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Original Article

Study of ascending aortic elasticity in the Chinese population with a high risk of aortic diseases

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Abstract: Purpose: To analyze aortic elastic properties (AEP) characteristics, dissection and elastic data of ascending aorta (AA) in the population with a high risk of aortic diseases. Methods: Forty five patients with artery diseases undergoing aortic digital subtraction angiography (DSA) were enrolled in this study. The maximal, minimal diameter and changes in diameter of ascending and descending aorta were measured, and the aortic stiffness index (ASI) and aortic distensibility (AD) were calculated. Results: The mean changes in diameter were (2.34 ± 0.95), (1.6 ± 0.71), (1.65 ± 0.68) and (0.99 ± 0.28) mm. The ASI of D1-D4 aorta was (9.67 ± 5.02), (15.54 ± 7.85), (13.78 ± 6.45) and (15.53 ± 4.74). AD ($mmHg^{-1}$) × 10^{-3} of D1-D4 aorta was (2.76 ± 1.65), (1.76 ± 1.15), (1.94 ± 1.23) and (1.33 ± 0.40). The ratio of diameter difference/minimal diameter was (7.18 ± 3.21), (4.6 ± 2.3), (4.96 ± 2.22) and (3.86 ± 1.16). The tapered angle of D2-D3 aorta was (2.47 ± 1.80)°. The maximal and minimal diameters of D1 aorta significantly differed between male and female subjects. Conclusion: DSA and artery pressure accurately measure the changes in diameter and artery pressure of aorta along with single beat. Aortic ASI and AD could be accurately calculated to precisely analyze AEP. Over aging and arteriosclerosis development, D2 aorta is the most vulnerable to elasticity attenuation, whereas D1 aorta is the least vulnerable part with certain elasticity.

Keywords: Endovascular repair, aortic arc, ascending aorta, stent-graft vessels, aortic elastic properties

Introduction

Along with the rapid development of endovascular appliance and technique, thoracic endovascular aneurysm repair (TEVAR) has been widely applied in the treatment of aortic diseases with small trauma, fast recovery and high efficacy, which could properly treat patients with complicated diseases. Thus, endovascular therapy is likely to replace traditional open surgery as a primary treatment for aortic diseases. However, no effective and reliable instruments have been designed for ascending aorta and aortic arch lesions. Among thoracic aortic diseases, the incidence of aortic aneurysms occurring in ascending aorta and aortic arch is approximately 45% and 10% and about 35% for descending aortic aneurysms and approximately 66.7% for aortic dissection of ascending aorta and aortic arc. Since ascending aorta and aortic arch include vital branches, such as CA, brachiocephalic trunk, carotid artery and subclavian artery, endovascular technique is merely suitable for treatment of descending aortic lesions, suggesting that over half of the patients fail to undergo TEVAR.

Recent studies have been conducted to tackle this challenge. In 1999, Kanji Inoue *et al.* guided the thread into main branches of the aortic arc. One-branched stent graft was transplanted in 14 cases and three-branched stent graft in 1 patient. In 2004, Williams *et al.* utilized stent graft to cover the left subclavian artery, introduced a cutting sacculus via the left brachial artery, removed the covered film from the opening of left subclavian artery and placed the bare stent for support, thereby restoring the blood supply of left subclavian artery and reconstructing the aortic arc. Chuter TA successfully applied branched stent graft to treat aortic arc lesions in one case. The patient was treated with right-left common carotid artery diversion surgery and left subclavian-left common carotid artery diversion surgery, one branched stent was released via right common carotid artery, the long

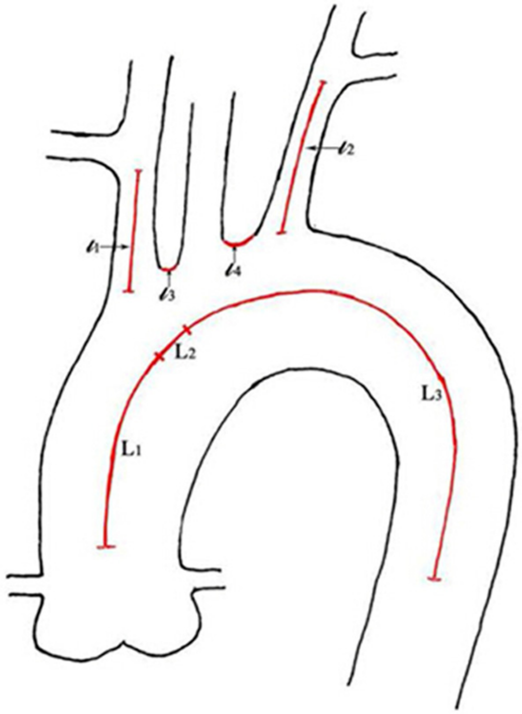

Figure 1. The position and length of aorta (L1: The length of proximal ascending aorta between 1 cm above the opening of coronary artery and initial position of brachiocephalic trunk branch).

