Three-Dimensional Image Overlay to Assist Endovascular Procedures

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ABSTRACT: The use of three-dimensional (3D) image guidance for endovascular procedures has increased over the last decade. This paper will discuss the background of the development of 3D rotational angiography and live 3D-roadmap techniques based on selective 3D rotational angiography. This paper will describe in more detail the application of novel 3D navigation tools, including the use of cone-beam CT and the use of merging techniques that allow for fusion of CT angiographic images and fluoroscopy. The technique and prerequisites for image fusion as well as advantages, disadvantages, and pitfalls will be discussed.

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A disadvantage of the classical 3D-RA technique is nonvisualization of thrombus. The same is true for conventional angiography. Calcifications, however, can be demonstrated using 3D-RA using either the source images showing some indirect signs of the presence of thrombus (discrepancy between angiographic lumen and location of calcification), or calcified plaque software. Recent software developments and use of flat-panel detectors allow for soft-tissue imaging, which yields images similar to CT. In fact, the rotating x-ray tube and flat panel detector can be considered to be a CT scanner. This technique, called cone-beam CT (available under the commercial names XperCT [Philips Healthcare], DynaCT [Siemens], InnovaCT [GE Healthcare]), uses a wider beam of x-rays as compared to the classical (multidetector) CT scanners, in combination with all the individual detectors of the flat-panel detector. For this reason a higher spatial resolution can be obtained (28 line pairs/cm for cone-beam CT, compared to 16 line pairs/cm for CT). A cone-beam CT protocol consists of 621 projections of 1,024 pixels × 792 pixels at the 30 cm × 40 cm zoom format (0.370 mm pixel pitch). The images are acquired at 30 frames per second, in 20.7 seconds. A low-dose protocol acquiring 312 images in approximately 5 seconds is also available. Disadvantages of the cone-beam CT technique are the lower contrast resolution and an increased susceptibility to beam hardening artifacts and “noise.”

The volume as obtained with cone-beam CT can also be used to guide needle-assisted procedures (XperiGuide, SynGo I-guide). This navigational tool creates an overlay of live fluoroscopy and 3D soft-tissue imaging that provides information on the planned needle path from entry point to target. Changes to the live fluoroscopy following adjustment of x-ray/detector distance, position, and/or magnification are transferred to the 3D reconstruction so that the matching is maintained throughout the procedure. Guidance graphics are superimposed onto the fluoroscopic data, and it is possible to superimpose the graphics onto slice data or volume data, thus achieving a better understanding of the needle position with respect to the surrounding soft-tissue structures that are not visible on the fluoroscopic images.

**TECHNICAL CONSIDERATIONS OF IMAGE MERGING**

High-quality imaging and precise navigation guidance are two prerequisites for the successful execution of endovascular procedures. However, most centers still rely on 2D fluoroscopy imaging alone for complex cases, even though a 3D perspective of the vasculature is desirable for catheter navigation and positioning of devices. Hence, it would be desirable to have a means of combining the data from several imaging systems to deliver the missing information during preparation and interventional treatment. One such tool is the VesselNavigator (Philips Healthcare). The VesselNavigator overcomes the missing 3D perspective and adds the information from the third dimension by combining previously acquired CT datasets and real-time fluoroscopy imaging. The CT dataset provides an accurate 3D model of the region of interest through segmentation and identification of key anatomical structures of the vessel tree. During the procedure, the VesselNavigator software overlays the 3D CTA volume on live fluoroscopy using alpha blending. The VesselNavigator work-up comprises four steps:

1. **Segmentation**

The CT dataset is imported into a dedicated 3D workstation. By means of a semiautomatic segmentation algorithm, the vasculature of interest is separated from bones and soft tissue in the CTA. The algorithm uses an optimized fast-marching algorithm to trace the vessels through the volume, and tags voxels that match vessel identification criteria. Using these tags the system can set specific colorization and translucency of vessels. This enables a plain view on the vasculature of interest, without the potential interference of overlapping vessels and bones (eg, pelvis, spine, or ribcage). This facilitates both the procedural planning as well as subsequent intraprocedural navigation.

