Morphometric predictors of endoleak type I in patients treated with thoracic endovascular aortic repair (TEVAR)

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Aims and objectives

The perioperative mortality and morbidity of thoracic endovascular aortic repair (TEVAR) is lower in comparison to open surgical repair of the thoracic aorta [1-4]. However, technical and clinical success in TEVAR is strongly dependent on proximal and distal deployment of the stent-graft. A proper stent-graft fixation can be very challenging especially in the aortic arch since there are a number of anatomic factors of the landing zone, such as a curved configuration, short length, severe tapering and the presence of side branches, that can lead to an incomplete apposition of the stent-graft to the aortic wall and to endoleak (EL) formation [5, 6].

Bird-beak configuration is defined as a lack of apposition of the proximal stent-graft to aortic wall, with a wedge shaped gap between the undersurface of the stent-graft and the aortic wall along the lesser curve and is associated with an increased risk of primary type Ia and II EL formation [6].

Type I ELs, occurring at the proximal (PLZ) and distal landing zone (DLZ) are crucial for TEVAR since they are frequent, often difficult to predict and typically need treatment as soon as diagnosed because of an increased rupture risk [7, 8]. Three dimensional (3D) quantification of the aortic arch morphology and landing zone geometry can be an important auxiliary for preoperative planning in challenging TEVAR cases.

The purpose of this study was to assess whether aortic arch and landing zone geometry, such as aortic arch angulation and conicity within landing zones, are associated with type I EL and bird-beak configuration after TEVAR.
Methods and materials

A total of 57 patients (40 male, 17 female, mean age 66.1 years) who underwent TEVAR for thoracic aneurysm disease (thoracic and thoracoabdominal aortic aneurysm, 34 TAA or 19 TAAA) as well as penetrating aortic ulcer (4 PAU) were included between 2001 and 2010 with a clinical and radiologic follow-up of at least 2 years. Patients with dissection, intramural hematoma, traumatic aortic transection etc. were excluded.

In 28 cases the Gore TAG® stent-graft device was implanted, in 16 cases with the Medtronic Valiant®, the Medtronic Talent® was used in 8 and the Cook Zenith® in 5 patients.

Pre- and post-operative Multislice-CTA was used for post-processing with a dedicated commercial software and an inhouse developed application using a 3D cylindrical intensity model that represents the intensity profile of an ideal 3D-cylinder, which is smoothed by a Gaussian function to model the image blur being generated during CT imaging [9, 10]. With an incremental process based on a Kalman filter the model is directly fitted to the 3D image data [9]. Thus we obtained the 3D centerline positions and 3D contour of the thoracic aorta as well as local vessel diameters along the centerline as a result (Fig. 1). Furthermore, the centerline of the thoracic aorta was investigated with regard to its bending in three dimensions.

Morphometric analysis focused on distances of the endovascular graft (EVG) from branches, aortic diameters, conicity and aortic curvature at PLZ and DLZ.

First, the distance between the proximal covered end of the stent-graft and the ostium of the left subclavian artery (LSA) as well as the distance between the distal covered end of the stent-graft and the ostium of the coeliac trunk (TRC) were measured along the centerline of the aorta on postoperative CTAs (Fig. 2A). These measurement positions were transferred to preoperative CTAs to use for analysis.

Conicity within the landing zones is the difference of the maximum aortic diameter 1 cm proximal and 1 cm distal to the postoperative position of proximal / distal stent-graft marker. Therefore, the maximal aortic diameters at 6 positions were defined:

First the transferred position of proximal / distal stent-graft marker to preoperative CTAs, second 1 cm proximal as well as 1 cm distal to the estimated position of the respective markers (Fig. 2B).
Furthermore, proximal apposition of the stent-graft in the inner curve of the aortic arch was documented focusing on the presence of a bird-beak configuration (Fig. 3).

To quantify the local curvature of the centerline at a particular position of the aorta cubic polynomials were fitted to the 3D centerline within a certain range (in our case +/-30mm with a spacing of 1mm, see Fig. 1). The local curvature of the centerline is analytically computed using first and second order partial derivatives of the fitted polynomials [10], and the radius of curvature is a result of the inverse of the curvature. In this analysis, we determined the radius of aortic arch curvature at the position of the proximal stent-graft marker.

