of multi-modal image data, such as CT or MR, and the live fluoroscopy roadmap image. Furthermore, the accuracy of the overlay and the clinical benefits are discussed.

Images for this section:

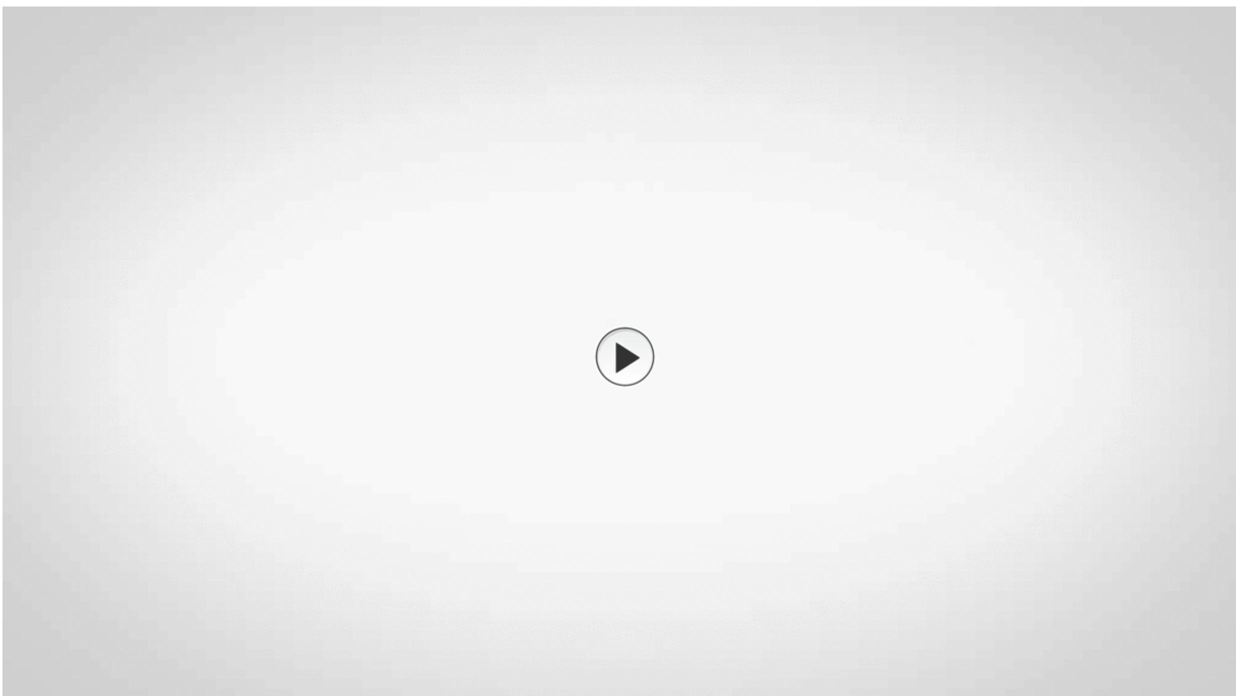

Fig. 1: multi-modality 3D roadmapping video [13].

Background

Traditional roadmapping is based on the superimposition of digital subtraction angiography (DSA) and the live fluoroscopy images. The DSA technique has been developed in the 1930's, and has first been used in interventional treatment in the 1960's. The DSA images show the vessel lumen filled with iodinated contrast medium, while the fluoroscopy images show the current location of the endovascular devices. It provides the vascular context to the real-time fluoroscopy and therefore helps to lowers the risk of inadvertent events, while lowering the use of iodinated contrast medium [1]. The roadmap is limited by its static projection incidence. Tortuous cerebral vessels and complex lesion morphology (e.g., complex aneurysms, AVM's etc.) often require many different working projections, which leads to extra contrast injections for new roadmaps. Dynamic 3D roadmap significantly improves on the traditional roadmapping technique by using a cone-beam CT reconstruction to supplement the fluoroscopy image with the 3D vasculature. This 3D model stays valid for different projection angles and focal distances, and therefore no new contrast injections are required [2,3].

CT/MR Roadmapping (Philips Heathcare, Best, the Netherlands) is an extension of the dynamic 3D roadmap. It involves an additional co-registration step of the multimodal data into the frame of reference of the cone-beam CT dataset.

The technique is illustrated by the figures in the sidebar. Figure 2 shows an AVM and impacted brain tissue in a MR acquisition. The live fluoroscopy image without contrast medium in Figure 3 shows the guide wire, but does not reveal its relation to the vasculature and the soft-tissue. The 3D dynamic roadmap in Figure 4 adds the 3D vascular context to the live fluoroscopy image. Figure 5 shows the fluoroscopy image, the 3DRA vasculature and a slab from the MR data. The MR slab is positioned parallel to the view port at the guide wire tip.

Images for this section:

Fig. 2: MR image showing an AVM.

Fig. 3: Fluoroscopy image showing the guidewire without context.

