

Aortic Valve Assessment. Anatomical Study of 100 Healthy Human Hearts

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Purpose – To assess anatomical characteristics of the aortic valve, so that they may be useful in diagnostic situations and surgical treatment.

Methods – The study analyzed 100 healthy fixed human hearts; 84% of them obtained from males, 61% of them from Caucasian individuals. The ages of the individuals ranged from 9 to 86 years (mean 30 ± 15.5 years). The characteristics assessed related to age, sex, and race were the following: number and height of the cusps, size of the lunulae, internal and external intercommissural distance, position of the coronary ostium in relation to the aortic valve, position of the ventricular septum in relation to the aortic valve, thickness of the cusps.

Results – All hearts assessed had a tricuspidal aortic valve. In regard to the height of the cusps and size of the lunula, the left coronary cusp was larger, followed by the right coronary cusp and the noncoronary cusp. The internal and external intercommissural distances had mean values of 24.6 ± 5.7 mm and 19.7 ± 7 mm, respectively. In regard to the position of the coronary ostia, in one heart two ostia emerged from the left coronary sinus, and in another, the ostium was supracommissural. The mean diameter of the aorta was 21.8 ± 3.6 mm, and there were no significant sexual or racial differences, but the diameter increased progressively with the increase in age. The thickness of the cusps did not show any significant difference in the 3 points assessed.

Conclusion – The aortic valve annulus did not show a perfect circumference, with some variations in the measurements of the annulus, in the cusps and in the relation with the ventricular septum.

Keywords: heart, anatomy, aortic valve

In recent decades, some events have increased the interest in the anatomy of the heart, one such event being the increasingly frequent use of conservative surgical techniques for repairing or replacing cardiac valves. Thromboembolic complications in the mechanical prostheses, as well as ruptures, restenoses and calcifications in the bioprostheses, are the major causes of morbidity and mortality in patients undergoing valvar replacement. This shows that, despite the great technological evolution and constant studies, an ideal substitute for the natural valve, either mechanical or biological, providing longevity and low thrombogenicity, is yet to be found¹⁻⁵. Because of that, conservative techniques have been progressively used in patients with valvopathies in a number of centers²⁻⁶. Thus, the interest in the morphology of cardiac valves, which during the 60's and 70's was limited to the pathological features due to the large number of valvar replacements, was extended. The more accurate knowledge of normal anatomy began to play an important role in the success of valvoplasties, as many decisions during surgery are based on the visual assessment of the changes. Detailed knowledge of the anatomical characteristics of the aortic valve should improve the understanding of its anatomy and help obtain better results in conservative procedures, promoting return to anatomical and functional normality. This precise knowledge also defines some details of the architecture of the aortic valve that are necessary for the development and manufacture of the prostheses. In addition, the knowledge and understanding of the structure and function of the normal and pathological cardiac valves are crucial for the selection of the patients for surgery and for planning the best treatment to be adopted.

Technical difficulties found in the surgical repair of the aortic valve result from its anatomical characteristics, as well as from the condition of its cusps^{2,7}. The closure mechanisms of the aortic valve are more precise than those involved in the dynamics of the atrioventricular valves, which have a larger coaptation surface and larger subvalvar structures which help the plastic corrections without replacement by prostheses⁷⁻¹¹.

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Specific studies of the anatomy of the aortic valve were carried out by Silver and Roberts¹², Swanson and Clark¹³, Thubrikar et al¹⁴, and Angelini et al¹⁵, aiming to better define peculiarities of this valve. In addition to performing an anatomical assessment, they analyzed some linear variables in each cusp and documented the presence of some fenestrations close to the commissural attachments.

Despite the above studies, there is a need for further investigation of this subject and this study aims to assess the anatomy of the aortic valve. Data about the cusps, the position of the ostia, and anatomical relations facilitate the conservative surgeries as well as those involving valve replacement.

Methods

This study analyzed 100 healthy hearts of individuals without previous heart disease. The hearts were fixed according to the technique of molding of cavities and structures with cotton embedded in 10% formalin¹⁶. 84% of the individuals were males, 61% Caucasians, and the ages varied from 9 to 86 years (30 ± 15.45 years). The cardiac mass varied from 107 to 463 g (259.47 ± 59.3 g). According to information provided by the Institute of Forensic Medicine of the State of São Paulo and by the analysis of pathologists, all hearts belonged to individuals without previous heart disease. In 90% of the cases, the cause of death related to trauma and, in the remaining 10%, death resulted from diseases not related to the cardiovascular system.

