

Morphology of the ascending aorta: a study on 114 Chinese patients

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ABSTRACT

Purpose: This study aimed to investigate the morphological characteristics of ascending aortic dissection in detail.

Materials and Methods: The ascending aorta was morphologically assessed in a consecutive series of patients between January 2009 and October 2014. A new assessment and evaluation method was used to describe 114 patients with ascending aortic dissection.

Results: A large difference was found in the degree of curvature between the ascending aorta with and without dissection. The shape of the former was straighter and steeper (control group R, 47.46 ± 6.40 mm; experimental group R, 59.70 ± 10.27 mm, $P < 0.001$). In the case of aortic dissection involving the valves, the proximal edge of the first entry was obviously close to the aortic sinus. The orientation of the entries was mainly around the 10 o'clock and 1–2 o'clock positions, and most of their shapes were fusiform (111; 70.02%). The distance of the distal extending dissection was associated with cases involving the branch arteries (involving three branches 441.40 ± 101.13 mm vs 159.85 ± 131.86 mm in others, $P < 0.001$).

Conclusion: The morphological features of the ascending aorta after dissection and the correlations among dissections, entries, and related factors were found.

Keywords: ascending aorta; dissection; intimal tear; morphology; computed tomography

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INTRODUCTION

Type A aortic dissection is a dangerous disease with an annual incidence of 2.9/100,000 (1) or more(2), accounting for 60% of all aortic dissections. It has the distinctive feature of a high mortality rate. The main treatment modalities include open surgery, endovascular surgery, and conservative treatment. Open surgery, which requires replacement of the ascending aorta and cardiopulmonary bypass, remains the gold standard treatment (3). However, for patients with systemic disease or those who cannot tolerate surgery (complicated by chronic obstructive pulmonary disease, diabetes, renal failure, or advanced age), when the surgical risk exceeds the benefits, choosing the treatment method becomes difficult (4).

With the development of endovascular techniques, patients who are unsuitable candidates for open surgery have successfully been treated with endovascular surgery. Jing et al. (5) were the first to perform a series of studies on the endovascular treatment of ascending aortic dissection. Endovascular treatment may be a better choice

because of the short duration of hospitalization and lower morbidity and mortality rates, but the endovascular treatment of aortic dissection is currently feasible only in some particular entry positions and special morphological cases (5). Due to the special anatomical location of the ascending aorta and its morphological characteristics, the application of endovascular treatment is severely limited.

Regardless of treatment type, preoperative imaging data are extremely important. The treatment method and results depend on the length, diameter, and curvature of the ascending aorta as well as entry size and location. Previous studies on the morphology of the aorta mostly reported on its diameter and length (6, 7). A more detailed investigation was performed of the morphological characteristics of the ascending aorta using the original measurement method to lay the foundation for our understanding of the development characteristics of aortic dissection and seek a better treatment choice.

MATERIALS AND METHODS

The imaging studies and medical records of all 473 patients who presented with ascending aortic dissection at our Hospital between January 2009 and October 2014 were analyzed. The initial exclusion criteria were incomplete data on computed tomography angiography (108 cases) and computed tomography (CT) scans that were not performed at our Hospital (36 cases). The additional exclusion criteria included having undergone open or endovascular surgery involving the ascending aorta and aortic arch for various reasons (143 cases) and the presence of a penetrating aortic ulcer or

intramural hematoma (50 cases) or other connective tissue diseases such as Marfan syndrome (22 cases). After screening, a total of 114 patients including 76 men (mean age, 51 years; range, 21–79 years) and 38 women (mean age, 58 years; range, 27–78 years) were included.

This study was approved by the Ethics Committee of our Hospital, and written informed consent was obtained from every participant. The study was conducted in compliance with the Declaration of Helsinki.

The CT scans were imported into the workstation (Aquarius iNtuition Edition ver. 4.4.6.80.2770; TeraRecon Inc., Foster, CA, USA) in Digital Imaging and COmmunications in Medicine format and a three-dimensional image was reconstructed. The bony skeleton was removed and the center lumen line was defined. As there is no standard method of measurement, the starting point was set as the ostia of the coronary artery and the end point was the bifurcation of the abdominal aorta for the measurement. CT imaging was used to measure the aortic morphological data and the imaging datasets were read in consensus by two experienced vascular surgeons who performed the aortic measurements and parameter calculations.

