Simplifying proximal isovelocity surface area as an assessment method of mitral valve area in patients with rheumatic mitral stenosis by fixing aliasing velocity and mitral valve angle

Alaa Mabrouk Salem Omar, Mohammed Ahmed Abdel-Rahman, Hidekazu Tanaka, Osama Rifaie

Medical Division, Internal Medicine Department, National Research Centre, Cairo; Department of Cardiology, Ain Shams University, Cairo; Department of Cardiovascular Medicine, Kobe University Graduate School of Medicine, Kobe

We aimed to test the ability of a simple equation using proximal isovelocity surface area method (PISA), created by fixing the angle to 100° and the aliasing velocity to 33 cm/s, to calculate mitral valve area (MVA) and assess severity in patients with rheumatic mitral stenosis (MS).

Methods and results: In a series of 51 consecutive patients with rheumatic MS, MVA was assessed by four methods, conventional PISA equation (PISA_{conventional}), simple PISA equation (PISA_{simple}), pressure half time (PHT), and planimetry (PLN) which was taken as the reference method. All methods correlated significantly with PLN with the highest correlation found in case of PISA_{conventional} and PISA_{simple} (r = 0.97, 0.96, p < 0.001), while the correlation in case PHT was relatively weaker (r = 0.69, p < 0.001). Bland–Altman analysis revealed that the level of agreement with PLN was better in case of both PISA methods than PHT and, moreover, were close to each other. The number of cases that showed agreement of severity grade with planimetry was better in case of PISA_{conventional} (42 cases) and PISA_{simple} (44 cases) than that in case of PHT (34 cases, p = 0.037). Finally, the measure of agreement with Cohen’s Kappa test was better in case of PISA_{conventional} and PISA_{simple} than that in case of PHT.

Conclusion: Provided that aliasing velocity is fixed at 33 cm/s, PISA can effectively predict mitral valve area and severity of MS by a simple equation, with the advantage of easy and accurate calculation over other methods.

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Keywords: Rheumatic mitral stenosis, Mitral valve area, Proximal isovelocity surface area
Introduction

The principal cause of mitral stenosis (MS) is rheumatic fever which remains endemic in developing countries; therefore, MS is still a major public health problem in these countries. Assessment of the mitral valve area (MVA) is of considerable importance being the main factor in the clinical evaluation of patients with MS used for the determination of various aspects of management, such as treatment options and long-term outcomes. Several echocardiographic techniques have been introduced as means of MVA assessment, two of which, the two-dimensional planimetry and pressure half-time (PHT) methods are currently the most widely used [1,2].

The PHT method, in particular, has gained widespread acceptance for MVA calculations, mainly because of its simplicity and acceptable reproducibility [2–4]. However, the clinical value of MVA calculated with the PHT method remains controversial because it can be affected by a variety of clinical conditions including significant aortic regurgitation and impaired left ventricular (LV) compliance [3,7–10]. The planimetry method itself was reported to be difficult to be calculated in 5% of patients because of poor echocardiographic windows, severe calcifications, or the presence of a mitral valve tunnel-like structure [8] that raises the need of an appropriate short axis cut to be used in calculation, hence the planimetry method is extremely operator dependant and needs much expertise. The proximal isovelocity surface area (PISA) method has been introduced as a promising tool for the assessment of MVA [9,10]. It is based on the principles of the continuity equation and the preservation of mass. PISA method correlates closely with reference methods in all studies. This advantage is outweighed, however, by being a difficult and time consuming technique. Recently, we reported that because of not being affected by changes in the net atrio-ventricular compliance that greatly affects the PHT method, PISA, despite being time consuming, should be used rather than PHT as an alternative to planimetry method if the latter is difficult to be measured [11]. The PISA equation used to calculate MVA in MS is:

\[
\text{MVA} = \frac{2 \pi r^2 \text{Val} \times \text{Vmax} \times 180}{\pi}
\]

Which requires the measurement of \(r\); the PISA radius after adjusting the color aliasing velocity (Val), the measurement of the early mitral flow velocity (Vmax), and the mitral valve angle (\(\alpha\)). It was reported that the mitral valve angle in most cases of rheumatic MS is close to 100°, and that this value can be used in the PISA equation without the need for the tedious manual measurement of the angle [12]. As such, three variables only are left to be measured, namely; the radius, Val and Vmax.