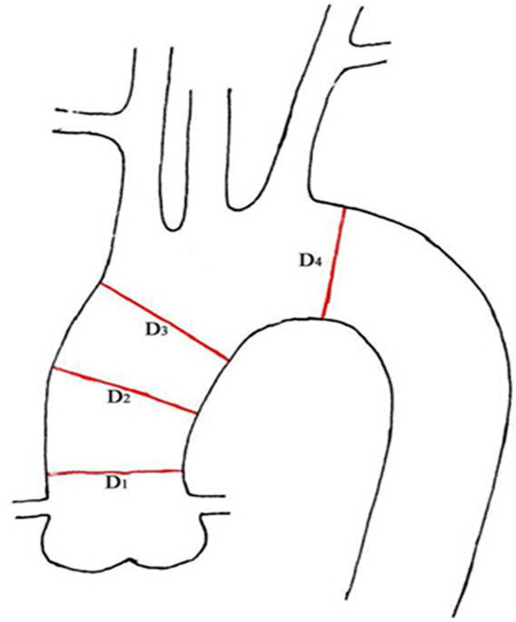

Figure 2. Design of the position of aortic diameter (D1: 1 cm above the opening of coronary artery; D2: Midpoint of D1 and D3 of the middle segment of ascending aorta; D3: Proximal end of initial position of brachiocephalic trunk branch; D4: Distal end of initial position of left subclavian artery, initial position of descending aorta).

and thin arm of the stent was inserted into the innominate trunk and the short and thick arm inside the aorta. Then, one stent graft was introduced via femoral artery and connected to the short and thick arm to reconstruct the aortic arc using the branched stent graft [1, 2]. However, the design of stent-graft vessels in these studies was individualized. The inclusion criteria were demanding. The surgical process was time-consuming and complicated. All these limitations make it difficult to widely apply these stent-graft vessels into clinical practice. In 2005, our study group invented "modular branched stent-graft system" model [3] and successfully applied it into animal models between 2005 and 2006 [4]. Subsequently, the dissection data of ascending and aortic arc related to modular branched stent-graft system were recorded and statistically analyzed by CTA reconstruction and vascular analysis software to preliminarily design the size of modular branched stent-graft system between 2007 and 2008 [5-8]. In this study, the Chinese population with a high risk of aortic diseases was enrolled, aiming to explore the changes in the elasticity index of ascending aorta and offer clinical theory for the instrumental design suitable for Chinese patients.

Materials and methods

Patients

This work was approved by the Ethic Committee of 301 General Hospital of People's Liberation Army. Forty five hospitalized patients undergoing aortic angiography between September 2010 and September 2011 were enrolled in this study, including 33 males and 12 females, (59.73 ± 9.69) years on average from 38 to 80 years. Fifteen patients had abdominal aortic aneurysms or Stanford B dissection and 30 had artery diseases (artery stenosis or occlusion) in other positions.

Exclusion criteria: A. Aged < 35 years and without complicated artery diseases; B. Pathological changes involving ascending aorta; C. Digital subtraction angiography (DSA) parameters and range, and imaging quality fail to meet the standard.

