European Journal of Radiology 110 (2019) 54–59

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Research Article

The effect of age and gender on tortuosity of the descending thoracic Aorta

Ahmed M. Tawfik[a,*], Donia M. Sobh[a], Basma Gadelhak[a], Hoda M. Sobh[b], Nihal M. Batouty[a]

[a] Department of Diagnostic and Interventional Radiology, Mansoura University, Faculty of Medicine, 35112, 12 El-Gomhoreya Street, Mansoura, Egypt
[b] Department of Cardiology, Mansoura University, Faculty of Medicine, 35112, 12 El-Gomhoreya Street, Mansoura, Egypt

ARTICLE INFO

Keywords:
Aorta
Tortuosity
Age
Tortuosity index

ABSTRACT

Background: To study the effect of age and gender on tortuosity of the descending thoracic aorta, and to evaluate inter-observer agreement of tortuosity index (TI) measurements.

Methods: Contrast-enhanced CT scans of 182 patients were analyzed by an experienced radiologist using routine 3D imaging software. The descending aorta was defined by proximal and distal endpoints. The software generated centerline length, and straight line distance between the 2 endpoints were measured. TI was calculated as: [centerline length / straight line distance -1] * 100. Impact of age on TI of the descending aorta was assessed using linear regression in both genders. To assess inter-observer agreement; TI measurements of 50 cases were repeated by 3 other independent readers.

Results: The mean (± SD) TI was 8.3 ± 2.6 in men and 8.9 ± 3 in women, with no significant difference between the 2 genders, $p = 0.208$. Moderate positive correlation was observed between TI and age ($r = 0.566$, $p < 0.00001$ and $r = 0.569$, $p < 0.00001$ in men and women, respectively). The 10-year-percent change was higher in women than men (13.3% and 9.5%, respectively). Inter-observer agreement for TI was good, intra-class correlation coefficient was 0.84 (95% CI: 0.76–0.89, $p < 0.0001$). Centerline length was poorly correlated to age ($r = 0.248$, $p = 0.048$ in men and $r = 0.369$, $p < 0.001$ in women). Body-surface-area-indexed centerline length was not significantly correlated to age ($p = 0.948$).

Conclusions: Tortuosity of the descending aorta increases with age in both genders. TI has acceptable inter-observer agreement and was better correlated to age than centerline length measurements.

1. Introduction

Age is a known major cardiovascular risk [1]. Arterial aging leads to structural changes in the elastin content of the arterial walls [2], and therefore age-related changes progress faster in the central elastin-rich arteries than in the muscular peripheral arteries [1,2]. The extent of age-related changes is also affected by other risk factors including hypertension, diabetes mellitus and renal disease among others.

Age-related changes result in stiffening and dilation of the aorta [3], and there are plenty of studies that demonstrated a steady increase in aortic diameter with age [4–6]. It is widely accepted according to current guidelines to interpret normal limits of aortic diameter in relation to age and gender [7].

Compared to the extensively studied diameter changes, fewer studies have addressed changes in aortic length with age. Most studies demonstrated an increase in length of the ascending aorta and the aortic arch with advancing age [8–11]. On the other hand, there is less known about the changes in length of the descending aorta, and the data available in the literature is controversial.

Several imaging modalities may be used for measuring the length of the descending aorta, and CT is an established method with its 3D capabilities allowing accurate and highly reproducible measurements. Previous CT and MRI studies measured the centerline length of the aorta with or without indexing to body proportions [8–10]. Another way of evaluating vessel lengthening and tortuosity is the tortuosity index, based on the ratio between the curvilinear vessel length and the line distance between proximal and distal endpoints [12]. This method is commonly used to evaluate aneurysms [13], and was used in a very recent study to investigate aortic elongation [14].

This CT study was performed to investigate whether the tortuosity index of the descending aorta increases with age; and the effect of gender. The secondary outcome was to assess the inter-observer agreement of the descending aorta tortuosity index.

