Original Article

Determination of Mitral Valve Area through Pressure Half-Time Measurements in the Left Atrium and Pulmonary Capillary Wedge

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Objective: To confirm the validity of the calculation in MVA applying the method of Doppler pressure half-time directly in left atrial (LA) and pulmonary capillary pressure curve.

Methods: Thirty-five patients with mitral valve stenosis underwent percutaneous mitral valvotomy (PMV) using the Cribier method with MVA measurement made using the traditional methods (Gorlin and echo-Doppler) and this propose. MVA values obtained were compared and a linear regression model was used to obtain formula for reciprocal calculations of the mitral valve area.

Results: A statistically correlation was found between the calculated values by all methods. The proposed method showed a strong correlation ($p < 0.05$) with the others mainly before valve opening. Simple reciprocal calculation formulas were found for mitral valve area assessment.

Conclusions: The proposed method for the calculation of mitral valve area using LA or Cap proved to be highly accurate and simple making it possible to safely monitor valvotomy procedures.

Key words: Pressure half-time, mitral valve area by half-pressure, left atrium of the half-pressure.

The mitral valve area (MVA) measurement, essential for the evaluation of mitral valve stenosis (MVS) severity, is typically performed by the Gorlin invasive formula, echocardiographic planimetry and pressure half-time performed with the echo-Doppler-cardiograph[1-5].

In 1997, during the *Congresso da Sociedade Brasileira de Hemodinâmina e Cardiologia Intervencionista* (Congress of the Brazilian Society of Hemodynamics and Interventional Cardiology), Haddad et al showed that there is a good correlation between mitral valve area values obtained by the Gorlin's method and those calculated by the Doppler pressure half-time method applied directly to the left atrial pressure curve[6].

The objective of this study was to evaluate the accuracy of MVA measurements obtained by the Doppler pressure half-time method applied to left atrial and pulmonary capillary wedge pressure curves, and assess its usefulness in monitoring percutaneous mitral valvotomy (PMV).

Methods

During an eighteen-month period, 35 patients with MVS and indication for percutaneous treatment underwent PMV as per the Cribier method[7-9]. Chart 1 displays the characteristics of the study population.

All patients selected were in normal sinus rhythm and initially underwent clinical and laboratory examinations. Cases were then discussed by a multidisciplinary team and referred to percutaneous therapy.

Before enrolling in the study, patients received detailed information about existing treatment options, risks and benefits, as well as ethical and methodological aspects of the study on percutaneous mitral valvotomy using Cribier's method. They were also informed about the use of MVA measurements using the half-time pressure applied to the left atrium and pulmonary capillary in order to monitor this procedure. All thirty-five patients decided on the percutaneous procedure with the monitoring procedure proposed and expressed their agreement in participating as research subjects by signing the Informed Consent form, as required by Resolution 196 of the National Health Board of the Ministry of Health, which sets guidelines for research in humans[10]. This study was conducted after the approval by the "Human Research Ethics Committees" of the institutions where the procedures were performed.

All PMV procedures were performed with the instruments

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of the Cribier kit, balloon catheters and device for cardiac output monitoring (Arrow-USA), as well as Toshiba and Siemens echo-Doppler-electrocardiographs.

Before and after the procedures, MVA measurements were calculated by the Gorlin method using the left atrial (GLA-1 e GLA-2) and pulmonary capillary (GCap-1 e GCap-2) pressure curves. With the echo-Doppler device, MVA was calculated by planimetry (Plan-1 and Plan-2). The Doppler valve area measurement (pressure half-time) was taken before and 24 hours after the procedure. There are reports about the inadvisability of calculating MVA by Doppler pressure half-time immediately after the opening of the mitral valve[11-13].

The methodology for measuring the mitral valve area with pressure half-time (PHT, PM or P1/2) originated in the observation made by Libanoff and Rodbard that when blood flows passively through a stenotic valve, the diameter of the valve can be estimated by measuring the time necessary for the maximum pressure gradient to reach half its value[3].

