Aortic distensibility in post-stenotic aortic dilatation: The effect of co-existing coronary artery disease

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Summary

Aortic distensibility is decreased in patients with coronary artery disease (CAD) and the angiographically normal aorta. To determine if the same is true in patients with aortic stenosis and post-stenotic dilatation, two groups were studied. Group A consisted of 15 patients with post-stenotic aortic dilatation and normal coronary arteries, and group B, 14 patients with post-stenotic aortic dilatation and CAD. The patients were compared to 18 normal subjects. The area of the first 6 cm of the aorta above the valve obtained by aortography was planimetered and the mean diameters were calculated. Distensibility was calculated using the formula:

$$\text{Distensibility} = \frac{2 \times (\text{changes of the aortic diameter})}{(\text{diastolic aortic diameter}) \times (\text{changes of the aortic pressure})}$$

Distensibility was greater in group A ($2.5 \pm .4$ cm². dynes^{-1}) compared to group B ($1.0 \pm .8$ cm². dynes^{-1}, $p < 0.001$). Distensibility in normal subjects reported recently from this laboratory ($3.4 \pm .4$ cm². dynes^{-1}) was greater compared to both groups A and B ($p < 0.001$). Thus, distentibility was decreased in patients with post-stenotic aortic dilatation. The further decrease in distensibility in patients with co-existing coronary artery disease may be partially related to abnormal nutrition of the arterial wall since the vasa vasorum of the ascending aorta are derived from the coronary arteries.

Introduction

Recently it has been demonstrated that distensibility of the ascending aorta in patients with coronary artery disease (CAD) and the angiographically normal aorta is significantly decreased when compared to that of the normal subjects[1]. It was hypothesized that CAD alters aortic distensibility not only in patients with the angiographically normal aorta but also in patients with the angiographically abnormal aorta. The present study was undertaken to test this hypothesis in patients with post-stenotic aortic dilatation secondary to aortic stenosis.

Material and methods

Twenty-nine consecutive patients (age 35 to 79 years) with valvular aortic stenosis and dilatation of the ascending aorta who underwent diagnostic cardiac catheterization were studied. Aortic dilatation was defined when aortic diameters at any levels were 2 standard deviations above the normal mean values (see below). Fifteen patients (9 male, 6 female) had normal coronary arteries (group A), and 14 patients (8 males, 6 female) had CAD (group B). For the purpose of this study, aortic stenosis was defined when the aortic valve area was $< 1.0 \, cm^2$; patients with significant aortic regurgitation were excluded prior to an entry into the study. Coronary artery disease was diagnosed when luminar narrowing $\geq 70\%$ ($\geq 50\%$ diameter narrowing) in one or more of the major coronary arteries was present. Nine patients (60%) from group A and 9 patients (65%) from group B were treated with nitrates, 8 patients (55%) from group A and 7 patients (50%) from group B were treated with digitalis, 3 patients (20%) from group A and 3 patients (22%) from group B were treated with β-blockers and 2 patients (13%) from group A and 2 patients (14%) from group B were treated with calcium channel blockers. Thus, therapy was similar in both groups.

Aortic pressures were measured before the injection of any contrast materials using fluid-filled catheters with a P23Db Statham-transducer and were recorded on photographic paper on Electronics for Medicine CR-12 or Hewlett-Packard 8800 recorder[2]. Left ventriculography was performed immediately after aortic pressure recordings and before coronary arteriography, with the injection of 0.7 ml/kg Hypaque 90% within 2–3 sec in the right anterior oblique and lateral projections; 35 mm films were obtained with a speed of 60 frames/sec. Left ventricular volumes were calculated from the single plane right anterior oblique ventriculography using the area-length method[3]. Segmental analysis of the left ventricular wall was performed using the method of Leighton et al[4]. Left ventricular ejection fraction was calculated from the left ventricular end-diastolic and end-systolic volumes obtained from ventriculography.

The silhouette of the first 8 cm of the ascending aorta at end-systole was outlined from the right anterior oblique projection ventriculography during the first or second sinus beat, using a Tagarno 35 CX projector (**Fig. 1**). Aortic diameters were obtained at four different levels. The first aortic diameter was obtained at the aortic orifice level. Three parallel lines to the first diameter were drawn with a distance of 2 cm between each line. The diameters were corrected for magnification. Aortic dilatation was defined when any of the aortic diameters was 2 standard deviations above the normal mean values.