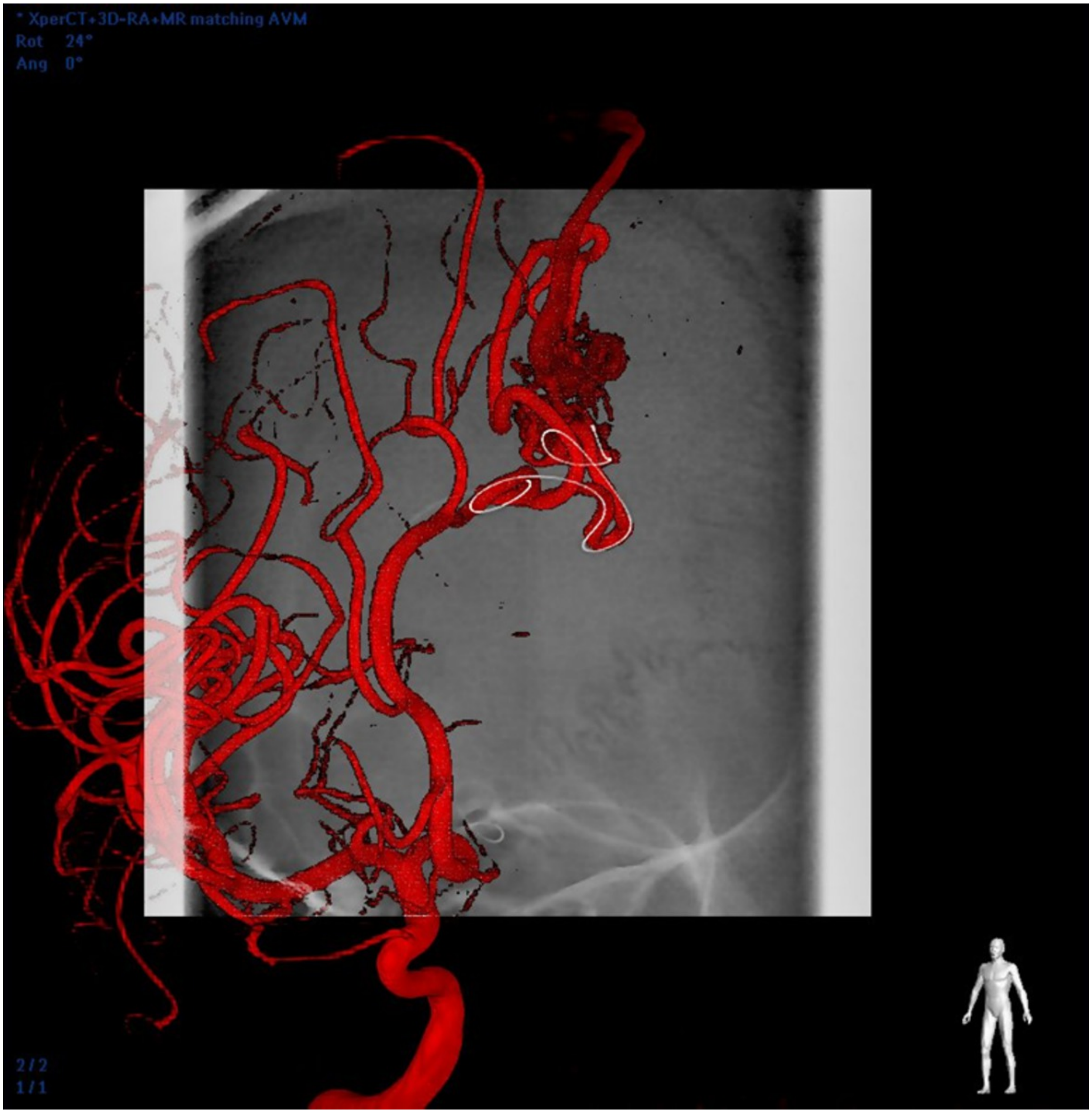

Fig. 4: Dynamic 3D Roadmap.