Later on, the application of this concept to Doppler methodology involved a slightly different technique in which the flow value substituted the pressure value[4]. The computer in the device automatically measures the peak velocity of the initial transmitral flow rate and, by mathematic calculation, determines the flow rate at which half of the pressure gradient occurs (peak height divided by 1.4). This flow rate value projected onto the rapid diastolic filling curve allows the automatic calculation of the time at which the maximum gradient falls to one half of its maximum value, and the Doppler (flow) pressure half-time is determined.

The pressure half-time (PHT / PM) remains relatively constant for a given valve area and over a large variation in flow[16]. For a valve area of 1 cm^2, PHT is 220 msec[3]. Therefore, the mitral valve area (MVA) given by the computer in the device is a result of the division of 220 by the PHT found.

Similar to the above-mentioned method for determining the MVA measurement by Doppler, a line is drawn along the left atrial or pulmonary capillary pressure curve, accompanying the initial phase of the diastolic "collapse" which corresponds to rapid passive ventricular filling ("b" on Figure 1). The connecting points in this line are the conventional "v" and "y" points in the left atrial or pulmonary capillary pressure curves. The maximum left atrial diastolic pressure peaks at the "v" point. Immediately after this point, the mitral valve opens. The "y" point corresponds to the nadir of the second negative wave of the atrial or pulmonary capillary pressure curve, and represents the start of the diastolic phase of slow ventricular filling.

Next, starting from the maximum diastolic pressure point ("v"), a vertical straight line is drawn down to the horizontal axis, and the half-point of this line is measured in millimeters ("c" on Figure 1). After that, a point is sought on the line corresponding to rapid ventricular filling (v-y line), which projection onto the horizontal axis corresponds to half the value of the maximum pressure peak that was previously measured ("d" on Figure 1).

The distance between these two projected vertical straight lines is also measured in millimeters ("X" distance on the figure). The pressure half-time (PHT/PM) is equal to the time it takes to traverse this X distance between the two straight lines. This can be easily determined using a simple rule of three and observing the velocity of the pressure curve inscription on appropriate paper. As shown on Figure 1, the standard velocity for all cases is 50 mm/sec.

Finally, dividing 220 by the PHT (PM), the mitral valve area is determined.

In order to compare MVA values obtained by the proposed method with those calculated by traditional methods, and evaluate their validity in monitoring percutaneous mitral valvotomy, the valvotomy procedures in this study were monitored. Six mitral valve area measurements were taken and stopped after a significant increment of mitral valve area above 100% of the previously calculated value, with any method used, and ideally, after obtaining an MVA of about 2 cm^2. A reduction in transmitral pressure gradient of more than 50% by the "three points" method was also used as a criterion of success[14].

Statistical analysis was done in two parts**:** 1) Bivariate Correlation Analysis (Pearson's Correlation) with the two measurements, taken before and after the procedure: Pearson's correlation measures the association among 2 (or more) variables. It is a dimensionless measurement (uses no units) that varies between -1 and 1. The closer the value is to the extremities, the greater the association among the variables. The closer the result is to zero (0), the smaller the association among the variables. On the other hand, the correlation sign measures the direction of this correlation. Negative relationships indicate that the variables are inversely proportional one to the other. Positive correlations indicate

n = 35	**Female = 24 (68.6%)** **Male = 11 (31.4%)**
(Previous commissurotomy)	04
Age	18 to 54 years of age (mean = 29)
Functional classification (N.Y.H.A.)	II = 16 III = 19
Wilkins' Echocardiographic index (echo score)	7 = 12 8 = 23
Valvulopathy and/or associated coronariopathy, atrial thrombosis, thromboembolism, mitral insufficiency > ++/4 (Sellers)	0

Chart 1 - Characteristics of the study population

that the variables are directly proportional to each other; 2) Linear Regression Analysis: In order to estimate the relationship among several measurements of interest (PMCap and PMLA, for example) relative to other measurements, a linear regression model was used as shown on Table 4. In this model, one can estimate the mitral valve area that would be obtained by echo-Doppler, even if the equipment was not available in the catheterization room.