Abbreviations: 3D, 3-dimensional; BSA, body surface area; CT, computed tomography; DA, descending aorta; MRI, magnetic resonance imaging; TI, Tortuosity index

* Corresponding author.
E-mail addresses: ahmedtawfik@edu.mans.eg (A.M. Tawfik), doniasobh2005@yahoo.com (D.M. Sobh), basmagadelhak@hotmail.com (B. Gadelhak), hodasobh@gmail.com (H.M. Sobh), nihalbatouty@gmail.com (N.M. Batouty).

https://doi.org/10.1016/j.ejrad.2018.11.017
Received 22 July 2018; Received in revised form 15 September 2018; Accepted 19 November 2018

2. Methods

2.1. Patients

This retrospective study was approved by our institutional review board. We retrieved all post-contrast CT scans of the thorax in the period between July 2017 and January 2018. Patients' records were reviewed and patients with cardiovascular disease, hypertension, diabetes mellitus, renal disease or history of smoking were excluded. The CT scans were reviewed to exclude cases with aortic aneurysms or dissections as well as marked mediastinal shift or significant spinal deformities. Poor quality scans with excessive motion or suboptimal vascular contrast were also excluded. Final number of patients was 182.

2.2. CT Image analysis and tortuosity index calculation

Images were retrieved on a standard workstation (ADW 4.6 GE Healthcare, USA) with commercially available volume viewer software. A 3D volume-rendered angiogram was reformatted. A radiologist with experience in cardiovascular imaging defined the descending aorta by 2 points, the proximal at the isthmus (2 cm distal to subclavian artery) [7], and the distal just above the celiac axis. An automated centerline between the 2 points was then generated. The centerline length of the descending thoracic aorta and the straight line length between the 2 points were documented (Fig. 1). The tortuosity index was calculated by the formula: [centerline length / straight line length -1] * 100 [15]. In addition, the mid DA diameter was measured in the perpendicular plane. The weight and height data were available in 94 patients; the body index was calculated according to a modified Gehan and George formula [16].

2.3. Inter-observer agreement of the tortuosity index

To assess the inter-observer agreement, the post-processing and measurements for the first 50 cases were also measured by 3 other independent readers. Readers were blinded to the age of the patient and to other's results.

2.4. Statistical analysis

Continuous data were presented as mean ± standard deviation (SD). Data was tested for normality using Kolmogorov-Smirnov test. Differences between the means were assessed using *t*-test in normally-distributed data and Mann-Whitney test in otherwise. Simple linear regression analysis was used to assess the association of each of TI, centerline length and diameter with age in each gender. Multiple regression analysis was used to assess the effect of both age and gender on TI.

The inter-observer agreement of TI measurement between the 4 readers was assessed by intra-class correlation coefficient (single measurement, absolute agreement, 2-way random-effects model [17]. The measurement error for repeated TI measurements was calculated as the within-subject standard deviation. The coefficient of variation was calculated as the ratio of the within-subject standard deviation to the overall mean. The repeatability was calculated as 2.77 * the within-subject standard deviation [18].

3. Results

The study included 182 patients (median age 53 years), 64 males and 118 females. The mean age ± SD was 46.9 ± 14.6 years in males and 50 ± 16.4 years in females, with no significant difference, $p = 0.398$. The means (± SDs) of the TI, centerline length and diameter of the descending aorta are listed in Table 1. The mean TI was 8.3 in males and 8.9 in females, with no significant difference between the 2 genders, $p = 0.208$. The centerline length and the diameter were significantly greater in men than women, $p = 0.00006$ and 0.03, respectively. The time taken for obtaining all measurements was less than 1 min.

3.1. Impact of age (and gender) on tortuosity index of the descending aorta

There was moderate positive correlation between TI and age in both genders, with comparable strength, ($r = 0.566$, $p < 0.00001$ and $r = 0.569$, $p < 0.00001$ in males and females respectively), Fig. 2. The linear regression equation was TI = 4.614 + 0.079 * Age for males and TI = 2.96 + 0.119 * Age for females. The 10-year percent change in TI was calculated as the regression estimate (beta) multiplied by 10 divided by the mean value. The percent change was higher in females than males (13.3% and 9.5%, respectively), Table 2.

Multiple regression analysis with age and gender as factors affecting TI revealed that the effect of age was still significant ($p < 0.0001$), while the gender had no significant effect ($p = 0.451$).

3.2. Impact of age on Centerline length

The absolute centerline length was poorly correlated to age in males ($r = 0.248$, $p = 0.048$) and females ($r = 0.369$, $p < 0.001$). The centerline length indexed to BSA in 94 cases was not significantly correlated to age ($p = 0.948$).

