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Coefficients of proportions of the atrioventricular valves: an anatomical study of valvar segments of normal individuals

Coeficientes de proporcionalidade nas valvas atrioventriculares: estudo anatômico dos segmentos valvares em indivíduos normais

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Abstract

Objective: **To describe the anatomical relationships that exist between the heart valve structures taking into consideration the segments of the fibrous annuli and the left ventricular volume**

Method: **Digital photographs of 41 hearts from autopsies performed by a Coroner's Office were analyzed. The photographs were processed using MATLAB® software, which supplies measurements of the valvar perimeter and area and the left ventricular volume.**

Results: **The average age of the studied corpses was 33 years old (standard deviation ± 17 years). Several correlations involving the tricuspid and mitral valves were tested, with strongly significant correlations found between the inter-commissural distance (ItD) and the perimeter of the anterior annulus (PA) of the tricuspid valve (r = 0.72; p-value < 0.05) and between the inter-commissural distance (ImD) and the perimeter of the posterior annulus (PP) of the mitral valve (r = 0.63; p-value < 0.05). The proportions between the parameters were PA/ItD = 1.36 ± 0.24 and PP/ImD = 1.38 ± 0.16.**

Conclusion: **The proportions between the perimeter of the anterior annulus (tricuspid) and the perimeter of the posterior annulus (mitral) and their respective distances have high statistical significance and can be applied as part of surgical techniques of valvar reconstruction.**

Descriptors: **Heart, anatomy & histology. Mitral valve. Tricuspid valve**

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Resumo

Objetivo: **Descrever as relações anatômicas existentes entre as estruturas das valvas cardíacas, levando em consideração os segmentos dos anéis fibrosos e o volume ventricular esquerdo.**

Método: **Analisaram-se fotografias digitais de 41 corações oriundos de necropsias feitas pelo Núcleo de Perícias Médico Legais. As fotos foram processadas em software em ambiente MATLAB®, que forneceu as medidas de perímetro e área valvares e o volume ventricular esquerdo.**

Resultados: **A média de idade dos indivíduos necropsiados foi de 33 anos, com 17 anos de desvio-padrão. Testaram-se diversas correlações envolvendo as valvas tricúspide e mitral, sendo encontradas correlações fortemente significativas entre a distância intercomissural (DIt) e o perímetro do anel anterior (PA) na valva tricúspide ($r = 0,72$ com $p<0,05$) e entre a distância intercomissural (DIm) e o perímetro do anel posterior (AP) na valva mitral ($r = 0,63$, $p<0,05$). As proporções entre os parâmetros foram: PA/DIt = 1,36 ± 0,24; AP/DIm = 1,38 ± 0,16.**

Conclusão: **As proporções entre o perímetro do anel anterior (tricúspide), o perímetro do anel posterior (mitral) e suas respectivas distâncias intercomissurais têm elevada significância estatística e podem ser aplicadas como parte das técnicas cirúrgicas de reconstruções valvares.**

Descritores: **Coração, anatomia & histologia. Valva Mitral. Valva tricúspide.**

INTRODUCTION

The analysis of the dimensions of the heart valves has advanced very much over the last few years following the introduction of biotechnology in medical research. Thus, 3-dimensional reconstructions using echocardiography, nuclear magnetic resonance or computed tomography have given us a better knowledge to plan surgical techniques of valve diseases. Even so, the return to anatomical studies has brought unexpected findings of great scientific value, highlighting the importance of post mortem research in cardiovascular surgery.

Research on valve diseases explains that pathological changes may be congenital, related to age, acquired or secondary to hemodynamics. As they get older, valves start to suffer a process of expansion and excessive bulging which does not generally result in insufficiency [1,2]. The case of valve insufficiency the consequent regurgitation may be the result of several pathological processes, such as rheumatic fever, degenerative diseases or even, infectious endocarditis, an acute disease caused by highly virulent microorganisms that culminates in severe heart injuries, as well as the involvement of one or more valve components (leaflets, fibrous annulus, chordae tendineae, papillary muscles) or abnormalities in the ventricle or the atrium [1,3].

The reason the ventricular chambers increase in size is to maintain the heart function stable after a specific injury. There is an increase in the radius (dilatation) of the cavity that loses its normal elliptical form, assuming a spherical shape. With this new shape there is an increase of the parietal tension at the apex, equalizing this tension with those of the medial region, although an increase in the medial region also occurs. With the continuity of the hypertrophic process, several genetic, biochemical and structural alterations can occur that can result in ventricular dysfunction [4]. When this process is due to valvar insufficiency, after valvuloplasty or valve replacement, it is possible to obtain a morphological ventricular change, with reversal of the remodeling process, a reduction of the sphericity and improvement of the hemodynamic function, decreasing considerably the process of ventricular dysfunction [5,6].