Using a pachymeter and a # 0 cotton thread, the Valsalva's sinuses were assessed as well as the 3 cusps of the aortic valve: left coronary cusp (LC), right coronary cusp (RC), and noncoronary cusp (NC), according to the following parameters:

Number and height of the cusps (fig. 1): height obtained by stretching the cotton thread from the bottom of the Valsalva's sinus until the free margins of the cusps in the middle point between the commissures, respecting its curve. This measure was then transferred to the pachymeter;

Size of the lunula (fig. 1) according to two parameters: width – assessed at the commissural level; and length –

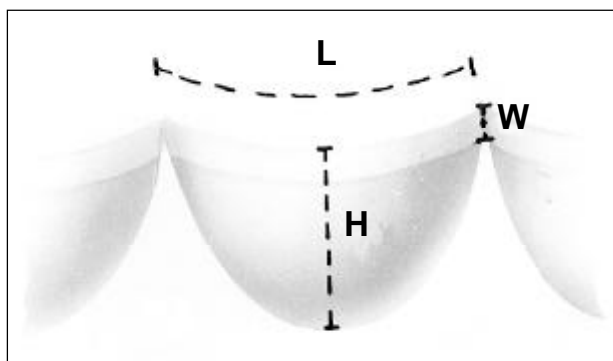


Fig. 1 – Sketch demonstrating the site of measurement in one of the 3 cusps. H – height of the cusp; W – width of the lunula; L – length of the lunula.

measured by stretching the cotton thread at the surface of each cusp at the free margins, following its curve;

Intercommissural distances (fig. 2): external – measured by stretching the cotton thread along the aortic wall uniting one commissure with the other, so that the addition of the 3 measures represents the aortic circumference; internal – obtained by uniting the commissures with the cotton thread at the smaller distance between them;

Position of the ostium and its relation with the correspondent Valsalva's sinus (fig. 3): using the cotton thread, the distance between the ostium and the commissures and the bottom of the Valsalva's sinus was measured;

Position of the ventricular septum in relation to the aortic valve (fig. 4), assessed in the following parameters: distance between the septal extremity and the RC-LC commissure (measure A); distance between the septal extremity and the RC-NC commissure (measure B); distance between the septum and the NC-LC commissure (measure C); aortic diameter (measure D).

The ratio $C/D \times 100$ was also established to determine the percentage of free area of the aortic valve annulus and, consequently, to evaluate the position and percentage of the area occupied by the septum in relation to the left ventricle outflow tract (LVOT).

Thickness of the cusps (fig. 5): grossly assessed at 3 different points of the surface of each cusp: free margins, bottom of the Valsalva's sinus, and the intermediate point between the other 2. The assessment of thickness was performed by visual inspection without using specific instruments because the tissue of the cusps is very delicate. Even though a histological study of the cusps would provide more accurate information, it was not carried out because the specimen had to be kept intact for further studies.

All parameters analyzed were related to sex, age and race.

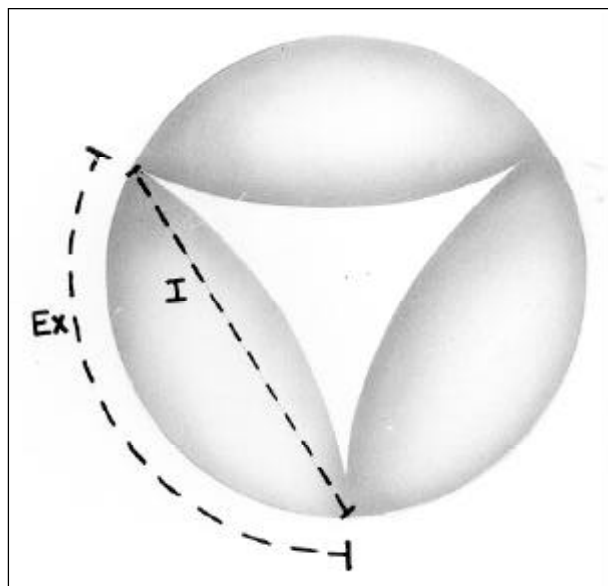


Fig. 2 – Sketch demonstrating the external (Ex) and internal (I) intercommissural distances.

