Imaging techniques in aortic valve and root surgery

Regeer, M.V.

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Chapter 12:

Prognostic implications of descending thoracic aorta dilation after surgery for aortic dissection

M.V. Regeer, B. Martina, M.I.M. Versteegh, A. de Weger, R.J.M. Klautz,
M.J. Schalij, J.J. Bax, N. Ajmone Marsan, V. Delgado

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Abstract

Background: The present study assessed whether descending thoracic aorta growth can be measured reliably on volumetric analysis using multidetector row computed tomography (MDCT) and whether increased growth influences freedom from another aortic intervention in survivors of acute type A aortic dissection.

Methods: A total of 51 patients (58±11 years, 61% male) who underwent surgery for type A aortic dissection DeBakey type 1 with ≥2 postoperative MDCT scans ≥5 months apart were included. Volumetric analysis of the descending thoracic aorta between the left subclavian artery and the level of the apex of the heart was performed with acceptable intraobserver variability. Growth of the complete, false and true lumen was estimated in ml/year and defined as slow growth when it was less than average growth rate and fast growth when it was more than average growth rate.

Results: The complete lumen volume increased from 133±8 ml to 163±9 ml after 3.5 years follow-up ($p<0.001$), with an average growth rate of 6.1 ml/year. The false lumen volume increased from 81±7 ml to 106±12 ml ($p=0.018$) with an average growth rate of 2.8 ml/year. The true lumen changed only slightly from 59±4 ml to 65±8 ml ($p=0.205$). The 5-year freedom from descending thoracic aorta intervention was significantly lower in fast growth of the complete lumen (80±9%) compared to slow growth (100%; $p=0.003$). Similar was true for growth of the false lumen (fast: 74±12% vs. slow: 100%; $p=0.042$).

Conclusion: Increased growth of the false lumen of the descending thoracic aorta after deBakey type 1 aortic dissection was associated with higher risk on secondary intervention on the descending thoracic aorta.

Introduction

Acute type A aortic dissection is a life threatening condition with an incidence of 2.9 per 100 000 patient-years.[1] Emergency surgery is the only option to improve the survival of patients with acute type A aortic dissection.[2] One of the objectives of acute type A aortic dissection surgery is restoration of adequate flow in the true lumen with obliteration, if possible, of the false lumen in the distal aorta.[3] This is particularly important since the presence of a complete patent false lumen (PFL) or only partially thrombosed false lumen (pTFL) is associated with worse outcome, higher reoperation rates and aneurysmal growth.[4-7] Aneurysmal growth has been associated with increased risk of adverse clinical events at follow-up and, accordingly, current guidelines recommend regular surveillance with multi-detector row computed tomography (MDCT) to monitor potential complications and growth of the descending thoracic aorta, especially when the false lumen is not completely thrombosed.[8] Reoperation on the descending thoracic aorta (with open surgery or endovascular stenting procedure) is indicated if aortic rupture or progressive aortic dilation are observed.[4,9] The MDCT data can be used to plan endovascular stenting procedures.[10] In order to reduce the intra- and interobserver variability of manual measurements of serial MDCT of the descending aorta and size of the PFL, automated algorithms to assess these aspects would be the preferred methodology.[11] The present study investigated whether descending thoracic aorta growth can be measured reliably on MDCT data using a semi-automated volumetric method. In addition, descending thoracic aorta growth and patency of false lumen were related to freedom from reoperation on the descending thoracic aorta.

Methods

Patients

Patients with acute type A aortic dissection DeBakey type 1 (dissection progressed distal from ascending aorta) who underwent surgical repair at the Leiden University Medical Center and who survived the initial hospital admission were considered eligible for this study. Fifty-eight patients who underwent postoperative contrast enhanced MDCT surveillance of the thoracic aorta (with ≥5 months elapsed between scans) were included in the present analysis. Clinical and surgical data were collected in the departmental Cardiology Information System (EPD-Vision®, Leiden University Medical Center, Leiden, The Netherlands) and retrospectively analyzed. Critical preoperative state was defined as suffering from ventricular tachycardia or ventricular fibrillation or aborted sudden death, preoperative cardiac massage, preoperative ventilation before anaesthetic room, preoperative inotropes or intra-arterial balloon pump or preoperative acute renal failure (anuria or oliguria <10ml/hour). The institutional ethical committee approved this retrospective evaluation of clinically acquired data and waived the need for individual written patient consent.

