Virtual Angioscopy and 3D Navigation: A New Technique for Analysis of the Aortic Arch after Vascular Surgery

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Abstract  Purpose: Anatomy of the aortic arch is highly variable and can be drastically altered by surgical or endovascular procedures. Detailed analysis of computed tomography (CT) scans is facilitated by reconstruction techniques such as virtual angioscopy (VA). In the present study, we have evaluated the benefit of VA for the assessment of aortic arch abnormalities in patients with prior surgical or endovascular procedures.

Material and methods: We analysed post-procedural CT scans available in 103 patients who underwent thoracic aortic procedures between 2006 and 2009 at our institution. Patients were classified into three groups: surgical (group A, n = 26), hybrid (group B, n = 27) and endovascular (group C, n = 50), procedures. A 64 LightSpeed® volume computed tomography (VCT) multidetector-row computed tomography was used, allowing maximal intensity projection, maximal projection rendering imaging and three-dimensional (3D) rendering of images. VA reconstruction was performed by applying volume-rendered thresholds and spatial rendering to generate endoluminal views.

Results: Multiplanar reformations (MPRs) detected 46 abnormalities in 39 patients: inadequate apposition of the proximal rim of a stent-graft (n = 21), abnormalities of the stent-graft itself (n = 11), aortic aneurysm (n = 6), residual intimal tears (n = 5) and secondary dissection (n = 3). VA provided additional information in 76% of cases (35/46) and was more contributive after endovascular repair than after open repair (group A: 54% (7/14), group B: 75% (9/12), group C: 95% (19/20)). VA improved localisation of abnormalities with respect to supra-aortic vessels, measured inadequate stent-graft apposition in relation to the aortic wall and precisely analysed kinking or inadequate apposition of overlapping stent grafts.
VA diagnosed three additional abnormalities: two false aneurysms and one retrograde dissection developed on a suture line.

Conclusions: VA conceptualises planar images by 3D reconstruction. It provides additional information in comparison with conventional CT scans by allowing precise localisation of abnormalities with respect to the aortic wall itself and supra-aortic vessels. Furthermore, it facilitates analysis of abnormalities in case of overlapping stent grafts.

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The anatomy of the aortic arch (i.e., curvature, angulations, length of its horizontal portion and the origin of the supra-aortic trunks (SATs)) is variable. Furthermore, drastic modifications of the patient’s anatomy, as observed in case of dissections, or after open or endovascular repair, make analysis by computed tomography (CT) scan more and more complex. The three-dimensional (3D) nature of the aortic arch is then difficult to assess in an axial plane: representation of the aortic arch in three dimensions is thus helpful. Detailed analysis may be improved by latest-generation reconstruction techniques using volumetric 3D rendering techniques such as virtual angiography (VA). VA, allowing endoluminal navigation in 3D, was described in 1996.1 It enables visualisation of the inner contours of the vasculature, similar to a camera inside vessels, for which it has been called ‘VA’.2 Preliminary results suggest its potential role for non-invasive evaluation of vascular diseases. It is based on the notion of active vision, meaning that only visual perception drives the motion of the virtual angioscope.3 The navigation mode allows high-precision manual analysis of the elements of the aortic arch under various viewing angles and better dynamic localisation of abnormalities in relation to SAT.4 However, VA has not yet been extensively evaluated.

The aim of this study was to evaluate the benefit of VA assessment of aortic arch abnormalities in patients following surgical or endovascular procedures, as a complement to standard multiplanar reformations (MPRs) from CT scan data. A vascular radiologist and a vascular surgeon independently analysed MPRs. After this first screening, VA was performed: this second screening was defined as positive when VA provided complementary information.

Material and Methods

Patients

Between January 2006 and March 2009, among patients undergoing thoracic aortic procedures at our institution, data of 103 patients with available follow-up CT scans were analysed. The aortic arch was involved in 73 cases. There were 75 men and 28 women with a mean age of 62.39 ± 15.81 years (range, 27–88 years).

Indication for intervention was degenerative aneurysms (N = 44), aortic dissections (N = 42, 30 acute and 12 dissecting aneurysms), traumatic aortic transection (N = 12), false aneurysms after aortic coartation surgical repair (N = 3), aorto oesophageal fistula (N = 1) and aneurysm of a right subclavian retro-oesophageal artery (arteria lusoria) (N = 1).