Results

Success was obtained in all patients, and two complications were recorded. The first was repeat interatrial septum puncture in 19 patients, attributed to a distortion of the interatrial septum secondary to cardiomegalia. The second was the development of mitral insufficiency (+ / 4) in five patients, although without hemodynamic repercussions.

The mitral valve area values obtained by any method, before and after the procedures, had statistically significant correlations as shown on Tables 1 and 2.

Comparing the data on Table 1, one can see that before valvar opening, the association between the values calculated by the proposed method and those obtained by the echo-Doppler-cardiograph device (PMD-1 and Plan 1) was greater than for those obtained by the Gorlin method (G-LA1 and G-Cap1). Nevertheless, this has no practical significance since only relationships under 0.3 are considered statistically weak.

After the procedures (Tab. 2), the intensity of the relationship between the two proposed methods and the others remained uniformly higher (over 0.7). There were also changes in correlations among the variables where some dropped and others increased. For further analysis, it is important to point out the good correlation of the values obtained via PMD-2 with those obtained by the proposed methods.

With the linear regression model, it was possible to use simple formulas for calculating the mitral valve areas obtained by other methods. For this, the measurements obtained for PMLA or PMCap can be used, and one can easily reach those determined by other methods (Tab. 3).

Discussion

The mitral valve area, one of the best parameters for the evaluation of mitral stenosis, is commonly calculated by catheterism or by echo-Doppler. With catheterism, the procedure used most often is the Gorlin technique that involves measuring cardiac output by thermodilution and complex formulas. These factors, associated with the need for additional equipment, catheters, and disposable materials, make percutaneous mitral valvotomy more complex and expensive.