Multi-detector row computed tomography

Contrast-enhanced MDCT studies were performed to evaluate the postoperative status of the thoracic aorta with a 16-, 64-, or 320-slice MDCT scanner (Aquilion, Toshiba Medical Systems, Tokyo, Japan). MDCT angiography data acquisition extended from above the aortic arch to the diaphragm, including the entire thoracic aorta. Data analysis was performed by 2 independent observers. First, the false lumen of the descending thoracic aorta was identified and qualified as completely thrombosed (TFL, which was defined as no contrast enhancement of the entire false lumen), partially thrombosed (pTFL, which was defined as part of the false lumen thrombosed and part of the false lumen contrast enhanced) or completely patent (PFL, which was defined as the entire false lumen contrast enhanced).

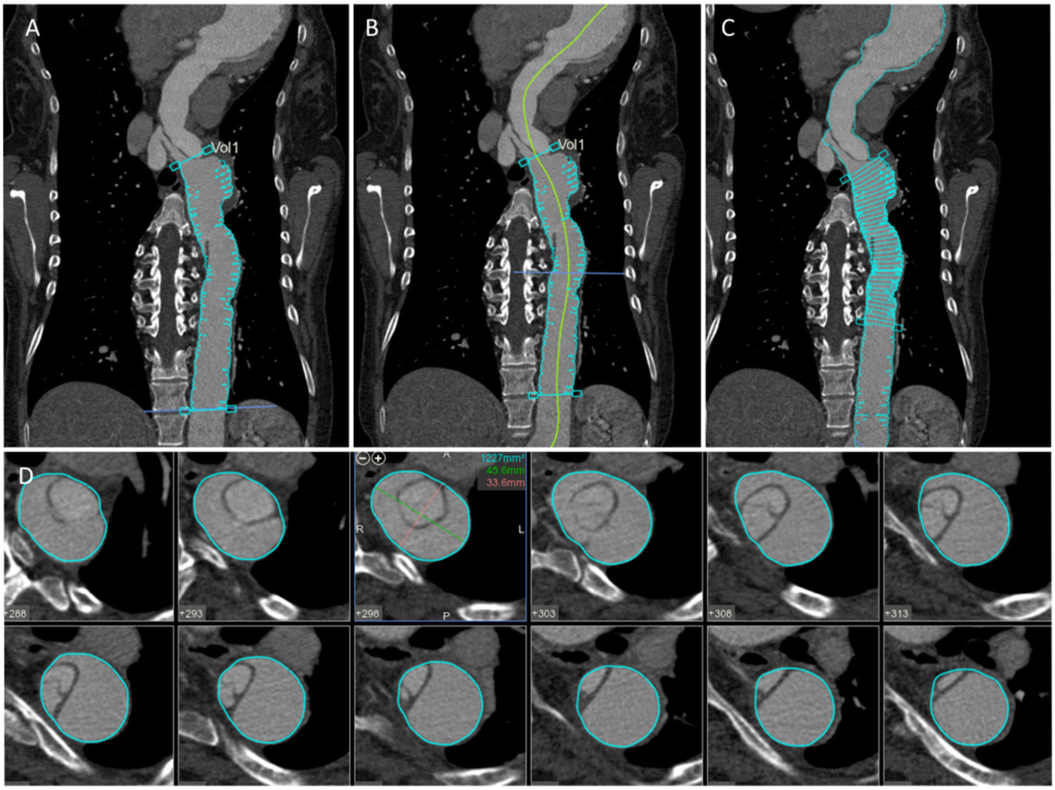

Figure 1. Volumetric measurement of the descending thoracic aorta.
A stretched multiplanar reformation of the aorta is automatically constructed by the software. A: The part of interest (between the left subclavian artery and the aorta at the level of the apex of the heart as assessed on the axial images) is selected for the volumetric analysis. B: The centerline is manually adjusted when necessary. C&D: Along the centerline, cross sections of the aorta every 0.5 mm along the length of the centerline were manually adjusted if the lumen was not correctly defined by the automated software.