There were many attempts to simplify the PISA equation [12–15], however, to the best of our knowledge, no study yet has assessed the application of a fixed value of Val in addition to angle \(\alpha\) in the equation used to calculate MVA by PISA.

Accordingly, we aimed in this study to compare the conventional PISA equation, with only fixing of Val to 33 cm/s, with a simple PISA equation, created by the combined fixing the angle to 100° and the Val to 33 cm/s, in addition to MVA measured by PHT, to the MVA measured by planimetry which was taken as the reference method.

Methods

Study population

A series of 56 consecutive patients with rheumatic MS and without prior history of percutaneous balloon mitral valvuloplasty were prospectively enrolled in this study from two centers (Ain-Shams University Hospital, Cairo, Egypt, and Kobe University Hospital, Kobe, Japan). This protocol was approved by the Institutional Review Board in Ain-Shams University and in Kobe University Graduate School of Medicine. All patients gave informed consent consistent with this protocol. Five patients (9%) were excluded from all subsequent analyses because of suboptimal images from poor echocardiographic windows. Accordingly, the patient study group consisted of 51 patients.

Echocardiography

All echocardiographic studies were acquired with a commercially available echocardiography system using a 2.5 MHz multi-frequency phased array transducer (Vivid 5 or 7; GE Vingmed Ultrasound AS, Horten, Norway). Digital routine grayscale two-dimensional cine loops from three consecutive beats were obtained at end-expiratory apnea from standard apical and LV short-axis views at depths of 12–20 cm. Sector width was optimized to allow for complete myocardial visualization while maximizing the frame rate. Gain settings were adjusted for routine clinical grayscale two-dimensional imaging to optimize endocardial definitions. The LV ejection fraction was assessed using the biplane Simpson’s method by manual tracing of the digital images. The peak and mean transvalvular pressure gradients were calculated with the modified Bernoulli equation. All echocar-
diographic data were reviewed by two experienced echocardiographers working separately and all measurements were made in ≥3 consecutive cardiac cycles and in ≥5 cycles if the patient’s rhythm was atrial fibrillation. The average values were used for the final analyses. For the assessment of intra-observer and inter-observer variability, all studies were redone for eight randomly selected cases in a different setting by the same operator (A.M.S.O.) and another operator (M.A.E) who was blinded to the results of the first operator.

Assessment of mitral valve area the proximal isovelocity surface area method using the conventional equation (PISA\textsubscript{conventional}) (Fig. 1A)

MVA determined with the PISA (PISA\textsubscript{conventional}) method is based on the analysis of the flow convergence proximal to the stenotic orifice. PISA\textsubscript{conventional} was obtained in the apical four-chamber view using the conventional equation of the hemispherical model corrected by the mitral valve angle:

\[
PISA_{\text{conventional}} = 2\pi r^2 \times (\text{Val}/\text{Vmax}) \times (\pi/180),
\]

where: \(r\) (cm) is the radius of the PISA cap, \(\text{Val}\) (cm/s) is the aliasing velocity of color Doppler, \(\text{Vmax}\) (cm/s) is the maximal velocity across the mitral valve in early diastole (i.e. maximum velocity of the E-wave), and \(\pi\) (degree) is the mitral valve angle. Color flow Doppler was applied on the mitral position and the aliasing velocity (Val) was selected, by shifting down the frequency, to 33 cm/s, followed by zooming the PISA flow and a cine loop was used to obtain the largest PISA cap radius (\(r\)) in early diastole by measuring the maximum distance between the apex of the triangle formed by both mitral leaflets at one end (defined as the point at which imaginary lines passing at the inner side of both leaflets would meet below the mitral valve with the color Doppler turned off), and the first line of aliasing at the other end (defined by the change of the color from red to blue). The mitral valve angle was measured manually with a protractor on external paper pictures (Fig. 1A).