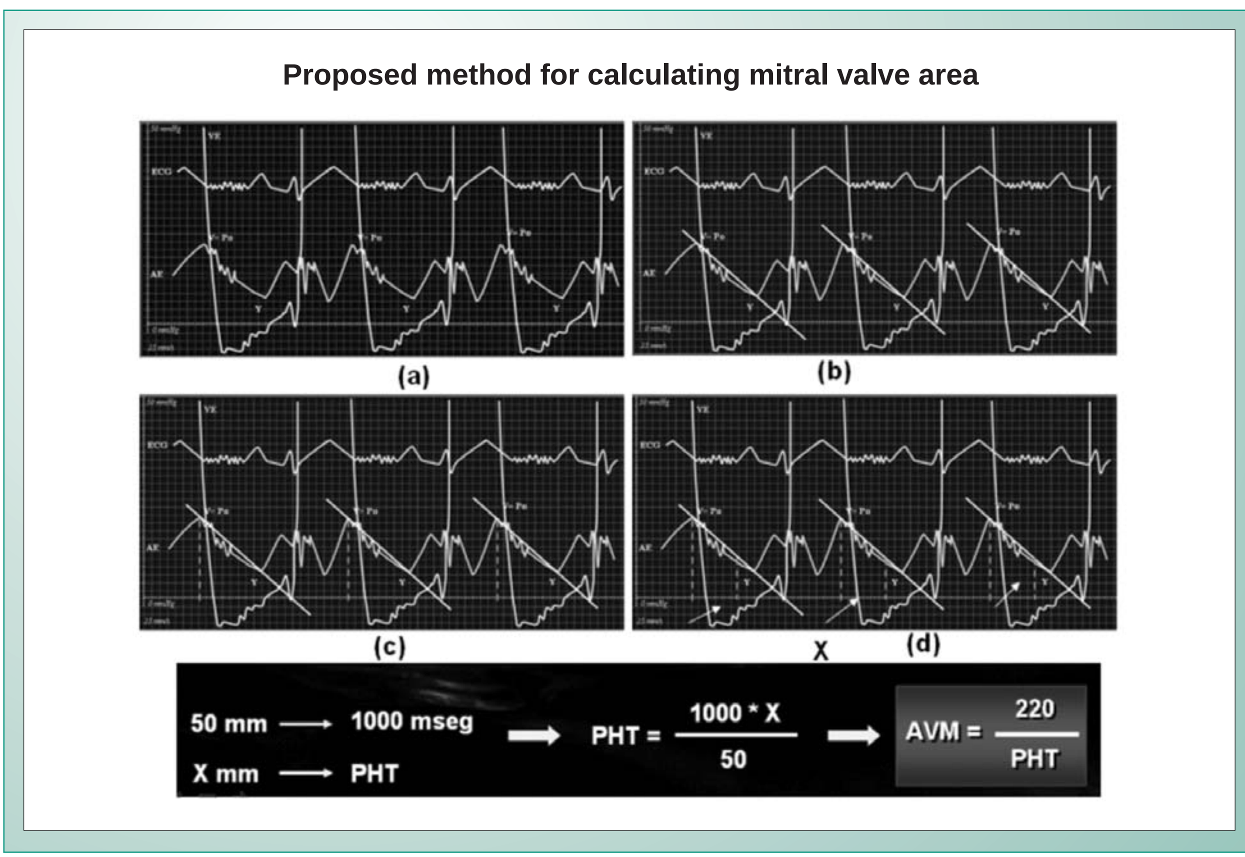

Fig. 1 - Proposed methodology. On (a) simultaneous pressure recording VE-AE. In (b) - line projected onto the LA pressure curve accompanying the rapid filling phase, between points v and y. In (c) - observe the projection of point v onto the baseline determining the vertical line that is measured in millimeters. The value of half this measurement is calculated and determined on the line that links points v and y. This calculated point determines a new line on the horizontal baseline. The time needed to cover distance X (between the two projected points) is the pressure half-time (PHT or PM). Dividing 220/PHT (PM), the valvar area is obtained. LA - left atrium; LV - left ventricle; PHT or PM - pressure half-time; EKG - electrocardiogram.

The Gorlin method is more appropriate for patients with sinus rhythm, no mitral regurgitation, normal left ventricular function, and no associated cardiac lesions. The presence of atrial fibrillation, tachycardia, mitral insufficiency, and low cardiac output make the method practically non-viable[15].

The observation that the PMD-based mitral valve area values correlate with those obtained by Libanoff's method and with anatomo-pathological findings[13], inspired the application of the Doppler pressure half-time method directly to pulmonary capillary and left atrial pressure curves. In this way, one would be sure to have truer mitral valve area values. These would be direct measurements of the valvar area applied to the instantaneous cavity pressure curve and not the flow record (an indirect assessment).

Before valvar opening, the application of the method to both pressure curves proved to be of great value and showed an excellent correlation with the echo-Doppler MVA measurements. With the Gorlin method, this correlation was weaker. After the valvotomy, the valvar area calculated using the pressure curve of the left atrium had an inverse association with that found with the Gorlin method (Tab. 2). On the other hand, in spite of the small differences, the method proved to be viable in any one of the alternatives, with high statistical significance both before and after valvar opening.

The MVA values calculated on the pulmonary capillary curve were always lower than those found on the left atrium curve. This was surely a consequence of the fact that the pressure curve representative of the initial rapid ventricular filling phase, or diastolic "collapse", observed on the capillary pressure curve, shows a slope smaller than on the left atrial pressure curve. The simultaneous pressure recording (Cap/LA) in Figure 2 illustrates this fact, where one can see, first of all, the 80 msec delay in the pulmonary capillary pressure curve inscription in comparison to that of the left atrium.