Measurement of the ascending aorta

Length and diameter.

The ostia of the coronary artery was defined as the starting point of the ascending aorta, while the proximal edge of the innominate artery was defined as the ending point. The distance between these two points was defined as the length of the ascending aorta. The ascending aorta was divided into three equal sections in which there were four measurement points. At these points, maximum and minimum diameters were measured in a plane perpendicular to the center line of the aorta. The mean diameter was measured based on the area of the plane.

Radius of curvature

Since the aortic curvature has not yet been defined, the radius of the curvature of the ascending aorta was defined to assess whether it turns steeply. The centerline of the ascending aorta was deemed as a part of the circle that is a sector of an arc based on a quasi-circular mathematical model. The angle (denoted as F) between the start and end points was measured. The formula $R = (180 \cdot L) / (F \cdot \pi)$ was used to calculate the radius of the curvature (R value). Turning the same angle, if the radius of the curvature is larger, it turns more slowly and is steep. Otherwise, it is a more curved shape (Fig. 1). To assess the difference between the morphology of the dissected ascending aorta and the normal ascending aorta, 114 subjects with a healthy ascending aorta and arch were also selected, and data on the normal ascending aorta using the same method were measured and the R values were compared between groups.

Measurement of entry

The most proximal intimal tear (entry) was defined as the first entry, the shapes were observed, and the quantity and its orientation were measured. For a

description of the orientation, the analog clock face was used. The ventral sagittal direction in the horizontal plane was defined as the 12 o'clock direction and measured clockwise. With the ostia of the coronary artery as the starting point, the coordinate was 0. The proximal edge position, distal edge position, center position, and length and width (or base and height) of the entries were measured. Since irregularly shaped entries were difficult to describe using the quantitative indexes, the number of entries was counted.

Measurement of dissection

The proximal and distal extending lengths of the dissection were measured. All measurements were based on the edges of the first entry. If the distal end extended to the iliac arteries, the measurement was made to the bifurcation of the abdominal aorta. Since some dissections occurred over the abdominal aorta, the distal extending distance was meaningful only when compared with the proximal extending distance; it has no practical significance in the measurement of length. The observations were focused on whether the dissections involved the three arterial branches. The dissection rotation was described. True and false lumen diameter measurements were made at the first entry position and the narrowest site.

All data are expressed as mean \pm standard deviation unless stated otherwise. Orientations are expressed using the analog clock face. Continuous variables were compared using the t test for two groups. Values of $P < 0.05$ are considered statistically significant. All data were analyzed using SPSS software (version 22.0; SPSS Inc., Chicago, IL, USA).

RESULTS

Patient demographic and ascending aorta characteristics

The mean ascending aorta length was 85.60 ± 11.41 mm (men, 85.23 ± 9.65 mm; women, 86.35 ± 11.50 mm). The aortic diameters of the men at four positions were 37.17 ± 8.38 , 33.03 ± 8.65 , 29.91 ± 7.70 , and 29.20 ± 6.87 mm (women: 36.81 ± 8.39 , 33.15 ± 8.79 , 30.26 ± 7.72 , and 30.53 ± 7.03 mm). Based on the measured angle F, R was calculated as 59.70 ± 10.27 mm. For the 114 subjects with a normal aorta, the mean R value was 47.46 ± 6.40 mm (t test, $P < 0.001$) (Table 1).

Entry

Sixty-five (57.02%) patients had a few entry points ($n \leq 2$), while 49 (42.98%) patients had multiple entry points ($n \geq 3$). A total of 172 entries were measured in this study. Fusiform entries accounted for 64.53% (111); triangular, 19.19% (33); irregularly shaped, 12.21% (21); and trapezoidal, 4.07% (7). The mean central location was 43.23 ± 35.41 mm, while the mean proximal edge position was 35.34 ± 35.43 mm. On segmentation of the ascending aorta into three sections, the number of first entries in the aortic proximal, middle, and distal sections was 64 (56.14%), 27 (23.68%), and 23 (20.18%), respectively. The positions and orientations of the first entries are shown in Fig. 2.

Table 1 Comparison of characteristics between cases and controls.