The endovascular stent planning module from the post-processing software (Vitrea FX 1.0; Vital Images, Minnetonka, MN) was used to perform the quantitative measurements as displayed in Figure 1. The software was able to recognize the thoracic aorta and reconstruct a stretched multiplanar reformation of the aorta. The descending thoracic aorta was selected for analysis from the left subclavian artery until the level of the apex of the heart (on the axial images). A centerline was drawn automatically through the aorta which could be adjusted manually when necessary. Along the centerline, every 0.5 mm cross sections through the aorta were performed and the contrast-enhanced lumen circumference was defined automatically. When the lumen was not correctly defined by the software, the cross sectional circumferences of the lumen could be manually adjusted. In patients with a PFL, the false and true lumen were both included in the complete lumen volumetric analysis. In patients with pTFL, the true lumen and the contrast-enhanced part of the false lumen were included in the complete lumen volumetric analysis. The volume of the lumen of the descending thoracic aorta was measured distal from the left subclavian artery until the level of the apex of the heart. In addition for patients with a PFL or pTFL, the volume of the true lumen was measured similarly and the (contrast-enhanced) false lumen volume was calculated by subtracting the true lumen volume from the complete lumen volume. Furthermore, the minimum and maximum aortic diameters of the aorta at the level of the left subclavian artery (proximal descending thoracic aorta) and at the level of the apex of the heart (distal descending thoracic aorta) were automatically obtained.

Surgical repair

After median sternotomy, arterial cannulation of the subclavian or femoral artery was performed in the majority of patients. In the remaining cases, cannulation was performed in the distal ascending aorta. Effort was made to identify and resect the primary entry tear. Valve-sparing root replacement, supracoronary ascending aorta replacement or aortic valve and root replacement were performed as previously described. 12-16 In every patient the distal ascending aorta and arch were inspected under deep hypothermic circulatory arrest. If a (re)entry tear was present in the arch, concomitant (hemi-)arch replacement was performed.

Statistical analysis

All data analyses were performed using the SPSS software (Version 20.0. Armonk, NY: IBM Corp). Categorical variables were reported as frequencies and percentages. Continuous variables were displayed as mean ± standard deviation if normally distributed and as median and interquartile range if non-normally distributed. Patients with TFL, PFL and pTFL were compared using chi-square test for categorical variables and ANOVA test or Kruskall Wallis test for normally and non-normally distributed continuous variables, respectively.

Change in descending thoracic aorta volume and diameter over time was assessed with repeated measures analysis of variance. Follow-up duration in years was incorporated in the model as covariate. Estimated marginal means ± standard error of the mean for the aortic root diameters were reported directly postoperatively and during follow-up. Regression analysis was used to assess the descending thoracic aorta growth rate in ml/year following the previously described instrumental variables approach.17 Assuming that descending thoracic aorta growth is linear, the estimate of the association between difference in descending thoracic aorta volume (in ml) and the follow-up duration (in years) was obtained by linear regression analysis without including an intercept. This estimate was used as a cut-off and patients were divided into two groups according to the growth of their aorta; slow growth (growth < estimate) were compared to fast growth (growth ≥ estimate). Kaplan Meier analysis was performed to assess freedom from secondary intervention on the distal descending thoracic aorta. Log-rank test was used to compare groups. In order to assess inter- and intra-observer variability, 23 scans were measured by both observers and repeatedly by one observer, respectively and coefficients of variation were calculated. All statistical tests were two-sided. A p-value <0.05 was considered statistically significant.

Results

The clinical characteristics of the 51 included patients (mean age 58±11 years, 61% male) are presented in Table 1.

Table 1. Baseline characteristics

	TFL (n=20)	**PFL (n=14)**	**pTFL (n=17)**	**p-value**
Age (years)	63±10	52±11	59±11	0.020
Male	8 (40%)	11 (79%)	12 (71%)	0.046
Body surface area (m^2)	1.86±0.21	2.06±0.18	2.00±0.20	0.019
Connective tissue disease	0 (0%)	3 (21%)	2 (12%)	0.112
Hypertension	8 (40%)	4 (29%)	8 (47%)	0.574
Critical preoperative state	3 (15%)	0 (0%)	1 (6%)	0.259
EuroSCORE II (%)	6.1 (4.4-13.6)	4.4 (3.9-6.0)	5.5 (4.1-9.0)	0.124
CPB time (min)	238±55	205±44	246±66	0.211
AoX time (min)	168±44	149±44	194±59	0.123
Aortic arch replacement				0.187
Hemi-arch	7 (35%)	5 (36%)	4 (24%)	
Total arch	6 (30%)	0 (0%)	5 (29%)	

Data are presented as mean ± standard deviation or median (interquartile range) or as number (percentage). AoX time: Aortic cross clamp time. CPB time: Cardiopulmonary Bypass time. EuroSCORE II: European System for Cardiac Operative Risk Evaluation. PFL: Patent false lumen. pTFL: Partially thrombosed false lumen. TFL: Thrombosed false lumen.