Besides this delay, there is an attenuation of the pressure level and inscription velocity of the entire pulmonary capillary wave, manifested by a smaller "v" wave amplitude, followed by a slower "pressure decline" that culminates at the "y" point, which is higher than the peak represented on the left atrial curve. It is as if the rapid ventricular filling phase on the pulmonary capillary curve were slower because of the delay and buffering of the pressure curve. This results in a similar average pressure gradient, although the left atrial pressure curve has greater amplitude, mainly because of its higher "v" wave[13,16]. Consequently, we can affirm that regardless of the method used (Gorlin or the proposed method), the mitral valve area obtained with the pulmonary capillary pressure curve is always slightly smaller than that obtained when the left atrial pressure curve is used.

Another factor that also seems to contribute towards this difference is the poor quality of pulmonary capillary recordings, due to the difficulties in determining them.

	PMCap-1	PMLA-1	PMD-1	Plan-1	GCap-1	GLA-1
PMCap-1	1					
PMLA-1	**0.9551**	1				
PMD-1	**0.8737**	**0.8897**	1			
Plan-1	0.7756	0.7813	**0.9049**	1		
GCap-1	0.5930	0.5614	0.4583	0.4085	1	
GLA-1	0.6980	0.6770	0.5926	0.5218	**0.9565**	1

** All correlations have significance (value of p <0.05; PMCap-1 - Proposed method with pulmonary capillary pressure curve (before); PMLA-1 - Proposed method with left atrial pressure curve (before); PMD-1 - Valve area, measured by Doppler pressure half-time(before); Plan-1 - Valve area by echocardiographic planimetry (before); GCap-1 - Valve area by Gorlin method, with pulmonary capillary pressure curve (before); GLA-1 - Valve area by Gorlin method, with left atrial pressure curve (before).*

Table 1 - Correlations among mitral valve area measurements before procedures. The figures in bold font emphasize the best correlations

	PMCap-2	PMLA-2	PMD-2	Plan-2	GLA-2	GCap-2
PMCap-2	1					
PMLA-2	**0.8309**	1				
PMD-2	0.7867	0.7273	1			
Plan-2	0.7699	0.7661	0.7697	1		
GLA-2	0.7184	**0.8781**	0.6873	0.7605	1	
GCap-2	0.7028	**0.8528**	**0.8037**	**0.8345**	**0.8957**	1

** All correlations have significance (value of -p <0.05); PMCap-2 - Proposed method with pulmonary capillary pressure curve (after); PMLA-2 - Proposed method with left atrial pressure curve (after); PMD-2 - Valve area, measured by Doppler pressure half-time (after); Plan-2 - Valve area by echocardiographic planimetry (after); GLA-2 - Valve area by Gorlin method, with left atrial pressure curve (after); GCap-2 - Valve area by Gorlin method, with pulmonary capillary pressure curve (after).*

Table 2 - Correlations among mitral valve area measurements after procedures. The figures in bold font emphasize the best correlations

Linear Regression	Coefficient of Determination – R2	F Test – P Value
PMD-1-0.259+(0.8191*PMLA-1)	R2-0.8164	Valor – P<0.01
PMD-1-0.306+(0.8834*PMCap-1)	R2-0.7814	Valor – P<0.01
Plan-1-0.553+(0.6011*PMLA-1)	R2-0.7392	Valor – P<0.01
Plan-1-0.579+(0.6603*PMCap-1)	R2-0.7339	Valor – P<0.01
PMD-2-0.489+(0.31528*PMLA-1+0.3235*PMCap-2)	R2-0.7802	Valor – P<0.01
GCap-2	0.7028	0.8528

PMD - Mitral valve area by Doppler pressure half-time (before = 1; after = 2); PMLA - Mitral valve area by proposed method with left atrial pressure curve (before = 1; after = 2); Plan - Mitral valve area by echocardiographic planimetry (before = 1; after = 2); PMCap - Valve area by proposed method with pulmonary capillary pressure curve (before = 1; after = 2); PMLA - Valve area by proposed method with left atrial pressure curve (before = 1; after = 2); R2 - Indicator of regression model quality adjustment. The closer it is to 1, the greater the adjustment; F Test - P Value - Tests the relationship among variables of the model. P <0.01: There is a correlation among the appointed variables.