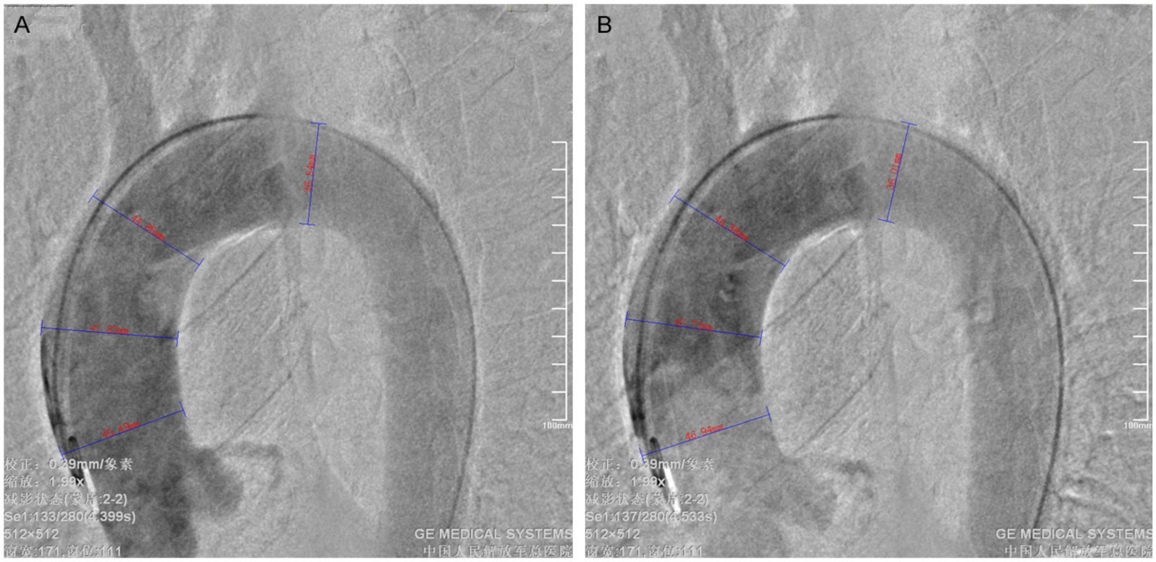

Figure 3. A: Data measurement under the staus of aortic coarctation; B: Data measurement under the status of aortic dilatation.

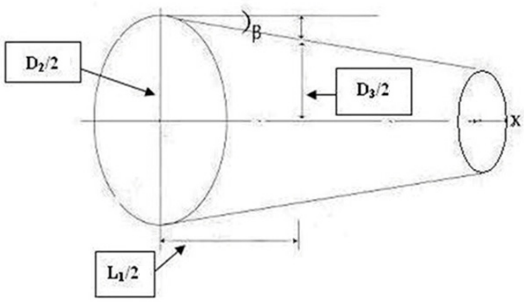

Figure 4. Tapered angle (β = tapered angle).

Equipment and software

Innova3100-IQ DSA (GE, U.S.) was utilized to rapidly produce high-resolution images. Lightspeed 16 CT scanmer was adopted (GE, U.S.), artery pressure measurement instrument (GE, U.S.), 4F femoral artery puncture needle and artery sheath (Cordis, U.S.), Gold-labeled double J-shaped catheter (Cook, U.S.), Double J-shaped angiography catheter (Cordis, U.S.), 0.035/180 cm supersmooth guidewire (TERUMO, Japan), 0.035/260 cm supersmooth guidewire (TERUMO, Japan), 0.035/260 cm supersmooth guidewire (Boston Scientifc, U.S.), SMART-DSA imaging system, GE MRI AW4.2.

Data collection

Collection of aortic angiography data: The patients were administered with topical infiltration anesthesia in a supine position. After femoral arterial or left brachial arterial puncture, angiography catheter (gold-labeled catheter or double J-shaped angiography catheter) was placed above aortic valve. The projection angle was adjusted to (39.74 ± 9.74)° in left anterior direction. The indexes of high-pressure syringe: pressure 500-700, 15-18 ml/second and the total dose 30 ml. Under subtraction angiography, the ascending aortic, aortic arc and descending aortic images of three single beats were consecutively captured. The angiography catheter was connected to the arterial pressure measurement devices. The ascending aortic pressure was recorded for subsequent use during angiography.

Collection of the length of ascending aorta: Our study group designed the "modular branched stent-graft system", and the length of ascending aorta (L1) was (53.48 ± 12.20) mm, as shown in **Figure 1**.

Data measurement

The obtained images were measured and analyzed by SMART-DSA. The software-equipped measurement tool was utilized to measure 1 cm above coronary artery, initial position of brachiocephalic trunk, the midpoint between two positions, left subclavian artery, initial position of distal descending aorta, maximal and minimal artery diameter, 10-15 images per single