3.3. Impact of age on diameter of the descending aorta

The descending aorta diameter was more strongly correlated to age in males than females, ($r = 0.829$, $p < 0.00001$ and $r = 0.725$, $p < 0.00001$ in males and females respectively). The 10-year percent change was higher in males than females (7.9% and 6.4%, respectively).

3.4. Inter-observer agreement of the Tortuosity index

The inter-observer agreement for TI was good, Fig. 3. The intra-class correlation coefficient between TI measurements by the 4 readers was 0.84 (95% CI: 0.76 – 0.89, $p < 0.0001$). The measurement error (within-subject standard deviation) was 1.27. The coefficient of variation was 13%. The repeatability was 3.5, i.e. the difference between 2 measurements for the same subject is expected to be less than 3.5 in 95% of cases.

4. Discussion

4.1. Impact of age (and gender) on tortuosity index of the descending aorta

In this study we demonstrated that the descending aorta tortuosity increases with age. There was moderate positive correlation between TI of the DA and age ($r = 0.56$). Overall, the TI was not significantly different between men and women. The association between TI and age was similar in both genders, and the effect of gender on the association between TI and age was not significant. However, it is worth noting that men had higher regression constant (i.e. TI at 0 age) than women. On the other hand, women had higher regression coefficient and hence higher percent change every year of age. This means that at younger age men have higher TI than women, while at older age group the reverse becomes true.

In a very recent study, Adriaans et al. investigated age related changes of the tortuosity ratios of the aorta. However, in their results, only the tortuosity of proximal DA (from left subclavian artery to level of pulmonary bifurcation) was associated with age, but not the distal DA. The correlation was weak in their study ($r = 0.38$) [14]. One technical difference in our study is that the multi-planar reformat was used for straight line distance measurement rather than the 3D image. Another point of difference is that the we did not include the most