Table 3 - Linear Regression Model

Calculations are customarily imprecise, and the gradients are always greater[17].

Currently, the most precise measurement of the transmitral gradient is obtained by simultaneous LV/LA pressure recordings. Nevertheless, LV/Cap values are very useful, especially in cases with a slight elevation in pulmonary capillary pressure or normal pressure. In these situations, transeptal puncture, with its possible complications, is unnecessary for measuring left atrial pressure since both pressures are practically the same [13]. However, in borderline cases and when capillary pressure is very high, left atrial pressure provides results that are more accurate[13,17].

Two findings of this study are of great practical importance. First, the good correlation between MVA values calculated with the proposed method and those obtained with echo-Doppler after valvar opening (Tab. 2). Literature on hemodynamics has pointed towards the inadvisability of using some MVA values, calculated by pressure half-time, for monitoring valvoplasty procedures[13]. The authors refer especially to those values calculated with Doppler in the catheterism room directly after valvar opening. They emphasize the significant immediate pressure changes that result from the increase in transmitral flow and the equally instantaneous modifications in left atrial complacency.

Additionally, a certain degree of valvar ring dilation was also observed immediately after the balloon valvotomies, which would represent another error factor in the MVA calculation if it were made right after the procedure.

In our patients, MVA calculation by pressure half-time using Doppler and by echocardiographic planimetry were made 24 hours after termination of the procedures, when cardiac hemodynamics have adapted and are closer to their true values. Since the results found by the proposed method showed a good correlation with Gorlin and even with echo-Doppler results, we can deduce, with little fear of being wrong, that this method can be used to monitor percutaneous valvotomy procedures. This applies both to left atrial and pulmonary capillary pressure curves.

The second finding of practical significance is that the echo-Doppler becomes dispensable in the catheterism room, simplifying the method and reducing percutaneous mitral valvotomy costs (having it in the room may still be justified in difficult transeptal puncture cases). This fact is significant when material costs, time needed for the procedure, specialized equipment, and personnel are taken into consideration.

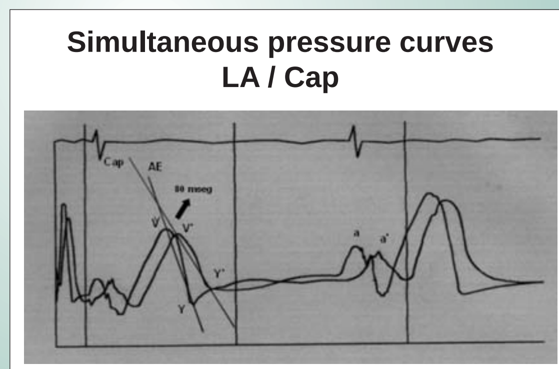

***Fig. 2** - Differences between left atrial and pulmonary capillary pressure curves.*

From this standpoint, the linear regression model mentioned above is very useful. Using simple formulas, one can determine MVA measurements that would be obtained either with the echo-Doppler device or by the Gorlin method, without needing to use these methods in the catheterism room. Depending on the results, the use of the formula with the MVA value found by pulmonary capillary pressure half-time would avoid [unnecessary] use of interatrial septum punctures and the echo-Doppler, for example.

Conclusion

We can conclude that, in comparison to current methods in use, mitral valve area values obtained by Doppler pressure half-time measurements applied directly to the left atrial and pulmonary capillary wedge pressure curves proved very accurate and statistically valid.

The recognition of the usefulness of monitoring percutaneous mitral valvotomy with the methodology proposed in this investigation, with calculations of the valvar area at each opening of the valvulotome arches or expansion of the balloon, will certainly lead to even better and safer results.

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