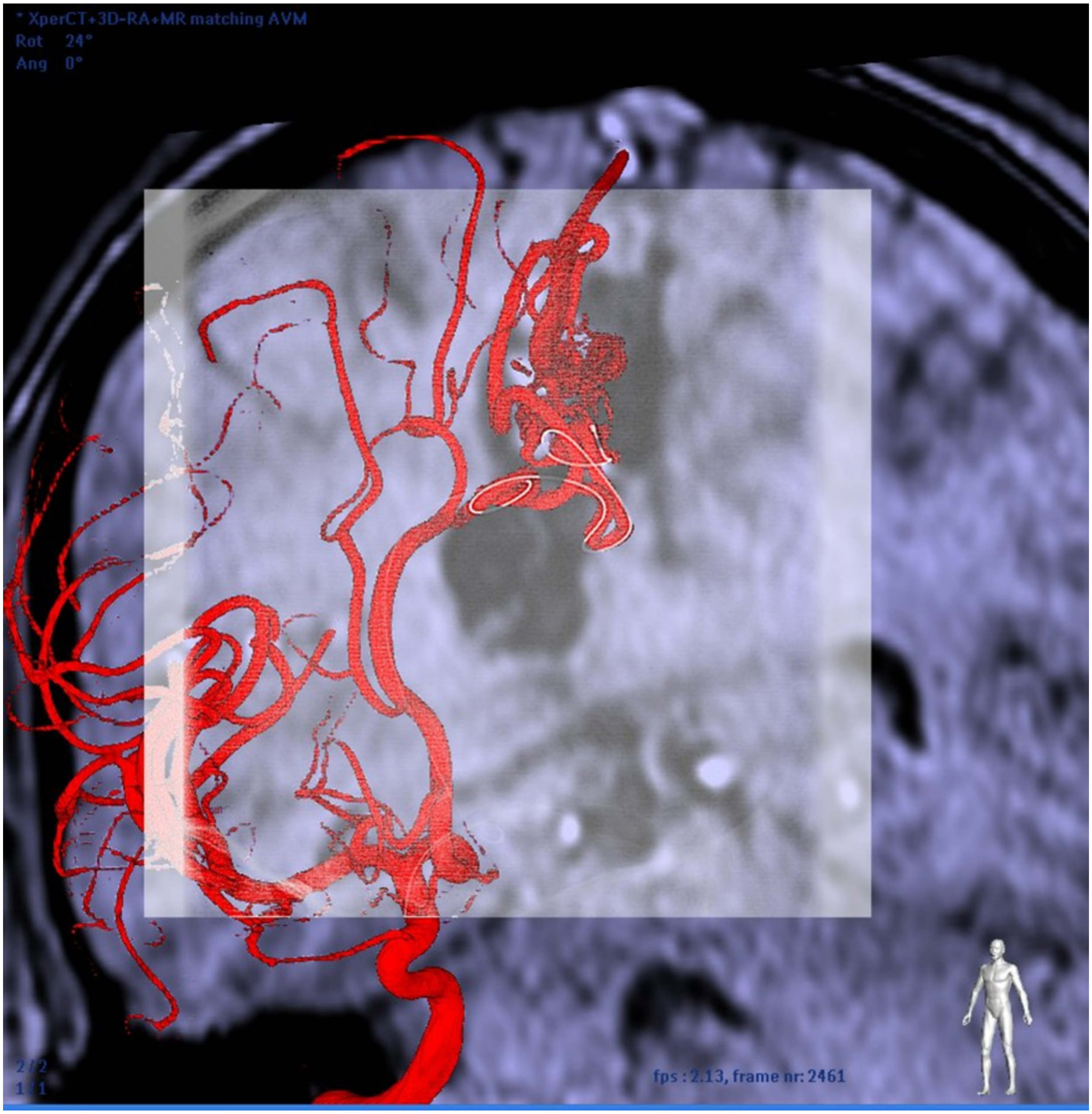

Fig. 5: MR Roadmap.

Imaging findings OR Procedure details

Workflow

1. The pre-procedural multi-modal data in DICOM format is imported into the interventional workstation from a PACS or disc.
2. Peri-interventionally, a cone-beam CT (optionally contrast enhanced) is acquired with the C-arm system, see movie below.

Fig. 6: Rotational cone-beam CT acquisition.
References: Ruijters D et al. (2009) Real-time integration of 3-D multimodality data in interventional neuroangiography. J Electron Imaging 18(3)

3. The cone-beam CT is co-registered with the multi-modal data, using a semi-automatic approach, by selecting the overlay tool on the 3D workstation. A coarse manual initialization in axial, coronal and sagittal viewing direction is performed by the operator. Then the fine co-registration can be performed by the software, see movie below. Finally, the co-registration result is to be visually inspected by the operator.