The proximal isovelocity surface area method without Mitral valve angle correction (PISA\textsubscript{simple}) (Fig. 1A and D)

Because the Val was used as a constant in our study, and because it was previously reported that mitral valve angle can be fixed as 100° in the PISA equation, MVA calculated by PISA could be simplified as follows leaving only two variables to be calculated, namely, PISA radius and Vmax:

\[
PISA_{\text{simple}} = 2\pi r^2 \times (\text{Val}/\text{Vmax}) \times (\pi/180) = 2 \times 3.14 \times r^2 \times (33/\text{Vmax}) \times (100/180) = (2 \times 3.14 \times 33 \times 100/180) \times (r^2/\text{Vmax}) = 115 \times r^2/\text{Vmax}
\]

The pressure half-time method (Fig. 1B)

MVA determined with the PHT method (PHT) was calculated in the apical four-chamber view using color Doppler echocardiography with
clearly visible mitral inflow color flow mapping. The cursor line was moved across the mitral valve tips to the most parallel alignment in relation to the color signal of the mitral inflow. Continuous wave Doppler was initiated and a clear spectral tracing of the mitral inflow wave was acquired. The deceleration time of the early mitral filling phase spectrum was obtained and MVA by PHT was then calculated using the equation MVA = 220/PHT 220/PHT (Fig. 1 B). From the same mitral flow envelopes, mean transmitial pressure gradient (PG) was calculated by means of manual tracing.

The planimetry method (Fig. 1C)

The smallest orifice of the mitral valve was identified by scanning from the left atrium in the direction of the LV apex using basal-LV short-axis view. The gain settings were adjusted until the lowest level was determined, at which the circumference of the mitral orifice was still visible. After identification of the frame with the orifice at its maximal opening in early diastole, MVA determined with the planimetry method (PLN) was measured by planimetry of its contours, and the result served as the gold standard for MVA calculation in this study (Fig. 1C). The severity of MS measured with PLN, as well as PHT and PISA, was defined as: mild if MVA was more than 1.5 cm², moderate if MVA was more than 1.0 and less than or equal to 1.5 cm², and severe if MVA was less than or equal to 1.0 cm².

Results

The study group consisted of 51 patients with MS for each of whom four complete sets of MVA calculations were obtained. The mean age was 48 ± 19 years, and 28 (55%) patients were female. The clinical and echocardiographic characteristics of all study subjects are summarized in Table 1. All patients had normal LV ejection function of 61 ± 6% (all ≥ 55%). Thirty patients (59%) were in sinus rhythm and 21 (41%) in chronic atrial fibrillation.

Reproducibility

The intraobserver and interobserver variability for PISAconventional were −0.01 ± 0.08 and 0.04 ± 0.13 cm², respectively; for PISAsimple were −0.02 ± 0.08 and 0.03 ± 0.15 cm², respectively; for PHT were 0.06 ± 0.11 and 0.05 ± 0.11 cm², respectively, and for PLN were, −0.04 ± 0.06 and 0.06 ± 0.11 cm² respectively. The interclass correlation coefficients for PISAconventional were 0.979 (p < 0.001) and 0.934 (p < 0.001), respectively; for PISAsimple were 0.981 (p < 0.001) and 0.932 (p < 0.001), respectively; for PHT were 0.868 (p = 0.001) and 0.829 (p = 0.003), respectively; and for PLN were 0.984 (p < 0.001) and 0.955 (p < 0.001), respectively.

Table 1. Clinical and echocardiographic characteristics of patients with mitral stenosis.