	Cases (n=114)	Controls (n=114)	P values
Age (years)	53.5±13.6	53.3±14.4	0.89
Male (n, %)	76 (66.7)	81 (71.0)	0.48
L (mm)	85.6±11.4	78.2±10.3	<0.001
F(°)	83.5±14.0	95.1±11.2	<0.001
R (mm)	59.7±10.27	47.46±6.40	<0.001

Table 2 Extending distance in the different direction.

	Cases	Retrograde distance, mm	Distal distance, mm	
Retrograde propagation (94.70%)	108	15.49 ± 9.65	-	
Distal propagation (99.12%)	113	-	330.26	±
Involving three branch arteries			178.97	
No (39.47%)	45	15.11 ± 9.12	159.85	±
Yes (60.53%)	69	14.39 ± 10.61	441.40	±
P value		0.710	<0.001	

Table 3 Position of proximal edge of First entry from different groups.

Involving the aortic valve	Cases	The position of proximal edge of First entry, mm	P value
No	78	38.09 ± 35.42	
Yes	36	-3.52±35.65	<0.001

Table 4 Propagation distance from the groups with different genders.

	male	female	P value
Cases	76	38	
Proximal propagation distance, mm	15.28 ± 10.25	± 13.45 ± 9.53	0.358
Distal propagation distance, mm	335.75 ± 171.51	± 319.28 ± 194.96	0.645

Table 5 Rotation of dissection from different groups.

Rotation	Multiple entries cases	Few-entry cases	P value
Yes	37 (75.51%)	22 (33.85%)	
No	12 (24.49%)	43 (66.15%)	<0.001

Table 6 Measuring result of the investigation of the ascending aorta dissection.

	Value	%
Sex (male)	76	66.70%
Aorta measurements(mm)		
Length	85.60±11.41	
D0	36.80±8.34	
D1	33.16±8.72	
D2	29.70±5.12	
D3	30.54±6.99	
R	61.07±8.09	
Entry measurements		
Middle position, mm	43.23±35.41	
Proximal-edge position, mm	35.34±35.43	
Shape fusiform	111	64.53%
Triangle	33	19.19%
Trapezoid	7	4.07%
irregular	21	12.21%
Dissection measurements		
Proximal extend, mm	15.49±9.65	
Distal extend, mm	330.26±178.97	
Valve involved	36	31.58%
Branches involved	69	60.53%
Rotate	59	51.75%
Rotate clockwise	12	20.34%
Rotate anticlockwise	47	79.66%
TID at the narrowest site, mm	16.93±9.67	
TID at the first entry site, mm	30.15±12.17	

Values are n, % (n/N), or mean±SD.

TID=true lumen diameter

D0-D3=the true lumen diameters of the ascending aorta on the four different measuring sites

Dissection

The number of patients with retrograde propagation was 103 (90.35% of the total number of patients; mean retrograde extending distance, 15.49 ± 9.65 mm). A total of 113 (99.12%) patients had distal extension. In the 69 (60.53%) patients with three involved branch arteries, the mean distal extending distance was 441.40 ± 101.13 mm, while it was 159.85 ± 131.86 mm in the remaining patients (Table 2). A total of 36 (31.58%) patients had an aortic valve in which the proximal edge position of the first entries was -3.52 ± 35.65 mm (Table 3). In the men (76 patients), the distal extending distance of dissection was 335.75 ± 171.51 mm, while in the women (38 patients) it was 319.28 ± 194.96 mm (Table 4). At the narrowest site, the true mean lumen diameter was 16.93 ± 9.67 mm; at the first entry position, it was 30.15 ± 12.17 mm.

Dissection rotation

A total of 59 patients (51.75%) had dissection rotation: 22 (33.85%) with few entry points and 37 (75.51%) with multiple entry points (Table 5). The results are presented in Table 6.

DISCUSSION

Ascending aortic dissection is a life-threatening emergency that requires timely surgery to reduce mortality rates. The mortality rate of the patients who

underwent timely surgery was 26.9%, while that of patients who receive drugs only was as high as 56.2% (8). The assessment of the morphological features of dissection through preoperative imaging plays an important role in guaranteeing surgical success (9). Determining how to quickly obtain more detailed dissection characteristics through imaging data is especially important. Recent morphological studies on ascending aortic dissection tended to be more focused on the ascending aorta's diameter, area, and volume in different positions. To our knowledge, no comprehensive study to date has focused on ascending aorta diameter, curvature, and entries and dissection location and morphological features. Moreover, the endovascular treatment of type B dissection, which has been confirmed to have the advantages of low mortality and complication rates, has been successfully developed. Previous studies (5, 9) have demonstrated that endovascular treatment may be feasible and lead to better clinical results in this short region of the ascending aorta. The specific anatomical location of the ascending aorta makes endovascular procedures challenging. Hence, a preoperative comprehensive investigation of dissection characteristic guarantees surgical success.