Table 1. Description of characteristics of D1-D4 aorta

Statistics	D1 (n = 45)	D2 (n = 45)	D3 (n = 45)	D4 (n = 26)	F value	*P*
Maximal diameter (mm)	35.53 ± 4.94	37.48 ± 5.32	35.54 ± 4.96	26.95 ± 3	28.46	0.000
Minimal diameter (mm)	33.2 ± 4.83	35.88 ± 5.32	33.89 ± 4.91	25.96 ± 2.93	25.09	0.000
Diameter difference (mm)	2.34 ± 0.95	1.6 ± 0.71	1.65 ± 0.68	0.99 ± 0.28	19.67	0.000
ASI	9.67 ± 5.02	15.54 ± 7.85	13.78 ± 6.45	15.53 ± 4.74	8.04	0.000
AD ($mmHg^{-1}$) × 10^{-3}	2.76 ± 1.65	1.76 ± 1.15	1.94 ± 1.23	1.33 ± 0.40	8.46	0.000
Diameter difference/minimal diameter × 10^{-2}	7.18 ± 3.21	4.6 ± 2.3	4.96 ± 2.22	3.86 ± 1.16	13.51	0.000

beat for three consecutive single beats (**Figures 2**, **3**).

Data calculation

Calculation of mean maximal, minimal diameter and diameter difference of D1-D4: The changes in aortic diameter were nonsynchronous. The maximal and minimal diameter did not occur simultaneously during the same phase. To accurately measure the diameter changes of each position, 10 to 15 images were captured per single beat. The mean maximal and minimal diameter of four positions was calculated from the average value of three single beats. The mean diameter changes were also calculated.

Calculation of ASI and AD: ATI = (InSBP-InDBP) × Dmin/(Dmax-Dmin). SBP: systolic blood pressure; DBP: diastolic blood pressure; Dmin: minimal diameter; Dmax-Dmin: diameter changes. AD=2 × (Dmax-Dmin)/(PP × Dmin) ($mmHg^{-1}$) × 10^{-3}. PP: pulse pressure.

Calculation of D2-D3 tapered angle: The tapered angle was approximately 1°. If the tapered angle was enlarged to certain degree, the strength of pulse wave reflex exceeded that of arterial inner membrane, and inner membrane rupture definitely caused the incidence of aortic dissection Combining with the maximal diameter of D2 and D3, the tapered angle of D2-D3 could be calculated (**Figure 4**).

Statistical analysis

SPSS 17.0 software was utilized for statistical analysis. Data were expressed as means ± standard deviation. The maximal, minimal diameter, diameter difference, ASI, AD and diameter difference/minimal diameter of D1-D4 were subject to variance analysis. If statistical significance was observed, paired comparison should be performed among different positions. Different parameters between two groups were statistically analyzed by *t*-test. $P < 0.05$ was considered to be significantly different.

Results

Characteristics of patients

All cases were successfully treated and relevant data were obtained. The descending aortic lesions were involved in certain cases during measurement. Thus, 19 patients were excluded in D4 due to the incidence of descending aortic lesions.

All patients were aged (59.73 ± 9.69) years on average; SBP: (134.73 ± 20.80) mmHg; DBP: (76.38 ± 9.22) mmHg; pulse pressure (58.36 ± 16.03) mmHg; aortic projection angle: (39.74 ± 9.74)°; tapered angle of D2-D3: (2.47 ± 1.80)°.

The mean maximal diameter of D1-D4 aorta was (35.53 ± 4.94) mm, (37.48 ± 5.32) mm, (35.54 ± 4.96) mm and (26.95 ± 3.00) mm. The mean minimal diameter was (33.2 ± 4.83) mm, (35.88 ± 5.32) mm, (33.89 ± 4.91) mm and (25.96 ± 2.93) mm. The mean changes in diameter were (2.34 ± 0.95) mm, (1.6 ± 0.71) mm, (1.65 ± 0.68) mm and (0.99 ± 0.28) mm. The ASI of D1-D4 aorta was (9.67 ± 5.02), (15.54 ± 7.85), (13.78 ± 6.45) and (15.53 ± 4.74). AD ($mmHg^{-1}$) × 10^{-3} of D1-D4 aorta was (2.76 ± 1.65), (1.76 ± 1.15), (1.94 ± 1.23) and (1.33 ± 0.40). The ratio of diameter difference/minimal diameter was (7.18 ± 3.21), (4.6 ± 2.3), (4.96 ± 2.22) and (3.86 ± 1.16).

