Introduction: Quantification of mitral regurgitation (MR) by two-dimensional (2D) transthoracic echocardiography (TTE) is based on the analysis of the proximal flow convergence (PFC) and the “vena contracta” (VC). This method assumes geometries and can be misleading. In contrast, three-dimensional (3D) echocardiography directly measures flow volumes and does not assume geometries, which allows for more accurate MR evaluation.

Aims: To report the 3D transesophageal echocardiography (3DTEE) feasibility for MR quantification and evaluate its concordance with 2D echo.

Methods: Twenty-seven consecutive patients undergoing 2D and 3DTEE for presurgical MR evaluation were studied prospectively. MR quantification was performed by classical 2D methods based on PFC. Diameters of the VC in orthogonal planes by 3DTEE were estimated, establishing the VC sphericity index as well as VC area (VCA) by direct planimetry. In case of multiple jets, we calculated the sum of the VCA.

Results: MR assessment by 3DTEE was feasible. An adequate concordance between VC measurements by 2D methods (TTE and TEE) was observed; however, there was a poor correlation when compared with 3DTEE. The sphericity index of the VC was: 2.08 (±0.72), reflecting a noncircular VC.

Conclusions: 3DTEE is a feasible method for the assessment of the MR true morphology, allowing a better quantification of MR without assuming any geometry. This method revealed the presence of multiple jets, potentially improving MR evaluation and leading to changes in medical decision when compared to 2D echo assessment.

KEYWORDS
mitral regurgitation, proximal flow convergence, three-dimensional echocardiography, vena contracta

1 INTRODUCTION

Mitral regurgitation (MR) is usually quantified by two-dimensional (2D) transthoracic and transesophageal echocardiography (TTE and TEE, respectively). Assessment of the proximal flow convergence zone (PFC) by echocardiography allows a reliable determination of the effective regurgitant orifice area (ERO) as well as the vena contracta (VC). The PFC is based on a hydrodynamic principle that establishes that flow converges and accelerates and as it approaches a circular regurgitant orifice, dispersing in a large concentric hemisphere with similar velocity.

Based on the continuity equation, the PFC radius is used to derive the ERO. This classical echocardiographic method is called PISA (proximal isovelocity surface area).
The neck adjacent to the PFC constitutes the VC. The diameter of the VC is also used during routine MR quantification. International echocardiographic guidelines recommend measuring this diameter on the anteroposterior axis of the mitral valve from either the long para-
sternal axis (LAP) or the three-chamber apical view.\textsuperscript{1,2}

For the VC to accurately reflect the regurgitant orifice, the latter
has to be circular. Nonetheless, this is rarely the case, while the PFC
may not be hemispherical. Therefore, the use of PISA to determine
the ERO can be misleading, particularly in the presence of eccentric and/
or multiple jets.

The introduction of 3D echocardiography (especially TEE) enabled
a more comprehensive evaluation of the mitral valve. A “full volume
or multiple jets. ERO can be misleading, particularly in the presence of eccentric and/
may not be hemispherical. Therefore, the use of PISA to determine
the ERO can be misleading, particularly in the presence of eccentric and/
or multiple jets.

The VCA adopts the actual morphology of the anatomical regur-
gitant orifice, potentially capturing the true geometry and size of this
orifice.

The aims of this study were to report the feasibility of mitral valve
3DTEE assessment and compare it with 2D echo modes.

2  | MATERIAL AND METHODS

We included all consecutive patients undergoing echocardiographic
evaluation prior to mitral valve surgery. All patients underwent 2DTEE
and 3DTEE evaluation.

2.1 | Echocardiographic examination

2DTEE and TEE as well as 3DTEE examinations were performed with a
Philips iE33 ultrasound system (Philips Medical System, Andover,
MA, USA). 2D, real time (“live”) 3D, and “triggered full volume” digital
images were recorded and acquired in digital cine loop.

2DTEE was performed according to standard techniques, estimat-
ing the left ventricle (LV) diameters along with the left atrial area and
volume. Biplane 2D Simpson and 3DTEE were used for the assess-
ment of LV ejection fraction and volumes.

At that point, TEE was performed with a 5.5-MHz new matrix-
array X7-2t transducer under sedation. Full volumes were acquired at
0, 45, 90, 120 and 180 degrees and analyzed in a workstation using a
Philips QLAB software version 9.0 (Philips Medical System). Best cap-
ture (without stitching artifacts) was chosen for the analysis of the mi-
tral apparatus. 3D mitral annular area and diameters were determined
by Philips QLAB software.

