Utility of Real-Time 3-Dimensional Transesophageal Echocardiography in the Assessment of Mitral Paravalvular Leak

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Background: Mitral paravalvular leak (PVL) is a potential complication of surgical valve replacement procedures. Real-time 3D transesophageal echocardiography (RT-3DTEE) has emerged as an efficient tool for providing essential information about the anatomy of mitral PVLs compared with 2DTEE findings. The purpose of this study was to evaluate the utility of RT-3DTEE in the assessment of mitral PVLs.

Methods and Results: The 3D characteristics of PVLs were recorded and compared with 2D findings. We included 34 consecutive patients with clinical suspicion of mitral PVL in the study. Mitral PVLs were detected in 26 patients (76%); 26 PVLs were identified by 2DTEE and 37 by RT-3DTEE. Moderate or severe mitral regurgitation was present in 23 patients (88%). The most common PVL locations were the septal and posterior regions. The median PVL size measured by RT-3DTEE was 7 mm long×4 mm wide. The median vena contracta of defect measured by 2DTEE and RT-3DTEE was 5 mm and 4 mm, respectively. The median effective regurgitant orifice area of defect measured by RT-3DTEE was 0.36 cm². The defect types were “oval” (54%), “round” (35%), “crescentic” (8%) and highly irregular (3%).

Conclusions: Compared with 2DTEE, RT-3DTEE provided detailed descriptions of the number, location, size and morphology of PVLs, which is essential for planning and guiding the potential corrective techniques. (*Circ J* 2016; **80**: 738–744)

Key Words: Mitral regurgitation; Paravalvular leak; Real-time 3D transesophageal echocardiography; 2D transesophageal echocardiography

Paravalvular leaks (PVLs: abnormal communication between the cardiovascular chambers adjacent to a prosthetic valve) are a potential complication of surgical valve replacement procedures.¹ The incidence of mitral PVLs, including small non-significant jets, is estimated to be as high as 17% and is more frequent when there is severe annular calcification, or following endocarditis.^{2–4} PVL is most commonly observed with mechanical valves, followed by bioprosthetic valves. The majority of PVL are crescent, oval or roundish-shaped and their track can be parallel, perpendicular or serpiginous.^{5–8}

Many patients remain asymptomatic and do not require further surgical intervention. However, symptomatic patients often have associated heart failure, hemolytic anemia, arrhythmias, and infective endocarditis.⁹ Historically reoperation has been the standard treatment, but it is associated with higher

morbidity and mortality.^{2,4,10} Transcatheter approaches to treatment of PVL have been recently proposed, especially in high-risk patients, and are increasingly performed in experienced centers.^{11–13}

Echocardiography remains the main modality for the diagnosis of the PVL. Evaluation of the PVL by transthoracic echocardiography is difficult because of technical challenges. Although 2-dimensional transesophageal echocardiography (2DTEE) is very sensitive in accurately identifying the presence of PVL (88%),¹⁴ setting the number, extent, shape and exact anatomical location of the PVL can be very challenging.^{15,16} Real-time 3-dimensional TEE (RT-3DTEE) is a novel imaging technique based on the acquisition and display of volumetric data sets in the beating heart. This permits a comprehensive evaluation of cardiac anatomy and function from a single acquisition.^{17–20} Several studies have demonstrated the concordance

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Figure 1. Mitral paravalvular leak (PVL) detected by 2DTEE and RT-3DTEE. (A) 2DTEE color-Doppler imaging showing an anterior mitral PVL with severe paravalvular regurgitation. (B) RT-3DTEE color-Doppler imaging of the same patient with black asterisk identifying an anterior (11 o'clock) PVL and red asterisk identifying a septal (1 o'clock) PVL. Note that only 1 PVL was identified by 2DTEE whereas 2 PVLs were identified by RT-3DTEE. Measurements of the length, width, and area were performed by planimetry using the QLAB multiplanar reconstruction tool (Philips Medical Systems). LA, left atrium; LV, left ventricle; Ao, aorta; LAA, left atrial appendage; RT, real time; TEE, transesophageal echocardiography.

between RT-3DTEE images and the real anatomy, and the superiority of RT-3DTEE over 2DTEE.^{18,21–25} This can be important in deciding whether the patient will undergo a surgical or transcatheter approach for the correction of the paravalvular regurgitation.