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>48 ± 19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (female/male)</td>
<td>28/23</td>
</tr>
<tr>
<td>Rhythm (sinus/atrial fibrillation)</td>
<td>30/21</td>
</tr>
<tr>
<td>Ejection fraction (%)</td>
<td>61 ± 21</td>
</tr>
<tr>
<td>Mean transmitial pressure gradient (mmHg)</td>
<td>11 ± 6</td>
</tr>
<tr>
<td>Severity of mitral stenosis defined by planimetry, n (%)</td>
<td></td>
</tr>
<tr>
<td>Mild</td>
<td>9(18)</td>
</tr>
<tr>
<td>Moderate</td>
<td>19(37)</td>
</tr>
<tr>
<td>Severe</td>
<td>23(45)</td>
</tr>
<tr>
<td>Severity of mitral regurgitation, n (%)</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>15(29)</td>
</tr>
<tr>
<td>Mild</td>
<td>30(59)</td>
</tr>
<tr>
<td>Moderate</td>
<td>6(12)</td>
</tr>
<tr>
<td>Severe</td>
<td>0(0)</td>
</tr>
<tr>
<td>Severity of aortic regurgitation, n (%)</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>24(47)</td>
</tr>
<tr>
<td>Mild</td>
<td>13(25)</td>
</tr>
<tr>
<td>Moderate</td>
<td>12(24)</td>
</tr>
<tr>
<td>Severe</td>
<td>2(4)</td>
</tr>
</tbody>
</table>
Correlations between MVA calculated by different methods: (Table 2, Fig. 2)

Linear regression analysis showed that MVA by conventional PISA equation (PISA conventional) correlated closely with the MVA by the planimetry method (PLN) ($r = 0.97$, $p < 0.001$). A similar correlation was also found between PLN and MVA by the simple PISA equation (PISA simple) ($r = 0.96$, $p < 0.001$). MVA calculated by the pressure half time method (PHT) showed a weaker but statistically significant correlation with MVA PLN ($r = 0.69$, $p < 0.001$).

Finally, PISA conventional correlated significantly with PISA simple ($r = 0.965$, $p < 0.001$).

From the previous observations, it can be concluded that the simple way used in our study to calculate MVA by PISA is comparable to the conventional equation with the advantage of easy calculation and is better than the other method used to calculate MVA, namely the PHT.

Agreement between different methods and planimetry

As decided by their correlations, and despite the lower correlation in case of PHT, all methods used in our study seemed reliable to assess MVA in comparison to PLN. However, when a Bland–Altman analysis was done to compare the differences between different methods against planimetry, it was found that the limits of agreement for PHT (upper limit of agreement, $-0.552$; lower limit of agreement, $0.532$, Table 3, Fig. 3) were worse than both PISA methods, which in turn were found to be very close to each other (PISA conventional: upper limit of agreement, $-0.18$; lower limit of agreement, $0.223$; PISA simple: upper limit of agreement, $-0.238$; lower limit of agreement, $0.199$, Table 3, Fig. 3).

Moreover, we compared the agreement severity classes for each patient when severity was defined by PLN against that classified by other methods. Table 4 summarizes severity grades of MS as decided by different methods.

It was found that 42 patients showed agreement of severity class by PLN and PISA conventional (PISA conventional: $1.15 \pm 0.42$ cm$^2$, PLN: $1.13 \pm 0.4$ cm$^2$), and only nine cases showed disagreement, seven of them had milder MS by PISA conventional (PISA conventional: $1.28 \pm 0.27$ cm$^2$, PLN: $1.13 \pm 0.4$ cm$^2$), and two had severer MS by PISA conventional (PISA conventional: $1.16 \pm 0.368$ cm$^2$, PLN: $1.35 \pm 0.36$ cm$^2$, Delta-PISA conventional: $-0.19 \pm 0.0$ cm$^2$).

### Table 2. Correlations against MVA by planimetry method.

<table>
<thead>
<tr>
<th></th>
<th>Linear regression ($n = 51$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r$</td>
</tr>
<tr>
<td>PISA conventional</td>
<td>0.97</td>
</tr>
<tr>
<td>PISA simple</td>
<td>0.96</td>
</tr>
<tr>
<td>PHT</td>
<td>0.69</td>
</tr>
</tbody>
</table>

Correlation coefficient ($r$), represents pearson correlation coefficient. PISA conventional: mitral valve area calculated by the conventional equation of proximal isovelocity surface area, PISA simple: mitral valve area calculated by the simple equation, of proximal isovelocity surface area, $115 \times r^2/V_{max}$, and PHT; mitral valve area calculated by the pressure half time method.