Patients were divided into three groups, according to the surgical technique.

Group A
Twenty-six patients were treated by open surgery:

- Aortic-root replacement (N = 7).
- Aortic-root replacement combined with enbloc reimplantation of the SAT (N = 12).
- Bentall procedure combined with enbloc reimplantation of the SAT (N = 3).
- Aortic arch replacement combined with an elephant-trunk technique (N = 4).

Group B
Twenty-seven patients were treated by hybrid surgery:

- Frozen elephant-trunk technique under cardiopulmonary bypass (N = 4).
- Stent-graft insertion after reimplantation of SAT into the ascending aorta through a median sternotomy (N = 11).
- Stent-graft insertion after extra-anatomical carotid-to-carotid bypass (N = 6).
- Stent-graft insertion after extra-anatomical revascularisation of the left subclavian artery (N = 6), to decrease the risk of paraplegia, or when the right-vertebral artery was stenosed or in case of left-internal-mammary artery coronary bypass.

Group C
Fifty patients treated by endovascular surgery thoracic endovascular aortic repair (TEVAR) only.

Stent-graft devices

Five different endovascular devices were used: 12 Gore Tag (W. L. Gore and Associates, Flagstaff, AZ, USA), 39 Talent Valiant (Medtronic Vascular, Santa Rosa, CA, USA), 21 Zenith TX (Cook Inc, Bloomington, IN, USA), 4 E³-vita open (Jotec Inc, Hechingen, Germany) and 3 Relay (Bolton Medical, Sunrise, FL, USA).

Data acquisition

All images were acquired on a 64-multidetector-row CT scan (General Electric Medical Systems, Milwaukee, WI, USA). The scanning range was set from the level of carotid bifurcation down to the femoral artery. Iohexol (Visipaque®, Amersham Health, SA, Velizy, France), measuring 120 ml, with an iodine concentration of 320 mg ml⁻¹, was injected intravenously at a rate of 3 ml s⁻¹. The timing of the start of imaging was determined in each patient by computer-assisted bolus tracking (Bolus Pro, Ultra; Philips...
Medical Systems). Technical parameters were as follows: 0.6 mm collimation width, 0.6 mm reconstruction increment, 0.3 pitch, 0.4 s X-ray tube rotation time, 100 kV tube voltage, 700 mA s tube load, standard abdominal filter and 40 cm field of view.

Image analysis

Image data sets were analysed on a dedicated platform (Advantage Windows Workstation 4.1, General Electric Medical Systems, WI, USA). Image analyses were performed by a senior vascular radiologist (EB) and a senior vascular surgeon (NL).

Maximum intensity projections (MIPs), curved multiplanar reformation (MPR), and 3D display volume-rendered images were reconstructed for each patient. In addition, oblique MPRs, images with coronal orientations, were systematically obtained for all patients to compensate the curvature of the aortic arch.

VA reconstruction was performed in all 103 patients: volume-rendered thresholds and spatial rendering (Volume viewer (General Electrical Medical Systems) Milwaukee, WI, USA) generated endoluminal views, and navigation mode was manual.

We used two fly-through navigation modes: ‘full navigation’ with 3D reconstructions of the aortic wall (Fig. 1) in all patients, and ‘empty navigation’ after aortic wall subtraction to only analyse stent-graft components (Fig. 2) only in patients treated with TEVAR.

Statistical analysis

All statistical calculations were performed by using StatView 5.0 software (Abacus Concept, Berkeley, CA, USA). The Fisher’s exact test was used to compare MPR and VA. Data are presented as mean ± standard deviation, unless otherwise indicated. A p value ≤0.05 was considered to be statistically significant.

Results

MPR analysis (first screening)

MIPs detected 46 abnormalities in 39 patients (37.9%):

- Fourteen aortic wall abnormalities were identified — five residual intimal tears in the aortic arch after surgery for type A, three secondary dissections and six aortic aneurysms.
- Eleven additional stent-graft abnormalities (mesh surface abnormalities, inadequate apposition between stent-graft components) were identified.

Occurrence of abnormalities varied, according to the type of graft: 58.3% with Gore Tag (7/12), 20.5% with Talent Valiant (8/39), 23.8% with Zenith TX (5/21), 33% with Relay (1/3) and none with E-vita open (0/4).

