APPLICATION OF GEOMETRICAL PRINCIPLE FOR STATISTICAL ESTIMATION OF AREA REDUCTION FACTOR IN IMPLANTED MITRAL VALVE PROSTHESIS

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ABSTRACT: AIMS AND OBJECTIVES: 1. To compare the mitral annulus area measured through indirect 2-dimensional Echocardiography and direct intraoperative measurement with implanted prosthesis area. 2. To determine the existence of area reduction factor (if any) after mitral valve implantation. **CONTEXT (BACKGROUND):** A frequent mismatch was observed between the anticipated mitral prosthesis dimensions through 2-D Echocardiography and actual best fit size of mitral valve prosthesis. The mitral valve prosthesis was observed of shorter length especially in anterior- posterior dimension on comparing the projected short axis dimensions of annulus by 2-D trans-thoracic Echocardiography. This fact encouraged researchers to investigate the existence of 'area-reduction' on geometrical and statistical parameters. **METHODOLOGY:** This hospital based longitudinal study was conducted in a tertiary set up for the duration of one year. Sixty-seven Rheumatic Heart Disease (RHD) patients with severe mitral valve disease were included with exclusion of simultaneous significant aortic valve disease. The 2-dimensional trans-thoracic echocardiography was performed on all these patients preoperatively and direct measurement was made intra-operatively to determine mitral valve annular dimensions. Geometrical principles in regards with area of ellipse and circle were used in order to detect the constant related with area reduction. Mean with standard deviation and t-distribution values were calculated for each variable. **RESULTS:** Prosthetic valve area was not found to be identical with annulus valve area. Calculated value of both coefficients (K_E and K_D) respectively were 1.961 and 1.644. Further the mean difference in area of annulus fibrosis ((Area echo- Area direct) by ECHO and intraoperatively was calculated as 192.8400(135.017-250.663) which was statistically significant { $t=6.5961(df=134)$; $p<0.0001$ }. **CONCLUSION:** This study proved the existence of reduction of area during mitral valve prosthesis implant mathematically; which may further affect the fluid dynamics and hemodynamic changes in post-operative period.

KEYWORDS: Prosthesis, Mitral Valve, Area-reduction, Geometry, annulus.

INTRODUCTION: Mitral valve is a complex three dimensional structure constituted by several sub units working in cohesion; The optimum synchronization of these substructures namely anterior and posterior mitral leaflet, annulus fibrosus, chordae tendinae, papillary muscle is critical for optimum functioning. In synchronization, they allows blood to flow unimpeded from left atrium to left ventricle during diastole and prevent regurgitation during systole that is normal functioning valve.¹⁻²

Annulus fibrosus, one of the key structure as described above; is actually a discontinuous band of connective tissue. The atriovalvular junction defines the hinge area from where the motion of leaflet takes place. Annulus fibrosus located deeper and 2millimeter external to this hinge. An

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anatomical unique feature needs to be mentioned here that Annulus fibrosus does remain in attachment with posterior leaflet of mitral valve but not with anterior leaflet. Rather the anterior leaflet maintains a continuity with aorto-mitral curtain that extend up to aortic valve annulus. Another important concern; is the presence of two dense fibrous anterolateral (left) and posteromedial (right) trigone at peripheral base of anterior leaflet. Bundle of His lies in close approximation of posterio-medial trigone hence sensitive to even trivially more exploitation during surgery. Crux is that mitral annulus is both a ill-defined and delicate structure.¹⁻³ Annulus fibrosus being adynamic structure (non fixed) takes several during various phases of cardiac cycle. It takes the shape of an Ellipse during diastole and becomes converted into a kidney shaped structure during systole. (where short axis diameter significantly reduces than the long axis diameter because of contraction of base of heart and displacement of aortomitral curtain towards centre of mitral orifice).³⁻⁴

2D echocardiography for all practical purposes is most commonly used modality to determine cardiac dimension and function.⁵⁻⁶ Direct method for measurement of cardiac dimension can be considered as reference standard because opportunity to measure precisely directly on diastolic arrested heart; but diastolic arrested heart definitely is not the physiological state.⁷⁻⁸

With the background above (ill-defined anterior mitral annulus, shape dependence on cardiac cycle) an incompatibility was frequently observed between the anticipated dimensions based on echocardiographical evaluation and actual prosthesis size. This fact encouraged researchers to think if this discrepancy is merely because of inability to perceive mitral annulus defiantly through Echocardiography (subjective error) or in reality there is the existence of a true 'Area Reduction Factor' Clinically if a oversize or undersize mitral valve prosthesis is implanted in designate mitral annulus it may compromise mitral annulus dynamicity and mitral valve area.

