A geometric reappraisal of proximal landing zones for thoracic endovascular aortic repair according to aortic arch types

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ABSTRACT

Objective: This study assessed whether the additional use of the aortic arch classification in type I, II, and III may complement Ishimaru's aortic arch map and provide valuable information on the geometry and suitability of proximal landing zones for thoracic endovascular aortic repair.

Methods: Anonymized thoracic computed tomography scans of healthy aortas were reviewed and stratified according to the aortic arch classification, and 20 of each type of arch were selected. Further processing allowed calculation of angulation and tortuosity of each proximal landing zone. Data were described indicating both proximal landing zone and type of arch (eg, 0/I).

Results: Angulation was severe (>60°) in 2/III and in 3/III. Comparisons among the types of arch showed an increase in proximal landing zones angulation ($P < .001$) and tortuosity ($P = .009$) depending on the type of arch. Comparisons within type of arch showed no change in angulation and tortuosity across proximal landing zones within type I arch ($P = .349$ and $P = .409$), and increases in angulation and tortuosity toward more distal proximal landing zones within type II ($P = .003$ and $P = .043$) and type III ($P < .001$ in both).

Conclusions: The aortic arch classification is associated with a consistent geometric pattern of the aortic arch map, which identifies specific proximal landing zones with suboptimal angulation for stent graft deployment. Arches II and III also appear to have progressively less favorable anatomy for thoracic endovascular aortic repair compared with arch I. (J Vasc Surg 2017;■:1-7.)

Thoracic endovascular aortic repair (TEVAR) represents a well-established alternative to open repair in individuals with suitable anatomic features, particularly in patients considered at high surgical risk but with a reasonable life expectancy after the procedure.[1]

Feasibility assessment and subsequent preoperative planning of endovascular treatment are based on post hoc analysis of patient contrast-enhanced computed tomography (CT) images.[2] TEVAR requires healthy proximal and distal landing zones of adequate diameter (<40 mm) and length (≥20 mm) and a viable iliofemoral or infrarenal aortic access route.[2,3] A steep aortic arch angulation, being considered highly predictive of endograft failure, represents a contraindication to TEVAR.[3] Notably, however, no consensus exists on how to measure and define critical arch angulations, with radius of curvature[4] being the method most commonly used in the instructions for use of commercially available endografts.

The actual planning of the endovascular procedure refers mainly to the identification of a proximal landing zone that provides adequate procedural safety and the greatest effectiveness and durability.[3] An insufficient proximal seal or an endograft migration, or both, lead invariably to an incomplete exclusion of the aortic pathology (ie, endoleak), with the inherent continued risk of aortic rupture, resulting in TEVAR clinical failure.[5] In this respect, the angulation of the proximal landing zone appears to be a crucial factor[3] because it increases the minimum length requirement of the landing zone for an effective deployment[6] and is associated with high displacement forces that increase the risk of endograft migration.[7-9] However, only heterogeneous definitions and methodology for measuring neck angulation have been reported thus far.[10,11]

Preoperative planning for endovascular repair of the aortic arch is described based on the aortic arch map reported by Ishimaru.[12] This classification defines the

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This work was supported in part by "Ricerca Corrente" and "5xmille" grants from Istituto di Ricovero e Cura a Carattere Scientifico Policlinico San Donato, San Donato Milanese (MI), Italy.

Author conflict of interest: J.A.v.H. and F.L.M. served as consultants and received unrestricted grants from 3Mensio Medical Imaging B.V., Bilthoven, The Netherlands.

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The editors and reviewers of this article have no relevant financial relationships to disclose per the JVS policy that requires reviewers to decline review of any manuscript for which they may have a conflict of interest.

0741-5214

http://dx.doi.org/10.1016/j.jvs.2016.10.113

proximal landing zones (0 to 4) as related to the origin of the supra-aortic vessels and indicates the requirement of a prophylactic rerouting of the involved aortic branches, which can be performed with a surgical extra-anatomic bypass[13] or with endovascular procedures with the use of fenestrated or branched endografts[14] or with the chimney technique.[15] Ishimaru's aortic arch map, however, does not account for relevant critical anatomic features, including landing zone angulation and tortuosity,[16,17] arch elongation, which typically increases with age,[18] and branch vessel angulation.