### Table 3. Bland–Altman analysis for agreement of different methods with planimetry.

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD of differences</th>
<th>Bias ± SE</th>
<th>Lower limit of agreement (95% CI)</th>
<th>Upper limit of agreement (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHT</td>
<td>$-0.01 \pm 0.277$</td>
<td>$-0.01 \pm 0.0224$</td>
<td>$-0.552$ ($-0.628$ to $-0.477$)</td>
<td>$0.532$ ($0.456$ to $0.608$)</td>
</tr>
<tr>
<td>PISA conventional</td>
<td>$0.021 \pm 0.103$</td>
<td>$0.021 \pm 0.008$</td>
<td>$-0.18$ ($-0.208$ to $-0.152$)</td>
<td>$0.223$ ($0.195$ to $0.251$)</td>
</tr>
<tr>
<td>PISA simple</td>
<td>$-0.019 \pm 0.11$</td>
<td>$-0.019 \pm 0.009$</td>
<td>$-0.238$ ($-0.268$ to $-0.207$)</td>
<td>$0.199$ ($0.168$ to $0.229$)</td>
</tr>
</tbody>
</table>
On the other hand, 44 patients showed agreement of severity class by MVA PLN and PISA simple (PISA simple: 1.13 ± 0.4 cm², PLN: 1.15 ± 0.4 cm²) and only seven patients showed disagreement, four of them had milder MS by PISA simple (PISA simple: 1.15 ± 0.26 cm², PLN: 1.09 ± 0.2 cm²) and three had severer MS by PISA simple (PISA simple: 0.94 ± 0.04 cm², PLN: 1.15 ± 0.07 cm²).

However, when severity was compared when classified according to PHT and PLN, it was found that only 34 patients showed severity agreement (PLN: 1.07 ± 0.3 cm², PHT: 1.05 ± 0.34 cm²), while

![Figure 3. Bland–Altman analysis for the assessment of agreement between different methods and PLN. No bias was detected in any method however the limits of agreement in case of PHT were worse than those of both PISA methods, which in turn, were very close to each other and to PLN.](image)

**Table 4. Severity of MS classified by different methods.**

<table>
<thead>
<tr>
<th></th>
<th>PLN</th>
<th>PISA conventional</th>
<th>PISA simple</th>
<th>PHT</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severity class:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild n(%)</td>
<td>9(18)</td>
<td>11(22)</td>
<td>11(22)</td>
<td>7(14)</td>
<td>0.037</td>
</tr>
<tr>
<td>Moderate n (%)</td>
<td>19(37)</td>
<td>19(37)</td>
<td>15(29)</td>
<td>27(53)</td>
<td></td>
</tr>
<tr>
<td>Severe n (%)</td>
<td>23(45)</td>
<td>21(41)</td>
<td>25(49)</td>
<td>17(33)</td>
<td></td>
</tr>
<tr>
<td>Agreement with PLN n (%)</td>
<td>42(82)</td>
<td>44(86)</td>
<td>34(67)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No agreement with PLN n (%)</td>
<td>9(18)</td>
<td>7(14)</td>
<td>17(33)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(milder than PLN/severer than PLN)</td>
<td>7(72)</td>
<td>4(3)</td>
<td>14(3)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All abbreviations as in Table 2

* p = 0.586, against severity agreement according to MVA PISA angle.

b p = 0.069, against severity agreement according to MVA PISA angle.

c 0.02, against severity agreement according to MVA PISA angle.
Table 5. Degree of agreement between severity by different methods against planimetry using Cohen’s Kappa test.