The median duration between surgery and the post-operative MDCT was 9 days and in the majority of patients, the post-operative MDCT was performed within the first month after surgery. On the post-operative MDCT, 20 (39%) patients had a TFL, 14 (28%) patients had a PFL and 17 (33%) patients had a pTFL. Patients with PFL were younger compared to patients with TFL and pTFL. Patients with TFL were more often female and had less often connective tissue disease, a smaller body surface area and a higher EuroSCORE II compared with patients with PFL and pTFL.

MDCT measurements of the descending thoracic aorta

Table 2 shows the MDCT measurements of the descending thoracic aorta post-operatively and at follow-up.

Table 2: Change in descending thoracic aorta measurements

	Post-operative	**Follow-up**	**p-value**	**Growth rate per year**
Volume complete descending thoracic aorta (ml)	133±8	163±9	<0.001	6.1±1.6
Volume false lumen descending thoracic aorta (ml) *(n=31)*	81±7	106±12	0.018	2.8±2.4
Volume true lumen descending thoracic aorta (ml) *(n=31)*	59±4	65±8	0.205	2.1±1.1
Minimum diameter proximal descending thoracic aorta (mm)	25.6±0.6	26.6±0.7	0.046	0.24±0.11
Maximum diameter proximal descending thoracic aorta (mm)	30.2±0.6	31.2±0.7	0.052	0.07±0.11
Minimum diameter distal descending thoracic aorta (mm)	26.0±0.7	26.9±0.8	0.205	0.16±0.15
Maximum diameter distal descending thoracic aorta (mm)	29.6±0.7	32.0±0.9	<0.001	0.45±0.13

Data are displayed as estimated marginal means ± standard error of the mean after a mean follow up duration of 3.5 years. In addition, estimated mean growth rates ± standard error of the mean in ml or mm per year are displayed.

The volume of the complete lumen was estimated 133±8 ml directly post-operative and increased to 163±9 ml (p<0.001) at follow-up. In patients with a pTFL and PFL (n=31), the false lumen increased from 81±7ml to 106±12 ml (0.018). The true lumen volume in the patients with pTFL and PFL remained more or less stable (59±4 vs. 65±8 ml, p=0.205). The diameter of the proximal descending thoracic aorta increased significantly during follow-up. A significant increase was also observed in the maximum diameter of the distal descending thoracic aorta.

