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Morphological Analysis of Healthy Aortic Arch

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WHAT THIS PAPER ADDS

This study provides a protocol of aortic arch morphology analysis in the different arch segments in a population comprising both control and patients with various pathologies. Using mathematical algorithms numerous morphometric and geometric parameters were calculated. Variations of these parameters according to age and sex, were assessed, which can affect the arch segments differently. These data are helpful for both clinical practice to improve endovascular arch treatment and research.

Objective/Background: This study aimed to describe an arch morphology protocol in a healthy population, and to assess the impact of age and sex.

Methods: A retrospective morphology evaluation was conducted in a population with no personal history of thoracic aorta surgery or pathology, through computed tomography (CT) imaging analysis, using a standardised protocol. Based on centreline three dimensional coordinates, a single investigator calculated a series of parameters in the arch zones and in the total arch, using Matlab scripts. These were categorized as: (i) morphometric data: diameter, length and aortic angle of each zone, total arch angle, and length; (ii) geometric data: tortuosity index (TI), arch width, assimilated curvature radius (CR_i), and attachment zone angles. Student or Mann—Whitney tests were used to compare parameter means. Their variability with age and sex was assessed through univariate and multivariate regression analysis.

Results: CT images from 123 subjects (mean ± SD age 53 ± 19 years) were reviewed. Significant correlation between age and morphology was found. The aorta expanded homogeneously and stretched heterogeneously with age because of posterior arch elongation. TI decrease, CR_i, and attachment zone angle increase were also observed with aging. Age remained significantly associated with these morphological parameters, independently of body surface area and hypertension. Sex also affected morphology: longer total arch length and higher CR_{arch} in men; lower zone 3 attachment angle in women

Conclusion: Using mathematical algorithms, and with a view to improving endovascular arch treatment, this study provides a standardised arch morphology protocol and objectively identifies both age related evolution and sex related variation in the different zones.

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INTRODUCTION

Thoracic endovascular aortic repair (TEVAR) of arch pathologies continues to be technically challenging, even with more than a decade of hindsight and despite the development of chimney techniques and fenestrated stent grafts.[1] The challenges are mainly related to the more complex morphology of the arch versus that of the descending aorta, leading to mismatch between stent graft and arch, lack of optimal sealing, and therefore potential risk of technical failure.[2—5]

These techniques have benefited from medical imaging progress with the adoption of more and more sophisticated dedicated software, enabling extraction of three dimensional (3D) quantitative information as part of the planning process and the use of fusion imaging techniques in the arch, all of which could, in the future, help optimise the procedure.

It is generally accepted that morphological characterisation and detailed aortic arch analysis will lead to a better understanding of the limits of endovascular repair in this

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segment, and thus improve results. However, such characterisation and analysis raises methodological issues regarding the complex 3D structure, with its helicoidal changes of plane from the proximal to the distal arch.[5] Most of the existing studies in this field have limitations related to their methodology which has inadequately represented the reality and complexity of arch anatomy.[6,7] Hence the need for a clear, reliable, and standardised protocol.

The available morphological data on proximal thoracic aorta have derived mainly from cardiological studies and have aimed to analyse aortic structural changes concomitant with functional changes as an indicator of atherosclerosis.[8] To the authors' knowledge, no studies have focused on aortic arch morphology as a surgical segment with its different zones, and nor have they evaluated the impact of physiological variables such as age and sex. Such quantitative information could be substantially beneficial for endovascular arch therapy.

The present cross sectional study aims to define an arch morphology protocol through assessment of global and segmental parameters in the healthy population, and to investigate the impact of age and sex on arch morphology.

MATERIALS AND METHODS

Study population

The healthy population was defined as subjects with no personal history of thoracic aortic pathology or surgery. Patients were screened from those admitted for various reasons between January and June 2014, for whom triple phase thoraco-abdominal computed tomography angiography (CTA) was performed with a slice reconstructed thickness $\leq$ 1 mm. Demographic and clinical data were collected. Specifically, as potential factors interfering with arch morphology, the following criteria were noted: body surface area (BSA), presence or not of hypertension, and statin therapy.