The purpose of this study was to evaluate the utility of RT-3DTEE in the assessment of PVL.

Methods

Patient Population and Echocardiographic Examination

The study group comprised 34 consecutive patients with clinical suspicion of mitral PVL (presence of the mitral valve prosthesis and signs and symptoms of congestive heart failure and/or significant hemolysis) referred to the echocardiography laboratory. After providing informed consent, patients were simultaneously examined under sedation (1–2 mg midazolam) with 2DTEE and RT-3DTEE. All echocardiographic studies were conducted with a Philips iE33 ultrasound system and an X7-2t transesophageal transducer (Philips Medical Systems, Andover, MA, USA). Heart rates of all patients were maintained between 60 and 80 beats/min. To recognize a PVL, 2DTEE and RT-3DTEE were carefully performed with a frame rate as high as possible in each patient.²⁶ The 3D zoom mode and full-volume wide-angle acquisition mode were used to acquire the 3D volumetric datasets of the prosthetic valve and the paravalvular defects. All 3D echocardiographic loops included at least 3 cardiac cycles. 2D and 3D images were transferred to the Philips Xcelera workstation. All images were analyzed by blinded, experienced echocardiographers.

The number of PVLs recorded was based on data acquired from 2DTEE, RT-3DTEE volume images and full-volume 3D color-Doppler findings (Figure 1). Echocardiographic images

were presented in the “surgical view”, with the aortic valve at the top of the mitral valve prosthesis (12 o'clock), the left atrial appendage at 9 o'clock and the medial commissure at the 3 o'clock position. Thus, according to its position on this virtual clock, the location of each PVL was reported (Figure 2A).^{27,28}

The severity of each PVL was evaluated by 2DTEE and RT-3DTEE using several parameters (Table 1):²⁹ area of the color-Doppler mitral regurgitant jet in the left atrium (jet area), the narrowest diameter of the leak jet (vena contracta), the flow in the pulmonary veins and the effective regurgitant orifice (ERO) area. The degree of mitral regurgitation (MR) was classified into 3 grades [I (mild), II (moderate), III (severe)] according to the recommendations.²⁹ The ERO area was determined by direct planimetry using RT-3DTEE and the QLAB multiplanar reconstruction tool (Philips Medical Systems), as previously described.³⁰ Also, the shape, width, length, and area of each PVL were analyzed and measured (Figure 3). The measurement of the area, width and length was also carried out by RT-3DTEE using the QLAB multiplanar reconstruction tool (Figure 4). RT-3DTEE findings were compared with surgical and fluoroscopy findings in patients who underwent redo surgical valve or percutaneous mitral PVL closure.

Statistical Analysis

Categorical variables are described as number (percentage) and were compared using the chi-square or Fisher's exact test, as appropriate. Continuous variables are described as mean $\pm$ SD for variables with normal distribution or as median (range) for variables not normally distributed. Comparisons among normal continuous variables were made using Student's t-test; for variables not normally distributed, Mann-Whitney U tests were used. $P < 0.05$ was considered statistically significant. SPSS for Macintosh version 21.0 was used for statistical analysis.

Figure 2. Schematics show the location of mitral paravalvular leaks (PVLs) in the “surgical view”. (A) Anterior PVL (between 9 and 12 o'clock on the annulus), septal PVL (between 12 and 3 o'clock along the interatrial septum), posterior PVL (between 3 and 6 o'clock) and lateral PVL (between 6 and 9 o'clock). Mitral PVLs location according to (B) 2DTEE and (C) RT-3DTEE. Ao, aorta; LAA, left atrial appendage; RT, real time; TEE, transesophageal echocardiography.

Table 1. Grading of Mitral Paravalvular Regurgitation by Echocardiography			
	Mild	Moderate	Severe
2D TEE			
Jet area (cm ²)	<4	4–9.9	≥10
Vena contracta (mm)	<3	3–6.9	≥7
Pulmonary vein flow	Dominant systolic wave	Dominant diastolic wave	Systolic wave reversal
RT-3DTEE			
Vena contracta (mm)	<3	3–6.9	≥7
ERO area (cm ²)	<0.2	0.2–0.39	≥0.4

ERO, effective regurgitant orifice; MPR, mitral paravalvular regurgitation; TEE, transesophageal echocardiography.