Aorta, entry, dissection, and rotation morphological method of describing ascending aortic dissection

Using aortic dissection measurements of 114 patients, the aorta, entry, dissection, and rotation (AEDR) method was developed to describe the ascending aortic dissection features in greater detail. In this method, the four elements (aorta, entry, dissection, and rotation) of this disease are described separately. The measurement of the ascending aorta's length L, four diameters D0–D3 at different locations, and radius of curvatures F and R, which were calculated based on F, were the main focal points. For entry, quantity, position (proximal edge, center position), and orientation were considered. The elements of the description for dissection include retrograde extending distance, distal extending distance, aortic valve, the three branch arteries, the true and false lumen diameters at the first entry site, and the narrowest location. For the description of dissection moving, the rotation of dissection was considered. The advantages of this approach included its usefulness for obtaining all of the morphological characteristics of dissection and the increased convenience of combining a larger amount of data and streamlining unnecessary data. The following points require consideration:

1. For Curvature measurement. In previous studies, there was no standard or representative method of measuring curvature. There are three main methods: (A) Borsa et al. (10) utilized different values between $\angle bc$ and $\angle ab$, which were formed using three lines (a, b, c) to express the angle of the descending aortic arch segment. This method was not used for the ascending aorta. (B) The circle method is commonly used worldwide. In this method, the middle of the aortic arch was measured, a circle was drawn around the contour of the aorta, and the radius of the circle was measured (11). Alternatively, the curvature of the aortic arch was quantified by calculating the arithmetic mean of the lesser curve radius of the curvature and the greater curve radius of the curvature at the level of the primary intimal tear (12). However, this approach ignores the changing morphological characteristics of the aortic arch since many aortas after dissection are not regularly curved. (C) Poullis et al. (13) defined the angle between the plane perpendicular to the aortic valve and the plane perpendicular to the cross-section at the origin of the innominate artery. Based on the above measurement methods, the representative original new aortic curvature was utilized in the present study. The formula $R = (180 \cdot L) / (F \cdot \pi)$ was used to calculate the radius of curvature R to indicate its value, but the R value alone has no real meaning since it compares only the curvatures of the different ascending aortas. The advantage of this method is that R is calculated based on F but not from the measurement.

2. Shape of the entry. A few studies focused on entries. Most focused attention on quantity, size, and position (14, 15). However, no study investigated shape. In this study, multislice spiral CT scans were imported into the workstation

and three-dimensional reconstruction was achieved. A plane perpendicular to the centerline of the aorta from the proximal to distal part was screened on the layers of the 0.5-mm-thick scan. In this manner, the initial appearance of the entries and the changes in the characteristics were observed. The entries can be attributed to three shapes: fusiform, triangle, and trapezoid. Fusiform was defined as it appeared from a point to the end of the disappearance also in the form of a point (Fig. 3A); triangle was defined as it initially appeared as a point which widened on one side after the sudden disappearance or in reverse (Fig. 3B); and trapezoid was defined as it suddenly appeared in the form of a side and disappeared in the same form (Fig. 3C). In addition to these three shapes, there is an irregular-shaped entry, whose features are difficult to describe.

Ascending aorta

There is nearly no difference between the length of the ascending aorta (from the coronary artery to the innominate artery) obtained in the present study and a previous study showing a length of 85 mm (14). From the beginning to the end of the ascending aorta, its diameter gradually reduces in line with normal changes in aortic tapering (6). The diameter of the ascending aorta in different parts measured in the present study was generally less than that reported by Rylski et al. (16) One possible reason is that their patients were mainly Caucasians (54/62, 87.1%) and only two were Asians, which also shows the obviously different sizes of the ascending aorta between the two ethnic groups. The radius of curvature of the ascending aortic dissection was much larger than that in the healthy subjects group (Table 1, $P < 0.05$). Smaller radius values represent more severe aortic curvature. The aorta after dissection is straighter than that in patients in the healthy subjects group. However, no relevant data are available regarding whether the morphological changes of the ascending aorta are affected by the presence of dissection or the ascending aortas are originally relatively straight before dissection. However, studies have indicated that a straighter aorta can help reduce the vertical stress on the aortic wall. Curvature has been confirmed as an independent risk factor for ascending aortic dissection (13). Hence, in the process of dissection, whether congenital aortic anatomical factors play an important role requires further study, and it is not sufficient for the study to focus solely on the morphological changes in diameter.

