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Segmental analysis of the ascending aorta: Definition of normality and classification of aortic dilatation

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Summary

To better define and classify ascending aortic abnormalities, we adapted the left ventricular dynamic segmental analysis concept to the ascending aorta. Ascending aortic diameters were measured from contrast aortography in 18 normal subjects at the aortic valve (level 1), and 2, 4, and 6 cm above the aortic valve (levels 2, 3, and 4). Diameters greater than two standard deviations (SD) above the mean normal values at any levels were considered abnormal. Aortograms of 102 consecutive patients with abnormal aorta were analyzed. Three patterns of aortic dilatation were identified: I (n=55), the largest aortic diameter was at level 2 (normal pattern); II (n=39), the aortic diameters increased from levels 1 to 4; III (n=8), all aortic diameters were greater than 2 SD above the mean normal values and increased from levels 1 to 4. Segmental analysis of the aorta provides an objective comparative basis for definition and classification of aortic dilatation and aneurysm.

Key words

Aorta-segmental analysis Aortic diameters Aortic dilatation

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Introduction

Dilatation of the ascending aorta, a well recognized abnormality, may be associated with serious complications[1~15]. The size and shape of the ascending aorta in normal humans and the architectural changes which occur in disease states have not been well classified. Terms such as aortic dilatation, aortic aneurysm, or poststenotic dilatation have been used without precise quantitative definition[2,16~24]. The present study was undertaken to define the size and shape of the normal ascending aorta, contrast these dimensions with the dilated ascending aorta in patients with wide spectra of underlying heart disease, and develop a classification of aortic dilatation based on quantitative segmental analysis.

Materials and methods

Eighteen normal subjects, whose ages ranged from 40 to 50 years (mean age 46±3.4 years), were studied (**Table 1**). Patients without hypertension, coronary artery disease, valvular disease, left ventricular functional or structural abnormalities, and cardiovascular disease of connective tissue origin were considered normal subjects[25]. All normal subjects underwent diagnostic cardiac catheterization for the evaluation of chest pain and proved to have normal coronary arteries.

One hundred and two patients, whose ages ranged from 19 to 80 years (mean age 58±23), and who had dilatation of the ascending aorta as defined below and underwent diagnostic cardiac catheterization with angiography, constituted the patient study group. The cardiovascular diagnoses of the patients are presented in **Table 2**. Sixteen patients had aortic stenosis, 22 aortic regurgitation, 12 coronary artery disease, 10 congenital heart diseases, two cardiovascular disease of connective tissue origin, 14 aortic stenosis plus coronary artery disease, 11 aortic regurgitation plus coronary artery disease, and 15 arterial hypertension plus coronary artery disease.

For the purpose of this study, aortic stenosis

Table 1. Demographic and hemodynamic characteristics of normal subjects

Males		8
Females		8
Age (years)		46±3.4
Aortic pressures (mmHg):	Systolic	121±18
	Diastolic	71±10
	Mean	89±12
LV pressures (mmHg):	Systolic	130±20
	Diastolic	7.4±4
RV pressures (mmHg):	Systolic	28.3±6
	Diastolic	4±2
Mean wedge pressure (mmHg)		10.5±2.9
Ejection fraction (%)		67±10
Stroke volume (cm^3)		90.1±20.1

LV=left ventricular; RV=right ventricular.

Table 2. Underlying cardiovascular diagnoses of patients with aortic root dilatation

Group	I (n=55)	II (n=39)	III (n=8)
Aortic stenosis	8(15%)	8(21%)	
Aortic regurgitation	15(27%)	6(15%)	1
Coronary artery disease	7(13%)	5(13%)	
Aortic stenosis plus coronary artery disease	8(15%)	6(15%)	
Aortic regurgitation plus coronary artery disease	5(9%)	4(10%)	2
Coronary artery disease plus hypertension	7(13%)	8(21%)	
Congenital heart disease	5(9%)	2(5%)	3
Connective tissue disorder			2

was defined as an aortic valve area $>1.0\,cm^2$ (based on hemodynamic studies); aortic regurgitation was defined angiographically. Coronary artery disease was defined as coronary artery luminal narrowing $\geqslant$70% (50% diameter narrowing) in one or more of the major coronary arteries as demonstrated by selective coronary arteriography. Arterial hypertension was defined as systolic arterial pressure $\geqslant$150 mmHg and/or diastolic arterial pressure $\geqslant$90 mmHg or patients who were treated with antihypertensive drugs[26].