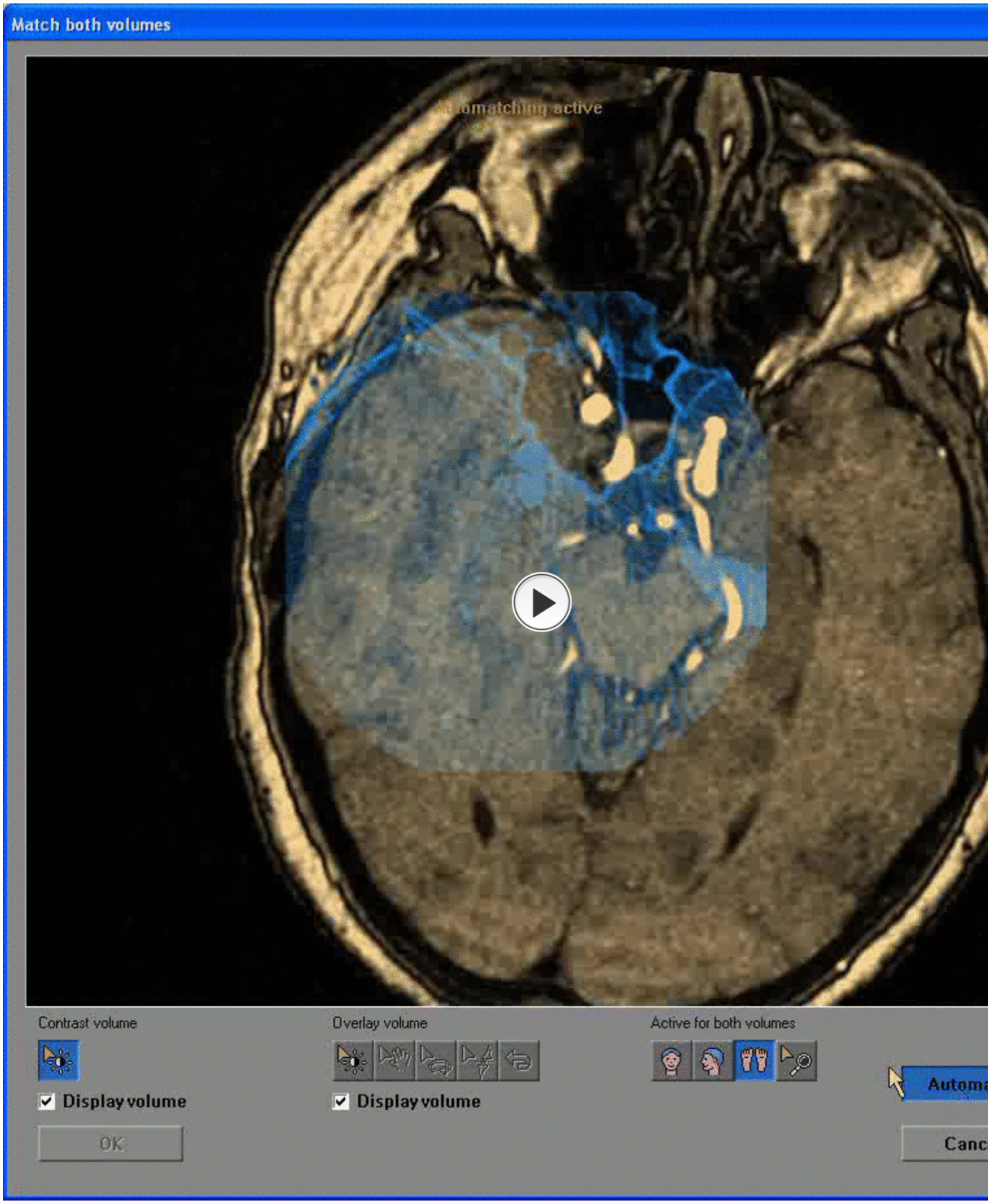

Fig. 7: Fast automatic MR - CT-conebeam co-registration.
References: Ruijters D et al. (2009) Real-time integration of 3-D multimodality data in interventional neuroangiography. J Electron Imaging 18(3)

4. The 3D roadmapping is activated by pressing the "3D Roadmap" button on the table side touch screen module.

There are several visualization options that can be chosen by the operator. The multi-modal data can be either visualized as a oblique slab that is always oriented parallel with viewport, see figure below. It is important to place the center of rotation within the lesion. In that way, the lesion stays within the rotated oblique slab when the gantry is rotated.

