

3D multimodality roadmapping in interventional neuroradiology

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► **A fused image allows better anatomical understanding and, consequently, more precise navigation.**

During minimally invasive neurovascular interventions, the fluoroscopic images with the live information on interventional endovascular devices, and pre-operative soft-tissue images (such as magnetic resonance (MR) or computed tomography (CT)), are usually shown on separate displays. This means that the interventionist has to perform a mental projection of the position of the endovascular device on to the soft-tissue data.

This article describes a method for fusing this information into a combined image, which may be of great clinical advantage, since it relieves the operator of performing this task during the intervention. Furthermore, a fused image allows a better anatomical understanding and, consequently, more precise navigation of the endovascular devices.

► **The machine-based method provides accurate real-time registration even when there are few landmarks.**

To provide the maximum benefit of such an augmented image, the live fluoroscopy data and the soft-tissue data have to be combined in real time, with minimum latency and an adequate frame rate (15 or 30 frames per second, depending on acquisition mode). The usage of the fused display during interventional treatment also requires the image to be easy to interpret, while manipulation should be interactive and simple to use. This article describes the steps that are necessary to achieve such a combined visualization [1] and discusses the clinical benefits.

Registration is the process of spatially aligning two image datasets (which may originate from different modalities), such that the corresponding morphology in both datasets overlaps. Two fundamentally different approaches can be distinguished when registering 2D fluoroscopy data to 3D volumetric data.

In the first approach, called image-based registration, the registration process is driven by the image content. There are a number of image-based 2D-3D registration algorithms

known in the literature for registering fluoroscopy images to either CT or MR images [2-7]. These algorithms, however, take a considerable amount of time to compute. Further, they need sufficient anatomical landmarks to be present in the 2D fluoroscopy image, which is not necessarily always the case.

The second approach is known as machine-based registration. With the introduction of motorized calibrated C-arm X-ray angiography, 3D reconstruction of the vasculature came within reach. Since 3D rotational angiography (3DRA) datasets are obtained with the same apparatus as the 2D fluoroscopy data, it is possible to calculate a registration, based on the state of the geometry (viewing incidence angles, source-to-detector distance, etc.) and calibration data. This, of course, assumes that there was no patient motion between acquisition of the 3DRA data and the fluoroscopy data [8-10].

This method also allows for obtaining a registration when there are insufficient landmarks present in the images (for example, due to the absence of iodinated contrast medium in the fluoroscopy images) [11]. A further advantage of machine-based registration is the fact that it can be computed in real time.

Methods and materials

Pre-processing steps

Before the treatment of neurovascular pathologies, soft-tissue data, such as MR or CT images, are often acquired for diagnostic purposes and/or treatment planning. The goal is to integrate the data into a fused visualization during the treatment. To achieve this objective, a 3DRA dataset is obtained at the beginning of the intervention. Before the 3DRA and soft-tissue data can be fused with the live fluoroscopy image stream, a pre-processing step has to be performed. In this step, the 3DRA

and soft-tissue dataset are registered, using an image-based registration algorithm.

Performing image registration of large 3D datasets during an interventional treatment poses a number of constraints on the registration method. In particular, the calculation time of the algorithm has to be limited, since it has to be carried out during the intervention. Since the implementation used is optimized to efficiently use the workstation's graphics hardware, it can perform the registration process within a mere eight seconds.

3DRA reconstructions may have a very high spatial resolution (a voxel can be as small as 0.15 mm), but tend to be rather noisy in the dynamic range. Therefore, the vessels, bones and intracranial sinuses are the only anatomical structures that are clearly visible and can serve as landmarks. It is therefore important that these structures are contained within the 3DRA reconstruction as well as in the soft-tissue data.

Since the focus is on cerebral applications and there are only limited local deformations of the anatomical structures within the head, a rigid registration can be used (that is, only a global translation and rotation). Rigid registration has the further property that it can be calculated relatively robustly and fast. Mutual information is used to drive the rigid registration [12], because it performs very well on intermodality registration and does not demand any *a priori* knowledge of the datasets. Optionally, the image-based registration is preceded by a rough manual registration.

A further pre-processing step forms the segmentation of the vessel tree in the 3DRA dataset. This is a moderately easy task since the iodinated contrast medium has a higher X-ray absorption than any other substance present in the dataset, and therefore the vessel structure can be rather easily distinguished from the surrounding tissues. Note that the entire pre-processing only has to be performed once, at the beginning of the intervention.