2. **Planning**

In the planning step, the user can interact with the (segmented) CTA to find optimal working projections...
to be used during the intervention. The projection angles can be stored, and later recalled to automatically steer the C-arm to the predefined rotation/angulation. Furthermore, in this work step the user can perform measurements and highlight important anatomical features by means of placing landmarks that will be visible during live guidance on the overlay image.

3. Registration: acquisition angiography system

(a) Cone-beam CT
For registration of the live fluoroscopy with the CTA volume, a low-dose cone-beam CT acquisition without injection of iodinated contrast is acquired before draping the patient. During patient preparation, the preacquired CTA volume is fused with the intraoperative cone-beam CT, based on anatomical landmarks visible in both 3D scans. For high accuracy of the overlay, calcifications of the vessels can be chosen as landmarks.

(b) Fluoroscopy (2 angles)
The registration step ensures that the fluoroscopy stream can be accurately superimposed on the 3D volume of the CTA. In order to register the orientation of the CTA to the coordinate space of the C-arm, the user acquires x-ray images (short fluoroscopy runs or single frames) from 2 different projection angles, with a delta of at least 20 degrees (in practice a delta of more than 40 degrees is used). Anatomical features from the 2 x-ray runs (predominantly bone structures) are matched with the corresponding features on the CTA. The system takes into account the inverse-perspective nature of x-ray, and allows for registration along normal axes, even when the delta angle is less than 90 degrees. Once this is complete, the fluoroscopy stream is accurately overlaid on the CTA, regardless of C-arm and table positioning. The registration can be performed by the physician at tableside using a touch screen with a sterile cover.

By using fluoroscopy for the registration step, a considerable dose reduction can be obtained. A Monte Carlo modeling software package (PCXMC, STUK) was used to estimate in an anthropomorphic mathematical phantom the difference in effective dose between a cone-beam CT and two oblique fluoroscopy projections for the purpose of registering the CTA with the live fluoroscopy. For this estimation a patient of 175 cm in height was assumed, while varying the patient’s weight between 60 kg and 90 kg. The abdominal aorta was assumed to be in the isocenter. The simulation of the cone-beam CT scan assumed the C-arm to be in propeller position, and using a low-dose protocol especially designed for the purpose of registration of the cone-beam CT to a diagnostic CT or MR dataset. For simulation of the two 3-second fluoroscopy projections, we modeled projection angles of +30° and -30° and used a dose rate of 2.5 R/min (at lowest dose settings).

Results of the simulation indicate that registration using a cone-beam CT yields an effective dose of between 1.53 and 1.66 mSv, while registration using two oblique fluoroscopy projections only results in an effective dose between 0.14 and 0.20 mSv. In perspective, a 6-second digital subtraction angiography run with 3 frames per second gives an effective dose between 0.91 and 1.46 mSv.

An additional advantage of the fluoroscopy registration is that it can be performed by the operator in a sterile fashion, with the patient already draped. Cone-beam CT registration is typically performed before draping, and therefore care should be taken that the patient does not move while being draped, as this would lead to misregistration (see below).

4. Live guidance
During live guidance, the VesselNavigator shows an overlay image of the CTA and the live fluoroscopy stream. The CTA is projected in the inverse perspective space of the x-ray beam and thus provides a visual roadmap to direct the catheter during intraprocedural navigation. The roadmap is synchronized, in real time, with changes in rotation, angulation, and lateral movements of the C-arm as well as with the table position, detector height, and magnification. According to user preference, the roadmap is either displayed as an outline or a volume-surface rendering of the segmented vessels, optionally with interpolation-based surface shading. When additional orientation is required, the volume rendering of the vessels can be combined with a semitransparent rendering of the soft-tissue.
Steps 1 and 2 above can be done at the physician’s convenience prior to the procedure. Steps 3 and 4 are carried out in the angiosuite, with the patient on the table.