VA analysis (2nd screening)

In all patients, VA evaluated the entire thoracic aorta (ascending aorta, aortic arch and thoracic aorta).

VA detected three abnormalities missed by MPR:

- Two false aneurysms on a bypass suture line (Fig. 3) in group A and one retrograde dissection originating on a suture line (Fig. 4) in group B.

In the 39 additional patients with abnormalities diagnosed by MPR, both the vascular radiologist and vascular surgeon agreed that VA provided additional information in 76% of cases (35/46):
In group A, VA provided additional information in 50% of cases (7/14). It allowed precise localisation of three residual intimal tears on the aortic arch and of one residual dissection. In these four patients, VA fly-through showed on a single view the location of the defect from the SAT (Fig. 3). In the three additional patients, 3D assessment of the length and surface of the intimal tear was deemed more accurate on VA.

In group B, VA provided additional information in 75% (9/12). In six patients, it measured the distance between inadequate apposition of the proximal rim of stent-graft at the level of the SAT (Fig. 5). In two patients, VA showed in a single view how many components of the stent-graft presented with an inadequate apposition (Figs. 5 and 6). VA showed stent-graft compression in one patient (Fig. 7). Measurements by VA were deemed more accurate in all cases.

Figure 3 Follow-up CT scan of an acute type A dissection treated by aortic-root replacement and *en bloc* reattachment of the SAT. VA precisely locates a tear adjacent to the teflon felt at the level of left subclavian artery.

Figure 4 Follow-up CT scan of a patient treated by stent-graft insertion after reimplantation of SAT into the ascending aorta: coronal cut (top right) shows retrograde dissection of the ascending aorta. VA precisely locates the intimal tear just on the suture line of the bypass to the SAT (top left image), and shows inadequate apposition of the proximal rim of the stent-graft.

Figure 5 Follow-up CT scan of a patient treated by a TEVAR for a traumatic aortic transection: MPR (bottom left) shows an inadequate apposition of the proximal rim of stent-graft at the level of the isthmus, VA additionally shows both the location and distance of the inadequate apposition from the SAT.

Figure 6 Follow-up CT scan of a patient treated by a TEVAR for a traumatic aortic transection: sagittal cut (bottom left), and axial cut (top right) shows an inadequate apposition of the proximal rim of stent-graft, VA shows in a single view the number of stent-graft components involved and allows accurate measurements.
In group C, VA provided additional information in 95% (19/20). In 15 patients, VA improved the localisation at the level of the SAT of inadequate apposition of the proximal rim of stent-graft. It provided a precise analysis of kinking in two patients (Fig. 8) and of inadequate apposition of overlapping stent-graft components in three patients (Fig. 9).

- Statistical analysis

We compared the respective accuracy of MPR (N = 39 patients) and of VA (N = 42 patients): although VA allowed diagnosis of an abnormality missed by MPR in three patients, the benefit is not statistically significant, according to Fisher’s test ($p = 0.67$, odds ratio (O.R.) 0.85, 95% confidence interval (C.I.) 0.47–1.53).

Analysis of the rate of additional information obtained by VA (76%, i.e., 35 in additional to 46 abnormalities diagnosed by MPR) found a statistically significant benefit (Fisher’s test, $p < 0.01$).

- Impact of VA finding on patient’s care

Data obtained only from VA analysis led to re-intervention in three patients:

- A 70-year-old patient had undergone a hybrid technique for an aortic arch aneurysm (prosthetic-arch replacement, followed by endografting of the descending thoracic aorta). Control CT at 1 month revealed a dissection of the ascending aorta, but monoplanar imaging was not able to precisely locate the entry site. VA confirmed a retrograde dissection from the proximal suture line back to the level of the right coronary ostium. This patient had a redo aortic-root replacement.

- Two patients (54 and 63 years old) had undergone TEVAR for descending thoracic aneurysms, the first patient with two stent grafts, and the second patient with three stent grafts. CT scan at 1 month, VA identified inadequate apposition between stent grafts,
which was treated by the ballooning of the inadequate overlapping zone.

- A fourth patient had aortic-root and arch replacement an en bloc reimplantation of the SAT for acute type A dissection. CT scan at 6-years follow-up showed a 70 mm-dissecting aneurysm of the descending aorta, but the intimal tear could not be precisely located. VA showed a rupture of the SAT block suture line under the Teflon felt near the left subclavian artery, feeding the distal false lumen. Endovascular treatment was not feasible and this 82-year-old patient was unfit for a complex re-intervention, due to severe co-morbidities.