Registering 2D fluoroscopy to 3DRA data

The machine-based registration involves projecting the 3DRA data on to the fluoroscopy images, based on the position of the C-arm. The X-ray C-arm system can rotate over three axes (Figure 1a): rotation around the L-arm, propeller movement of the C-arm, and roll movement of the C-arm. The 3DRA dataset has to be rotated to match the orientation of the C-arm system.

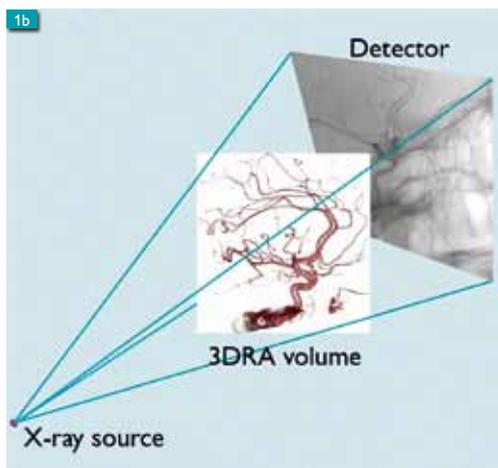
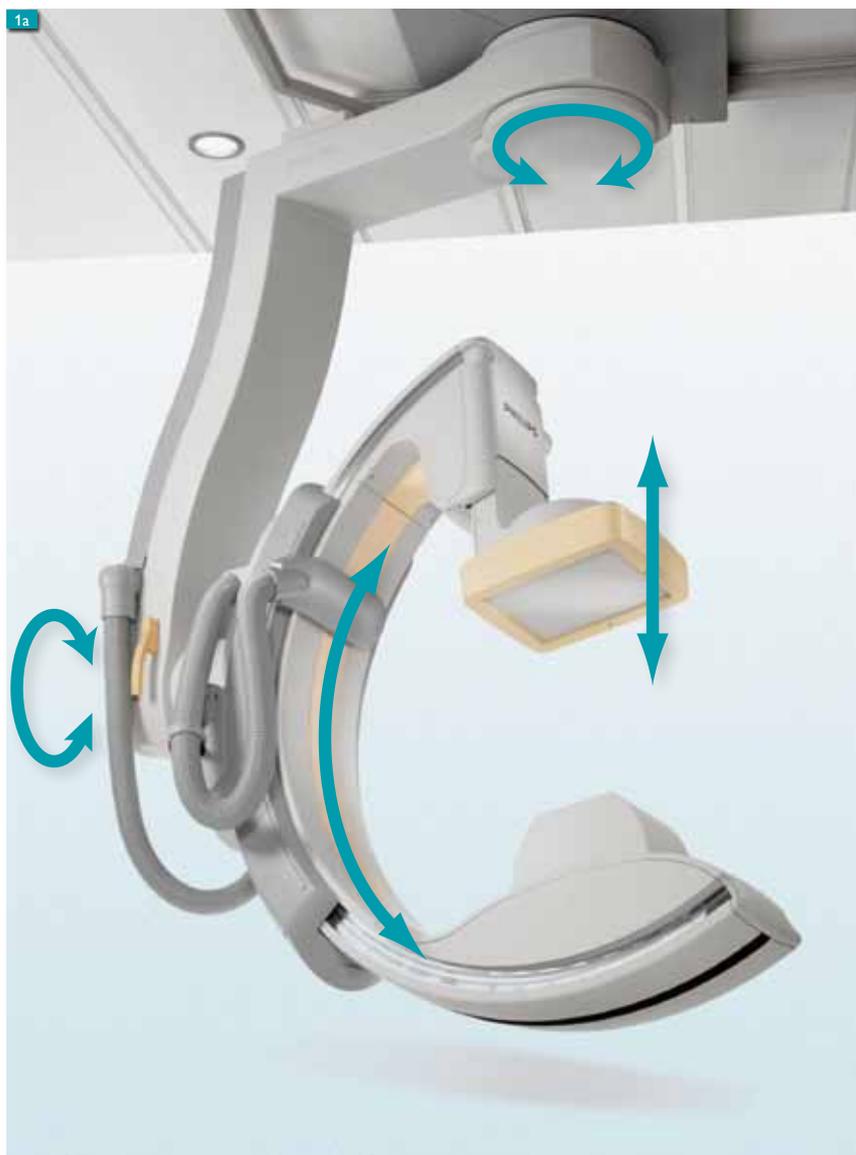


Figure 1. Registering 2D fluoroscopy to 3DRA data. The 3DRA dataset has to be rotated to match the orientation of the C-arm system.

▲
Figure 1a. The degrees of freedom of the C-arm geometry.

◀
Figure 1b. The virtual projection of a 3DRA dataset on a fluoroscopy image.