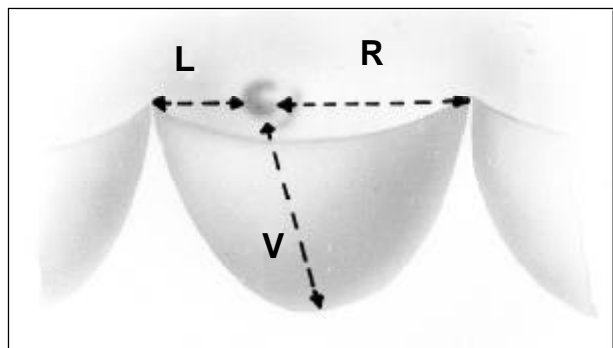


Fig. 3 – Sketch of the position of the ostium in relation to the left commissure (L); right commissure (R) and bottom of the Valsalva's sinus (V).

Results

All hearts analyzed had tricuspid aortic valves.

The mean height of the cusps was 15.0 ± 1.98 mm and the LC cusp had the largest dimensions, followed by the RC and the NC cusps, whose dimensions were similar. The same pattern was observed for the width and length of the lunula, whose mean values were 4.4 ± 0.96 mm and 30.2 ± 7.1 mm, respectively (table I).

In regard to the intercommissural distances, the external intercommissural distance was larger in the LC Valsalva's sinus, followed by that of the RC and NC. The internal intercommissural distance, however, was larger in the NC sinus, followed by that of the LC and RC. The mean external intercommissural distance was 24.6 ± 5.7 mm and the internal was 19.7 ± 7.0 mm; the mean individual values of each valve were grouped according to sex, age and race (table II).

In regard to the position of the coronary ostia, in one

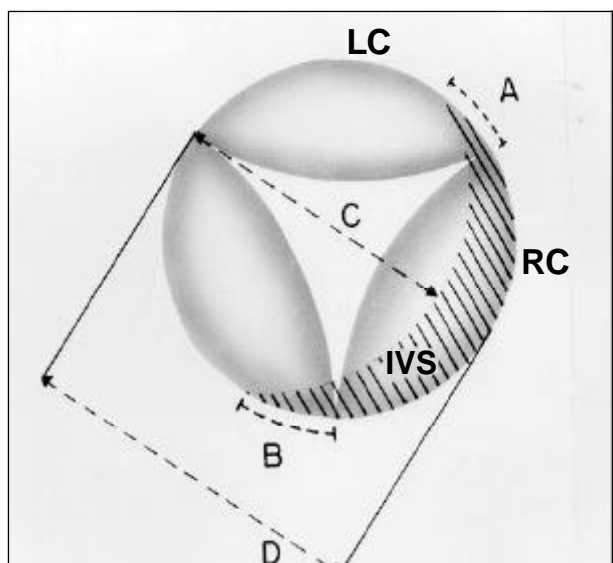


Fig. 4 – Sketch of the position of the ventricular septum (IVS) in relation to the aortic valve. LC – left coronary; RC – right coronary; NC – noncoronary; A- distance between the septal extremity and the RC-LC commissure; B- distance between the septal extremity and the RC-NC commissure; C- distance between the septum and the NC-LC commissure; D- aortic diameter.

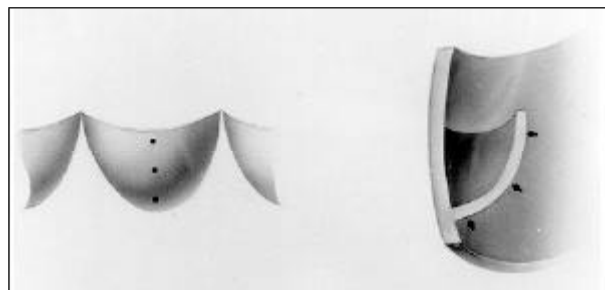


Fig. 5 – Sketch (front and side view) demonstrating the 3 sites of evaluation of the thickness of the cusps.

case, both ostia were in the LC sinus and, in another case, the ostium was supracommissural. In the remaining cases, there were small variations regarding the position of the respective ostium in relation to the correspondent Valsalva's sinus (table III).

Studying the position of the ventricular septum (IVS) in regard to the aortic valve annulus and its structures, the mean values of the A, B and C measurements were, respectively, 9.5 ± 5.3 mm; 5.7 ± 4.2 mm; and 19.2 ± 2.9 mm. There were no statistically significant differences in regard to sex, race and age. The mean aortic diameter (measure D) was 21 ± 3.6 mm, and there were no significant sexual and racial differences. The measure D, however, was smaller in hearts of individuals under the age of 40 years, and it showed a progressive increase with age. Therefore, the ratio $C/D \times 100$ showed mean values of 89.1 ± 14.6 mm, and it was larger in the hearts of individuals under the age of 40 years (table IV).

