Does It/Will It Work:
Utility of Fusion Imaging for the Aortic Arch

Current benefits of fusion imaging and potential future enhancements to aid in endovascular intervention.

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The latest generation of hybrid rooms is equipped with advanced imaging tools such as fusion imaging. Although several publications have studied the impact and accuracy of fusion in the abdominal area,[1-4] few data are available regarding its utility in the aortic arch.

Fusion imaging is achieved by merging data from preoperative CTA (or less frequently MRA) with live fluoroscopy. Registration for these two different data sets is usually performed using bony structures and/or vascular calcifications or a previously implanted endograft. Registration can be either two-dimensional (2D)/three-dimensional (3D), which is performed by superimposing the 3D bone model obtained from the CTA on to the bony structures on 2D fluoroscopic images (which requires two perpendicular 2D images), or 3D/3D by superimposing the CTA 3D bone model and aortic calcifications on to a 3D bone model obtained from an on-table cone-beam CT. The 2D/3D registration is currently the gold standard in the abdominal aorta, because it is easy and fast to set up, requires less radiation, and can be easily performed by scrubbed physicians from the tableside.[1]

The accuracy of image fusion in aortic territories outside of the abdomen is currently a topic of ongoing research. One study specifically evaluated the accuracy of fusion during thoracic endograft implantation.[5] Among the 18 patients treated, the median misalignment of the fusion overlay was 8.9 mm (range, 0–37.2 mm) with 3D/3D registration and 17.3 mm (range, 13.6–28.1 mm) with 2D/3D registration. In all patients, fusion imaging was manually realigned with the first angiographic run.

The aortic arch is a relatively fixed structure within the thorax, and therefore, fusion should be accurate in this area. However, it presents new challenges for the current fusion technologies because of (1) the effect of different patient positions during CTA acquisition and in the hybrid suite, which can make registration challenging and inaccurate; the position of the arms in particular can make a significant difference due to the change in the position of the spine; (2) respiratory and cardiac motion; and (3) vascular anatomic deformation induced by the insertion of the stiff endovascular materials (eg, wire, sheaths, delivery system).[2] As a result, it is necessary to have a quick fine-tuning option available from tableside to adjust the registration at any time during the procedure.

CURRENT BENEFITS OF FUSION IN THE ARCH

Dose and Contrast Reduction

Fusion imaging provides a continuous display of the vascular structures without the need for fluoroscopy. This allows positioning of the gantry and table, choice of working C-arm angulations, and adjustment of collimation and magnification without x-ray use. The impact on dose reduction is not clearly identified for standard thoracic endovascular aneurysm repair (TEVAR),[1] but fusion has been found to significantly reduce air kerma and dose area product during coronary procedures.[6] Fusion imaging also allows for injection of less con-

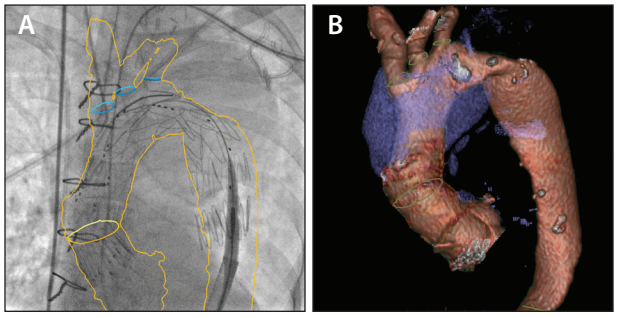

Figure 1. Endovascular repair of a chronic arch dissection with a triple inner-branched endograft. The fusion mask associates the aortic silhouette with the landmarks positioned by the operator; the ostia of the target vessels are shown by the blue circles, and the distal anastomosis of the previous surgical graft is shown by the yellow circle (A). A 3D VR fusion mask can also be used during the procedure with the true and false lumen depicted in different colors (B).

trast medium during catheterization of target vessels for branched or fenestrated endografts.[1,3,4] Moreover, zero-contrast thoracic endograft implantation has been reported using techniques such as transesophageal echocardiography (TEE) or a wire positioned in the left subclavian artery to accurately align the fusion mask.[7]

Planning Lines and Automated Gantry Positioning

Fusion has more recently evolved from the basic 3D model created using preoperative CTA to a more complex model that integrates other useful information selected by the operator. For example, during preparation of the fusion mask, the centerlines of flow of different target vessels can be used to accurately identify their origins, and then the vessels' ostia can be positioned on the fusion mask to aid cannulation. It is also possible to mark the planned proximal and distal landing zones of the endograft or to underline the anastomosis of a surgical graft (Figure 1). These planning lines allow continuous visualization of all relevant surgical landmarks and are used during the procedure to identify (without the need for x-ray) the gantry positions perpendicular to each target vessel ostium or the best working angles to accurately deploy the endograft.