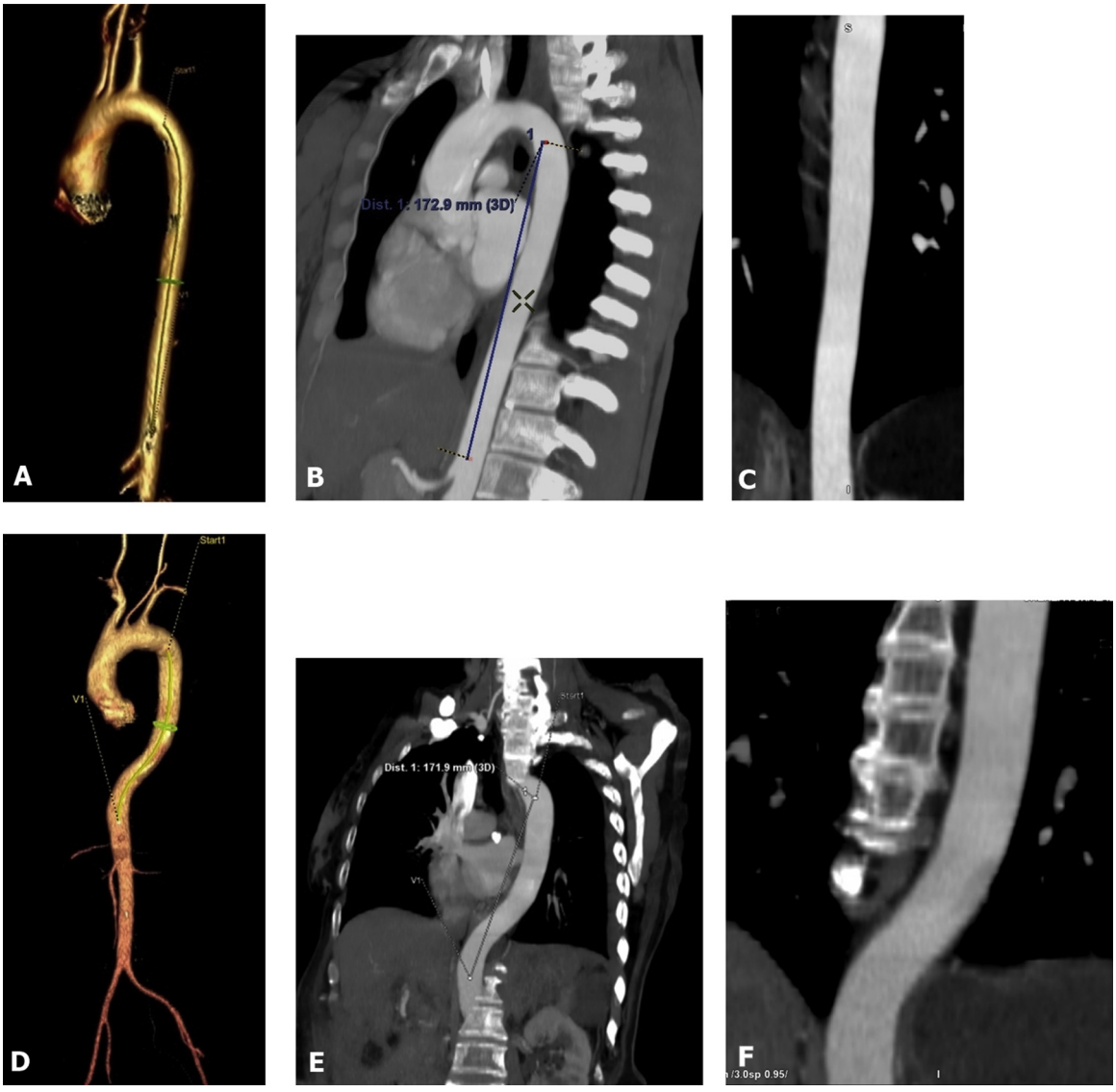

Fig. 1. Tortuosity index measurement in 2 different patients. **Upper panel:** 30-year old female. **(A)** Volume rendered CT image showing proximal and distal endpoints of measurement and centerline length (18.3 cm). **(B)** Multi-planar reformatted CT image showing the straightline length between the same 2 endpoints (17.3 cm). The TI was [18.3 / 17.3 -1] * 100 = 5.8. **(C)** Curved reformat showing slight tortuosity of the descending aorta. **Lower panel:** 66-year old female. **(D)** Volume rendered CT image showing centerline length (19 cm). **(E)** Multi-planar reformatted CT image showing the straight line length (17.2 cm). The TI was 10.5. **(F)** Curved reformat showing marked tortuosity of the descending aorta.

Table 1
Tortuosity index, centerline length and diameter of the descending aorta according to gender.

	Male	Female	Difference	P value
Tortuosity Index	8.3 ± 2.6	8.9 ± 3	0.6 ± 0.4	0.208
Centerline length (cm)	18.5 ± 2.5	17.2 ± 2.2	1.2 ± 0.36	0.00006*
Diameter (mm)	23.4 ± 4.1	22.15 ± 2.9	1.26 ± 0.52	0.03*

Data are presented as mean ± SD. * Statistically significant.

proximal segment of DA just distal to the left subclavian artery; as it is inherently curved, and therefore better assessed by radius of curvature rather than tortuosity ratio; hence this segment was included in several other studies which demonstrated age-related changes in aortic arch curvature with unfolding and widening of the curve [9,10,19]. On the other hand, the tortuosity ratio is more appropriate for assessment of originally straight-shaped arteries (e.g. the DA distal to the isthmus).

4.2. Impact of age on Centerline length

The association between the absolute centerline length of the DA and age was poor, and even when the centerline length was indexed to BSA, the correlation with age was not significant. This highlights the advantage of the TI as a ratio between the centerline length and straight line distance between the 2 end points of the vessel, while the mere centerline length measurement is clearly affected by body size.

There is some discrepancy between the results of previous studies that used centerline length measurement. In 2 previous studies, in addition to our results, no significant correlation was present between the length of the DA and age [8,9]. Three other studies demonstrated an increase in the length of the DA with advancing age [10,14,19]. The variable results might have been caused by lack of agreement on the use of either the absolute centerline length, or the length adjusted to BSA; to body-mass index or to the subject's height. Another cause of variability is the use of different definitions of the DA.