This study attempts to calculate area reduction factor in 2D echocardiography and direct intra operative measurement modalities in reference with mitral valve prosthesis area.

MATERIALS AND METHODS: This collaborative observational study was conducted in department of Cardiothoracic and vascular surgery with the aid of Department of Community Medicine in a tertiary care center for a period of one year. All Rheumatic Heart Disease (RHD) patients with severe mitral valve disease i.e. valvular area <1 cm² (severe Mitral Stenosis), regurgitant valve with jet reaching up to pulmonary vein (severe Mitral Regurgitation), combined stenotic and regurgitant lesion were included in the study while patient with simultaneous significant aortic valve disease and/or coronary artery disease patients with mitral valve involvement were excluded. The reason behind the exclusion criteria lies in the probability of these two ailments to alter left ventricular geometry independently. All the 67 recruited patients were duly informed about the aims and objectives of study before taking informed consent.

The 2-dimensional trans-thoracic echocardiography was performed on all these patients preoperatively to determine mitral valve annular dimensions by traditional method. Anterior-posterior (short axis) of mitral valve annulus was obtained by parasternal long axis view. The posterior annulus was located at the junction of leaflet and the left atrium, and the anterior annulus was located at the junction of left atrium and the aortic root. Transverse that is commisuro-commusural axis (long axis) measurement of mitral annulus made in the apical four chamber view at the junction of leaflet and the left atrium.

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Direct measurement was made intra-operatively with the black braided silk thread, Vernier calipers and sub-millimeter demarcated metric steel scale. All the calculations were done at the diastolic arrested heart (non-physiologic state) through left atriotomy at Waterson groove. All the measurements were done from hinge line of anterior mitral leaflet to left atrium at mid-point of A₂ segment for anterior-posterior (short) axis. Commissuro-commissural (long) axis was measured from anterior-lateral commissure to posterior-medial commissure at hinge point of annulus to left atrium.

This study takes the following mathematical presumption-

Area of the circular prosthetic mitral valve* constant (K)= Area of the elliptical mitral valve annulus

$$\text{OR } \pi r^2 * K = \pi a * b \dots\dots\dots(1)$$

$$\text{OR } \pi \{D/2\}^2 * K = \pi \{A/2\} * \{B/2\} \dots\dots\dots(2)$$

$$\text{Hence } K = AB/D \dots\dots\dots(3)$$

Where A= Long axis of mitral valve annulus

B= Short axis of mitral valve annulus

D= Diameter of prosthetic valve

Further-

$$K_D = A_D B_D / D \dots\dots\dots(4)$$

And

$$K_E = A_E B_E / D \dots\dots\dots(5)$$

Where

K_D= constant derived through intra-operative direct measurement of long axis (A_D) and short axis (B_D)

K_E= constant derived through Echocardiographic measurement of long axis (A_E) and short axis (B_E)

And K_R= K_E/ K_D.....(6)

Where, K_R= Reference (relative constant) constant for K_E in relation with K_D

RESULT: The mean values and dispersions of constants for Echocardiographic measurement and direct measurement derived through the equations are shown in table-1.

Constant	Mean Value	Standard Deviation	95% Confidence Limit
K_E	1.961	0.149	1.663 to 2.259
K_D	1.644	0.087	1.470 to 1.818
K_R	1.202	0.119	0.964 to 1.440

Table-1-Mean values and dispersions of constants for Echocardiographic measurement and direct measurement derived through the mathematical equations

This is obvious from the table (and from equation-1) that prosthetic valve area is not identical with annulus valve area; as the value of both K_E and K_D calculated is much higher than 1. A multiplication factor 1.961 through Echocardiographic measurement and of 1.644 through direct measurement was calculated to measure the area of annulus from prosthetic valve area; hence establish the “Area Reduction” while implanting prosthesis.