The gross assessment of the thickness of the cusps, evaluated in 3 points of their surface showed no differences and was practically constant.

Discussion

Considering that the present study aimed to analyze only normal hearts, the selection of the material played an extremely important role. Before being included in the sample, all hearts were carefully analyzed and had the hypothesis of previous heart disease excluded; therefore the possibility of obtaining of anatomical pieces with morphological alterations due to cardiac disease or to repercussion of functional disorders in other organs was very remote.

A point that deserves to be discussed is heart weight. According to Gardner et al¹⁷, the mean heart weight in males is around 328g, varying from 256g to 390g and, in females, it is around 244g, ranging from 198g to 270g. Linzbach¹⁸, however, states that the weight of the human heart without pathological alterations can reach 500g. In situations where the work of the heart is chronically increased, as in athletes or workers who exercise intensely, the increase in heart weight is not caused by an increase in the number of muscle fibers but by an increase in the thickness and length of these fibers. In addition, as already demonstrated by several authors, the heart weight is directly related to the individual body surface^{19,20}.

Table I - Mean values of the height of the cups and size of the lunulae (width and length) in mm								
Measure	Valve	Mean Value	Sex		Age range		Race	
			Male	Female	< 40	≥ 40	Caucasian	Non-Caucasian
Height	LC	15.2	15.2	14.9	15.0	16.2	15.3	15.1
	RC	15.0	15.2	14.5	14.9	16.2	15.1	15.0
	NC	14.9	15.0	14.6	14.8	15.5	14.9	14.8
Width	LC	4.6	4.6	4.3	4.5	4.9	4.5	4.6
	RC	4.4	4.4	4.2	4.4	4.6	4.3	4.5
	NC	4.3	4.3	4.2	4.3	4.6	4.3	4.3
Length	LC	30.6	30.7	29.3	30.0	34.1	30.2	30.9
	CD	30.1	30.4	27.9	29.4	33.9	29.9	30.3
	NC	30.0	30.3	28.2	29.4	33.5	29.6	30.6

LC - left coronary; RC - right coronary; NC - noncoronary.

Table II - Mean values of the external and internal intercommissural distances (in mm)								
Intercommissural Distance	Valve	Mean Value	Sex		Age range		Race	
			Male	Female	< 40	≥ 40	Caucasian	Non-Caucasian
External	LC	25.2	25.4	23.5	24.4	29.3	24.0	25.5
	RC	24.5	24.5	23.8	23.6	29.4	23.1	25.2
	NC	24.1	24.4	22.1	23.6	27.0	23.3	23.8
Internal	LC	19.8	20.0	18.5	19.3	22.7	18.8	21.4
	RC	19.2	19.2	18.7	18.7	22.2	17.9	20.9
	NC	20.0	20.1	19.1	19.6	22.3	18.5	21.8

LC - left coronary; RC - right coronary; NC - noncoronary.

Table III - Mean values of the distances of the ostium and its relation to the corresponding Valsalva's sinus (in mm)								
Distance between the ostium and	Valsalva's sinus	General mean	Sex		Age range		Race	
			Male	Female	< 40	≥ 40	Caucasian	Non-Caucasian
Left commissure	LC	9.6	9.7	9.3	9.3	12.0	9.5	9.8
	RC	11.1	11.2	10.7	10.7	13.9	11.2	11.1
Right commissure	LC	11.0	10.9	10.8	10.5	13.4	10.5	11.6
	RC	11.1	11.3	9.9	10.8	13.0	10.7	11.7
Bottom of the Valsalva's sinus	LC	13.3	13.4	13.0	13.0	14.9	13.3	13.4
	RC	14.8	15.0	13.8	14.6	16.1	14.9	14.7

LC - left coronary; RC - right coronary.

Among the data obtained in our study, some proved to be more interesting than others for the study of the aortic valve and its relations.