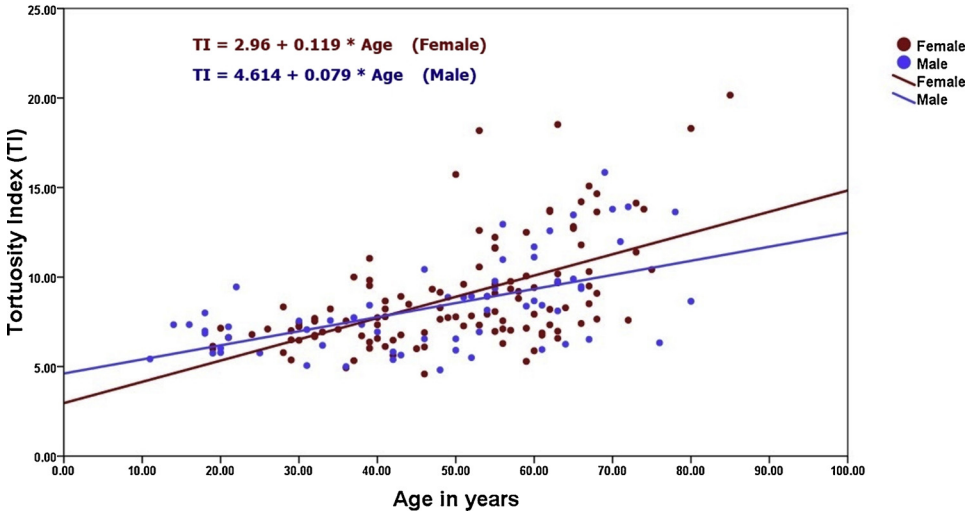

Fig. 2. Tortuosity index in relation to age in both genders. The linear regression lines are indicated for both genders.

Table 2
Linear regression analysis of each of TI, centerline length and diameter of the descending aorta in relation to age.

	Male				Female			
	R	Beta	% change	P value	R	Beta	% change	P value
Tortuosity Index	0.566	0.079 ± 0.015	9.5%	< 0.00001	0.569	0.119 ± 0.016	13.3%	< 0.00001
Centerline length (cm)	0.248	0.034 ± 0.017	1.8%	0.048	0.369	0.056 ± 0.013	3.2%	< 0.001
Diameter (mm)	0.829	0.185 ± 0.016	7.9%	< 0.00001	0.725	0.143 ± 0.013	6.4%	< 0.00001

R = correlation coefficient; Beta = regression estimate; % change = 10-year percent change.

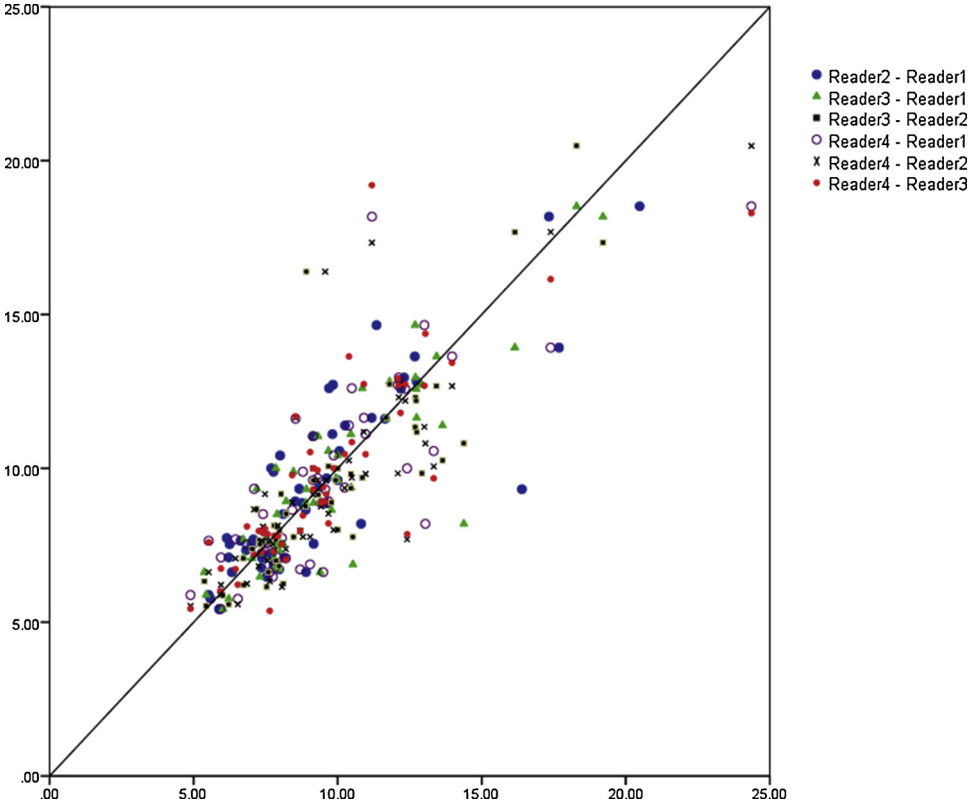

Fig. 3. Scatterplot of paired readers TI measurements. The line of perfect agreement is shown. The closer the data points to this line, the better the agreement.