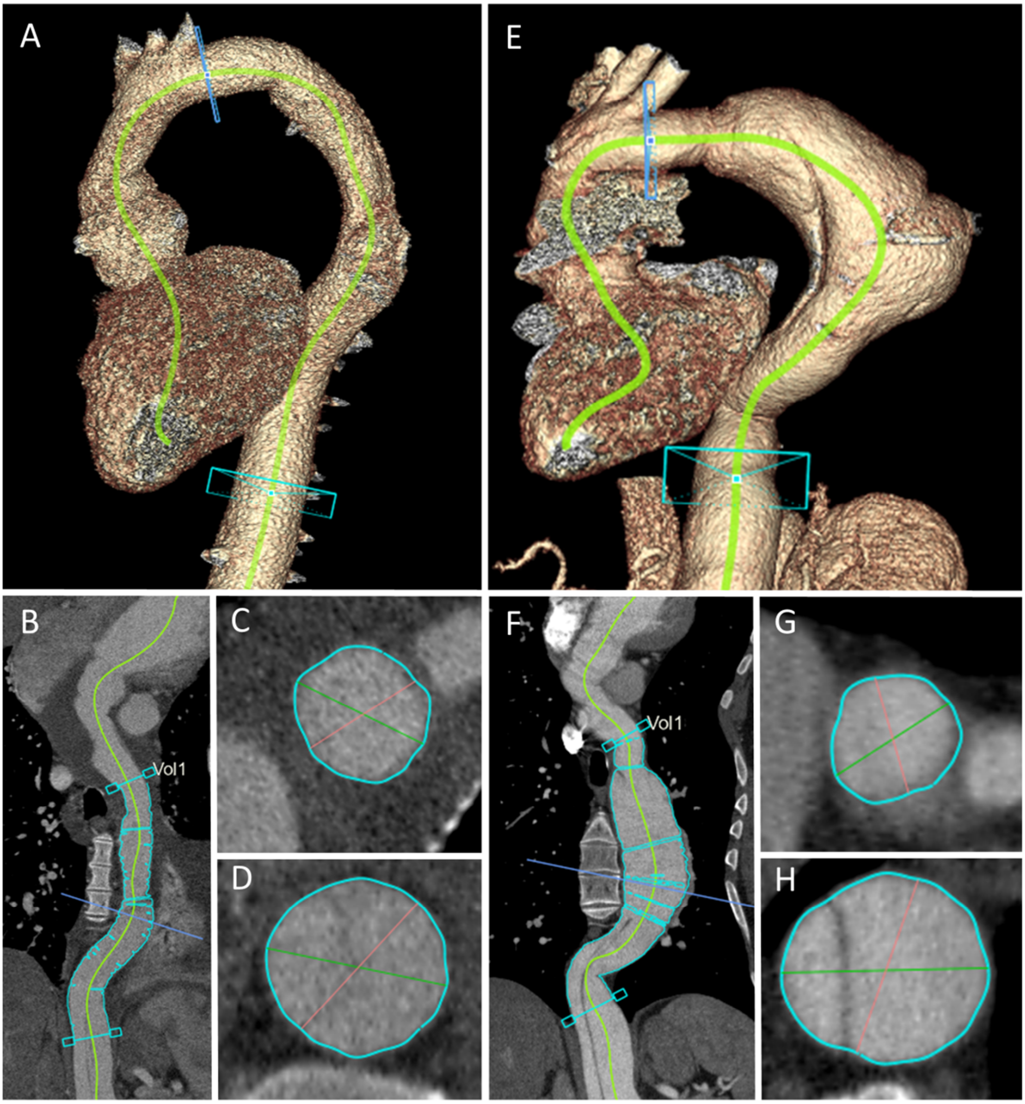

Figure 2. Example of a patient with a fast growing descending thoracic aorta.
A-D: Images of the postoperative MDCT. A: 3 dimensional image of the descending thoracic aorta. B: Volume of the descending thoracic aorta (125 ml). C: minimum and maximum diameter of the proximal descending thoracic aorta (21.3 mm and 23.8 mm). D: minimum and maximum diameter of the distal descending thoracic aorta (29.5 mm and 31.4 mm). E-H: Images of the follow-up MDCT, 33 months after postoperative MDCT. E: 3 dimensional image of the descending thoracic aorta with an aneurysm of the descending thoracic aorta. F: Volume of the descending thoracic aorta (284 ml). G: minimum and maximum diameter of the proximal descending thoracic aorta (20.4 mm and 22.9 mm). H: minimum and maximum diameter of the distal descending thoracic aorta (31.3 mm and 35.1 mm).