3  | QUANTIFICATION OF
MITRAL REGURGITATION

3.1 | 2D echocardiographic assessment

MR quantification took into account the VC and ERO (PISA method).\textsuperscript{1}
VC was derived from the diameter adjacent to the PISA region (an-
teroposterior mitral valve axis or a three-chamber apical view) dur-
ing systole at the point of best jet visualization. A VC >7 mm was
considered severe MR. The ERO (by PISA method) was derived from
the following formula:

\[
ERO = \text{Regurgitant flow /velocity through the orifice.}
\]

\[
ERO = (r^2) \times (2\pi) \times \text{aliasing velocity/Vmax peak MR velocity.}
\]

\[
r \text{ is the PISA radius and } \pi \text{ is equal to 3.14. Vmax is the peak MR veloc-
ity measured by continuous-wave Doppler. The ERO was estimated
at systolic time and from the view where PISA was clearer and larger
displayed. MR was estimated as severe if ERO >0.4 cm}^2.\]

3.2 | 3DTEE assessment

MR quantification was performed using the multiplanar imaging tool
(QLAB software), which displays three planes of 2D echo simultaneously.

Two orthogonal image planes parallel to the regurgitant jet direc-
tion were manually cropped across the regurgitant jet; a third crop-
ning plane, which was perpendicularly oriented to the jet direction,
was then moved along the jet direction until the cross-sectional area
at the level of the vena contracta was visualized. The frame with the
largest VC in systole was magnified, and VCA was measured by direct
planimetry of the color Doppler flow signal. To analyze the circularity
of the regurgitant orifice, the ratio of the long axis to the short axis of
VCA (L/S ratio) was calculated.

A sphericity index was calculated using the ratio of the major axis
to the minor axis of the VC. By direct mapping (VCA planimetry), VCA
was measured at the transverse plane (Fig. 1, lower right quadrant).
The average VCA (VCA av) was derived from two orthogonal VC diam-
eters. As in 2D echo, the 3D VC was measured at an anteroposterior
mitral valve axis and compared to the 2D VC values.

The regurgitant jet number per patient was determined in all pa-
tients (Fig. 2). In case there were more than one jet, we performed
VCA planimetry of each jet and added them together to obtain the
total VCA (total VCA planimetry, Fig. 3).

4  | STATISTICS ANALYSIS

A prospective cross-sectional study was conducted.

The quantitative variables were expressed as mean ± standard de-
viation or medium and interquartile range according to their distribu-
tion. Categorical variables were reported as percentages.

Comparisons of categorical variables were made through simple
chi-square test. An alpha of <.05 was defined to accept statistical
significance.

Agreement was evaluated with Bland and Altman method and Lin
coefficient.

5  | RESULTS

Our study included 27 patients (14 men, 13 women; mean age
60.9 ±14. 9 years). Fourteen patients had degenerative mitral valve
disease, type II Carpentier classification: five patients with chordal rupture, three with Barlow’s disease, and two status postsurgical repair, while eight patients had type III Carpentier disease: one status postmyocardial infarction, two with a history of endocarditis, and one with congenital mitral cleft. Twenty-one of 27 (77%) had surgical mitral valve repair/replacement for severe MR.

Patient characteristics, including hemodynamic data and echocardiographic measurements, are shown in Table 1.
5.1 | 2D assessment

VC diameter by TTE (LAP) was 0.60 ±0.13 mm and by TEE (three-chamber apical view) was 0.64±0.15 mm. The ERO by TTE (PISA) was 0.50 ±0.18 cm $^2$ and by TEE was 0.52 ±0.20 cm $^2$.

5.2 | 3DTEE assessment

We were able to measure the VC diameter and perform VCA planimetry (3DTEE) in all cases. Mean minor VC diameter was 0.56±0.20 mm, while average (major and minor axis) VC diameter was 0.85±0.26 mm. Mean VCA by average of orthogonal planes was 0.62±0.40 cm $^2$ and VCA direct planimetry was 0.82±0.37 cm $^2$. Nineteen (70%) patients had more than one PFC while in 11 of 19 (57.9%) patients was able correctly to individualize each PFC and measured VC and VCA (Fig. 4). Total VCA planimetry (Σ of each VCA) was calculated as 0.92±0.32 cm $^2$. The sphericity index of the VC was 2.08±0.72 (Fig. 5).

5.3 | Comparison between 2D and 3D quantification methods

There was good agreement between 2D methods, whereas 2D and 3D methods had poor agreement owing to an underestimation of VC and ERO values by 2D echo (Table 2).

6 | DISCUSSION

2D echocardiographic quantification of MR by PISA method assumes that the ERO is circular. Nevertheless, 3D assessment has demonstrated that true ERO is not circular but linear and amorphous and in many cases divided into multiple orifices.$^5–^8$
In the present study, we obtained VC values (area and orthogonal diameters) by 3DTEE without assuming geometries. This quantification technique was quick and feasible.

VCA size and morphology assessment by 3D color Doppler constitutes an approximation of the ERO. In the present study, sphericity index confirmed that the shape of the VC was not circular (Fig. 5).