Procedures:

Aortography was performed in the 60° left anterior oblique projection; 30~40 m*l* of Hypaque® 90% was injected within two to three sec into the root of the aorta two~three cm above the aortic valve. A 35 mm film was obtained at a speed of 60 frames per second. Left ventriculography was performed in the 30° right anterior oblique projection; 0.7 m*l*/kg Hypaque® 90% was injected within three to four sec. A 35 mm film was obtained at a speed of 60 frames per second[25].

Quantitative method:

The silhouette of the first 8 cm of the ascending aorta in the left anterior oblique projection aortogram, and in the right anterior oblique projection (obtained from the left ventriculogram) were outlined[25,26] (**Fig. 1**). Frame-by-frame analysis was obtained for each angiogram to define the end-systolic and end-diastolic frames. The internal diameters of the ascending aorta in end-systole and end-diastole were determined at four different levels. The first diameter was at the aortic valve orifice level. The second, third, and fourth levels were defined by three lines parallel to the first aortic diameter; the space between each line was 2 cm. All the diameters measured by the same investigator, were corrected for magnification and body surface area and were expressed in cm. From these measurements it became obvious that the shape of the ascending aorta did not change from systole to diastole; thus, only the systolic diameters were used for further analysis.

Aortic dilatation was diagnosed when at least one of the four diameters of the ascending aorta was greater than two standard deviations above the mean values obtained from the normal subjects. Patients with aortic dilatation (as defined above) were subdivided into three groups according to the shape of the ascending aorta

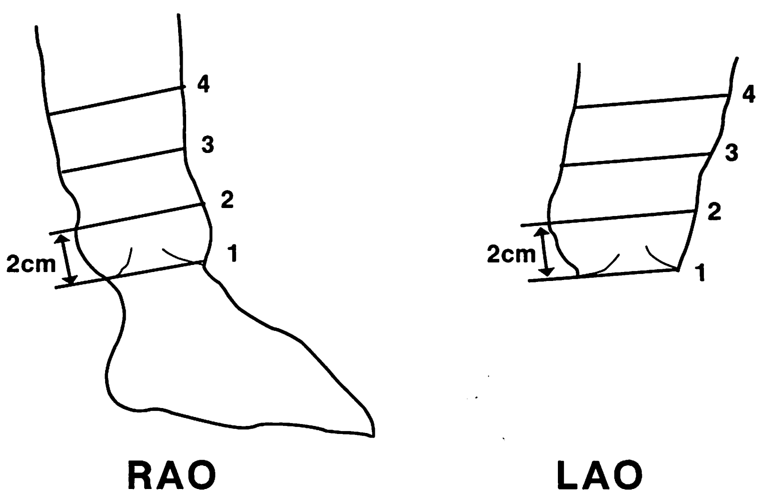

Fig. 1. Silhouettes of the ascending aorta in the right anterior oblique (RAO) **and left anterior oblique** (LAO) **projections.**

Lines indicate the levels at which aortic diameters were measured.

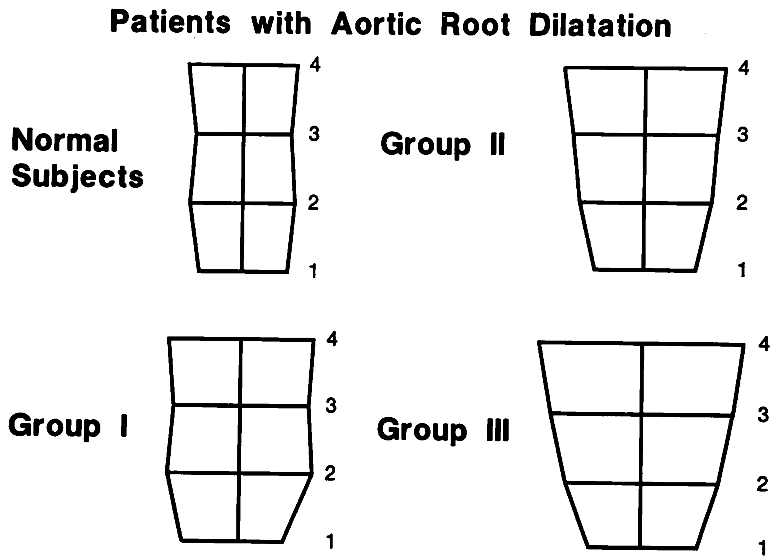

Fig. 2. Morphologies of the ascending aorta in normal subjects and patients with aortic root dilatation as reconstructed from the measurements of the aortic diameters.