Analysis of six parameters of D1-D4

The maximal, minimal diameter, diameter difference, ASI, AD and diameter difference/minimal diameter) of D1-D4 were subject to variance analysis. Statistical significance was

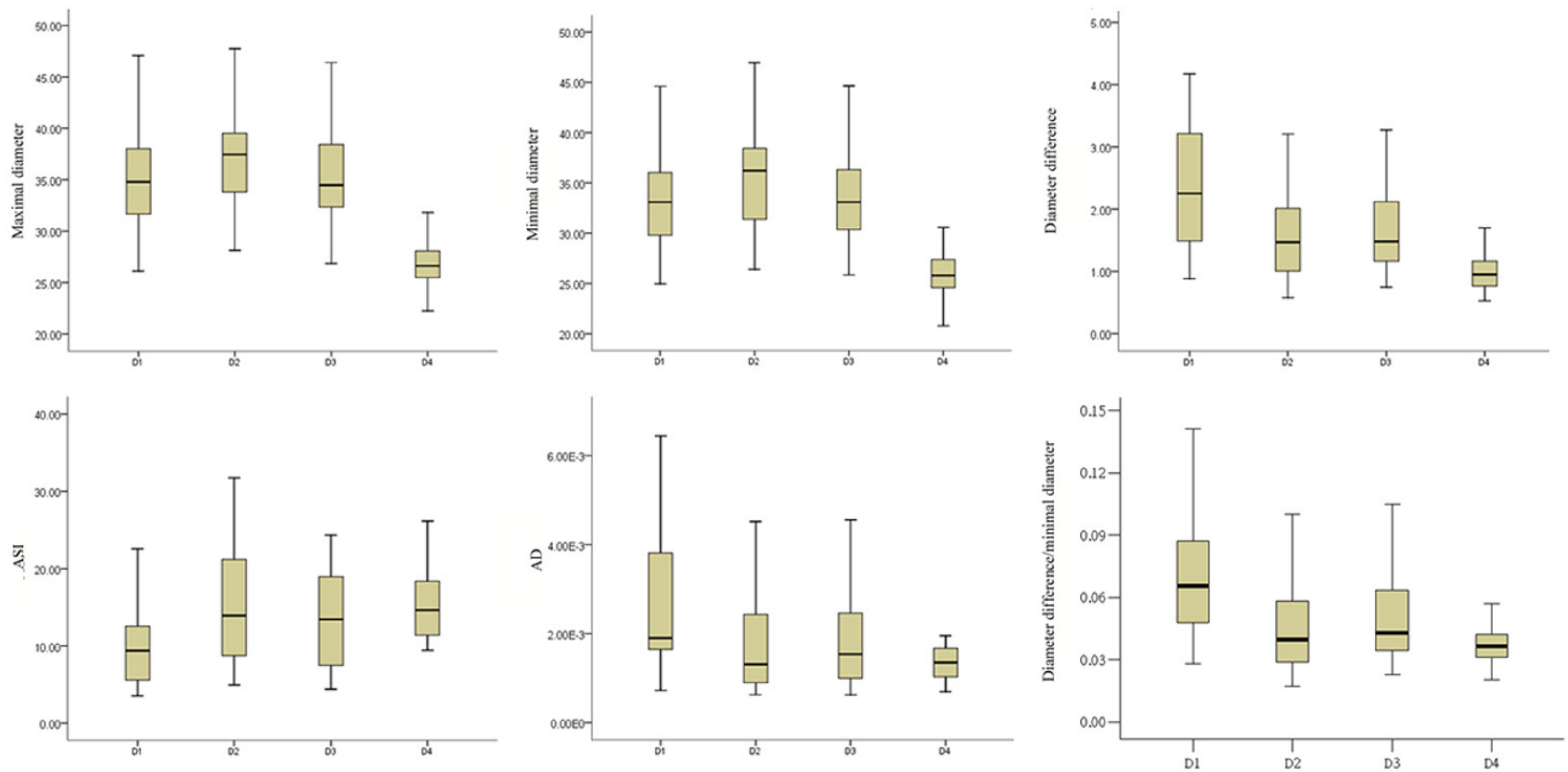

Figure 5. Boxplot of six parameters among D1-D4.