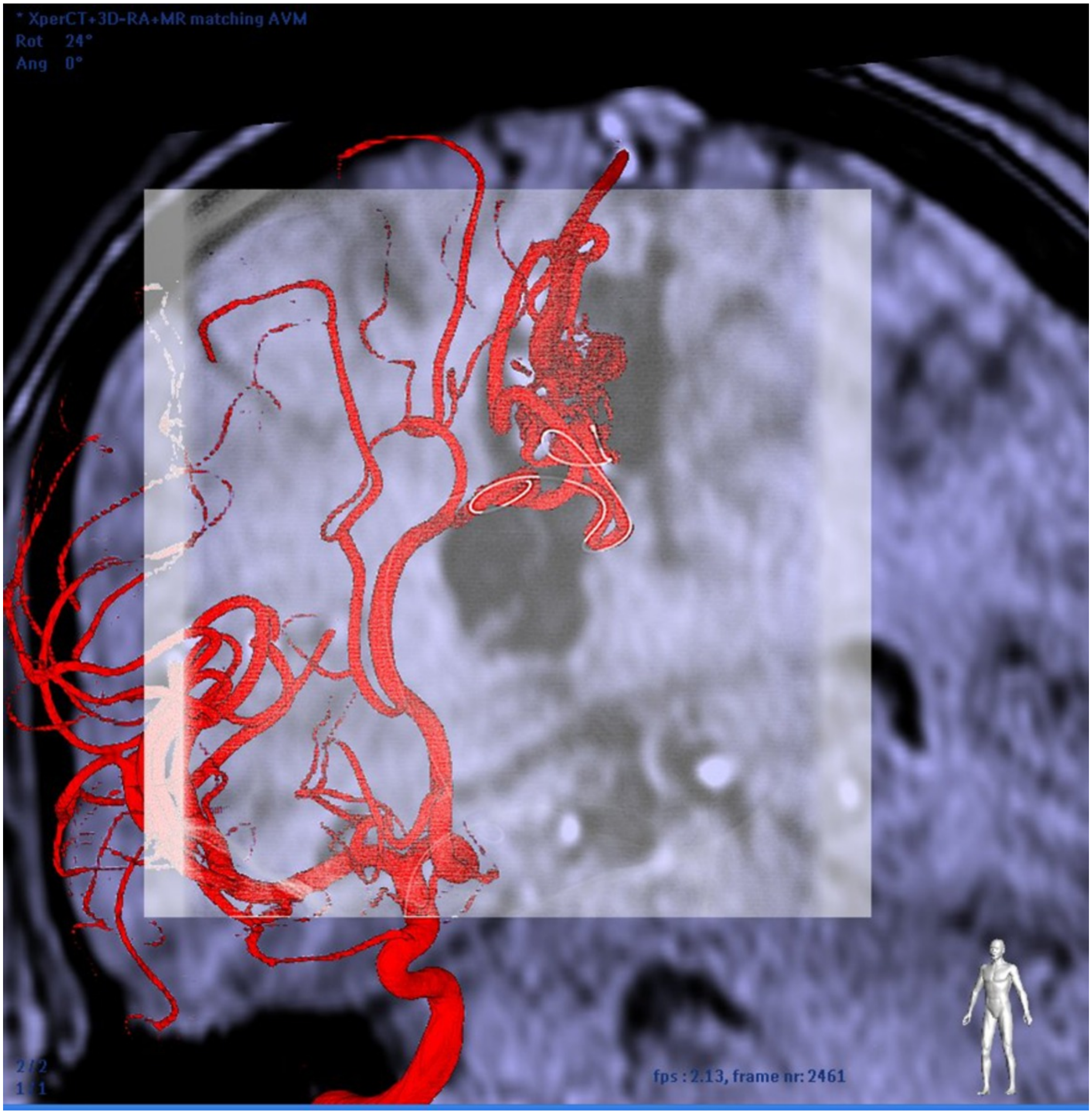

Fig. 5: MR Roadmap.
References: Ruijters D et al. (2011) Validation of 3D multimodality roadmapping. Phys. Med. Biol. 56:5335-54

Alternatively, the multi-modal data can be shown in volume render mode, see movie below. The cone-beam CT can then optionally be hidden. In that case the cone-beam CT is used for co-registration purposes only.