Measurement of the size of the annulus of the valves depends intrinsically on the method by which the heart is preserved, as measurements performed on annuli of preserved valves result in a smaller size than those in fresh hearts. In pathological conditions, such as in regurgitation, the circumference of the annulus is significantly greater. When the percentage of reduction of the fibrous annulus is smaller, the minimum value obtained during systole, is relatively greater than in normal samples [7].

In respect to the correction of changes that can occur in heart valves, in particular with valvar insufficiency, several surgical techniques have been proposed, for the majority of which, reconstruction of the valvar annulus is the main goal. Thus, a correct knowledge of the anatomy of the annulus of the valves is of great importance, as is knowledge of the volume of the ventricular chambers, which directly influences the pre- and postoperative functioning of these valves and can contribute significantly to the success of valvuloplasties. Accordingly, the present work aims at describing the existing anatomic relationships among the different structures of heart valves taking into consideration the segments of the fibrous annuli and the left ventricular volume and subsequently proposing coefficients for the manufacture of adequate prostheses for valvuloplasties.

METHOD

Forty-one hearts from over 14-year-old male and female patients were analysed. The measurements were achieved using photographs of fresh hearts, originating from necropsies performed in a Coroner's office.

The hearts from the necropsies underwent a process in which the heart valves were completely exposed. Subsequently, the heart was positioned to obtain the best images. Photographs of the valves were made using the Kodak EasyShare® DX3215 Zoom digital camera, on a support (tripod) in order to keep the angle and distance of the anatomic sample fixed during all the procedure. In sequence, lateral incisions in the ventricles were performed, exposing the interior of these chambers and other photographs were taken. A scale in millimeters was placed to the side of the sample at the same height as the required measurement. The photographs were processed on a computer using software specially developed for the project.

The software was developed in MATLAB® [8] and provided measurements of:

- Total perimeter of the annuli of the tricuspid and mitral valves;
- Area of each valvula and the total area that it occupied;
- Inter-commissural distance of the heart valves;
- Circular area of the left ventricle at its mid-point;
- Size of the greatest axis of the left ventricle;
- Perimeter and area of the valvar lascinias;
- Volume of the left ventricle;

To perform the measurements the operator defined demarcations on the image to be the opening settings for the program. Once the demarcations were defined, the measurements were obtained from the software and converted into pixels per centimeter. The volume was obtained by approximating the ventricle to a revolution ellipsoid [9-11].

The results provided by the software are reported in tables, graphs and figures presented in the results.

RESULTS

Digital photographs corresponding to 41 necropsies performed from December 2003 to April 2005 were analysed. The average age was 33 years with a standard deviation of 17 years, and a range of 15 to 85 years. In each case three groups of images were obtained, of the heart valves, the mid-point cross-sectional area and the interior of the left ventricular chamber (showing the septum and the anterior lascinia of the mitral valve). Each case was measured three times by the same observer (Table 1).

Table 1. Table of characterization of the patients

Variable	Mean	Standart deviation	Minimum value	Maximum value
Age	33 anos	17 anos	15 anos	85 anos
Weight	72 kg	11 kg	55 kg	100 kg
Height	171 cm	7 cm	145 cm	185 cm
CMI	1.8	0.2	1.5	2.2

Validation of the method

Initially proof of the accuracy of the software was achieved. This was done using a standard 2.0 x 2.0 cm square delimited on millimetered paper, of which photographs were taken with the same camera and at the same angle utilized in the necroscopic evaluation. The mean obtained from ten measurements performed at different times was 4.01 cm^2 for the area with a standard deviation of 0.02 cm^2; the percentage deviation in relation to the true value, 4.00 cm^2, was 0.003%. For the perimeter, the mean of ten measurements was 8.02 cm with a standard deviation of 0.03 cm; in this case the percentage deviation was 0.002% compared to the correct value of 8.00 cm.

Software applied to the heart samples

Tricuspid valve

The mean values found for the variables with the respective standard deviations are on Table 2:

Table 2. Statistics of the variables obtained of the mitral valve

Variable	Mean	Standard deviation	Minimum value	Maximum value
Tricuspid anterior area	2.92	0.97	1.22	5.02
Tricuspid anterior perimeter	4.42	0.74	3.06	5.62
Tricuspid septal area	1.80	0.56	0.82	3.22
Tricuspid septal perimeter	3.00	0.41	2.32	4.06
Tricuspid posterior area	1.51	0.45	0.63	2.67
Tricuspid posterior perimeter	2.28	0.38	1.59	3.23
Tricuspid total area	6.28	1.79	3.17	10.08
Tricuspid total perimeter	9.61	1.20	7.20	12.06
Tricuspid intercomissuraldist.	3.24	0.54	2.12	4.52

All variables were corrected according to age, weight and height. For this correction multiple regression was performed for each variable in respect to the co-variables (age, weight and height), followed by normalization to the lowest value of the measurements was performed.