Normal values obtained from 18 normal subjects (age 40 to 50 years) who underwent diagnostic cardiac catheterization for evaluation of chest pain and proved to have normal coronary arteries, normal left ventricular diastolic volumes, ejection fraction, wall motion and wall thickness. None of the normal subjects had any evidence of myocardial, valvular, or congenital heart disease or arterial hypertension. The normal aortic diameter ± 1 SD at levels 1, 2, 3 and 4 were $2.6 \pm .3$, $3.7 \pm .1$, $3.1 \pm .1$ and $3.2 \pm .2 \, cm$, respectively.

The area of the aorta between the first and fourth diameter was measured by planimetery;
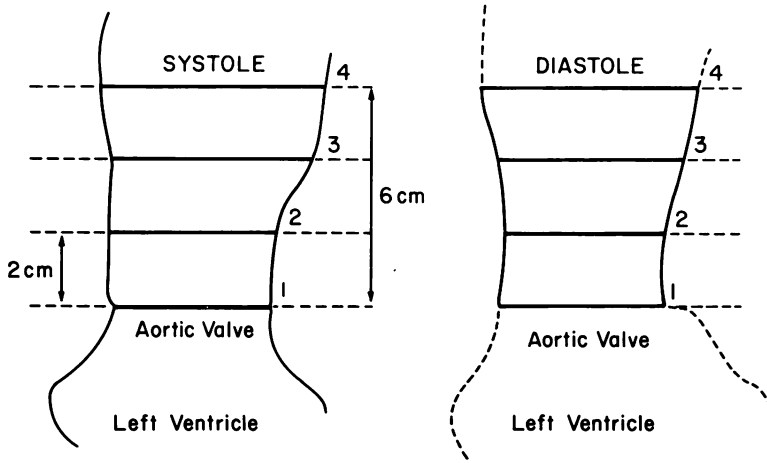
Fig. 1. Left ventricular end-diastolic and end-systolic frames.
The lines indicate the levels where aortic diameters were measured.

from the area the mean aortic diameters (systolic and diastolic) were calculated. Aortic distensibility was calculated from the mean aortic diameters (planimetry) and the changes of the aortic pressures.

Elastic properties of the wall of blood vessels are usually expressed by Young's modulus and can be obtained by the formula:

$$E = \frac{\triangle p}{\triangle de} \times \frac{2de \cdot di^2 \; (1 - \sigma^2)}{de^2 - di^2} \quad \text{where}$$

E=elastic modulus, p=changes of intravascular pressure, de=changes of the external diameters of the vessel, di=changes of the internal diameters of the vessel, σ=a constant with a value for blood vessels of approximately 0.5, as can be obtained from the Poisson's formula. Distensibility of the blood vessels is related to elastic modulus and can be obtained by the formula:

$$\text{Distensibility} = \frac{1}{E \, (h/d)} \quad \text{where}$$

h is the thickness of the vessel and d is the diastolic diameter of the vessel. In vessels with thin walls in relationship to lumen, as is the aorta, distensibility can be obtained using the formula:

$$D = \frac{2 \triangle d}{d \triangle p} \quad {}^{1,5 \sim 10)}$$

(also see Appendix).

Statistical analysis was performed using analysis of variance and Student's t test[11].

Results

The demographic and hemodynamic data for patients with post-stenotic aortic dilatation with and without CAD are shown in **Table 1**.

Aortic diameters and distensibility in groups A and B

Systolic aortic diameters at levels 1, 2, 3 and 4 for both groups are shown in **Table 2**. Systolic aortic diameters were not different between the two groups.

In group A the mean (planimetry) systolic aortic diameter was 3.84±0.5 cm, and the mean diastolic aortic diameter was 3.67±.05 cm. The change of the mean aortic diameter (from diastole to systole) was .17±.1 cm (**Table 2**). The change of aortic pressure (from diastole to systole) was 50.0±21 mmHg (**Table 1**). The distensibility of the aorta was 2.5±1.4 cm²· dynes⁻¹ (**Table 2**).