In the present analysis, the external intercommissural distance proved to be the largest in the LC Valsalva's sinus, followed by the RC and the NC. Analyzing the internal intercommissural distance, however, we observed some changes, with larger values in the NC sinus, followed by the LC and the RC in most of the studied groups, emphasizing the observation that the aortic valve annulus has variable dimensions and that it is not a perfect circumference at the level of the commissures. Vollebergh and Becker²¹, studying the intercommissural distances of 200 human hearts, also demonstrated variations; the RC sinus, however, was the largest one followed by the NC and LC sinuses, just the

opposite of our observations. In addition, Thubrikar et al²² showed that, in *in vivo* investigations of canine hearts, the aortic valve is a dynamic structure and that the geometrical parameters change at each cardiac cycle. An exclusively anatomical investigation of the specimen would be mainly useful to provide information that the surgeon would need at the moment of approaching the aortic valve. Studies of specimens show some aspects such as *rigor mortis*, that differ from the heart at the time of a surgery²³ and the retraction after fixation. The influence of these factors is more significant in the ventricular chambers. Tei et al²⁴, in a control group of a study of the right atrioventricular valve and in a comparative evaluation between 3 groups, observed similar values for nonfixed and fixed hearts, as well as for those evaluated by echocardiograms. Scholz et al²⁵ and

Table IV - Mean values of the position of the ventricular septum and its relation with the aortic valve (in mm)

Measures	Mean Value	Sex		Age range		Race	
		Male	Female	< 40	≥ 40	Caucasian	Non-Caucasian
A	9.5	9.3	9.8	10.3	9.6	8.7	10.6
B	5.7	5.9	4.6	7.1	7.3	5.3	6.2
C	19.2	19.3	18.7	18.4	20.6	18.8	19.8
D	21.8	19.8	21.6	2.5	25.9	21.6	22.1
Ratio C/D	89.1	89.2	88.3	8.6	80.8	88.1	90.6

A- distance between the septal extremity and the RC-LC commissure; B- distance between the septal extremity and the RC-NC commissure; C- distance between the septum and the NC-LC commissure; D - aortic diameter.

Maron et al²⁶, in a study of cardiac mass, valvar circumferences and ventricular thickness, found similar results.

Knowledge of the design of the normal aortic valve, responsible for its efficiency and longevity, as well as the knowledge of variations of its geometry is important for the conservative surgical techniques and for the development and manufacture of prostheses similar to the natural valve^{9,13,22,27}. In this regard, Fontes et al²⁸ carried out an interesting study in which the aortic root proved to have a structure similar to a sphere, encompassing the aortic valve and its annulus. This information has important implications in the manufacture of prostheses that must conform to this anatomical configuration.

When we analyze the size of the lunula, the mean of the intercommissural distances and the mean height of the cusps in relation to sex and age, the values are greater in the hearts of males and these values increase with age. Krovetz et al²⁹, in a clinical study relating age and the size of the aortic valve, observed that there is an increase in the volume of the aorta with the increase in age and also that, after the age of 40 years, the aortic valve and its annulus become progressively dilated. This supports the findings of our study.

Our gross evaluation of the thickness of the cusps performed at 3 different points did not show any significant change. We know there are structural alterations and differences in thickness of the cusps, but these can only be demonstrated through specific microscopic studies. We chose the gross examination, however, because in surgeries, some decisions are made during the procedure based only on the surgeon's observations. Sahasakul et al³⁰, with the aid of a highly accurate micrometer, measured different points of the aortic valve in 200 human hearts. They observed that in hearts of women <20 years, the thickness

of the middle part of the LC and NC cusps was greater than in the other points. They also noticed that the thickness of each cusp increased significantly with age, not only during childhood and adolescence but also in adulthood. These variations, however, were not statistically significant when compared with the other parameters.

Another point to be considered is the relation between the ventricular septum (VS) and the aortic valve and the LVOT. The ratio C/D was higher in hearts of individuals <40 years of age and progressively decreased with the increase in age. This may suggest that perhaps LVOT shows a trend to proportionally decrease its area in relation to the aortic diameter with increasing age. This may be related to some clinical process leading to hypertrophy of the muscle structures – VS and the muscle of the free wall of the LV – combined with an increase in the aortic diameter. Considering still the relation between VS and the aortic valve, a practical consideration plays an important role in surgical cases, where it is necessary to widen the aortic valve annulus to place the valvar prosthesis. According to Stolf et al³¹, who widened the aortic valve annulus in 25 patients with the diagnosis of stenosis or dysfunction of the aortic prosthesis with satisfactory results, the perfect knowledge of the position of the VS help the access and the surgical procedure without major risks of damaging the VS and severe consequences, such as infarctions of the VS.

In conclusion, we observed that, after the study of the described parameters, the aortic valve annulus proved not to be a perfect circumference, showing some variations in its measurements, as well as in the measurements of the cusps, in the relations of the 3 cusps and of the VS. In regard to sex, age and race, the intercommissural distances in males were greater, and there was also a progressive increase of the aortic diameter with increasing age.

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