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Another table compares the extent of overestimation of area of mitral valve annulus by calculating the mean difference of the area of mitral valve annulus and mean difference of constants (K_E and K_D) measured through indirect (Echo-cardiography) and direct (intra-operative) measurement (Table-2).

Area of mitral valve annulus		Variable	Mean Value	t-distribution value
ECHO	Direct			
1238.246 (± 195.717)	1045.406 (± 140.767)	Mean difference of area (Area _{echo} - Area _{direct})	192.8400 (135.017- 250.663)	6.5961(df=134) P<0.0001
		Mean difference in constants (Mean K_D - Mean K_E)	0.317 (0.275-0.358)	15.150 (df=134) P<0.0001

Table-2: Comparison of overestimated area of mitral valve annulus measured through indirect (Echo-cardiography) and direct (intra-operative) measurement

This can be interpreted that Echocardiographic estimations for short and long axis (represented by the area) are significantly on the higher side as compared to direct measurements. Moreover mean difference in constants was also detected significantly higher by a factor of around 30% for echocardiographic measurement.

DISCUSSION: As mentioned above, ill-defined margins of anterior mitral annulus may accentuate the probability of overestimation of mitral annulus short axis (anterior-posterior dimension). Foster et al in their study also endorsed the possibility of significant overestimation in anterior-posterior axis by conventional method of 2-dimensional trans-thoracic echocardiography.⁹ This overestimation was calculated by a incremental percentage by 23%.⁹ The same diagnostic modality (2-D Echocardiography) was also adapted in this study hence this incremental percentage in anterior-posterior dimension during peak systole may well be applied to this study as well.

The reason for this overestimation lies in essential requirement of optimal plane formation by 2-D transthoracic echocardiography which is indeed difficult due to anatomical peculiarities and geometrical complexities.^{6,9}

All the direct measurement is performed on diastolic arrested heart (non -physiologic state) intra-operatively. Diastolic dimensions of the arrested heart are higher particularly in anterior-posterior axis. In a study conducted in California, this diastolic mitral annulus dimension was found to be increased by 26%.⁵ Direct method as having the better precision, can be considered as reference standard.

This study measured the area of ellipsoid mitral annulus by both echocardiography and direct measurement and detected a significant difference between them.

Various studies report the normal mitral valve area in a range estimation rather than point estimate depending on measuring modalities apart from other factors.⁶⁻¹³ On one hand, cadaveric study reports the mitral valve dimension $5.04 \pm 0.1 \text{ cm}^2$; while on other hand, on autopsied heart the

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area was detected $6.37 \pm 0.2 \text{ cm}^2$.¹⁰ Echocardiographic studies performed in order to determine the mitral valve dimensions report a range estimate from 3 cm^2 - 8.7 cm^2 .^{5-6 & 11-13}

With due consideration of understanding the variable dimensions of mitral valve with different measurement modalities; this study also takes into account the direct intra-operative anterior-posterior axis measurement as reference standard. An area reduction factor of around 64% was still detected if one implants circular mitral valve prosthesis in elliptical annulus. What can be possible clinical implication of this study? This significant area reduction may be because of loss of dynamicity of mitral annulus and non-continuity of annulus fibrosus to prosthetic valve leaflets.

This fact may lead to loss of near complete annulus hinge, which becomes restricted only at two point in bi-leaflet and at single point in tilted single disc mechanical prosthesis. Another concern is the; height of mitral valve prosthesis in comparison to hinge of atrio- valvular junction, which further reduces area and alter flow dynamics. Additionally every prosthetic valve has an outer and an inner diameter so effective functional orifice area is always lesser than anticipated. All these factors in unison effectively reduce the area and may culminate into gradient across valve prosthesis.

This gradient may not be sufficient initially to produce overt clinical manifestation but with time it may alter the flow dynamics. Now this altered state may translate into hemolysis, endocarditis (inflammatory changes), systemic thromboembolism and thrombotic occlusion of valve prosthesis.¹⁴⁻¹⁵ Systemic anticoagulants are advised to reduce the above mentioned complications but they themselves may produce bleeding complications.¹⁴⁻¹⁵ With this discourse it may be concluded that mitral valve repair always a better option over mitral valve replacement if clinically acceptable and feasible.¹⁶ This shift in surgical strategy will maintain the same area as granted naturally without any reduction and hence no further clinical complications.

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