In group B the mean (planimetry) systolic aortic diameter was 3.4±.7 cm, and the mean diastolic aortic diameter was 3.37±.8 cm. The change of the mean aortic diameter (from diastole to systole) was .06±.04 (**Table 2**). The

Tabel 1. Demographic and hemodynamic data of patients with post-stenotic aortic dilatation

	Group A, n=15 (Normal coronary arteries)	Group B, n=14 (CAD)	p
Age	59.3±11	63.4±9.5	NS
Sex (male: fenale)	9: 6	8: 6	NS
Body surface area	1.8±0.19	1.86±0.22	NS
Left ventricular diastolic volume index (cm³/M)	105±37	90±35	NS
Ejection fraction (%)	61±19	58±19	NS
Heart rate (beats/min)	74±13	72±10	NS
Systolic aortic pressure (mmHg)	118±28	112±25	NS
Diastolic aortic pressure (mmHg)	73±14	65±18	NS
Mean aortic pressure (mmHg)	91±20	86±19	NS
Pulse pressure (mmHg)	50±21	53±19	NS
Aortic valve area (cm²)	0.75±0.27	0.77±0.28	NS

CAD=coronary artery disease; NS=not significant.

Table 2. Aortic diameters and aortic distensibility

	Group A, n=15 (Normal coronary arteries)	Group B, n=14 (CAD)	p
Systolic diameter (cm)			
Level 1	3.1±0.5	2.9±0.7	NS
Level 2	3.8±0.6	3.7±0.6	NS
Level 3	4.0±0.6	3.9±0.7	NS
Level 4	4.5±0.7	4.1±0.5	NS
Mean diameter (planimetry)			
Systolic (cm)	3.84±0.5	3.43±0.7	NS
Diastolic (cm)	3.67±0.5	3.37±0.8	NS
Systolic minus diastolic (cm)	0.17±0.1	0.60±0.04	<0.001
Distensibility (cm²·dynes⁻¹)	2.5±0.4	1.0±0.8	<0.001

NS=not significant.

change of aortic pressure (from diastole to systole) was 53 ± 19 mmHg (**Table 1**). Distensibility of the aorta was $1.0 \pm .8$ cm²·dynes⁻¹ (**Table 2**).

The mean systolic aortic diameter was not different between groups A and B. The change of the aortic diameter, however, was greater in the patients without CAD compared to the patients with CAD ($.17 \pm .1$ cm vs $.06 \pm .8$ cm, $p < 0.001$). Distensibility of the aorta was lower in the patients with CAD (group B) compared to the patients without CAD (group A) ($1.0 \pm$ $.8$ cm²·dynes⁻¹ vs 2.5 ± 1.4 cm²·dynes⁻¹, $p < 0.001$).

Discussion

The results of this study show that in patients with post-stenotic aortic dilatation and co-existing CAD, distensibility of the ascending aorta is significantly decreased when compared to patients with post-stenotic aortic dilatation and normal coronary arteries. These differences may be related to atherosclerotic

lesions of the aortic wall and/or to abnormal nutrition of the arterial wall[12,13].

Atherosclerotic changes in the intima of the arterial wall include lipid infiltration and smooth muscle proliferation. Atherosclerotic changes in the media of the arterial wall include an increased amount of elastin and collagen, abnormal elastin and an increase of proteoglycans of interstitial cells. The aortic wall in experimental animals with atherosclerosis contains approximately twice as much collagen and elastin as control animals. Aortic wall thickness in experimental atherosclerosis was increased significantly, related mainly to intimal fatty and fibrous plaques. All these changes occur without luminal changes of the aorta[14~20].

The changes in the elastic properties of the aorta may also be related to changes in the nutrition of the aortic wall. The outer part of the aortic wall is supplied by small vessels, the vasa-vasorum, which for the ascending aorta are derived from the coronary arteries, for the aortic arch from the brachial arteries, and for the thoracic aorta from the intercostal arteries[21~25]. Heistad et al[25] indicated that vasa vasorum provide a considerable amount of blood supply to the thoracic aorta, and speculated that decreased blood flow of the aortic wall during acute hypertension might contribute to aortic media necrosis. Willens et al[23] observed necrosis of the middle third of the aortic media of the descending aorta following ligation of intercostal arteries in dogs. Barsky and Rosen[26] described infarction in the central zone of the media of the ascending aorta in patients with aortic dissection related to medial cystic necrosis, and concluded that this lesion may be related to lack of sufficient blood supply.