### CLINICAL APPLICATIONS

Merging combines real-time feedback of fluoroscopy with optimal soft-tissue contrast of CT/MR. The technique of fusion imaging can be used in almost all endovascular procedures, but its main benefit will be in complex interventions that require multiple changes of the position of the C-arm with respect to the length axis of the patient, and procedures that require change of angulation and skew during the various steps of the procedure. Previously acquired CTA data can provide the required information not only for planning but also for guiding the endovascular procedure.

Merging brings large-volume imaging into the angiosuite. Tracking of the table in combination with CT therefore can offer a single roadmap from the groin to the feet and head for different steps during a procedure. This technique will reduce the need for contrast usage, and selective catheterization can even be performed without using any contrast.

Given the high prevalence of renal insufficiency in patients undergoing endovascular procedures and its dependence on nephrotoxic contrast injections, the ability to minimize contrast load confers a benefit to patients. A good example is the treatment of type II endoleaks after endovascular aneurysm repair (EVAR) or cases of superselective (chemo) embolization. In these cases, usually multiple vessel bifurcations need to be crossed, with each bifurcation requiring a different angulation of the x-ray tube in order to be able to navigate efficiently (Figure 1). The technique has also been applied successfully in emergency embolization of patients with visceral or trauma-related hemorrhage (Figure 2). Other applications include carotid stenting, EVAR, thoracic endovascular aneurysm repair, and fenestrated/branched endografting (FEVAR). A study that compared a historical cohort with a group of patients that was treated with the use of perioperative guidance of FEVAR by means of fusion of preoperative cone-beam CT with multidetector CT showed a statistically significant reduction of contrast dose (94 cc vs 136 cc). In this study, there was a trend toward lower operative times (330 minutes vs 387 minutes) and fluoroscopy times (81 minutes vs 90 minutes), however this difference did not reach statistical significance.

It has been demonstrated in the animal model that the use of merging techniques can improve technical success rates in complex recanalization procedures while reduc-
The use of 3D navigation with image merging reduces the need for multiple (3D) roadmaps: the use of CT roadmaps allows straightforward interpretation through direct coupling with fluoroscopy and makes it possible to select optimal working angles throughout the procedure on the basis of the 3D diagnostic CT angiography. The reuse of diagnostic CT data can thus reduce the amount of contrast medium used and reduce procedural time and radiation exposure to the patient and to the staff.

Potential pitfalls are inappropriate matching of CT volume and fluoroscopy, leading to misregistration. One also has to keep in mind that the insertion of rigid (stent) delivery systems into the vascular system can significantly alter the anatomic relations, due to “stretching out” of the vessels. The origin of major side branches (eg, the renal artery, the common iliac artery) usually does not get displaced in a significant way (Figure 3). Respiratory movements can also add to misregistration. Software algorithms that allow for correction of misregistration due to respiration and device rigidity are under development. With the use of merging techniques it remains important to always check proper (and intraluminal) position of the delivery system and device prior to its deployment.

**CONCLUSION**

Merging CTA and cone-beam CT/fluoroscopic images is feasible, and preliminary results look promising. Merging will allow further reduction of radiation exposure, contrast dose, and procedure time. Its main use and ben-
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Figure 3. AP view of live registration in patient with left common iliac artery aneurysm (arrow) with 4 Fr diagnostic catheter in place demonstrating good matching of overlay and catheter (arrowheads); no anatomical distortion is caused by the diagnostic catheter (A); AP view of live registration after insertion of rigid guidewire and balloon-expandable covered stent (arrowheads) showing stretching out of the external iliac artery (arrow) leading to loss of proper match between overlay and position of catheter in the segment of the external iliac artery; note the unchanged position of the origin of the common iliac artery (curved arrow) (B).

REFERENCES