Rotation of the 3DRA dataset has to be further corrected for deviations from the ideal calculated orientation based on the calibration data [13, 14]. The calibration procedure only needs to be performed approximately once every six months. After the rotation of the 3DRA dataset into the appropriate orientation, there

still remains the task of projecting it with the proper perspective (Figure 1b). The perspective depends on the X-ray source-to-detector distance and the detector dimensions.

The 2D-3D correspondence between the 3DRA dataset and the fluoroscopy image can be calculated in a mere 1.5 microseconds, and thus can be done in real time. The accuracy of the calibrated machine-based 2D-3D registration was measured on five Philips Allura FD20 C-arm X-ray angiography systems. The registration was least accurate at the corners of the 3DRA reconstruction volume. The maximal deviation of the 2D fluoroscopy image and the projected 3DRA image was 0.4 mm at the corners of the reconstruction volume. The average deviation at the corners was 0.2 mm.

Fused visualization

The visualization should unite the soft-tissue data, the 3DRA data, and the live fluoroscopy stream into a single fused image (Figure 2). It should be possible to interpret such a fused image quickly and easily during the intervention. It is therefore mandatory to combine the large amount of information in a way that is easy to digest and that conveys all the relevant information.

The fluoroscopy data that overlays the background can contain some anatomical landmarks, relevant to the physician. The most important part of the fluoroscopy image, though, is the area inside the vessels, since this is where the endovascular devices are moved. The 3DRA dataset provides a high-resolution 3D representation of the relevant vessel structures. The fluoroscopy image stream, containing the real-time status of the endovascular devices, is mapped onto the 3D vasculature.

In the combined visualization, the part of the fluoroscopy image that is not projected on top of the 3D vasculature can be suppressed, since its content makes a less significant contribution to the final image. The endovascular devices are located within the region that coincides with the 3D vessel structures, and therefore this region of the fluoroscopy image can be additionally enhanced.

The morphological MR or CT dataset holds the soft-tissue structures relevant to the procedure as well as some pathological processes that may not be visible in the 3DRA or fluoroscopy data (Figure 2a). The most relevant parts of the soft-tissue data can be visualized by choosing a slab (Figure 2d), whose location, orientation and thickness can be interactively altered by the operator at any time.

Alternatively, it is possible to select a representation of the soft-tissue data, whereby an octant, quarter, or half is cut open (Figure 3). The location and orientation of the intersection can be interactively changed. The 2D-3D registration, which was calculated in the first pre-processing step, is applied to the position of the soft-tissue data.

Discussion

Being able to see the live fluoroscopy image within the context of the 3D vasculature and soft-tissue information is of great clinical relevance. The combination of the fluoroscopy image with the 3DRA vessel tree gives added value. This is because the guide wire and catheter positions can be located with respect to the vessel tree without additional contrast injection (Figure 2b, c). In the meantime, the C-arm position and the X-ray source-to-detector distance can be altered freely. Even during rotations of the C-arm, the machine-based 2D-3D registration will always be up to date.

The clinical interest in the so-called 3D-roadmapping has been described before [9]. The additional visualization of the soft-tissue data allows correlating the position of the guide wire and catheter to anatomical information and pathologies, which are only visible in the soft-tissue data. That this information is available in real time is the fact that makes it especially suitable for navigation.

The addition of soft-tissue visualization to the 3D-roadmapping technique, and especially high-quality MR datasets, brings extra information that may be important for the operator's decision making, and can increase safety during the procedure as well as shorten the operating time. In embolizations of brain arteriovenous malformations (b-AVMs) or intracranial tumors using liquid adhesives or particles, the exact position of the catheter tip is crucial.

The obvious goal is to embolize the pathological structures and avoid spilling over to normal vessels supplying normal brain tissue. In these situations, the complex vessel anatomy can be difficult to comprehend. In such instances, the 3D multimodality roadmapping may prove to be of great value, especially since it is possible to freely rotate the 3D volume with controls located at the interventional table.