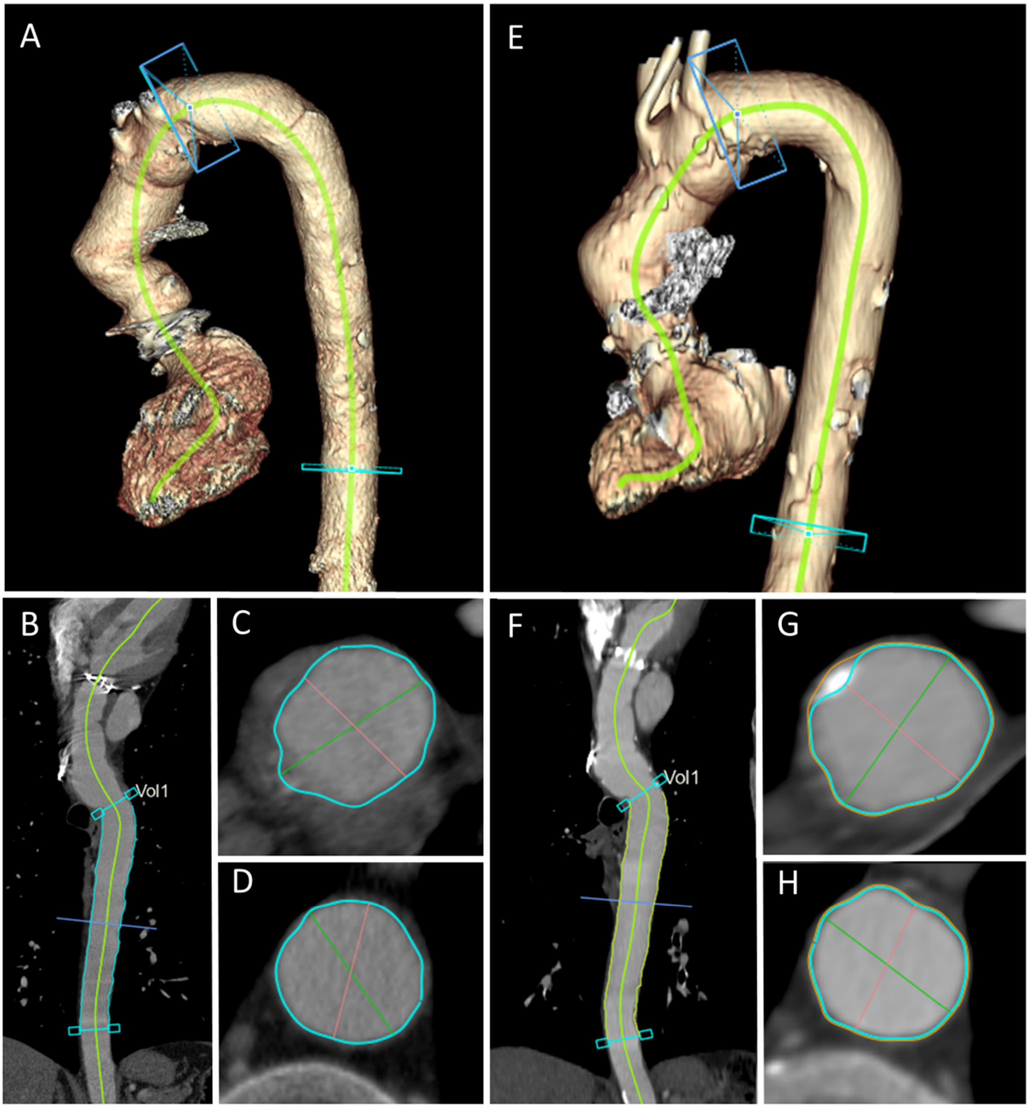

Figure 3. Example of a patient with a stable descending thoracic aorta.
A-D: Images of the postoperative MDCT. A: 3 dimensional image of the descending thoracic aorta. B: Volume of the descending thoracic aorta (105 ml). C: minimum and maximum diameter of the proximal descending thoracic aorta (25.0 mm and 30.3 mm). D: minimum and maximum diameter of the distal descending thoracic aorta (23.5 mm and 24.9 mm). E-H: Images of the follow-up MDCT, 132 months after postoperative MDCT. E: 3 dimensional image of the descending thoracic aorta at follow up. F: Volume of the descending thoracic aorta (111 ml). G: minimum and maximum diameter of the proximal descending thoracic aorta (26.3 mm and 31.8 mm). H: minimum and maximum diameter of the distal descending thoracic aorta (22.7 mm and 25.7 mm).

Descending thoracic aorta growth rate

Linear regression analysis showed significant growth of the descending thoracic aorta in complete lumen volume with an estimated growth rate of 6.1 ml/year. The false lumen volume increased with 2.8 ml/year on average. The true lumen growth was estimated 2.1 ml/year, Patients with fast growth of the complete lumen did not differ from patients with slow growth in terms of gender, age and history of hypertension. The number of patients who used oral anticoagulants after surgery was comparable between the fast and slow growth rate groups.

Figure 2 shows an example of a patient with fast growth rate. The volume of the descending thoracic aorta was 125 ml directly post-operatively. After 33 months of follow-up, the volume increased to 284 ml. This patient underwent distal secondary intervention of the aneurysm of the descending thoracic aorta. Figure 3 shows an example of a patient with slow growth rate. The volume of the descending thoracic aorta was 105 ml post-operatively and 111 ml after 11 years of follow-up.

Freedom from secondary aortic intervention during follow-up

Secondary intervention on the descending thoracic aorta during follow-up was performed in 6 patients. Endovascular repair was performed in 1 patient because of anastomotic leakage. Open repair on the descending thoracic aorta was performed in the other 5 patients because of descending thoracic aorta aneurysm formation >6.0 cm. Fast growth of the descending thoracic aorta was not per se an indication for secondary intervention. The freedom from secondary intervention on the descending thoracic aorta after 5 years follow-up was 80±9% in the group with complete lumen fast growth rate compared to 100% in the complete lumen slow growth rate group (log-rank p=0.003). In particular, patients with pTFL had significantly worse 5 year freedom from secondary intervention (75±11%) compared to patients with TFL and PFL (both 100%; p=0.008). In the patients with pTFL and PFL, the false lumen fast growth was associated with worse freedom from secondary intervention after 5 years (74±12%) compared to false lumen slow growth (100%; p=0.042). On the contrary, the growth rate of the true lumen was not associated with secondary intervention. Kaplan Meier curves are provided in Figure 4. In addition, patients who underwent secondary intervention had a significantly larger complete lumen descending thoracic aorta growth rate with compared to in patients without secondary intervention (25.6 ml/year vs. 5.6 ml/year, respectively; p=0.041).