After this, the correlation between the inter-commissural distance and the perimeter of the anterior annulus of the tricuspid was tested and the coefficient of correlation was obtained $r = 0.72$ with a p-value < 0.05 (Figure 1).

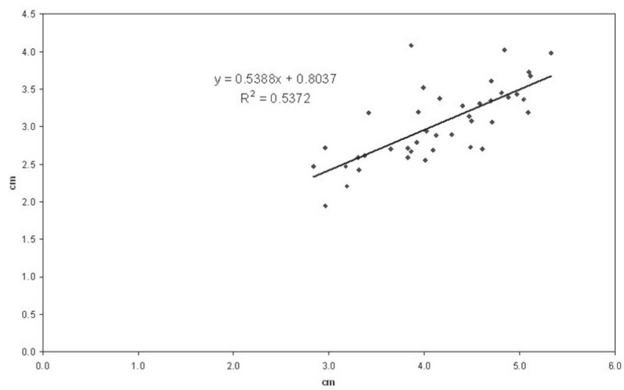

Fig. 1 - Perimeter of the posterior annulus versus the inter-commissural distance of the tricuspid valve with equation obtained by adjusting minimum squares

Given the significant correlation between the variables above, the ratio perimeter of the anterior annulus / inter-commissural distance was estimated: mean 1.36, standard deviation 0.24, minimum value 0.92 and maximum value 1.82.

2. Mitral valve

The mean values calculated for the variables with the respective standard deviations are on Table 3:

Table 3. Statistics of the variables of the mitral valve

Variable	Mean	Standart deviation	Minimum value	Maximum value
Mitral anterior area	2.94	0.73	1.71	4.88
Mitral anterior perimeter	4.60	0.62	3.37	5.96
Mitral posterior area	1.74	0.54	0.84	3.01
Mitral posterior perimeter	3.47	0.46	2.75	4.55
Mitral total area	4.72	1.21	2.59	7.76
Mitral total perimeter	7.92	1.16	4.20	10.13
Mitral intercomissural dist.	2.46	0.35	1.80	3.16
Mitral lascínia area	5.92	1.26	3.95	9.63
Mitral lascínia perimeter	6.75	0.89	5.14	10.63

After this, the following correlations between variables were tested:

- Internal perimeter of the Lascinia x Perimeter of the posterior annulus
- Total perimeter of the valvar annulus x left ventricular volume
- Inter-commissural distance x perimeter of the posterior annulus
- Total area of the valve x left ventricular volume
- Greatest axis of the left ventricular x total area of the valve
- Area at the mid-point of the left ventricle x total area of the valve

The results for the coefficients of the Pearson correlation for the above tests indicated high correlations between the inter-commissural distance and perimeter in the posterior annulus in the mitral valve (r= 0.63 with a p-value < 0.05) - Figure 2.

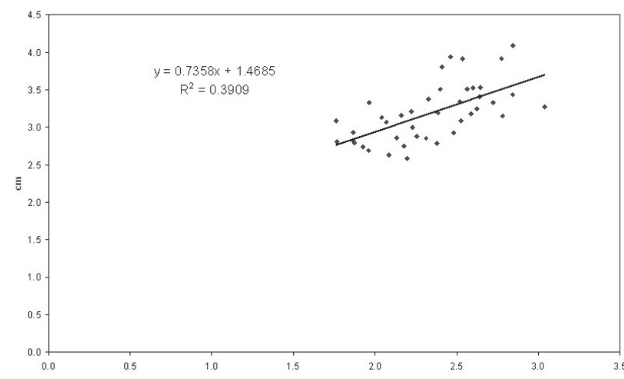

Fig. 2 - Perimeter of the posterior annulus versus inter-commissural distance of the mitral valve with equation obtained by adjusting minimum squares.

Given the significant correlation between the above variables, the ratio perimeter of the posterior annulus / inter-commissural distance was estimated giving: mean 1.38, standard deviation 0.16, minimum value 1.08 and maximum value 1.75.

Left ventricle

The mean values found of the variables with the respective standard deviations are on Table 4:

Table 4. Statistics of the variables associated with the left ventricle

Variable	Mean	Standard deviation	Maximum value
Greatest axis of the left ventricle	7.54	0.79	9.19
Mid-point area left ventricle	15.41	4.41	26.77
Mid-point perimeter left ventricle	14.17	1.97	19.03
Left ventricle volume	77.67	27.16	155.08

The parameters obtained in the photographs of the left ventricle were utilized in the relationships with the mitral valve, as demonstrated above.

