

TECHNICAL NOTE

3D Image Fusion to Localise Intercostal Arteries During TEVAR

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Purpose: Preservation of intercostal arteries during thoracic aortic procedures reduces the risk of post-operative paraparesis. The origins of the intercostal arteries are visible on pre-operative computed tomography angiography (CTA), but rarely on intra-operative angiography. The purpose of this report is to suggest an image fusion technique for intra-operative localisation of the intercostal arteries during thoracic endovascular repair (TEVAR).

Technique: The ostia of the intercostal arteries are identified and manually marked with rings on the pre-operative CTA. The optimal distal landing site in the descending aorta is determined and marked, allowing enough length for an adequate seal and attachment without covering more intercostal arteries than necessary. After 3D/3D fusion of the pre-operative CTA with an intra-operative cone-beam CT (CBCT), the markings are overlaid on the live fluoroscopy screen for guidance. The accuracy of the overlay is confirmed with digital subtraction angiography (DSA) and the overlay is adjusted when needed. Stent graft deployment is guided by the markings. The initial experience of this technique in seven patients is presented.

Results: 3D image fusion was feasible in all cases. Follow-up CTA after 1 month revealed that all intercostal arteries planned for preservation, were patent. None of the patients developed signs of spinal cord ischaemia.

Conclusion: 3D image fusion can be used to localise the intercostal arteries during TEVAR. This may preserve some intercostal arteries and reduce the risk of post-operative spinal cord ischaemia.

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INTRODUCTION

Paraparesis resulting from spinal cord ischaemia is a dreaded complication after thoracic endovascular repair (TEVAR). The blood supply to the spinal cord is complex, with considerable individual variation. However, the more intercostal arteries in the distal descending aorta that are obliterated during invasive procedures, the higher the risk of compromising inflow to the Adamkiewicz artery and of post-operative paraparesis.^{1–4}

Localisation of intercostal arteries by digital subtraction angiography at the time of stent graft deployment is often not possible because of their posterior orientation and small calibre. Pre-operative image fusion with 2D/3D overlay has proven to be a useful tool in complex abdominal endovascular aortic repair (EVAR).^{5–7} This technical note describes how image fusion can be used to localise the origins of the intercostal arteries in the distal descending

aorta during TEVAR as an aid to minimising the risk of spinal cord ischaemia.

TECHNIQUE

The workflow of image fusion and intra-operative guidance varies somewhat among manufacturers of angiographic equipment. The hybrid operating suite used in the present study is equipped with an Artis Zeego C-arm and a Syngo XWP workstation (Siemens Healthcare, GmbH Forchheim, Germany) and some specifications below apply to this equipment.

Pre-operative image processing

A pre-operative multi-detector computed tomography angiogram (CTA) is obtained before the procedure. To enable detection of intercostal arteries slice thickness should be <1 mm. The CTA is imported to the workstation of the operating suite (Syngo X-workplace, InSpace tabcard).

The ostia of intercostal arteries in the aortic segment of the planned distal attachment are marked manually with rings on multi-planar reconstructed (MPR) images (Fig. 1). The diameter of the ostia does not affect the ability to mark them as long as they are visible on the pre-operative CTA.

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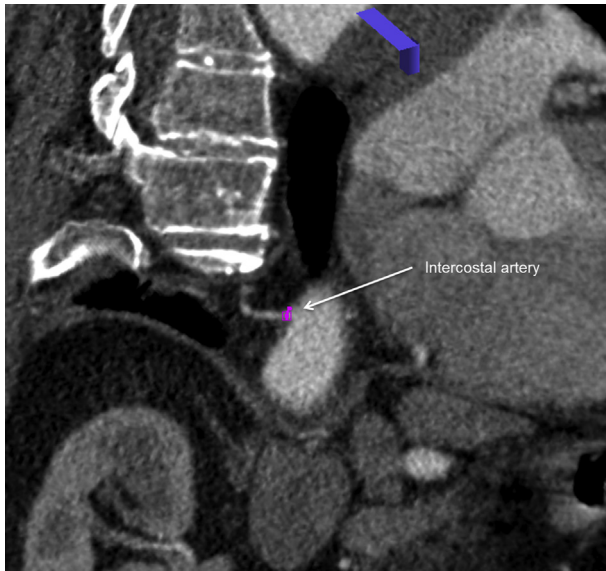


Figure 1. 3D planning: MPR image with manually added graphic marking the origin of an intercostal artery.

The targeted distal landing site is carefully chosen during pre-operative planning, allowing enough longitudinal aortic length for adequate distal attachment and seal while preserving as many intercostal arteries as possible above the coeliac trunk. High priority should be given to assuring a sufficient distal seal zone, especially in angulated aortic anatomy to avoid proximal stent graft migration. The site chosen is marked with a large circumferential ring in the aortic lumen, orthogonal to its centreline. The ostia of the coeliac trunk, the superior mesenteric artery, and the renal arteries are also marked with rings (Fig. 2A and B).