Table 3. Aortic root diameters of normal subjects and patients with aortic root dilatation

	Normal subjects		Patients with aortic root dilatation					
			Group I		Group II		Group III	
	RAO	LAO	RAO	LAO	RAO	LAO	RAO	LAO
I	1.40±0.25	1.38±0.20	1.69±0.38	1.83±0.51	1.63±0.23	1.68±0.22	1.88±0.32	1.91±0.32
II	1.81±0.35	1.90±0.29	2.38±0.50	2.64±0.54	2.14±0.38	2.32±0.32	2.76±0.41	3.20±0.42
III	1.49±0.22	1.61±0.22	2.17±0.46	2.45±0.58	2.45±0.36	2.52±0.28	3.10±0.22	3.81±0.32
IV	1.52±0.25	1.67±0.27	2.35±0.48	2.58±0.53	2.59±0.37	2.82±0.27	3.80±0.32	4.60±0.30

RAO=right anterior oblique projection; LAO=left anterior oblique projection.

(**Fig. 2**); *group I*: the greater aortic diameter was at level 2; *group II*: the aortic diameters increased from levels 1 to 4; *group III*: all the aortic diameters were greater than two standard deviations compared to mean normal values and increased from levels 1 to 4 (**Table 3**).

Statistical evaluation was performed using analysis of variance and the Student's t test[27].

Results

The demographic and hemodynamic characteristics of patients with aortic root dilatation are shown in **Table 4**.

1. Aortic diameters in normal subjects:

The mean value±1 standard deviation of the ascending aortic diameters are shown in **Table 3** and **Fig. 3**. The mean value for the systolic aortic diameter in the right anterior oblique projection at level 1 was 1.4±0.25 cm/m², while it was 1.81±0.35 cm/m² at level 2. As in **Table 3**, the systolic aortic diameter at level 2 was greater compared to the diameters at levels 1 and 3 ($p<0.01$) and level 4 ($p<0.05$); the diameters at levels 2, 3, and 4 were significantly

Table 4. Demographic and hemodynamic characteristics of patients with aortic root dilatation

Groups		I	II	III
Age (years)		64±9	58±17	38±20
Sex		38 M/17 F	20 M/19 F	6 M/2 F
Aortic pressures (mmHg):	Systolic	130.5±26	139.2±23.2	136±27.1
	Diastolic	67.1±13	98.8±11.7	70.1±11.2
	Mean	93.7±17	97.28±19.9	94.1±19.1
LV pressures (mmHg):	Systolic	145.2±24	141.3±23	146±17
	Diastolic	18.2±11	20.5±13.9	20.8± 8.7
RV pressures (mmHg):	Systolic	35.2±11.2	43.4±14.2	28.2±10
	Diastolic	7.9± 3.1	9.7± 2.9	6.11± 4.1
Mean wedge pressure (mmHg)		13.8± 2.2	18.6± 6.3	11.2± 7.1
Ejection fraction (%)		65±0.31	54±0.28	60±0.24
Stroke volume (cm^3)		80.1±16.2	69.2±12.2	58.2

LV=left ventricular; RV=right ventricular.

greater compared to diameters at level 1 ($p<0.01$); there was no difference between level 3 and 4 diameters.

The mean systolic diameters in the left anterior oblique (LAO) projection at level 2 were 1.9 ± 0.29 cm/m^2 and significantly greater compared to the diameters at levels 1 and 3 ($p<0.005$); the systolic diameter at level 1 was shorter compared to the diameters at levels 3 and 4 ($p<0.01$); there was no difference between the level 3 and 4 diameters. The systolic diameters at levels 1 and 2 obtained in the right anterior oblique (RAO) projection (not shown in **Table 3**) were not different compared to the diameters at levels 1 and 2 obtained from the left anterior oblique projection. The systolic diameters at levels 3 and 4 obtained from the left anterior oblique projection were greater when compared to diameters 3 and 4 obtained from the right anterior oblique projection ($p<0.02$).

2. Systolic aortic diameters in patients with dilatation of the ascending aorta (Table 3, Fig. 3):

1. Group I: The greater aortic diameters in this group were at level 2 (sinus of Valsalva). The mean systolic aortic diameters in the right anterior oblique projection are shown in **Table 3**, and the systolic aortic diameters at level 1 were significantly shorter compared to the diameters at levels 2 and 3 ($p<0.001$), and level 4 ($p<0.05$). There was no difference between the diameters at levels 3 and 4. The mean systolic aortic diameters in the left anterior oblique projection at level 1 were 1.83 ± 0.51 cm/m^2 (**Table 3, Fig. 3**), and were significantly less compared to the diameters at levels 2, 3, and 4 ($p<0.001$). There was no difference between the diameters at levels 3 and 4.