Aortic distensibility may be influenced by other factors unrelated to aortic wall structure such as age, aortic valve area, pharmacologic agents, and left ventricular performance[27~33]. In the present study patients were selected carefully in order to exclude any differences which may be related to age, left ventricular function, and other hemodynamic parameters, and all the above mentioned parameters were similar.

The effect of contrast material on aortic distensibility is not known. To minimize contrast material effect on aortic distensibility, only the first or second sinus beat was analyzed after the injection of contrast material. Further, the effect of contrast material, if any, is expected to be similar in both groups. The effect of pharmacologic agents on aortic distensibility also is not known. Patients in both groups, however, were treated with similar pharmacologic agents. Thus differences in therapy per se cannot explain differences in aortic distensibility. Bias may be another factor which may account for differences demonstrated between the two groups. All measurements, however, were performed by the same investigator, without knowing the coronary anatomy and aortic pressures. Thus bias cannot explain the differences in aortic distensibility between the two groups.

Decreased distensibility of the ascending aorta in patients with CAD and the angiographically normal aorta has been reported recently from our laboratory[1]. The present study shows that the presence of CAD markedly decreases distensibility of the ascending aorta in patients with post-stenotic aortic dilatation as well. It appears, therefore, that CAD alters the elastic properties of the aorta in patients with the angiographically normal aorta and the patients with post-stenotic aortic dilatation. Decreased aortic distensibility in patients with CAD may contribute to the spectrum of the disease in terms of pathogenesis and symptoms.

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APPENDIX

Elastic modulus (E) is given by the equation:

$$E = \frac{\Delta P}{\Delta de} \times \frac{2de \cdot d^2 \ (1 - \sigma^2)}{de^2 - di^2} \qquad (1)$$

(ΔP = changes in pressure, de = changes of the external diameter of the vessel, di = internal diameter, σ = constant with a value of approximately 0.5 for the blood vessels, as can be determined from the Poisson's formula).

Equation (1) can be expressed as:

$$E = \frac{\Delta P}{\Delta de} \times \frac{2de \cdot di^2 - (1 - \sigma^2)}{(de + di) \cdot (de - di)} \qquad (2)$$

$$\text{or} \quad E = \frac{\Delta P}{\Delta de} \times \frac{2de \cdot di^2 \ (1 - \sigma^2)}{(de + di) \cdot 2h} \qquad (3)$$

since de-di is equal with the wall thickness.

In cases where the wall of the vessel is thin in relationship to diameter (as it is the case with the aorta), the internal and external diameters are approximately equal (de or di = d). Thus the equation 3 can be expressed as:

$$E = \frac{\Delta P}{\Delta d} \times \frac{2d \cdot d^2 \ (1 - \sigma^2)}{2d \cdot 2h} \qquad (4)$$

$$\text{or} \quad E = \frac{\Delta P}{\Delta d} \times \frac{d^2 \cdot (1 - \sigma^2)}{2h} \qquad (5)$$

$$\text{or} \quad Eh = \frac{\Delta P}{\Delta d} \times \frac{d^2 \cdot (1 - \sigma^2)}{2} \qquad (6)$$

$$\text{or} \quad \frac{2\Delta d}{\Delta d} = \frac{d^2 \cdot (1 - \sigma^2)}{E \cdot h} \qquad (7)$$

$$\text{or} \quad \frac{2 \triangleleft d}{d \cdot \Delta P} = \frac{d \cdot (1 - \sigma^2)}{E \cdot h} \qquad (8)$$

$\sigma = 0.5$ and $\sigma^2 = 0.25$; since $(1 - \sigma)$ is approximately equal to 1 the equation 8 can be expressed as:

$$\frac{2\Delta d}{d \Delta P} = \frac{1}{\dfrac{E \cdot h}{d}} \qquad (9)$$

The equation 9 defines the distensibility of the wall of the vessels which is related inversely to elastic modulus E.