The technique may also be of great assistance for targeting areas of a b-AVM that are to be partially embolized, thereby avoiding so-called

► **Seeing the live fluoro image in the context of the 3D vasculature and soft tissue is of great clinical relevance.**

► **Multimodality roadmapping may prove to be of great value in embolizations, where the position of the catheter tip is critical.**



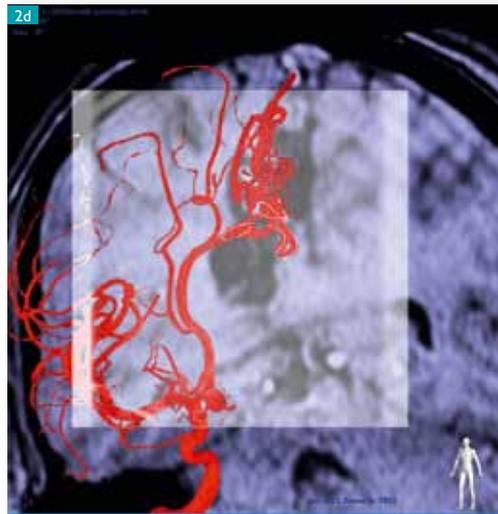
◀◀
Figure 2a. An MR image, showing an AVM and impacted brain tissue.



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Figure 2b. The live fluoroscopy image without contrast agent shows the guide wire, but does not reveal its relation to the vasculature and the soft tissue.



◀◀
Figure 2c. The fluoroscopy image mixed with the vessel tree from the 3DRA dataset adds the vascular context to the live data.



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Figure 2d. 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.

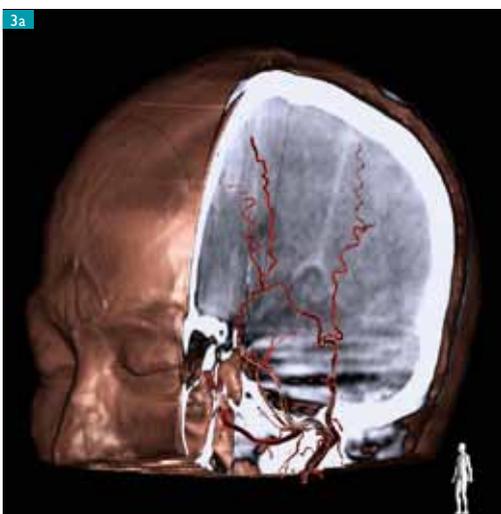
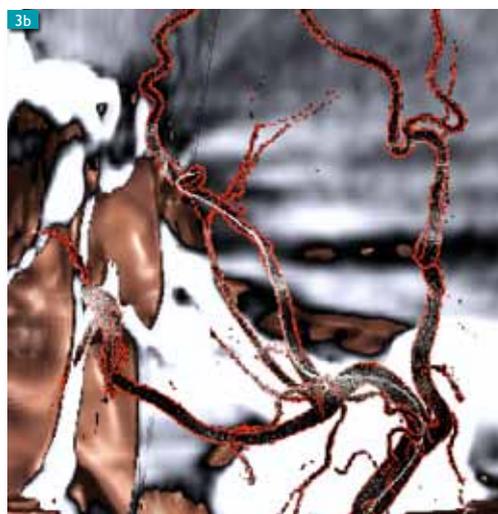


Figure 3. The soft-tissue dataset can be combined with the 3DRA data and displayed with an octant, quarter, or half cut open.



◀◀
Figure 3a. A quarter is cut out of a soft-tissue dataset, while the 3DRA vessels are overlaid with the live fluoroscopy information.

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Figure 3b. A zoomed fragment of the left image, showing the micro guide wire.

piece-meal embolization, as well as for avoiding high-risk treatment close to eloquent areas of the brain. The exact position for delivery may also be important for intra-arterial delivery of other compounds, such as cytostatic agents for tumors, growth factors for stroke and degenerative brain disorders. This is a rapidly developing and growing field of application.

Conclusions

This article presents a method of fusing real-time fluoroscopy, 3DRA data and soft-tissue data into a combined image, and its application in neuro-endovascular procedures. The combination of the fluoroscopic image with the 3DRA vessel tree, known as 3D-roadmapping, offers the

advantage that the spatial relationship between the endovascular device and the surrounding vessel morphology can be determined without additional contrast injection, while the position of the C-arm geometry can be altered freely.

The steps necessary to achieve this data fusion are described. A fast automatic image-based registration of the 3DRA dataset and the soft-tissue dataset had to be developed in order to bring the pre-operative data in the coordinate frame of the C-arm equipment. The machine-based registration between the 2D fluoroscopy image and the 3DRA data only depends on the

incidence angles, the X-ray source-to-detector distance and the calibration data [1]. It can be easily calculated in real time. Possible clinical applications are identified, and the ways in which the presented method could be employed in those applications are demonstrated.

The strength of the described approach lies in its real-time nature, which is primarily achieved by the on-the-fly 2D-3D registration, and the fast fused visualization. The interactive real-time aspect contributes to the 3D perception of the anatomy and pathologies during an intervention ■

► **Interactive real-time registration contributes to the 3D perception of the anatomy during an intervention.**

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