Discussion

Since the first report by Dake in 1994, endovascular management of descending thoracic aortic diseases (TEVAR) has emerged during the last decade as a valuable alternative to conventional surgery. Endovascular repair carries a relatively low mortality and morbidity risk, although it is associated with specific complications, such as endoleaks, stent-graft migration and device collapse. Long-term results of TEVAR are still unknown.

We believe that better understanding of the factors influencing the outcome of TEVAR relies on accurate CT scan imaging and on analysis of specific complications. Recent advances in cross-sectional imaging and MPR on a dedicated platform have established CT angiography a gold standard for pre- and post-procedural assessment of patients undergoing TEVAR.

Follow-up by serial CT scans after TEVAR is mandatory to identify eventual abnormalities, such as lack of application of the proximal rims and as uncompleted expansion of overlapping components. Recent improvements, such as dynamic CT scan interpretation diameter variations of the aorta at specific levels, have previously been reported. Although VA has been described since 1996, no valuable study of its value has yet, to our knowledge, been published. In our series, MPR identified abnormalities in 39 patients. In addition, VA not only provided additional information in most of these patients, but also identified defects in three additional patients. In other words, (1) MPR is a valuable screening technique after open or endovascular surgery of the thoracic aorta, and (2) VA is a useful adjunct not only to further document the findings of MPR, but also to identify defects that could be

Figure 10  VA shows lack of apposition of the proximal rim of various devices after TEVAR.
either missed or misinterpreted by MPR alone. Endoluminal fly-through visualises components on a single view. VA in 'empty navigation' compared with MPR is not disturbed by stent-graft artefacts and provides a fine analysis of the abnormalities. It has already been advocated for the analysis of the fenestrated stent grafts. Fig. 5 shows partial expansion of overlapping stent-graft components at the level of the aortic isthmus, where there is an acute angle between the aneurismal process and the descending thoracic aorta.

Analysis by VA of the abnormalities at the level of the suture line of standard grafts allows the understanding of the mechanism of this complication, where standard MPRs prove difficult in interpretation, as demonstrated in Fig. 4.

Among factors that influence the outcome of TEVAR, there is a need to analyse the proximal landing zone (length, angulation and wall morphology) and its influence on proximal stent-graft fixation, which is essentially mechanical. According to Muhs, a lack of device-wall apposition between the aortic wall and the leading edge of a stent-graft is a factor in stent-graft collapse, which compromises distal flows and may cause acute thoracic aortic obstruction.

The accuracy of VA in assessing the proximal landing zone is shown in Fig. 10.

Comparison of VA abnormalities comparison on CT scan follow-up should allow detection of millimetre stent-graft migration, and a better understanding of the specific complications of TEVAR such as endoleaks and of stent-graft fractures.

Our study has several limitations. It is a retrospective analysis of data of 103 patients, 77 of whom were treated by TEVAR alone or combined with conventional surgery. So far, our policy has been to carefully monitor all patients, whenever an abnormality is diagnosed. In some cases with aneurysm formation, the patient’s status was a contraindication to surgery: it is thus impossible to demonstrate that improved screening of patients has improved patient’s care. 3D reconstruction, VA parameters and interpretation are operator dependent. This is why two physicians performed screening: interestingly enough, no discrepancy of diagnosis between the two physicians occurred.

Although the potential risk of complications is hardly predictable, we propose a relative value scale of abnormalities found:

- Some should prompt rapid re-intervention — false aneurysm at the suture line, type I endoleak related to a lack of stent-graft apposition.
- Some need to be closely followed — they may disappear upon follow-up, but they also may extend and warrant surgical or endovascular correction. Lack of stent-graft apposition is known to be associated with a risk of collapse and of type I proximal endoleak. The persistence of an antegrade or retrograde dissection may be an indication for complementary intervention, whereas stable minor stent-graft abnormalities may be considered as benign.

Conclusion

Based on this experience, we consider that VA offers additional information when compared with MPR. VA conceptualises plan images in 3D reconstruction. It allows precise localisation of abnormalities with respect to the aortic wall itself and to supra-aortic vessels. Furthermore, it facilitates analysis of abnormalities in case of overlapping stent grafts.

Conflict of Interest

None.

Funding

None.

References

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