2. Group II: The diameters in this group increased from levels 1 to level 4 (**Table 3, Fig. 3**). The mean systolic aortic diameters in the right anterior oblique projection were 1.63 ± 0.23 cm/m^2 at level 1, and they were significantly shorter ($p<0.001$) compared to the diameters at levels 2, 3, and 4. The systolic diameters at level 4 were greater compared to the diameters at levels 2 and 3 ($p<0.005$ and <0.05, respectively). The aortic systolic diameters at level 3 were greater compared to the diameters at levels 2 ($p<0.05$). The mean systolic aortic diameters in the left anterior oblique projection were 1.68 ± 0.22 cm/m^2 at level 1, and were less compared to the diameters at levels 2, 3, and 4 ($p<0.001$) (**Table 3**). The systolic aortic diameters at level 4 were greater compared to

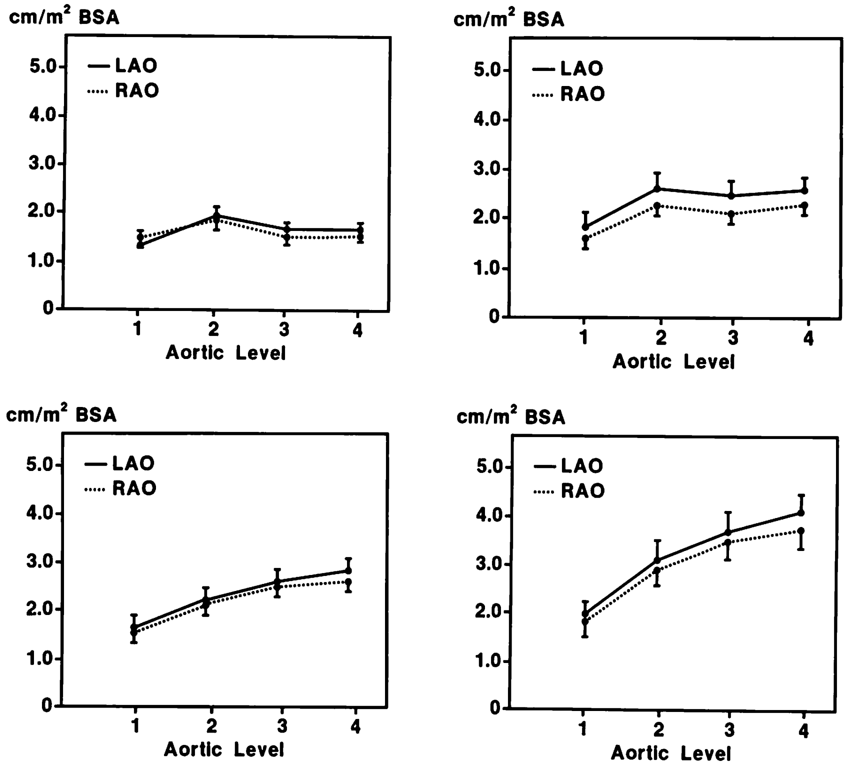

Fig. 3. Aortic diameters in normal subjects in the left anterior oblique (LA⇨) **and right anterior oblique** (RAO) **projections at 4 different levels above the aortic valve** (upper left), **and aortic diameters in patients with aortic root dilatation** (Group I upper right, Group II lower left, and Group III lower right) **in the LAO and RAO projections at 4 different levels above the aortic valve.**

BSA = body surface area.

the diameters at levels 2 and 3 ($p<0.02$ and <0.005 respectively). The systolic aortic diameters at level 3 were greater compared to the diameters at level 2 ($p<0.05$).

3. Group III: In this group all of the aortic diameters were greater than 2 standard deviations above the mean normal diameters and increased from level 1 to 4 (**Table 3, Fig. 3**). The mean systolic aortic diameters in the right anterior oblique projection were 1.88 ± 0.32 cm/m^2, and significantly shorter compared to the diameters at levels 2, 3 and 4 ($p<0.01$). The systolic aortic diameters at level 4 were greater compared to the diameters at levels 2 and 3 ($p<0.01$). The systolic aortic diameters at level 3 were greater compared to the diameter at level 2 ($p<0.05$). The mean systolic aortic diameter in the left anterior oblique projection at level 1 was 1.91 ± 0.32 cm/m^2, and it was less compared to the diameters at levels 2, 3 and 4 ($p<0.01$ and <0.05 respectively). The aortic diameters at level 3 were greater compared to the diameters at level 2 ($p<0.05$).