<table>
<thead>
<tr>
<th>Degree of agreement</th>
<th>Kappa</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>According to PISA_{conventional}</td>
<td>0.723</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>According to PISA_{simple}</td>
<td>0.781</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>According to PHT</td>
<td>0.473</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

All abbreviation as in Table 2.

17 patients showed disagreement, 14 of them had milder MS by PHT (PLAN: 1.21 ± 0.48, PHT: 1.32 ± 0.23 cm²) and three had severer MS by PHT (PLAN: 1.62 ± 0.14 cm², PHT: 1.18 ± 0.29 cm²).

Overall, severity class agreement with PLAN was significantly different between methods (p = 0.037) apparently because of fewer cases of agreement between PHT and PLAN. Moreover, there was a strong trend towards fewer cases with severity class agreement by PHT compared to PISA_{conventional} (p = 0.069) and this difference was significant when compared with PISA_{simple} (p = 0.02) (Table 4).

The measure of agreement against PLAN using Cohen’s Kappa test was strongest for PISA_{conventional} and PISA_{simple} (k = 0.723, 0.781; respectively, both p < 0.001) while it was lower for PHT compared to the former two (k = 0.473, p < 0.001). (Table 5).

From the above results it can be concluded that; first, PHT is not as good method as PISA to calculate MVA or to judge severity of mitral stenosis according to MVA because of larger limits of agreement by Bland–Altman analysis, and significantly more cases of disagreement with the reference method, and second, PISA, calculated by the conventional equation and the simple method are both accepted tools to assess MS severity compared to the reference method.

Discussion

Our study demonstrated that MVA calculated by the simple equation of PISA, $115 \times r^2/V_{max}$, is comparable to the conventional equitation used to calculate MVA by PISA and effectively predicts MS severity.

It has been previously reported that PHT is an inaccurate measure of MVA if MS is associated with fast cardiac rhythms, nonlinear Doppler velocity curves, or conditions associated with changes in atrial or ventricular compliance, [3,5,6,11,16]. Moreover, differences between PHT and planimetry of more than 0.3 cm² have been found in 20% of patients [7,17]. We have also recently reported that these differences between planimetry and PHT might be due to extreme values of net atrioventricular compliance 4,11. The PISA method, on the other hand, has been validated in almost all conditions that tend to render PHT inaccurate. [4,9,18–20], and moreover, in our recent report, differences between MVA calculated by planimetry and PISA were not affected by the changes in the net atrioventricular compliance values that render PHT inaccurate as a measure of MVA.

The most important disadvantage of the PISA method in calculating MVA is that it is time consuming and difficult. The causes for this difficulty lie in the following causes: (1) The need for calculation of many variables before applying them into the PISA equation, namely the PISA radius (r), the aliasing velocity (Val), maximum early diastolic velocity across mitral valve (Vmax), and mitral valve angle (z). (2) The mitral valve angle needs manual calculation on an external thermal paper image. (3) Expertise needed for defining the points between which the PISA radius is measured and the appropriate Val by which the PISA cap is clear enough to allow easy measurement of the radius.

There were many trials to simplify the PISA equation [12–15], however, PISA remains unpopular for the assessment of MVA in patients with MS, and, to the best of our knowledge, no study was concerned on studying the calculation of PISA using a universally fixed Val, apparently, because of the aforementioned confusion of choosing an appropriate Val, and the concerns about the accuracy of the measurement of the PISA radius.

In the previous studies concerning the use of PISA in calculation of MVA, the methods used in selecting Val were variable between studies and even inside each study. From our experience, the effort paid in selecting an appropriate Val is not of great importance, and, moreover, adds great difficulty and confusion in the real clinical settings when the conventional PISA equation is to be used for the purpose of MVA calculation.

In our study, we used a straightforward way of simplification of the PISA equation depending on the following:

First, previous reports said that in rheumatic mitral, mitral valve angle is nearly 100° [12], which was reproduced in our study by finding that the mean angle in our study subjects was 103.7 ± 8.9°. Accordingly we used a fixed value of 100° as the mitral valve angle in all patients.