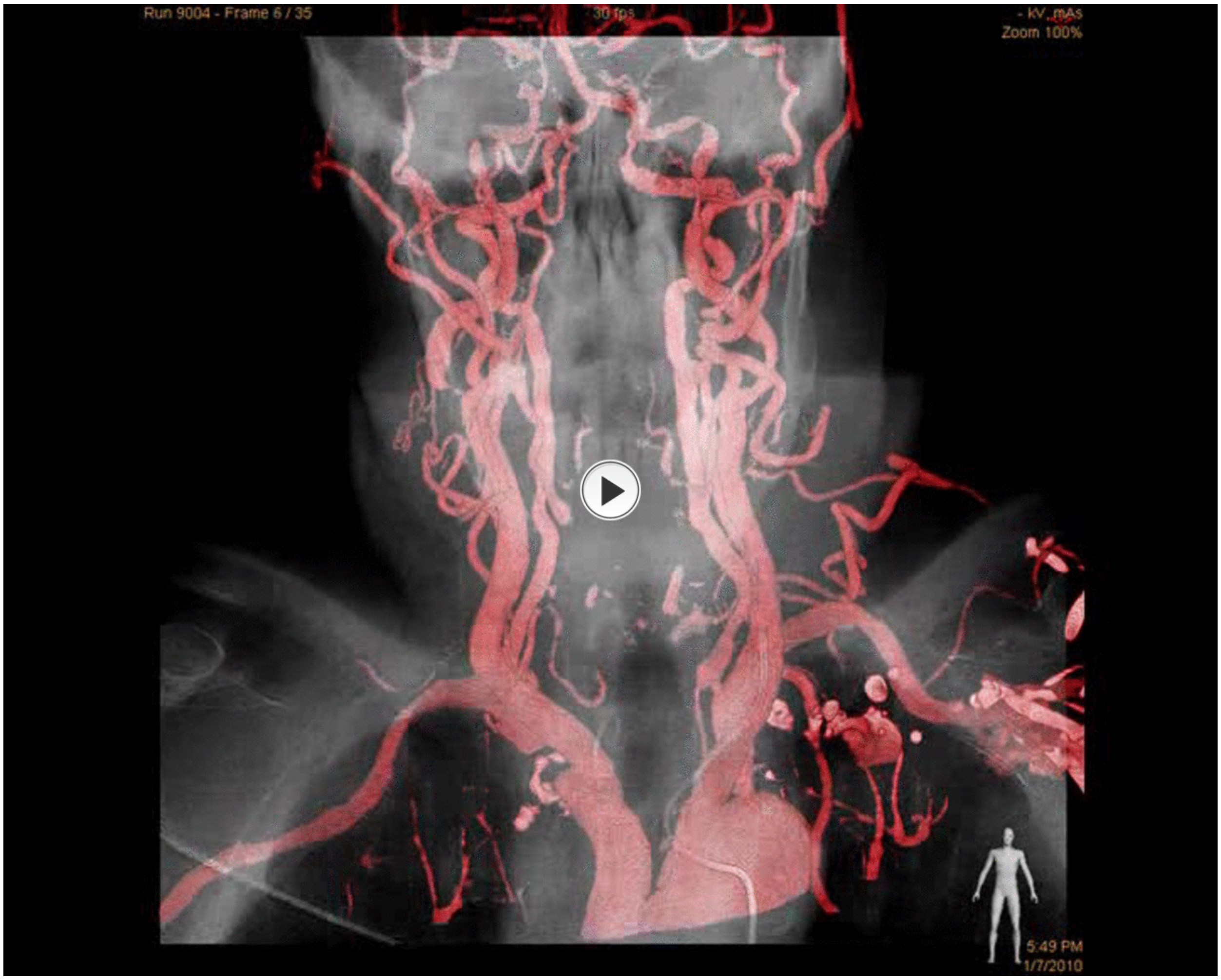

Fig. 8: CTA Roadmap, showing real-time compensation for table movements.
References: Courtesy of Dr. Maleux, UZ Leuven, Belgium

Accuracy

The accuracy of the automatic multimodal registration algorithm was validated using a head phantom to deliver a ground truth [4].
On average an absolute residual translation error of 0.515 mm (std = 0.017, min = 0.495, max = 0.588) and a mean absolute residual rotation error of 0.241 degrees (std = 0.031, min = 0.180, max = 0.307) was obtained, which corresponded to sub-voxel accuracy.
During the roadmapping phase the projection of the cone-beam CT dataset on fluoroscopy can be performed very accurately; The average deviation of the detector center amounts to about 0.1 mm in-plane, the displacement of the focal spot is about 0.17 mm and the average rotational error is less than 0.1 degrees [4].
Analogous to the advice of Fahrig and Holdsworth [5], the clinical systems are recalibrated every 6 months.

Conclusion

In this poster the steps that need to be taken to perform multi-modality 3D roadmapping have been explained. The fused visualization may be used to improve the localization of arterial feeders and drainage veins of the AVM (see figures 5 and 9), hemorrhage, hematoma cavities, and fistula. Furthermore, contrast medium induced nephropathy (CIN) has been reported to occur in approximately 10%-30% of patients with preexisting renal insufficiency [6-9]. Therefore, for those patients image guidance based on previously acquired CTA or MRA data fusion with fluoroscopy (see figure 8) may become tremendously helpful.

Clinical results have been described by Levitt et al [10]. They successfully combined pre-interventional CTA and MRA with real-time imaging at the time of angiography, and reported that the technique can reduce radiation and iodinated contrast exposure, and expands the application of angiographic technology in cerebrovascular and other neurosurgical diseases. Clinically relevant potential to lower contrast media use and a reduction of the risk of thromboembolic events is reported by Lin et al [1], when the multimodality roadmapping method is used for navigation in areas ranging from the aortic arch level to the proximal internal carotid arteries. Outside the neurological field, Gupta and Radaelli [11] have described how the presented method can also be applied in transarterial chemoembolization (TACE). The fusion of the 3DRA with diagnostic CT or MR angiography enables valuable multimodal visualizations of feeding vessels and tumors. The 3D roadmapping, using the live 2D fluoroscopy, allows a smooth catheter placement into the feeding vessels. Kobeiter et al. have used the described multi-modal roadmap to perform thoracic endovascular aortic repair without any contrast injection at all [12].

Overall, it can be concluded that the 3D roadmapping technique is considered a valuable method for accurate navigation and helps to reduce x-ray dose and use of a harmful iodine contrast agent [1,2,11].

Images for this section:

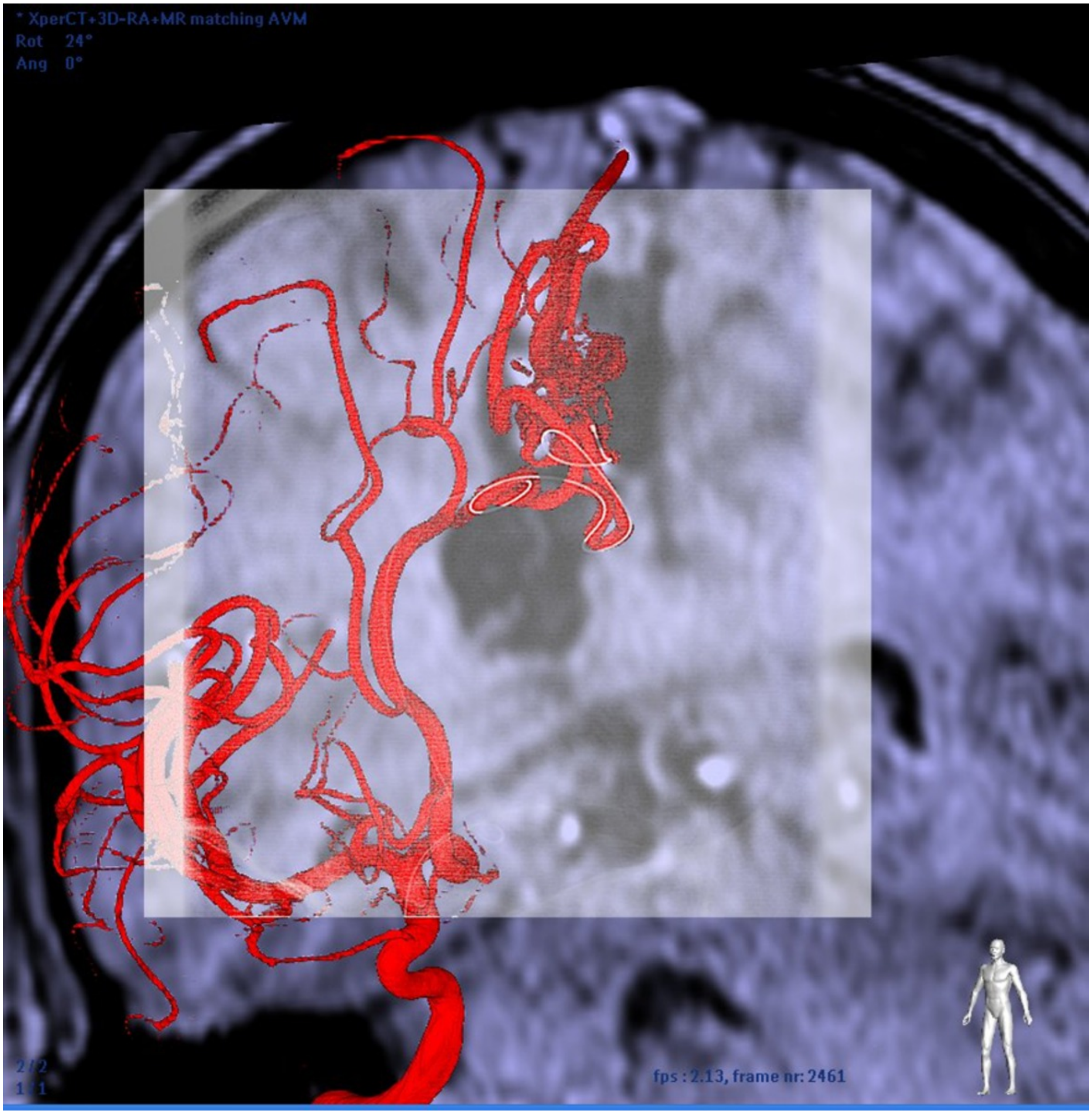

Fig. 5: MR Roadmap.