Our aim was to assess whether the additional use of the aortic arch classification in type I, II, and III, originally developed for predicting difficult carotid stenting,[19] may complement the aortic arch map by providing valuable information on the geometry of the arch landing zones and suitability and planning for TEVAR.

ARTICLE HIGHLIGHTS

- **Significance:** The authors investigate whether a combination of two standard aortic arch classifications is clinically useful for preoperative planning of thoracic endovascular aortic repair.
- **Type of Research:** Retrospective single center cohort study
- **Take Home Message:** Type II and type III aortic arches are associated with greater angulation, especially in aortic landing zones 2 and 3.
- **Recommendation:** The authors suggest to combine Ishimaru's aortic arch map classification of landing zones 0-3 with the aortic arch classification of types I to III to better plan thoracic endovascular aortic repair.
- **Strength of Recommendation:** 2. Weak
- **Level of Evidence:** C. Low or very low

METHODS

This study reviewed anonymized thoracic CT angiography scans from patients undergoing diagnostic evaluation for various indications at our institution in 2015 and was approved by the local Ethic Committee. The need for patient informed consent was waived because of the retrospective nature of the analysis and the use of anonymized data.

Only thin-cut (1.0 mm or 1.5 mm) CTs of patients with a healthy aortic arch with visible origins of the supra-aortic branches were considered. Exclusion criteria were age <60 years, diameter of the thoracic aorta >40 mm, radius of arch curvature <20 mm, bovine arch, previous aortic surgery, and presence of radiologic signs of aortic dissection, intramural hematoma, or penetrating aortic ulcer. Aneurysmatic aortas were excluded because the original description of the aortic arch classification[19] was based on healthy aortas. Aortas with radius of curvature <20 mm were excluded because the latter defines a steep aortic arch angulation that could alter the measurements of the proximal landing zone angulation and represents a contraindication to TEVAR, according to instructions for use of stent graft manufacturers. Bovine arches were excluded because this anatomic configuration does not allow a reproducible definition of Ishimaru's aortic arch map.

Suitable cases were stratified according to aortic arch classification.[19] In detail, the diameter of the left common carotid artery was measured at its origin in axial view. Multiplanar reconstruction images were then used to create a parasagittal view for each scan to visualize the origin of the brachiocephalic trunk and the top of the aortic arch in one frame. Finally, the distance between the origin of the brachiocephalic trunk and the top of the arch was used to classify each case as a type I, type II, or type III arch (Fig 1). Two observers (H.W.d.B. and F.S.) independently assessed CT scans for exclusion and inclusion criteria. Overall, 20 cases of each type of arch were selected.

Further processing, based on three-dimensional multiplanar reconstruction, was performed with 3Mensio Vascular 8.0 software (3Mensio Medical Imaging B.V., Bilthoven, The Netherlands), which provides specific functions for automatic measurements. Four markers (A-D) were placed in axial view at the level of the top of the pulmonary artery bifurcation. Points A and B are a midluminar point of the ascending and descending aorta at the height of the bifurcation of the pulmonary trunk. Points C and D are two points within the same plane where the distance between the ascending aorta and descending aorta is the smallest (Fig 2). Different variables were then measured as follows:

The radius of arch curvature was defined as half of the shortest distance between C and D (Fig 2, *A*). The aortic arch tortuosity index was defined as shortest distance between A and B divided by the center lumen line distance between A and B (Fig 2, *B*). Center lumen line lengths of each landing zone were measured in view perpendicular to the center lumen line (Fig 2, *C*). Zone 0 was measured starting from level of the top of the pulmonary artery bifurcation because this marks the beginning of the arched part of the ascending aorta. Zone 3 by definition has a length of 20 mm. The ratio of the outer curvature length to the center lumen line length of the arch (ie, between point A and B) was measured with the outer curvature function (Fig 2, *D*).

The angle between the flow axis of each proximal landing zone and the hypothetical body of the lesion to treat, analogous to the β angle as defined in the Society for Vascular Surgery reporting standards for endovascular abdominal aorta repair (EVAR),[20] was determined. For this purpose, the center lumen line tangent angle function was used, which calculates the angle between tangent lines drawn for any two points along the center lumen line (Fig 3, *A*). The β angles of each proximal