4.3. Impact of age on diameter of the descending aorta

In line with the current literature [4–6], the diameter of the DA was greater in men than women and there was moderate association to age. In addition, the correlation with age was stronger in men than women as well as the 10-year percent change.

4.4. Inter-observer agreement for TI

The inter-observer agreement of the TI measurements between the 4 readers was good, and the repeatability of the measurement was acceptable.

Other advantages of TI measurement are that it is readily performed on routine contrast enhanced CT scans using routine commercial software; it is easy, needs no pre-experience or learning curve and is not time consuming. The measurement is applicable to use with MRI as well.

4.5. Importance of tortuosity of the DA

But why is it important to study the tortuosity and lengthening of the descending aorta and the effect of age? First, the descending aorta length has a direct impact on the aortic pulse wave velocity (PWV), an accepted measurement of central arterial stiffness in humans that is calculated based on the carotid-to-femoral distance divided by the time delay between carotid and femoral pulse waves [8]. The ascending aorta is excluded from such measurement, but an extensively long and tortuous descending aorta theoretically causes underestimation of the distance factor in PWV calculations [2]. Second, a recent study demonstrated that the degree of aortic tortuosity on routine chest X-ray may be an indicator of LV diastolic function [20]. Another study demonstrated correlation between aortic tortuosity on chest X-ray on one hand and visceral fat obesity and ankle-brachial index on the other [21]. CT provides more accurate measurement of aortic tortuosity and could be used to explore the relationship between tortuosity and different atherosclerotic determinants and results.

Third, knowledge of the effect of age on length and tortuosity of the aorta in non-diseased aortas is the base for understanding the pathogenesis of aortopathies including aortic aneurysm formation and dissection [22].

Finally, aortic tortuosity is important to study before interventional procedures, nonetheless stent graft deployment for thoracic endovascular aortic repair (TEVAR) of aortic aneurysms, as higher aortic tortuosity increases the risk of endoleaks and other major complications [13].

4.6. Tortuosity of other vessels

Other than the aorta, arterial tortuosity was described in the retinal, carotid and cerebral arteries, as well as veins. The mechanical factors involved in vessel tortuosity are complex, and it is thought to result from varying degrees of effects of high blood pressure or flow, reduced axial tension, and weakening of the arterial wall due to elastin degradation. Studies have linked vessel tortuosity to age, hypertension, genetic defects and diabetes mellitus [12]. In the current study we attempted to demonstrate the effect of age on otherwise healthy arteries; that is the reason why patients with hypertension and other cardiovascular risk factors were excluded from this study.

4.7. Study limitations

The main limitation to this study is its retrospective nature. The blood pressure measurements among other clinical and laboratory findings were not available and we relied on patient's history for exclusion of known cardiovascular disease, hypertension, diabetes or smoking. Further prospective studies are encouraged with assessment of the effect of various risk factors on the tortuosity of the aorta including atherosclerotic plaque burden.

5. Conclusions

In conclusion, this study demonstrated that the tortuosity of the descending aorta increases with age in both genders. The tortuosity index as a measurement of descending aorta tortuosity has an acceptable repeatability and was better correlated to age than centerline length measurements which are gender- and body size-dependent.

Funding

This work received no funding or grants.

Conflict of interest

The authors report no relationships that could be construed as a conflict of interest.