Table 2. Description of characteristics of different genders

Statistics	Male	Female	F value	T value	P
D1 (n = 45)	33	12			
Maximal diameter (mm)	36.46 ± 4.92	32.97 ± 4.19	0.26	2.18	.034
Minimal diameter (mm)	34.08 ± 4.91	30.78 ± 3.8	0.49	2.10	.041
Diameter difference (mm)	2.39 ± 0.86	2.19 ± 1.21	5.06	0.52	.611
ASI	9.02 ± 4.24	11.47 ± 6.62	7.35	-1.20	.251
AD ($mmHg^{-1}$) × 10^{-3}	2．88 ± 1.71	2.41 ± 1.48	0.40	0.85	.401
D2 (n = 45)	33	12			
Maximal diameter (mm)	38.37 ± 4.92	35.02 ± 5.81	0.77	1.93	.060
Minimal diameter (mm)	36.71 ± 5.12	33.59 ± 5.41	0.20	1.78	.082
Diameter difference (mm)	1.67 ± 0.66	1.43 ± 0.83	1.11	1.00	.324
ASI	14.56 ± 7.72	18.22 ± 7.92	0.02	-1.40	.170
AD ($mmHg^{-1}$) × 10^{-3}	1.86 ± 1.17	1.47 ± 1.10	0.23	1.03	.311
D3 (n = 45)	33	12			
Maximal diameter (mm)	36.31 ± 4.69	33.42 ± 5.28	0.04	1.77	.084
Minimal diameter (mm)	34.58 ± 4.79	32 ± 4.94	0.00	1.58	.121
Diameter difference (mm)	1.73 ± 0.69	1.42 ± 0.6	1.09	1.40	.169
ASI	13.2 ± 6.84	15.37 ± 5.18	3.64	-1.00	.325
AD ($mmHg^{-1}$) × 10^{-3}	2.10 ± 1.32	1.50 ± 0.81	6.77	1.86	.072
D4 (n = 26)	17	9			
Maximal diameter (mm)	27.56 ± 2.78	25.79 ± 3.21	0.15	1.46	.157
Minimal diameter (mm)	26.51 ± 2.64	24.91 ± 3.31	0.63	1.35	.189
Diameter difference (mm)	1.05 ± 0.24	0.89 ± 0.34	3.68	1.41	.171
ASI	13.93 ± 3.74	18.54 ± 5.14	0.61	-2.62	.015
AD ($mmHg^{-1}$) × 10^{-3}	1.46 ± 0.38	1.08 ± 0.31	0.72	2.59	.016

observed in relevant parameters among D1 to D4 (all $P < 0.05$), as shown in **Table 1**.

To further validate the level of significance and details of six parameters among D1-D4 aorta, Student-Newman-Keuls (SNK) method was adopted to conduct paired comparison and found that the maximal diameter of D4 significantly differed from those of D1, D2 and D3, whereas no statistical significance was noted in maximal diameter among D1, D2 and D3 aorta. The minimal diameter of D4 aorta significantly differed from those of D1, D2 and D3. The minimal diameter of D1 significantly differed from that of D3, whereas no statistical significance was observed in minimal diameter between D2 and D3 aorta. The diameter difference of D4 aorta significantly differed from those of D1, D2 and D3. The diameter difference of D1 significantly differed from those of D2 and D3, whereas no statistical significance was observed in diameter difference between D2 and D3 aorta. ASI of D1 aorta significantly differed from those of D2, D3 and D4, whereas no statistical significance was found in ASI among D2, D3 and D4. AD of D1 aorta significantly differed from those of D2, D3 and D4, whereas no statistical significance was found in AD among D2, D3 and D4. The ratio of diameter difference/minimal diameter of D1 aorta significantly differed from those of D2, D3 and D4, whereas no statistical significance was found among D2, D3 and D4, as illustrated in **Figure 5**.

Statistical analysis between both male and female patients

Five parameters of D1-D4 aorta were statistically compared between different genders. The maximal and minimal diameter of D1 aorta, and ASI and AD of D4 significantly differed, whereas no significant difference was observed in other positions, as shown in **Table 2**.

Statistical analysis among different age groups

Five parameters of D1-D4 aorta were statistically compared among different age groups. The AD of D2 aorta significantly differed, whereas no significant difference was observed in other positions, as shown in **Tables 3**, **4**.

Discussion

Aortic elastic property is subject to the influence of age, arteriosclerosis, hypertension and dyslipidemia, *etc* [9-11]. The breakage of elastic fiber and sediment of collagen fiber lead to enlarged arterial diameter and reduced vascular distensibility, which may affect the buffering capacity of artery [12-19]. These parameters reflect the ASI and AD of artery, captivating