DISCUSSION

The gold standard utilized to measure the variables is echocardiography. Singh & Mohan [12] and Ormiston et al. [13] made measurements for some of the variables described above utilizing echocardiography. These works show that there are small differences among the measurements, probably resulting from particularities of the methods employed. A comparison with our results shows concordance with the literature.

Evangelista et al. [14] published a study in which they compared the values of valvar areas of non-heart disease individuals involved in necroscopic and echocardiographic studies, concluding that the majority of the values are similar, however the area of the tricuspid valve in the echocardiographic examination in an apical view, was seen to be smaller than the area calculated in the necroscopic series.

The validation of the method was achieved by the analysis of a standard object with a known size showing that the method is accurate, presenting small inherent variations.

Some variables such as the volume of the left ventricle and the area of the anterior tricuspid annulus presented a greater standard deviation in relation to the mean, mainly due to the great variability inherent to human beings.

The mean values of the parameters of the heart valves are greater in men than women. However, this characteristic is inverted when these values are considered in relation to the body surface area [15].

An analysis was made to characterize the variables that significantly influenced the parameters measured. In this necroscopic study, the body weight of the individual was what most influenced the measurements obtained. The body surface area and height showed very little influence. Even so, for the initial matrix of parametric values, a multiple regression was performed to eliminate the influence of these variables, with the effect of age being eliminated in the same way.

The correlation found in the tricuspid valve between the inter-commissural distance and the perimeter of the anterior annulus is a result that is the basis of many of the surgical techniques currently used in the reconstruction of this valve. The inter-commissural distance can easily be obtained during the surgical procedure. Utilizing the ratio calculated in normal individuals, decreased by two standard deviations, an adequate prosthesis size for the reconstruction of the dilated anterior annulus in tricuspid insufficiency can be inferred, with a confidence interval of more than 95%. The standard error found in the proportion between the parameters is significantly low, which corroborates with the accuracy of the values obtained.

Several studies found in the literature teach us that the area of the normal mitral valve varies from 4 to 6 cm^2, validating the data found in this study [5,16].

Different correlations were analysed in an attempt of identifying which variables in the mitral valve are associated and which can be utilized as a model of normality in the evaluation of pathologic structures. The main correlation found was between the perimeter of the posterior annulus and the inter-commissural distance (r=0.63), even though all the other correlations have statistical significances as the p-values < 0.05, with a confidence interval greater than 95%. A strong correlation among the perimeter of the lascinia and the posterior annulus (r=0.26, with $p<0.05$) was not confirmed, probably due to the type of anatomic incision used to attain the measurements. In the surgical field, however, measurement of the perimeter is achieved with the ventricle preserved, and this correlation should be tested under these conditions in future studies.

It is consensus that valvar dysfunctions associated with dilated cardiomyopathy are related to dilatation of structures such as the fibrous annulus, left ventricle and atrium, swelling of the tendinous cords and dysfunction of the contraction of the papillary muscles and of the left ventricular wall. Focalizing on the structures of the mitral valve, many authors affirm that in regurgitating valves the distance between the fibrous trigones remains constant, as this is part of heart fibrous skeleton, with the posterior annulus being responsible for the dilatation and valvar insufficiency. Because of these findings, many techniques of valvuloplasty have been proposed, such as the technique of Braile et al. [17], utilized in our service.

Hueb et al. [18], however, found in an analysis of preserved hearts that there is dilatation both of the fibrous regions and of the muscle regions of the mitral annulus, thus it is proportional and not exclusively in the posterior portion.

Thus, the ratio between the perimeter of the posterior annulus and the inter-commissural distance was calculated, giving a significant difference confirmed by the low standard error. As in the tricuspid valve, this proportion can be utilized in the surgical procedure to choose the size of the prosthesis for valve reconstruction.

In respect to the measurements of the left ventricle, a result similar to published values for the ventricular volume was obtained. It is believed that the left ventricular cavity of the cadaver has a conformation that approximates it much closer to that existent at the end of the systole than to the end of diastole in live individuals. The heart rarely stops in systole, but stops in a hyper-relaxed state (more than a physiological diastole) with a slow process of ischemic contracture of all of the myocardium occurring after a variable time that causes a degree of reduction of the left ventricular cavity much greater than a physiological systole [12].

Less significant relationships were found, but still significant, between the perimeter and the area of the mitral valve with the ventricular volume, making the utilization of the variables to infer with the volume impossible.

CONCLUSION

The proportions between the perimeter of the anterior annulus (tricuspid), the perimeter of the posterior annulus (mitral) and its respective inter-commissural distances have high statistical significances and can be applied to surgical techniques of valve reconstruction.

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