Discussion

Segmental analysis of the left ventricular silhouettes in systole and diastole may reveal significant diseases even in patients with normal left ventricular size and overall left ventricular systolic performance[28]. Thus, segmental analysis in certain cases is necessary to define the presence or absence of abnormalities. The definition and classification of abnormalities in the ascending aorta, however, have been based purely on the morphology and objective criteria and not on careful subjective measurements[2,16~24,29~33].

Hirst et al.[2] defined aortic aneurysm "as a dilatation of an artery". In 1961, Ellis, Cooley, and DeBakey[16] reported dilatation of the aortic root ring and ascending aorta in patients without features of the Marfan syndrome or other known changes of aortic dilatation and originated the term "annuloaortic ectasia". Eisen and Eliot[17] described aortic aneurysm in patients with cystic medial necrosis of the ascending aorta as "symmetric or asymmetric dilatation of the ascending aorta". Keene et al.[18] described their angiographic findings in patients with aneurysm as follows: "The aortogram in all patients showed the typical enlargement of the aortic root and ascending aorta.... Aneurysms varied considerably in size, and the size of aneurysms alone did not determine the type of X-ray configuration in most cases". Mintz et al.[19] using cross-sectional echocardiography measured the aortic diameters at the aortic valve level, above the sinus of Valsalva and at the descending aorta in a study where the echocardiograms were used to define aneurysm of the descending aorta. DeMaria et al.[20] compared echocardiographic and angiographic aortic diameters in normal subjects and patients with aortic aneurysm at one single level and defined aortic aneurysm as "a localized dilatation of the aortic wall". Lemon and White[21] studied patients with angiographically diagnosed annuloaortic ectasia and patients with aortic insufficiency. They measured only the maximal aortic diameter which was greater in patients with annuloaortic ectasia (7.6 ± 2.4 cm) as compared with patients with aortic insufficiency (4.2 ± 0.6 cm). Godwin[23] using computed tomography defined 40 mm as the upper normal limit of an aortic diameter in the ascending aorta and about 30 mm of the aortic diameter in the descending; any excess over these measurements was considered aneurysmal. Lindsay, DeBakey, and Beall[24] described aneurysms as fusiform and saccular. "In the former, circumferential dilatation, a result of a diffuse area of weakness, produces a spindle-shaped deformity. In the latter, balloon-like dilatation occurs, beginning at a narrow neck. Many aneurysms are not pure examples of either".

The diameters of the ascending aorta in normal subjects at the level of the aortic valve and at the level of the sinus of Valsalva reported previously are similar compared to the diameters of the present study. The normal values for the aortic diameters at levels 3 and 4, however, have not been defined previously. In the present study the normal diameters for the ascending aorta at 4 different levels have been defined. These values should be used to define an abnormality in disease states. Any value greater than 2 standard deviations above the normal mean valves at any levels should be considered abnormal. Such comparisons will help to define minor degrees of aortic abnormalities, and to better classify aortic dilatation. This segmental analysis has helped us to define three distinct types of aortic dilatation (**Fig. 2**).

Type I: the greatest aortic diameter was at level 2 (2 cm above the aortic valve). The shape of the ascending aorta is similar to the normal aorta (normal pattern) in this type of aortic dilatation. Aortic regurgitation was the most common underlying cardiovascular abnormality in this type of aortic dilatation (**Table 2**).

Type II: the aortic diameters increased from the aortic valve level, to level 4. The shape of the ascending aorta in this type of dilatation differed from the normal aorta (diffuse symmetric dilatation). Aortic stenosis was the most common underlying cardiovascular abnormality in this type of aortic dilatation (**Table 2**).

Type III: all the aortic diameters were 2 standard deviations above the normal mean values and increased from level 1 to level 4 (saccular aneurysm).

Although aortic regurgitation was more common in type I dilatation and aortic stenosis was more common in type II dilatation, the type of aortic dilatation cannot be predicted from the underlying cardiovascular disease. The present study demonstrated, however, that approximately 60% of the patients with aortic dilatation had aortic valvular disease (30% aortic stenosis, 30% aortic regurgitation), 15% had arterial hypertension, 12% had atherosclerotic cardiovascular disease, and 8% had other cardiovascular disorders.

Present technologies including magnetic resonance imaging permit accurate imaging of the aortic silhouette[34~36]. Segmental analysis of the aorta with quantitative definition and classification of ascending aortic dilatation should lead to more precise nosology in ascending aortic disease.

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