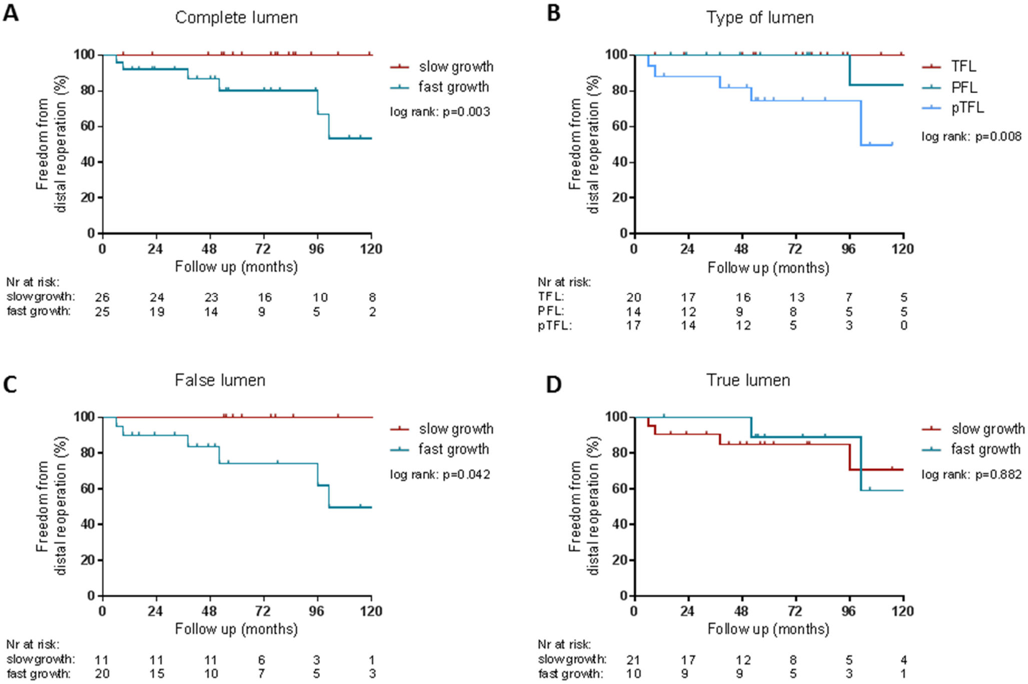

Figure 4: Kaplan Meier freedom from reoperation

A: Freedom from distal reoperation for complete lumen slow growth compared to fast growth. B: Freedom from distal reoperation for type of false lumen. TFL: thrombosed false lumen, PFL: patent false lumen, pTFL: partially thrombosed false lumen.C: Freedom from distal reoperation for false lumen slow growth compared to fast growth. D: Freedom from distal reoperation for true lumen slow growth compared to fast growth.

Inter- and intra-observer variability

The intra-observer variability, calculated as 1.96 standard deviation of the mean difference, was 4.7 ml for the volumetric measurement. The variability for the maximum diameter measurement was 2.7 mm for the proximal descending thoracic aorta and 1.6 mm for the distal descending thoracic aorta. This resulted in a coefficient of variation of 1.1% for the volume and 3.0 and 1.9% for the measurement of the maximum diameter of the proximal and distal descending thoracic aorta, respectively. Inter-observer variability was 27.0 ml for the volumetric measurement with a coefficient of variation of 6.5%. The inter-observer variability of the measurement of the proximal and distal maximum diameter of the descending thoracic aorta was 6.9 and 5.5 mm, respectively, with a coefficient of variation of 7.4 and 6.5%, respectively.

Discussion

The main findings of the present study can be summarized as follows: in survivors of acute type A aortic dissection undergoing emergent surgery, fast growth rate of the descending thoracic aorta, especially of the false lumen when patent or only partially thrombosed, was associated with higher rates of secondary intervention of the descending thoracic aorta. The present MDCT-based software provides an automated and reproducible measure of the growth rate of the descending thoracic aorta with low intra-observer variability. In addition, distinction between the false and true lumen volume can be made and this study shows that in particular increase in false lumen is associated with a higher risk on secondary intervention.