Intra-operative image fusion

Intra-operative cone-beam CT (CBCT) without contrast is done initially during the procedure (i.e. using the 5s DCT Body Care protocol). The acquisition is automatically transferred and reconstructed to CT like images on the post-processing workstation. The 3D/3D registration between the pre-operative CTA and the intra-operative CBCT is

performed in two steps: first by a rough alignment of the thoracic vertebrae in the two datasets, and then with more detailed adjustments for vascular calcification and aortic wall contour (Fig. 3). In patients with previously implanted vascular devices, such implants are also excellent landmarks for image registration.

2D/3D overlay

The marked rings from the pre-operative CT are overlaid on the live fluoroscopy screen (using the syngo iPilot Dynamic function) (Fig. 2C). As the insertion of stiff devices may deform the anatomy, the accuracy of the overlay is confirmed and adjusted if needed by alignment with an intra-operative pre-deployment angiography. This final adjustment can be based on the origins of larger aortic branches, such as the renal arteries, the coeliac trunk, or the superior mesenteric artery, and on the contour of the aortic lumen. Previous nearby implants, such as stent grafts, coils, or clips, are also very helpful, when available. The origins of the intercostal arteries are often not visible.

Distal stent graft deployment

The distal stent graft is precisely deployed at the targeted site, guided by the overlaid markings. Care is taken to do this in a C-arm projection perpendicular to the aorta. This is achieved by adjusting the C-arm angulation until the large aortic ring depicting the targeted landing site is reduced to a straight line.

Experience with seven cases

Six men and one woman (mean age 66.7 years, range 52–85) were treated by TEVAR and a distal landing site in the distal descending aorta, using 3D fusion image guidance. All procedures were performed under general anaesthesia and all patients received pre-operative spinal fluid drainage. The drainage was inserted in the operating room before the induction of anaesthesia and maintained for up to 72 hours post-operatively in the absence of spinal cord ischaemia symptoms.

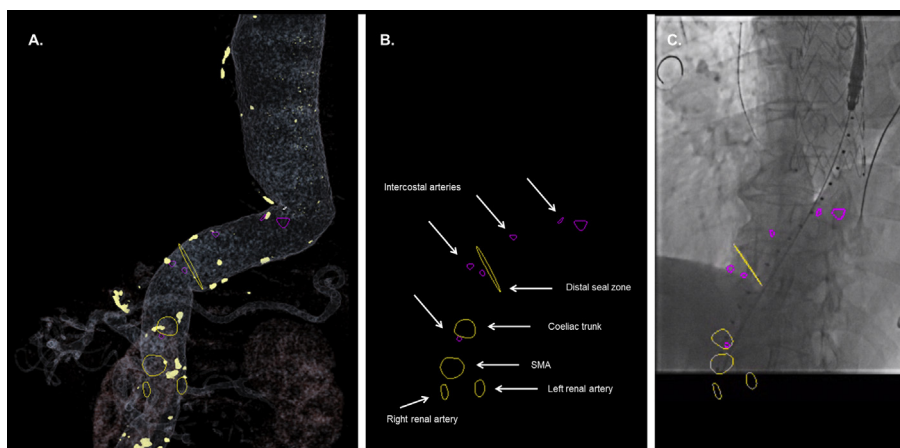


Figure 2. (A) 3D planning: Volume rendered 3D image with manually added 3D graphics marking the planned seal zone, ostia of the intercostal arteries above and below the planned seal zone as well as the ostia of renal arteries. (B) 3D graphics alone. (C) 2D-3D overlay of the 3D graphics on live fluoroscopy image for guidance.

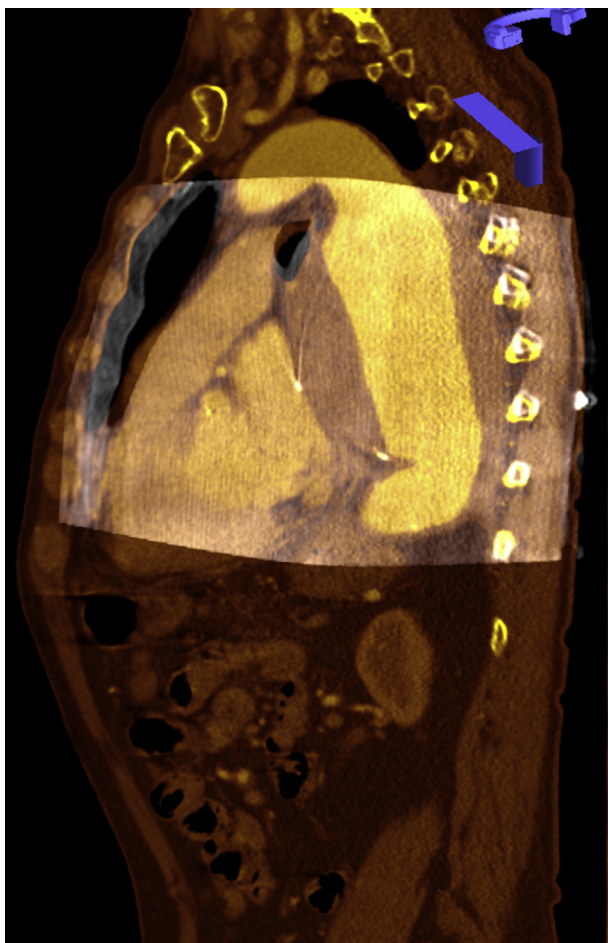


Figure 3. 3D-3D fusion: Fusion of the pre-operative CT with the intra-operative unenhanced CBCT, based on outline of aortic wall and aortic wall calcifications.