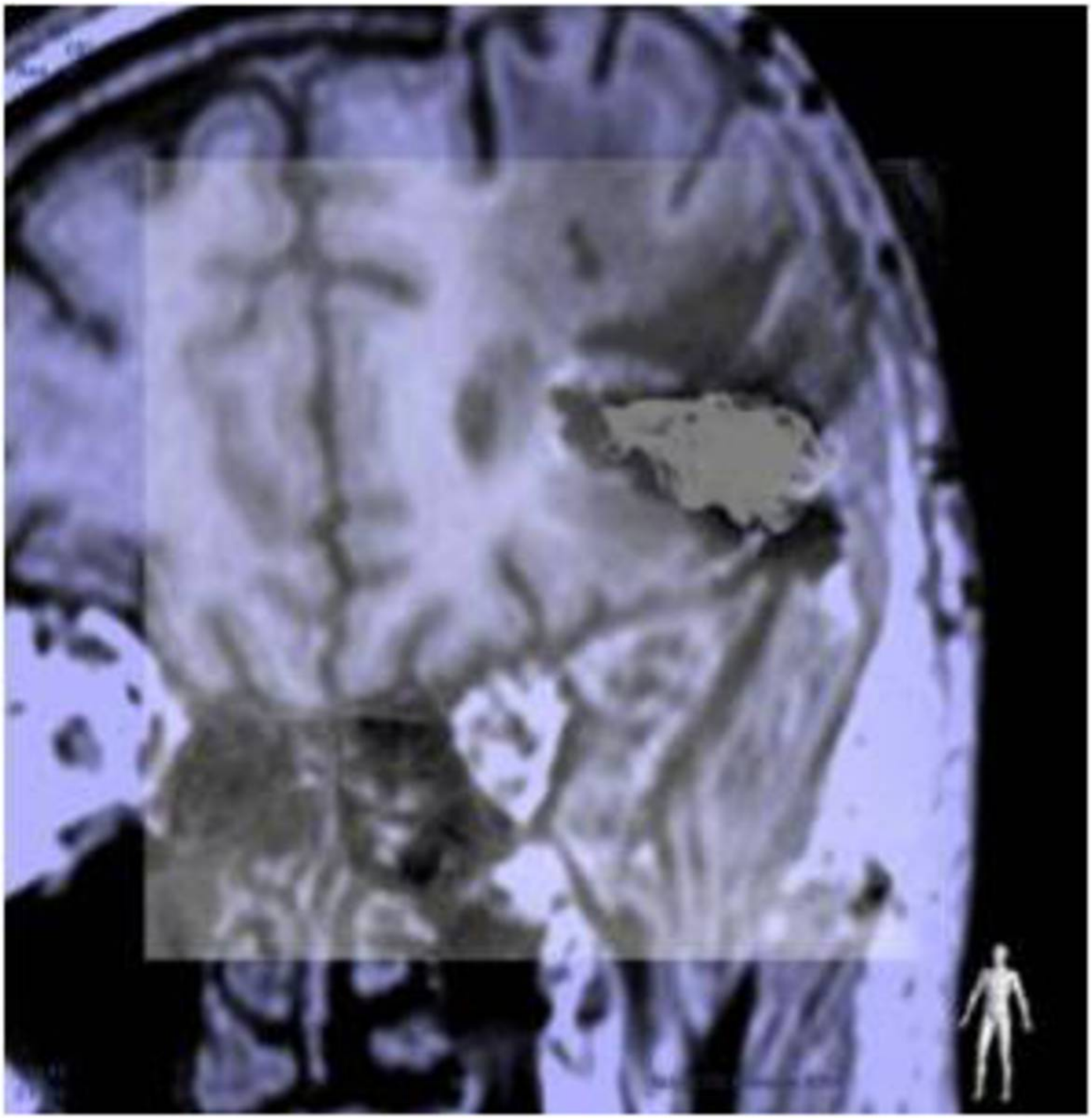

Fig. 9: Embolization of an AVM, using the MR roadmap.

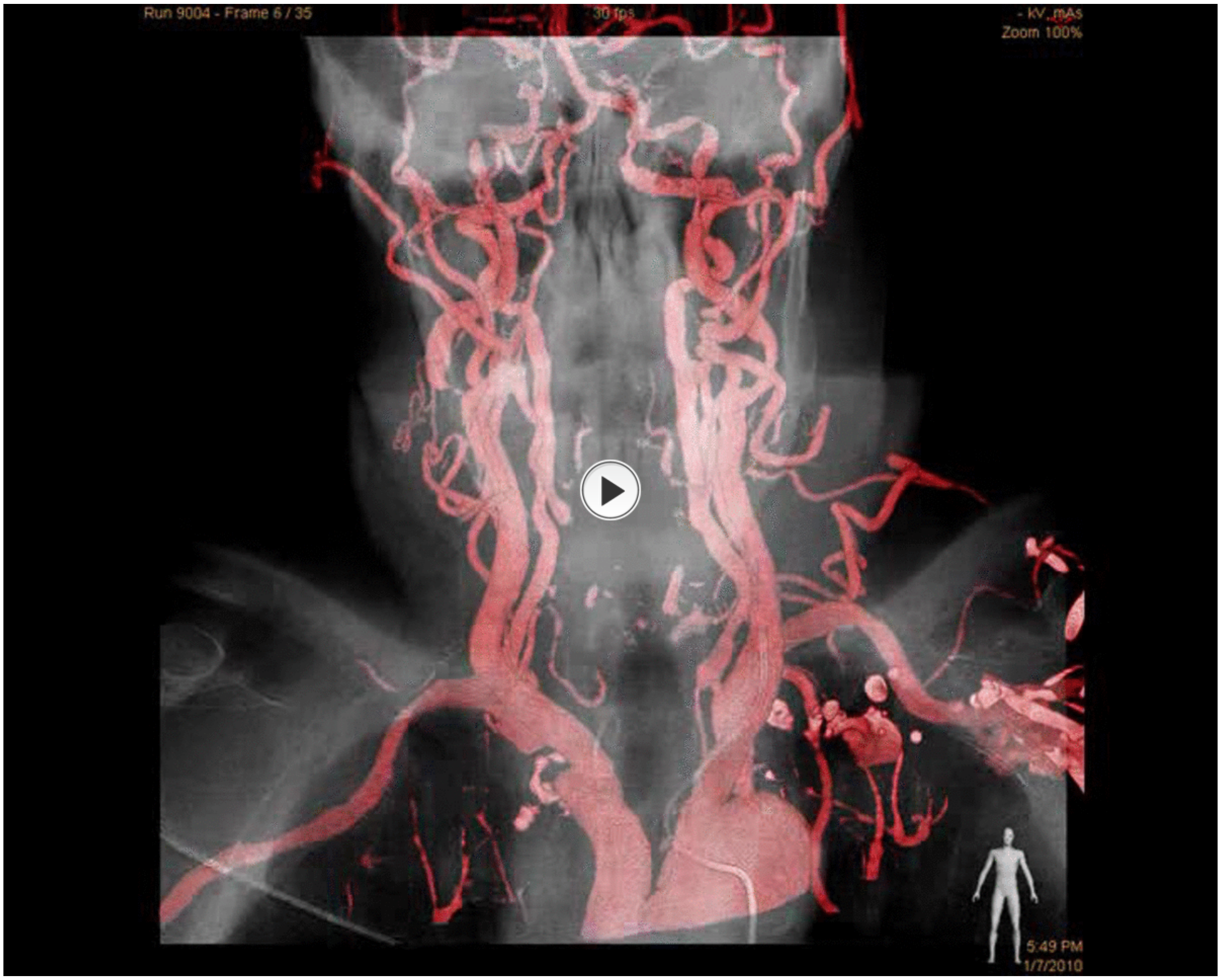

Fig. 8: CTA Roadmap, showing real-time compensation for table movements.

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