The latter finding reflects what is observed in daily practice: the regurgitating orifice has a diverse and tough-to-classify morphology, which explains the lack of agreement between the VCA by 3DTEE and the ERO by 2D. On the other hand, to quantify MR by 2DTTE or TEE, VC was measured only in an anteroposterior diameter, which theoretically corresponds to its narrow profile. In addition, there was no concordance between the VC measured at the anteroposterior view by 2DTTE or 2DTEE when compared to the average VC diameter by 3DTEE. The latter findings may be due to the fact that the MR jet crosses the regurgitant orifice with
TABLE 2 Agreement among 2D ETT, 2D TT3, and 3DTEE

<table>
<thead>
<tr>
<th>Measurement</th>
<th>CI 95% Bland and Altman Agreement</th>
<th>Lin coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC 2DTEE (mm) vs VC 2DTEE</td>
<td>-0.25 to 0.17</td>
<td>.67</td>
</tr>
<tr>
<td>VC 3DTEE (mm) vs VC 2DTEE</td>
<td>-0.38 to 0.32</td>
<td>.14</td>
</tr>
<tr>
<td>VC 3DTEE (mm) vs VC 2DTEE</td>
<td>-0.27 to 0.43</td>
<td>.14</td>
</tr>
<tr>
<td>ERO 2DTEE cm² vs ERO 2DTEE</td>
<td>-0.28 to 0.20</td>
<td>.78</td>
</tr>
<tr>
<td>ERO 2DTEE vs AVC' 3DTEE</td>
<td>-0.897 to 0.218</td>
<td>.30</td>
</tr>
<tr>
<td>ERO 2DTEE vs AVC' av AVC</td>
<td>-0.825 to 0.074</td>
<td>.20</td>
</tr>
<tr>
<td>Total AVC planimetry cm² vs ERO TTE 2D</td>
<td>-0.887 to -0.011</td>
<td>.23</td>
</tr>
</tbody>
</table>

VC, vena contracta; 2DTEE, two-dimensional transthoracic echocardiography; 2DTEE, two-dimensional transesophageal echocardiography; 3DTEE, three-dimensional transesophageal echocardiography; AVC, area of vena contracta; ERO, effective regurgitant orifice; AVC, area of vena contracta planimetry; av AVC, average orthogonal diameters

variable angulation and thereby, it is difficult to define by theoretical models.

Probably one of the most useful findings during MR assessment with 3D color flow reconstruction is the display of more than one jet with its corresponding and independent proximal convergence flow. In those cases, the VCA was accurately measured separately by mapping each area. The summation of these areas determined the total VCA. We believe that such degree of precision is not feasible by 2D methods and it is likely the cause for underestimation.

Defining a gold standard for MR quantification constitutes a major challenge. In the present study, ERO by PISA as well as the 2D VC diameter was not taken as a reference owing to the theoretical error of assuming a circular orifice.

In this population, a large proportion of patients underwent surgical valve repair/replacement (77%), showing severe remodeling of the left atrium, LV, and mitral ring, which reflects the degree of MR severity and chronicity. On the other hand, only 19% of patients had a 2D VC diameter >7 mm, highlighting how the use of a single VC assessment will likely reduce the echocardiographic sensitivity. In that venue, ERO measured by PISA (both TTE and TEE) performed better than VC, identifying 69% of patients with severe MR (ERO>0.4).

There was also no agreement between the direct VCA measurement by 3DTEE and the 2D ERO. As previously stated, 3D technique should be more precise as it does not assume geometries in their calculation. Currently, there are no 3DTEE cutoff values for MR severity; direct VCA measurement is likely to be more useful for surgical decision making. Such decision is typically the result of the interplay of imaging and clinical findings along with therapeutic strategies.

Other investigators have also measured the 3D VCA, but they have used TTE. In the study by Zeng et al., an VCA cutoff value of 0.41 cm² was identified in patients with moderate to severe MR, demonstrating optimal sensitivity and specificity. Nonetheless, that study used 2D echo as gold standard. Kahler et al. found significant VC asymmetry by TTE, while they did not measure multiples VCA as we found with TEE. TTE requires an optimal acoustic window and only allows measurement of single VC.

Currently, there is no standardization of MR grading by 3DTEE, this methods appears more reliable and should be used to base therapeutic decisions.

6.1 | Limitations

Spatial resolution and temporary capture of color 3DTEE is still suboptimal, which could overestimate MR quantification. The presence of atrial fibrillation, high in this patient subset, impairs the ability to perform 3D color volume capture.

7 | CONCLUSIONS

Mitral valve assessment by 3DTEE was feasible and demonstrated poor agreement with 2D echo. The use of 3DTEE allowed evaluation of multiple VCA, defining in greater detail the morphology of the regurgitant orifice. Such detailed assessment may change surgical indications as well as its approach (mitral valve replacement versus repair, surgical versus catheter-based).

REFERENCES


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