References

[1] A. Benetos, B. Waeber, J. Izzo, et al., Influence of age, risk factors, and cardiovascular and renal disease on arterial stiffness: clinical applications, Am. J. Hypertens. 15 (2002) 1101–1108.
[2] J. Blacher, M.E. Safar, Large-artery stiffness, hypertension and cardiovascular risk in older patients, Nat. Clin. Pract. Cardiovasc. Med. 2 (2005) 450–455.
[3] M.F. O'Rourke, W.W. Nichols, Aortic diameter, aortic stiffness and wave reflection all increase with age and isolated systolic hypertension, Hypertension 45 (2005) 652–658.
[4] A. Wolak, H. Gransar, L.E. Thomson, et al., Aortic size assessment by noncontrast cardiac computed tomography: normal limits by age, gender, and body surface area, JACC Cardiovasc. Imaging 1 (2008) 200–209.
[5] S.S. Mao, N. Ahmadi, B. Shah, et al., Normal thoracic aorta diameter on cardiac computed tomography in healthy asymptomatic adults: impact of age and gender, Acad. Radiol. 15 (2008) 827–834.
[6] F.Y. Lin, R.B. Devereux, M.J. Roman, et al., Assessment of the thoracic aorta by multidetector computed tomography: age- and sex-specific reference values in adults without evident cardiovascular disease, J. Cardiovasc. Comput. Tomogr. 2 (2008) 298–308.
[7] L.F. Hiratzka, G.L. Bakris, J.A. Beckman, et al., ACCF/AHA/AATS/ACR/ASA /SCA/SCAI/SIR/STS/SVM Guidelines for the diagnosis and management of patients with thoracic aortic disease: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines, American Association for Thoracic Surgery, American College of Radiology, American Stroke Association, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of Interventional Radiology, Society of Thoracic Surgeons, and Society for Vascular Medicine, Circulation 121 (2010) e266–e369.
[8] J. Sugawara, K. Hayashi, T. Yokoi, H. Tanaka, Age-associated elongation of the ascending aorta in adults, JACC Cardiovasc. Imaging 1 (2008) 739–748.
[9] A. Redheuil, W.C. Yu, E. Mousseaux, et al., Age-related changes in aortic arch geometry: relationship with proximal aortic function and left ventricular mass and remodeling, J. Am. Coll. Cardiol. 58 (2011) 1262–1270.
[10] B. Rylski, B. Desjardins, W. Moser, J.E. Bavaria, R.K. Milewski, Gender-related changes in aortic geometry throughout life, Eur. J. Cardiothorac. Surg. 45 (2014) 805–811.
[11] M. Boufi, C. Guivier-Curien, A.D. Loundou, et al., Morphological analysis of healthy aortic arch, Eur. J. Vasc. Endovasc. Surg. 53 (2017) 663–670.
[12] H.C. Han, Twisted blood vessels: symptoms, etiology and biochemical mechanisms, J. Vasc. Res. 49 (2012) 185–197.
[13] C.K. Chen, I.P. Liang, H.T. Chang, et al., Impact on outcomes by measuring tortuosity with reporting standards for thoracic endovascular aortic repair, J. Vasc. Surg. 60 (2014) 937–944.
[14] B.P. Adriaans, S. Heuts, S. Gerretsen, et al., Aortic elongation part I: the normal aortic ageing process, Heart (2018), https://doi.org/10.1136/heartjnl-2017-312866 [Epub ahead of print].
[15] S.A. Morris, D.B. Orbach, T. Geva, M.N. Singh, K. Gauvreau, R.V. Lacro, Increased vertebral artery tortuosity index is associated with adverse outcomes in children and young adults with connective tissue disorders, Circulation 124 (2011) 388–396.
[16] R.D. Mosteller, Simplified calculation of body-surface area, N. Engl. J. Med. 317 (1987) 1098.
[17] T.K. Koo, M.Y. Li, A guideline of selecting and reporting intraclass correlation coefficients for reliability research, J. Chiropr. Med. 15 (2016) 155–163.
[18] J.M. Bland, D.G. Altman, Measurement error, BMJ 313 (1996) 744–753.
[19] D. Craiem, G. Chironi, A. Redheuil, et al., Aging impact on thoracic aorta 3D morphometry in intermediate-risk subjects: looking beyond coronary arteries with non-contrast cardiac CT, Ann. Biomed. Eng. 40 (2012) 1028–1038.
[20] S. Kurisu, K. Nita, Y. Sumimoto, et al., Effects of aortic tortuosity on left ventricular

diastolic parameters derived from gated myocardial perfusion single photon emission computed tomography in patients with normal myocardial perfusion, Heart Vessels (2017), https://doi.org/10.1007/s00380-017-1095-z [Epub ahead of print].
[21] M. Mochida, H. Sakamoto, Y. Sawada, et al., Visceral fat obesity contributes to the tortuosity of the thoracic aorta on chest radiograph in poststroke Japanese patients, Angiology 57 (2006) 85–91.
[22] M. Lescan, K. Veseli, A. Oikonomou, et al., Aortic elongation and stanford B dissection: the Tübingen Aortic Pathoanatomy (TAIPAN) Project, Eur. J. Vasc. Endovasc. Surg. 54 (2017) 164–169.