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Navigation in the True/False Lumen in Dissection Cases

Endovascular treatment of chronic aortic dissections is feasible, but navigation between the different aortic lumens is challenging, and entry tears can be difficult to identify using fluoroscopy. Fusion imaging can be used to create 3D volumes of the true and false lumens (Figure 2), which can be used alternatively during the procedure and are especially helpful when catheterizing target vessels originating from the false lumen. Furthermore, entry tears can be identified and marked with planning lines to ease access from the true into the false lumen and vice versa.

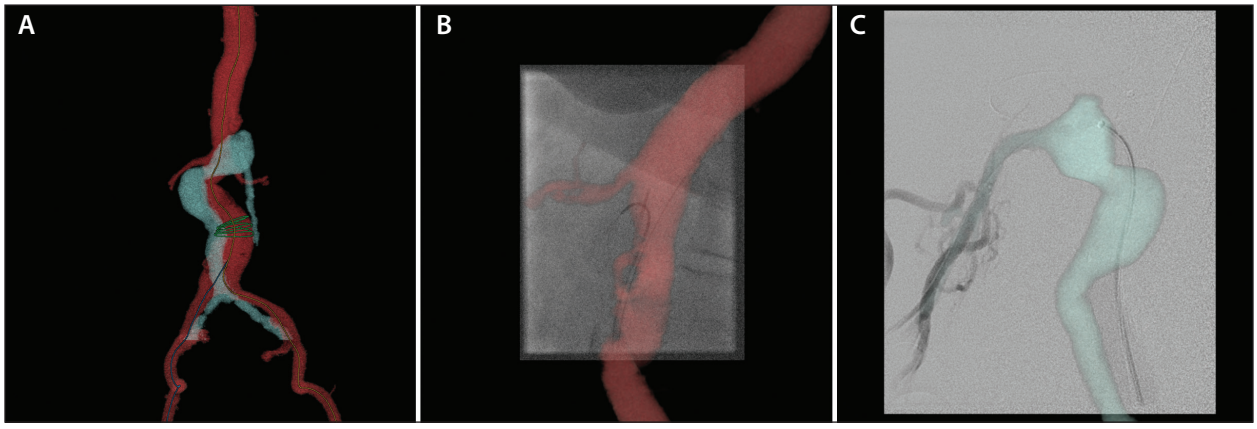

Figure 2. Two different segmentations are performed, one for the true lumen (red) and one for the false lumen (blue) (A). During the procedure, the true lumen fusion mask is used to access the false lumen (B). The false lumen fusion mask is then used to catheterize the superior mesenteric artery (C).

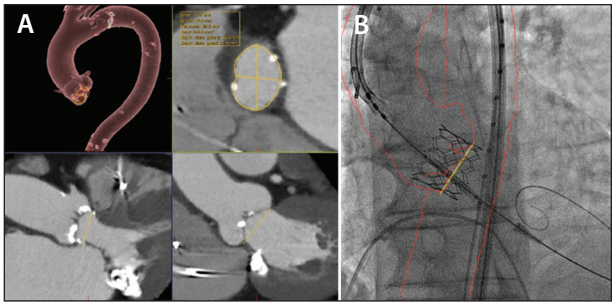

Figure 3. TAVR planning based on CTA that includes automated aortic segmentation, measurements of the native aortic valve dimensions for prosthesis sizing, and determination of the optimal fluoroscopic projection (A); 3D overlay on fluoroscopy with optimal x-ray working angulation, showing the segmented aorta (red) and the perpendicular planning line for the aortic annulus (Valve Assist 2) (B).