Survivors of an acute type A aortic dissection require regular surveillance with non-invasive imaging techniques of the native descending thoracic aorta to identify potential complications such as further progression of the dissection and aortic rupture or aneurysm formation.[4,5,8] Current guidelines recommend performing this measurement in stretched views along a center line of the descending thoracic aorta to provide the true cross sectional area.[8] The change in diameter of the descending thoracic aorta over time is approximately 1 mm/year.[4-7] Besides the underlying aortopathy (i.e. Marfan syndrome) and cardiovascular risk factors (i.e. hypertension), the status of the false lumen plays an important role in the growth of the descending thoracic aorta.[4,6,7] Kimura et al. showed a significant difference in growth rate of the proximal descending thoracic aorta between PFL (1.9±3.8 mm/year) and TFL (-0.7±2.8 mm/year; p<0.001).[6] Similar results were described by Fattouch et al. with a significant higher growth rate in PFL (2.8±0.4 mm/year) compared to TFL (1.1±0.2 mm/year; p=0.001).[4] However, these studies did not differentiate between complete thrombosis or partial thrombosis of the false lumen. According to Song et al., the descending thoracic aorta growth rate was largest in pTFL (5.5±9.1 mm/year) compared to PFL and TFL (3.8±5.6 mm/year and -0.9±3.9 mm/year, respectively; p=0.005).[7] The present study shows in addition that it is in particular the false lumen that enlarges during follow-up in patients with a PFL of pTFL in contrast to the true lumen volume which remains more or less stable.

Patients with faster growth rate of the descending thoracic aorta are more frequently referred for secondary intervention on the descending thoracic aorta to prevent aortic rupture, as we show in the present study. The status of the false lumen plays an important role in the growth rate of the descending thoracic aorta and therefore affects the need for secondary intervention. Patients with PFL had significantly worse 5-year freedom from secondary intervention on the descending thoracic aorta (72±3%) compared to TFL (97±1%; p<0.001).[4] Secondary interventions on the descending thoracic aorta, whether it was an open or endovascular procedure, were most often performed in pTFL compared to PFL and TFL.[7] In the present study, faster growth of the false lumen was associated with higher need for secondary aortic intervention.

Clinical implications

Current guidelines recommend regular follow-up in patients after acute type A aortic dissection: 1 month after the treatment, after 6 months, 12 months and then yearly.[8] If a stable course has been documented in the first postoperative year, less-strict imaging intervals may be sufficient. However fixed criteria for a stable course have not been proposed in the current guidelines. The present study shows that there is an increased need for secondary intervention on the descending thoracic aorta in patients with fast aortic growth (≥6.1 ml/year). Especially in patients with accelerated growth of the false lumen of ≥ 2.8 ml/year, secondary intervention might be needed in the future. This may be used after the first year of follow-up as a cut off to determine the timing of follow-up and may help physicians to individualize surveillance of patients with a faster growth rate (needing more frequently CT evaluation) and patients with slow growth rate (preventing unnecessary radiation). The effects of this approach should be evaluated in future prospective studies.

Study limitations

The study was limited by its retrospective nature and small sample size. Only patients who survived the initial postoperative period and underwent MDCT at follow-up were included in the study, this might have introduced selection bias. Secondary intervention was performed in 1 patient with anastomotic leakage and in 5 patients with aneurysm formation with a diameter exceeding 6.0 cm. The growth rate itself was not taken into account in decision making whether a secondary intervention was needed. However, MDCT follow-up schemes may already have been adapted in patients with a faster growth rate. To eliminate this potential bias, strict predefined follow-up schemes should be used in future studies. In addition, the present study identified a cut-off of 6.1 ml/year to define fast growth of the complete lumen; this should be validated. The small sample size of the present study hampered multivariable analysis to identify factors associated with faster growth. Furthermore, whether early secondary intervention in patients with fast growth will improve survival should be evaluated in future long term follow-up studies.

The present method did not evaluate aortic arch growth rate; however, there were 2 patients with isolated aortic arch dilation during follow-up who underwent secondary intervention on the aortic arch. These secondary interventions were not included in the present analysis. Lastly, the semi-automated method to measure the descending thoracic aorta volume is more time-consuming compared to measuring aortic diameters. In some patients, only very small adjustments were needed and the volume was obtained in an almost entirely automated fashion. In some patients (particularly the patients with pTFL), it was difficult to define the precise delineation of the aortic lumen and manual adjustments were needed resulting in longer analysis times.

Conclusion

Survivors of acute type A aortic dissection should be closely monitored with MDCT to evaluate complications and annual growth rate of the native descending thoracic aorta. Volumetric measurement of the descending thoracic aorta seems a reliable method with low intra-observer variability. The present study showed that increased growth of the complete lumen and in particular of the false lumen of the descending thoracic aorta after deBakey type 1 aortic dissection was associated with higher risk on secondary intervention on the descending thoracic aorta.

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