Two patients had an isolated descending aortic aneurysm and had not had a previous aortic procedure. Five had a chronic expanding aortic dissection and four of them had previously been treated by open surgical arch reconstruction and frozen elephant trunk. One patient with chronic aortic dissection had previously had both open repair with a tube graft and a subsequent extension with a thoracic stent graft. The left subclavian artery was patent in six of the seven patients (Table 1).

The median ostial diameter of the intercostal arteries that were planned to be preserved was 1.7 mm (min 0.8 mm—max 3 mm). The vessel calibre was not a limitation for marking them as long as they were visible on the pre-operative CTA. Therefore a good quality CT is preferable. The ostia as well as the planned distal landing zones were marked in all cases.

3D image fusion was feasible in all cases. As the overlay accuracy was based on nearby landmarks such as larger aortic branches and not directly on the intercostal arteries, their patency was checked by follow-up CTA after 1 month, which confirmed that all intercostal arteries planned for preservation were still patent. None of the patients developed signs of spinal cord ischaemia.

DISCUSSION

Intra-operative image fusion and 3D navigation enables visualisation of soft tissue elements that are not easily discernible using conventional fluoroscopy only, with or without contrast enhancement.⁸ In this report, an image fusion technique is put forward for visualisation of the intercostal arteries during thoracic endografting, to minimise the risk of spinal cord ischaemia and paraparesis. The initial

Table 1. Patients and procedural characteristics.

Patient	Age	Sex	Pathology	Previous aortic procedure	LSA	Stent graft	Iodine dose, g	Radiation dose, μGym^2	N intercostal arteries between stent graft edge and coeliac trunk ^a	
									Planned to preserve	Patent on follow-up CT
1	67	M	CEAD	Open repair with tube graft and TEVAR	Occluded chimney	Cook Zenith	9.6	NA	4	4
2	70	M	CEAD	FET	Patent	Valiant Medtronic	9.6	26325	3	3
3	70	F	TAA	—	Patent	Cook Zenith	12	2281	2	2
4	65	M	CEAD	FET	Patent	Cook Zenith	26.4	12024	1	1
5	85	M	TAA	—	Patent	Valiant Medtronic	NA	12886	3	3
6	58	M	CEAD	FET	Patent	Cook Zenith	10.8	22249	1	1
7	52	M	CEAD	FET	Patent	Valiant Medtronic	19.2	38370	1	1

CEAD = chronic expanding aortic dissection; TAA = thoracic aortic aneurysm; FET = Frozen Elephant Trunk; LSA = left subclavian artery; NA = not available.

^a In patients treated for CEAD only intercostal arteries originating from the true lumen are counted.

plan regarding the length of the aorta to be covered was not affected, and no extra stent grafts were used. However, extra focus was given to accurate deployment of the distal part of the stent graft as depicted by the 3D graphics, and thereby sparing intercostal arteries below this point.

The study was not powered to show that saving particular intercostal arteries minimised the incidence of spinal cord ischaemia after TEVAR. However, the described method enables intra-operative guidance for accurate distal stent graft deployment, giving the opportunity to spare intercostal arteries when possible. This could be valuable when long aortic segments are covered and when collateral blood flow to the spinal cord is already compromised by coverage of the subclavian or hypogastric arteries.

Technical development has enhanced the usefulness of 3D image fusion for guidance during endovascular aortic repair. Studies have demonstrated reduction in radiation and contrast dose, particularly in complex abdominal procedures such as FEVAR and BEVAR.^{6,7} Schulz et al. (2016) recently described image fusion in TEVAR.⁹ The accuracy of the 2D/3D overlay is not always perfect, and occasionally needs to be adjusted during interventions for high precision.¹⁰ Until now, the technique has mainly been employed to visualise the ostia of large aortic branches such as the subclavian artery, the renal arteries, the coeliac trunk, and the superior mesenteric artery. The dorsal route and the small calibre of intercostal arteries make them difficult to visualise with conventional angiography in projections that are also suitable for stent graft deployment. Image fusion therefore offers a valuable new tool for localisation of these important vessels.

CONCLUSION

3D image fusion during TEVAR can be used to visualise the origins of the intercostal arteries. This may be useful for optimal placement of stent grafts in the thoracic aorta, ensuring an adequate seal and attachment without covering more intercostal arteries than necessary.

CONFLICT OF INTEREST

Giasemi Koutouzi and Mårten Falkenberg have a research collaboration with Siemens Healthcare GmbH.

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