Entry

Overall, nearly 60% of patients had a few entry points ($n \leq 2$). With regard to entry shape, fusiform accounted for a majority (64.53%), followed by the triangle (19.19%) and the irregular shapes; trapezoidal entries were rare. Orientation was mainly around the 10 o'clock and 1–2 o'clock positions. Both are located in the greater curvature of the aorta, which also implies that the impact of the bloodstream may be the most severe here.

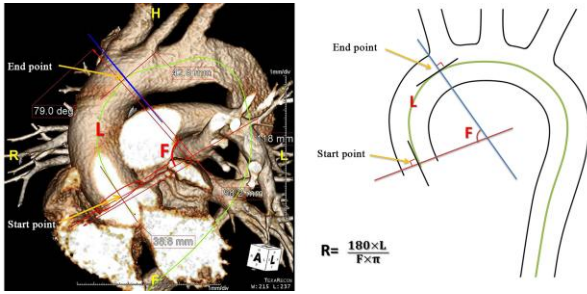


Figure 1 Illustration of the predefined radius of curvature. R was calculated based on the F which is measured between the perpendicular to the plane at the start and the end points and the length of ascending aorta. Smaller values of radius represent more severe aortic curvature.

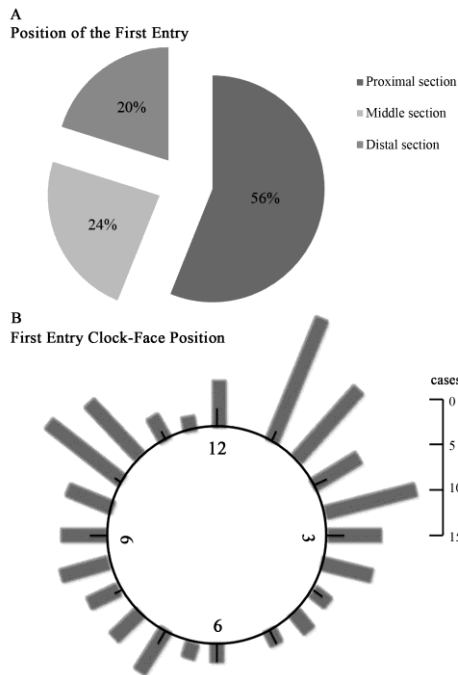


Figure 2 (A) Positions of the first entry distributed in the three sections of the ascending aorta; (B) O'clock-face positions of the first entry, it demonstrates that entries mostly happen around 1 to 2 O'clock and 10 O'clock orientation.

The mean center position of the entries was about 40 mm distal to the coronary artery, and it was away from the aortic sinus. However, in patients with aortic dissection involving the aortic valves, the proximal edge of the entries was -3.52 ± 35.65 mm, while that in patients without aortic valve involvement was 38.10 ± 35.42 mm. This shows that the closer the position of the proximal entry to the aortic sinus, particularly when the proximal edge is near the aortic sinus, the