Table 3. Description of characteristics among different age groups

Statistics	< 50 years	50-60 years	60-70 years	> 70 years	F value	P
D1 (n = 45)	8	15	15	7		
Maximal diameter (mm)	36.67 ± 5.06	33.71 ± 4.75	37.2 ± 4.6	34.57 ± 5.4	1.53	.221
Minimal diameter (mm)	33.96 ± 4.97	31.5 ± 4.66	34.86 ± 4.76	32.39 ± 4.78	1.38	.262
Diameter difference (mm)	2.7 ± 1.21	2.21 ± 0.84	2.34 ± 0.89	2.18 ± 1.09	0.52	.669
ASI	8.73 ± 6.22	9.21 ± 5.54	9.79 ± 3.19	11.5 ± 6.23	0.43	.731
AD ($mmHg^{-1}$) × 10^{-3}	3.86 ± 2.37	2.88 ± 1.49	2.25 ± 1.02	2.33 ± 1.82	1.96	.136
D2 (n = 45)	8	15	15	7		
Maximal diameter (mm)	38.45 ± 4.6	35.33 ± 5.09	39.31 ± 5.08	37.06 ± 6.38	1.57	.212
Minimal diameter (mm)	36.33 ± 4.52	33.72 ± 5.37	37.82 ± 5.11	35.82 ± 5.86	1.57	.212
Diameter difference (mm)	2.12 ± 0.77	1.61 ± 0.69	1.49 ± 0.61	1.24 ± 0.68	2.35	.086
ASI	10.5 ± 5.92	14.18 ± 8.33	17.44 ± 7.63	20.12 ± 6.45	2.58	.066
AD ($mmHg^{-1}$) × 10^{-3}	2.73 ± 1.48	1.97 ± 1.20	1.36 ± 0.75	1.03 ± 0.33	4.45	.008
D3 (n = 45)	8	15	15	7		
Maximal diameter (mm)	36.32 ± 3.85	33.19 ± 4.15	37.01 ± 5.45	36.54 ± 5.7	1.82	.158
Minimal diameter (mm)	34.34 ± 3.87	31.68 ± 4.25	35.38 ± 5.49	34.92 ± 5.23	1.68	.187
Diameter difference (mm)	1.99 ± 0.73	1.51 ± 0.68	1.62 ± 0.64	1.62 ± 0.71	0.88	.459
ASI	10.88 ± 6.84	13.58 ± 6.85	14.75 ± 6.03	15.45 ± 6.3	0.80	.501
AD ($mmHg^{-1}$) × 10^{-3}	2.74 ± 1.55	1.97 ± 1.21	1.64 ± 0.95	1.61 ± 1.23	1.67	.189
D4 (n = 26)	2	12	8	4		
Maximal diameter (mm)	27.45 ± 0.85	26.59 ± 2.54	26.88 ± 4.24	27.92 ± 2.67	0.20	.898
Minimal diameter (mm)	26.59 ± 1.13	25.73 ± 2.46	25.66 ± 4.17	26.92 ± 2.48	0.21	.890
Diameter difference (mm)	0.86 ± 0.28	0.87 ± 0.16	1.22 ± 0.3	1 ± 0.36	3.29	.050
ASI	18.4 ± 9.95	15.93 ± 3.55	12.28 ± 2.08	19.36 ± 6.61	2.97	.054
AD ($mmHg^{-1}$) × 10^{-3}	1.17 ± 0.67	1.27 ± 0.36	1.61 ± 0.23	1.03 ± 0.44	2.75	.067

SNK method was adopted to perform paired comparison. The AD of D2 aorta in patients aged > 60 years significantly differed from that in their counterparts aged < 60.

Table 4. Comparison of AD of D2 aorta among different age groups (mmHg-1) × 10^{-3}

Age grouping	N	A = 0.05 subset	
		1	2
> 70 years	7	1.03	
60-70 years	15	1.36	
50-60 years	15	1.97	1.97
< 50 years	8		2.73
Statistical significance		.120	.109

attention from physicians of all specialties. The maximal, minimal diameter and blood pressure are contained in these two formulas.

Measurement methods of the diameter include: chest and esophageal ultrasound [20], CTA [21] and MRI [22]. However, these methods have their own limitations. Chest ultrasound yields limited visual field and is unable to detect the condition of descending aorta. Esophageal ultrasound may induce nausea, vomiting and cough, or esophageal perforation, hemorrhage and even death and fails to display the upper segment of ascending aorta due to gas blockage. CTA is likely to generate artifacts caused by eddy-current. The measurement accuracy is not satisfactory [21]. MRI fails to achieve 3D reconstruction and image rotation [23]. DSA is traumatic and the sample is relatively difficult to obtain. Thus, healthy controls were not included in this study. Another reason is to understand the dissection and elasticity characteristics of ascending aorta in a Chinese population with high risk of aortic diseases. Consequently, all enrolled subjects had aortic diseases or arterial diseases at other positions.