Second, we have previously reported that using an aliasing velocity of 33 cm/s was found to be sufficient to produce a PISA cap that was big enough to measure the PISA radius [11], and accordingly,
a fixed value of 33 was used in place of Val in all patients in our study. Applying those two fixed value of 100° and 33 cm/s in place of x and Val respectively has lead to the rearrangement of the PISA equation to be $115 \times r^2/V_{\text{max}}$, leaving only two variables to be measured namely the PISA radius and $V_{\text{max}}$.

We found that the use of this simple equation to calculate MVA correlated well with the reference method and was not different than the conventional equation of calculating MVA by PISA because $\text{PISA}_{\text{conventional}}$ and $\text{PISA}_{\text{simple}}$ correlated similarly with PLN ($r = 0.97, 0.96$; respectively), in addition to a strong correlation between PISA Conventional and $\text{PISA}_{\text{simple}}$ ($r = 0.956$). Moreover, the degree of agreement between MS severity decided by PLN and $\text{PISA}_{\text{conventional}}$ was similar to that between PLN and $\text{PISA}_{\text{simple}}$ ($k = 0.723, 0.781$; respectively).

The lower degree of agreement between PLN and PHT found in our study assures the less reliability of the PHT as method to estimate MVA in patients with MS.

Fig. 1 shows an example of calculating MVA by different methods, where $\text{PISA}_{\text{conventional}}$ and $\text{PISA}_{\text{simple}}$ showed perfect agreement with PLN, while PHT did not.

**Clinical application**

In clinical practice, there is no real gold standard to estimate MVA or MS severity by echocardiography. As discussed earlier, PHT method carries many fallacies in this regard. Planimetry method, despite being considered as the echocardiographic gold standard, carries in itself some difficulties in being impossible in patients with bad echocardiographic views or severe mitral valve calcification, and being tedious, time consuming and expertise demanding in the instance of having mitral valve tunnel like structure. Compared to all that, PISA assessment by the simple equation in our study was found very easy to carry out, because it needs no special skill more than applying color and zoom on the mitral position and decreasing the Val to 33 cm/s. Accordingly, we advice to use this method of PISA assessment of MS in patients where the planimetry method is difficult to be done.

**Study limitations**

This study included a relatively small number of patients. Future studies with larger patient populations are necessary to verify the relationship between the PISA radius and MS severity. Although we used the planimetry method as the gold standard, it has some limitations in that it may be influenced by severe leaflet or subvalvular calcification, asymmetrical leaflet affection, imaging technique or poor image quality. Careful selection of patients included in our study could avoid most of these limitations. The major problem was the funnel shaped structure that was seen in significant large number of patients that had symmetrical affection of both leaflets. To avoid this limitation, we have measured the distance between the anterior and posterior mitral leaflets in the LV parasternal long-axis view in its narrowest area for these patients. When viewing the LV short axis, planimetry of the mitral valve was not done until making sure that the level of measurement was the level that had the smallest distance between anterior and posterior leaflets, which was closest to the smallest distance obtained from the LV parasternal long-axis view; and thus serving as the narrowest area possible by planimetry of the mitral orifice. Newly developed imaging modalities, such as three-dimensional echocardiography, magnetic resonance imaging or computed tomography may reduce the operator dependence of the planimetry method and overcome most of its limitations. Finally, Although Gorlin’s method using cardiac catheterization remains the standard technique for direct assessment of MVA, this method has its own limitations and errors of as much as 20–40% may be encountered [16,21]. Moreover, MVA determined with the echocardiographic planimetry method has been shown to closely correlated with anatomic MVA [1,22,23], and has been used as the gold standard for MVA calculation in many centers [13,16].

**Conclusion**

Provided that aliasing velocity is fixed at 33 cm/s, PISA can effectively predict mitral valve area and severity of MS by the equation; $\text{MVA} = 115 \times r^2/V_{\text{max}}$, with the advantage of easy calculation over other methods used to evaluate MVA by echocardiography.

**References**