Statistical evaluation was performed with Fisher’s exact test and Mann-Whitney U-Test.
Fig. 1: Result of the three dimensional (3D) model-based segmentation of the thoracic aorta with two perpendicular 2D sections of the original preoperative CTA data set (right), an magnification of the aortic arch (top left) and a 2D orthogonal section to the centerline with local diameters (bottom left): 3D contour (red), 3D centerline (white), transferred centerline position of the proximal stent-graft marker from the postoperative image (green), as well as the centerline range (blue, +/- 30mm) used for computing the curvature of the aorta at the position of the proximal stent-graft marker are demonstrated. CTA, computed tomography angiography.

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**Fig. 2:** Distance- measurements of the endovascular graft (EVG). A. Based on the first postoperative CTA distance (A) between the proximal covered end of the stent-graft and the ostium of the left subclavian artery (LSA), as well as the distance (B) between the distal covered end of the stent-graft and the ostium of the coeliac trunk (TRC) were measured. B. After transferring measurement positions to preoperative CTA the maximal aortic lumen diameters at 6 positions were defined to analyze conicity: at the transferred position of proximal (C) / distal (F) stent-graft marker; 1cm proximal (D/G) as well as 1cm distal (E/H) to the estimated position of the respective markers. BCA, brachiocephalic artery; LCA, left carotid artery; LSA, left subclavian artery; TRC, coeliac trunk; CTA, computed tomography angiography.

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Fig. 3: Bird-beak configuration of the proximal landing zone of the stent-graft. Incomplete apposition of the proximal landing zone of the stent-graft to the inner curvature of the aortic arch (distance to the inner curve, 12mm; protruding edge, 17mm; angle of the bird-beak, 47 degrees).

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Results

12% of patients presented with type Ia (7/57), 7% patients with type Ib EL (4/57) and 28% with bird-beak configuration (16/57).

Conicity at PLZ and DLZ increased the risk for EL type Ia and Ib (p= 0.016, p=0.006 respectively).

LSA overstenting was significantly associated with EL Ia (p=0.036).

The presence of bird-beak configuration showed significant correlation with steeper aortic arch (mean radius of curvature 41.5mm, p=0.049) as well as a short distance (mean 13.3mm) between left subclavian artery (LSA) and proximal endovascular graft (EVG)-marker (p=0.036). Neither a correlation was found between bird-beak and the occurrence of ELs (p=0.388) nor between aortic arch curvature and the occurrence of ELs (p=0.554).
**Table 1:** Results of thoracic aortic geometry and endoleaks / bird-beak configuration. PLZ, proximal landing zone; DLZ, distal landing zone; LSA, left subclavian artery; P, P-value; No., number; n. a., not applicable.

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Conclusion

The results demonstrate different morphological aspects that can result in technical failure of TEVAR.

One morphological factor, that can influence technical success of TEVAR is conicity / tapering of the LZ, leading to exclusion from TEVAR, if being too distinct confirming conclusions from other groups [11-13]. As seen in this analysis distinct conicity within the LZ was predictive of the presence of postoperative type Ia and Ib ELs.

Furthermore, due to angulation within the distal aortic arch TEVAR can result in an improper apposition of the proximal stent-graft in the vicinity of the LSA ostium leading to proximal type I, type II or even combined type I and II ELs [8, 14]. As reported before, combined EL (EL Ia and II) were significantly associated with LSA coverage [15]. Also in this analysis LSA coverage was significantly associated with EL type I.

In the literature are numerous factors associated with an increased risk of primary type Ia EL formation. A lack of complete apposition of the proximal end of the stent-graft at the inner curve of the aortic arch, a so-called bird-beak configuration, is reported to be one of them and was associated with an increased risk for a proximal type I EL [6]. In patients with aortic pathology a bird-beak sign of the stent-graft was more often observed requiring proximal fixation in zones 2 and 3 [16], and also in patients with steep aortic arch, as trauma patients [12]. However in aneurysm patients, as seen in this analysis, the radius of the aortic arch can strongly vary. So we observed a significant correlation between a smaller radius / steeper aortic arch and the presence of a bird-beak sign in these patients. But no significant correlation between the presence of bird beak configuration and EL type I could be demonstrated, probably due to the small number of patients in each of the groups. The Gore Conformable TAG Endoprosthesis and the Zenith Pro-Form TX2 are designed to conform to the aortic arch [17, 18] and such patients might benefit from this type of stent-grafts. These modern stent-grafts show a bird-beak sign more rarely [17, 19].

To conclude, conicity at both landing zones as well as LSA coverage have an increasing risk of EL type I after TEVAR. Steeper aortic arch at the PLZ has an effect on EVG-deployment favoring bird-beak configuration. Hence preoperative image based analysis should include these parameters to identify patients, who might benefit from improved risk stratification and an individual follow-up scheme.