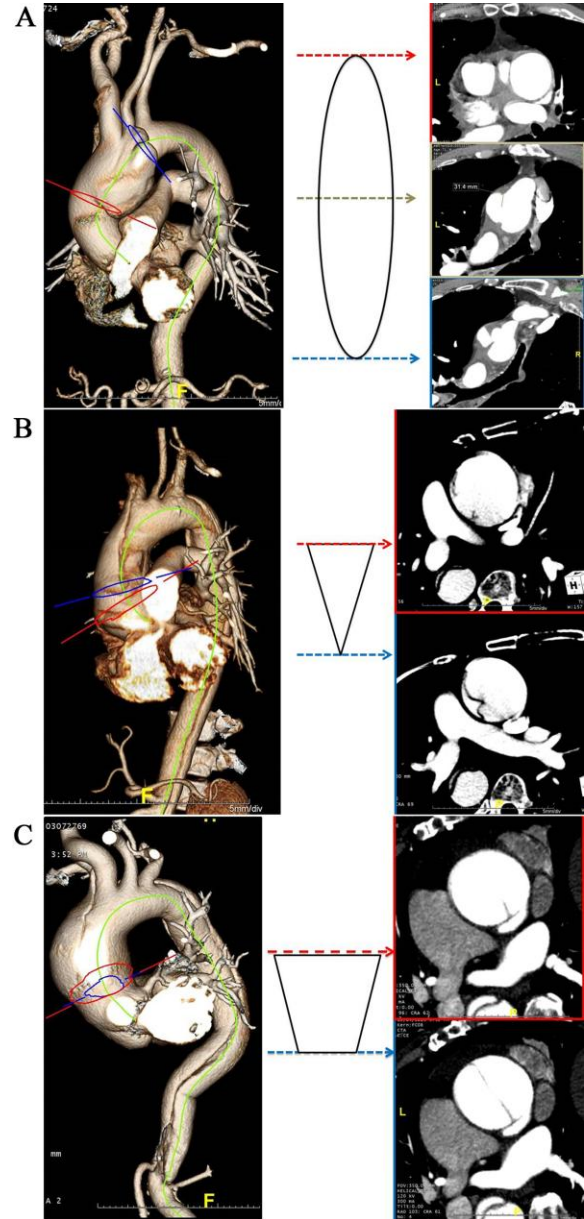


Figure 3 Illustration of the fusiform (A), triangle (B), and trapezoidal (C) shapes. Red plane shows the proximal edge of the first entry, and the blue one indicates the distal edge. Gray plane shows the middle site of the entry.

dissections commonly involve the aortic valve (Table 3). The current prerequisite for endovascular treatment of an ascending aortic dissection is that the landing zone be > 20 mm (16). Although the transcatheter aortic valve implantation procedure has already been used in the endovascular treatment of severe aortic regurgitation, the two methods involved in the treatment of ascending aortic dissection have yet to be combined.

Dissection

In patients with ascending aortic dissection, retrograde propagation is very common (86.84%), but the distance is short (15.49 ± 9.65 mm), which may be related to the length of the ascending aorta. Distal extension occurred in a majority (97.37%) of patients, indicating that the ascending aortic dissection easily extends distally. It often propagates distally to a farther distance; hence, whether it involves important branches of the aorta (such as the celiac trunk, superior mesenteric artery, and renal artery) should be considered prior to surgery. In cases involving the three branches, the dissections usually extend distally to the iliac artery; in other cases, the mean distance was <160 mm. There was a statistically significant difference (Table 2). Among the sexes, the mean distal extending distance of the dissection of the male group was longer, but there was no significant difference (Table 4). At the first entry site, no obvious differences were found between the true and false lumen diameters. The true lumen diameter was smaller than that obtained by Huang et al. (14) (30.15 vs 37.6 mm), which was related to the different groups between them, but a smaller stent device was needed for Chinese people with ascending aortic dissection. The true and false lumen diameters were different apparently at the narrowest site. Hence, caution must be exercised when the catheter system is passed through this part.

Rotation of dissection

For description of dissection moving, the significant

differences were found in the occurrence of dissection rotation between multiple entries cases and the few-entry cases (Table 5). Dissections with multiple entries often vertically extend in the distal direction, while cases with few entry points usually extended straight. This finding indicates the different propagation characteristics in cases with different numbers of entries. It is possible that more entries provided more different propagation directions, although it is likely associated with the changes of hemodynamics.

For ascending aortic dissection, the use of endovascular treatment remains exploratory. However, the minimal invasiveness, low mortality rate, and low incidence of complications due to endovascular treatment are incomparable to open surgery, which indicates its great potential and prospective use. Surgeons could extract more details of aortic morphological data preoperatively using the AEDR description method, which would benefit the operation strategy establishment; however, many great future challenges remain to be overcome.

This comprehensive and detailed study of the morphology of the ascending aortic dissection is the first to examine worldwide data. This study reported the morphological features of the ascending aorta after dissection and the correlations among dissections, entries, and related factors. In addition, the AEDR description method is more conducive for enabling comprehensive and convenient access to relevant morphological data.

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