BSA was calculated according to the Dubois method. Hypertension was defined as systolic blood pressure $\geq$140 mmHg and/or diastolic blood pressure $\geq$90 mmHg and/or requiring antihypertensive medications.

Assessment of aortic morphology was performed through retrospective CTA analysis according to the protocol outlined below. Patients with unavailable or unsuitable CTA, owing to inadequate arterial opacification or imaging protocol, were excluded.

All data and CT imaging used were anonymised. Because of the retrospective design and according to French law it is neither necessary nor possible to obtain approval of an ethical committee (Comité de Protection des Personnes [CPP]) for this type of non-interventional study. Moreover, CPPs are not entitled to issue waivers of approval for this type of study.

Imaging analysis protocol

All patients underwent CTA with a 64 detector row CT scanner (Siemens Sensation 64; Siemens, Erlangen, Germany). Axial CT images were transferred to a dedicated vascular software workstation (Endosize; Therenva, Rennes, France). A series of morphological parameters was measured and calculated. All measurements were performed by a single investigator according to the standardised protocol.

This protocol comprised different steps. First, two seed points were selected, one proximal in the ascending aorta and the other distally in the femoral arteries. This enabled an automatic aortic segmentation and extraction of 3D centreline (CL) of the aorta. Owing to the fact that CTAs analysed were non-electrocardiogram gated, and in order to normalise the protocol, for the proximal seed point a fixed anatomical landmark at pulmonary trunk bifurcation level was adopted. CLs were automatically generated and visually verified before validation. Manual optimisation was applied in instances of deviation from the middle of the aorta.

Second, the 3D coordinates (x, y, z) of each point generated at 1 mm increments along the CL were extracted. The aorta was then divided into four anatomical zones,[9] where the position of the different anatomical landmarks was mapped to the CL: pulmonary trunk bifurcation, distal edge of innominate artery, left common carotid artery, left subclavian artery (LSA), and fourth thoracic vertebral body upper edge. These landmarks defined the points Z_0, Z_1, Z_2, Z_3, Z_4, respectively (Fig. 1A, B). Thus, Ishimaru zone 0 was located between points Z_0 and Z_1, zone 1 between points Z_1 and points Z_2, and so on.[9]

Finally, using specifically developed Matlab scripts, the different morphological parameters were analytically computed.

Below, these morphological parameters are categorized into two groups: (1) elementary morphometric data comprising diameter, length, and aortic angulation of each zone, as well as total arch length and angle; (2) geometrical data, including arch width, tortuosity index, assimilated curvature radius, and attachment zone angulations.

Measurement definitions

Diameters were measured external wall to external wall in a plane perpendicular to the CL at different levels[10]: D_0, D_1, D_2, and D_3, respectively, at the levels of points Z_0, Z_1, Z_2, and Z_3 (Fig. 1A, B).

Based on the 3D coordinates, length was measured for each zone along the CL as the curvilinear distance: for L_0, between points Z_0 and Z_1; for L_1, between points Z_1 and Z_2; for L_2, between points Z_2 and Z_3; for L_3, between points Z_3 and Z_4. The total curvilinear arch length (L_{arch}) was calculated as the sum of L_0, L_1, L_2, and L_3 (Fig. 1C).

Aortic angulations θ_{Zi} ($0 \leq i \leq 3$) were measured as the angles between two planes. These planes were perpendicular to the CL at the points marking the beginning and end of each zone. These points correspond to the points Z_0, Z_1, Z_2, Z_3, and Z_4. The total arch angle (θ_{arch}) corresponds to the angle between points Z_0 and Z_4.

Arch width (W_{arch}) was measured as the linear distance between points Z_0 and Z_4.[8]