In almost all formulas of aortic elasticity, brachial arterial pressure has been adopted. These formulas fail to accurately measure the aortic blood pressure due to hypertension and atherosclerosis, and arterial wall become thickened and arterial wall structure may change over aging. The stiffness of central artery increases earlier and more severe than peripheral artery, making the increase in the pulse pressure of central artery is larger than that in peripheral artery. Thus, the formula fails to accurately reflect the ASI [24-26]. In this study, central aortic pressure of the ascending aorta was adopted in the formula.

Our study demonstrated that compared with the initial position of D4 descending aorta, the maximal and minimal diameter of D1-D3 ascending aorta was significantly larger than those of D4, especially D2 aorta of middle segment of ascending aorta. In this position, the largest diameter of ascending aorta, the smallest changes of diameter difference, the highest ASI and the lowest AD were found. The tapered angle of D2 aorta relative to D3 was (2.47 ± 1.80)°. Previous studies demonstrated that arterial tapered angle of 1° caused pulse wave reflex of hemodynamics [27]. It is demonstrated that arterial distensibility enhanced the incidence of aortic dissection [28]. In this study, the most significant aortic elasticity attenuation was observed in D2 ascending aorta. Opposite to D2 aorta, the maximal and minimal diameter was basically equivalent between D1 and D3, whereas the diameter difference and AD were significantly higher and ASI significantly lower compared with other positions, indicating that the aortic elastic properties of D1 were the best.

In this study, the maximal and minimal diameter of D1 aorta significantly differed between male and female subjects, consistent with previous findings [29]. Over aging, the difference tended to become smaller due to decreased hormone secretion after menopause and gradually aggravated arteriosclerosis. In this study, the aged patients complicated with arterial diseases were selected. Hence, the statistical difference in the maximal and minimal diameter of D1 aorta demonstrated D1 aorta is the least likely to have elasticity attenuation and maintain the elasticity for the longest time. ASI and AD of D4 aorta significantly differed, probably because initial position of descending aorta was involved in certain cases, data loss of D4 aorta and statistical error caused by small sample size. In addition, AD of D2 aorta significantly differed between patients aged > 60 and < 60 years, consistent with previous findings.

In this study, the morphology of ascending aorta gradually evolved into curved "waist drum" shape along with aging and the incidence of arteriosclerosis. First, consistent morphology between stent-graft vessels and ascending aorta could guarantee close adhesion between stent-graft vessels and vascular wall, thereby minimizing hemodynamic and hydrodynamic effect of stent-graft vessels upon ascending aorta. Second, the radial supporting force exposed on the head and middle sections of stent-graft vessel models should be differentiated. Larger radial supporting force is required at the head end and smaller force at the middle part of the stent, because the elasticity of D1 aorta is the best. The absence of radial supporting strength probably causes internal leakage and stent shift by insufficient or unstable anchoring. The distensibility of D2 aorta is reduced. Excessive radial supporting force possibly leads to vascular rupture.

Regarding the morphological and elasticity characteristics of ascending aorta, enlarged diameter of middle segment of D2 ascending aorta, elasticity attenuation and elasticity maintenance of initial position of D1 ascending aorta were found. In theory, the landing zone of stent-graft vessels should be proximal to the direction of coronary artery as possible, but not conceal the opening of coronary artery. Otherwise, consequential outcomes may be caused. However, whether the landing zone proximal to aortic opening affects the function of aortic valve, such as insufficient closure of aortic valve, remains to be further elucidated.

In this study, the diameter changes in D1, D2 and D3 ascending aorta significantly differed from those in initial position of D4 descending aorta, especially D1 aorta. Further test demonstrated that the ratio of diameter difference/ minimal diameter of D1 aorta significantly differed from those of D2, D3 and D4. No statistical significance was observed in the ratio among D2, D3 and D4. During descending aortic endovascular treatment, the stent with a diameter larger than the arterial diameter by 10%-15% was chosen to guarantee the stability of stent anchoring. Consequently, the selection of D2 and D3 aortic stents could conform to the principle of descending aorta, whereas for those proximal to the opening of ascending aorta, stent-graft vessels with a diameter longer than the measured artery should be selected to guarantee stable anchoring. According to the calculated proportion, the diameter of stent-graft vessels of D1 aorta should be 18.6%-27.9% larger than that of the measured arteries. Considering the discrepancy of morphology and elasticity characteristics between ascending and descending aorta, whether the selection could guarantee full anchoring of stent-graft vessels and prevent the rupture of ascending aorta by radial supporting force remain to be deeply investigated.

Disclosure of conflict of interest

None.

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