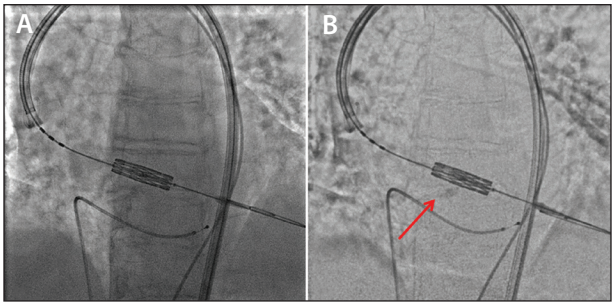

Figure 4. Aortic valve deployment without advanced image processing (A) and aortic valve deployment with calcification enhancement processing (red arrow highlights the calcified area) (B).

OTHER USEFUL IMAGING APPLICATIONS

Over the past few years, the concept of multimodal image integration to guide interventional procedures has been adopted for use during transcatheter aortic valve replacement (TAVR).[8,9] Preprocedural imaging plays a crucial role in prosthesis sizing and identifying the best access route.[10] TEE was initially used, but CTA has been adopted as a first-line option because multiple studies have proven its superiority in the planning phase of these procedures.[11-13] Additionally, data obtained from CTA are also useful during valve implantation to optimize x-ray working views and align the beam parallel to the valve annulus (Figure 3).[14-16] Traditionally, this step required repeated aortograms, thus leading to high doses of contrast media and ionizing radiation.[15]

Image registration has to be performed quickly during these challenging procedures so as to not interfere with clinical care. Therefore, it is essential to follow a defined and repeatable workflow. The first step is planning, which delivers a segmented CTA data set of the aorta and different planning lines, such as the annulus plane. In the second step, the image fusion application (Valve Assist 2, GE Healthcare) provides a default registration, which is then optimized during a third step using a landmark such as the noncoronary cusp. A pigtail catheter is positioned in the cusp during acquisition of the intraoperative angiogram, and this position is colocated with the same landmark on the CTA. Image fusion is then available during the procedure without requiring further user interaction.

For optimal results of TAVR, the valve needs to be positioned in the correct orientation with respect to the annulus; the problem is that the latter is not directly visible on x-ray imaging. The aortic annulus can usually be indirectly localized using calcifications that are commonly seen surrounding the valve in these patients, although this can be difficult due to the projection superimposed on the spine. In cases in which the working view is dictated by the orientation of the annulus plane, it is impossible to avoid this superimposition. Fortunately, advanced image processing techniques can be applied to selectively enhance calcified structures using the motion of the calcifications during the cardiac cycle (Valve Assist 2) (Figure 4). This advanced 2D image processing uses an image mask, created by combining previous images in the same geometric configuration, which is then subtracted. The result is that moving structures that are darker than their background are selectively enhanced.

TOMORROW'S TOOLS

Expanding image fusion capabilities is challenging. Offering a more automated and accurate registration would be desirable, and this would likely need to incorporate the deformation the aorta undergoes when endovascular materials are introduced and during cardiac and respiratory physiologic motion.

On the other hand, instead of adjusting a predefined anatomic model to the x-ray fluoroscopic image, perhaps an augmented 3D model could be created that contains deformation information gathered during the interventional procedure. Data obtained from CTA can be used to create a high spatial resolution 3D model, the high temporal resolution of the x-ray can be used to collect the dynamic data, and the two can then be combined. Other imaging data from modalities such as ultrasound (transthoracic echocardiogram or TEE) could also provide interesting data for image fusion. Postprocedural echocardiographic imaging after TAVR is very common and provides an accurate assessment

of valve position and shape, hemodynamic parameters (eg, maximal velocity, mean gradient, left ventricle function), and aortic regurgitation.[17] Integration of these elements into an augmented CT data set could potentially facilitate any further assessment of the patient's condition.

CONCLUSION

The benefits of fusion imaging identified in the other aortic segments such as dose reduction, optimization of x-ray working views, and support for endovascular navigation and vessel catheterization should also apply when the technology is used for intervention in the arch. Other advanced image processing initially developed for TAVR, such as calcification and stent enhancement, could also be used to support endovascular intervention in this domain. The next step will be to enhance the fusion mask with real-time information provided by other imaging modalities such as echocardiography. ■

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