Results

Patient demographics and medical history are shown in [Table 2](#). All patients had a mechanical prosthesis implanted (91% bileaflet; 9% monoleaflet). There were 6 patients (18%) with a history of redo valve surgery, and 5 patients (15%) who had undergone percutaneous PVL closure. We achieved high-quality 2D and 3D images of the prosthetic mitral valves, with a mean frame rate of 33±4 and 13±3 Hz, respectively.

Mitral PVLs were detected by 2DTEE and RT-3DTEE in 26 patients (76%); 26 PVLs were identified by 2DTEE and 37 PVLs were identified by RT-3DTEE. Of the patients, 10 (39%) had more than 1 PVL; 7 (27%) patients had 2 PVLs and 3 (12%) patients had ≥3 PVLs ([Table 3](#)). Severe paravalvular MR by 2DTEE was present in 17 (65%), moderate in 6 (23%) and mild in 3 (12%) patients. Severe paravalvular MR by RT-3DTEE was present in 16 (61%), moderate in 7 (27%) and

mild in 3 (12%) patients ($P>0.05$) ([Table 3](#)).

According to 2DTEE, the location of the 26 PVLs was septal in 10 (38%), posterior in 2 (8%), lateral in 8 (31%) and anterior in 4 cases (15%). The location of the PVL could not be specified in 2 cases (8%). They were PVLs located in a posterior position and with very eccentric jets. According to RT-3DTEE, the location of the 37 PVLs was septal in 13 (35%), posterior in 5 (13%), lateral in 11 (30%) and anterior in 8 cases (22%) ($P>0.05$) ([Table 3](#)). They were identified by 2DTEE as 8 septal (73%), 2 posterior (40%), 10 lateral (77%) and 4 anterior (50%) PVLs. There was no right correspondence between 2DTEE and RT-3DTEE in 10 patients (38%), in whom the location could not be established by 2DTEE or in whom more than 1 PVL was detected by RT-3DTEE ([Table 3](#)).

The median PVL size measured by RT-3DTEE was 7 mm long (range 3–36) by 4 mm wide (range 2–10). The median vena contracta of defect measured by 2DTEE and RT-3DTEE

Figure 3. Shape of mitral paravalvular leaks. (A) Round: length of the defect equivalent to the width of the defect. (B) Oval: length of the defect greater than the width of the defect. (C) Crescent: defect has a half-moon or arc shape (D). Highly irregular: defect has cutting edges and could be multi-fenestrated.

Figure 4. Evaluation of a mitral paravalvular leak (PVL) by real-time 3D transesophageal echocardiography (RT-3DTEE). (A) RT-3DTEE imaging with asterisk identifying a lateral (7 o'clock) mitral PVL. (B) RT-3DTEE color-Doppler imaging with asterisk identifying the severe paravalvular mitral regurgitation. (C) Measurements of length, width, and area were performed by planimetry using the QLAB multiplanar reconstruction tool (Philips Medical Systems). Ao, aorta; LAA, left atrial appendage.

was 5 mm (range 3–8) and 4 mm (range 2–10), respectively ($P>0.05$). The median ERO area of defect measured by RT-3DTEE was 0.36 cm^2 (range 0.15–2.10); 0.18 cm^2 (range 0.16–0.26) for mild paravalvular MR, 0.29 cm^2 (range 0.17–0.51) for moderate paravalvular MR and 0.78 cm^2 (range 0.24–2.10) for severe paravalvular MR (Table 3). The most

common defect type by RT-3DTEE was “oval” ($n=20$, 54%). Also, there were 13 (35%) “round”, 3 (8%) “crescent”, and 1 (3%) “highly irregular” shaped defects (Table 3). 2DTEE was not able to show these characteristics.

Surgical treatment was performed in 4 patients with heart failure and severe paravalvular MR. The site and dimensions

Table 2. Characteristics of Patients With Clinical Suspicion of Mitral PVL

Mean age, years	67±9
Male sex, n (%)	17 (51)
Medical history	
Hypertension, n (%)	9 (26)
Diabetes, n (%)	5 (15)
Coronary artery disease, n (%)	2 (6)
Atrial fibrillation, n (%)	22 (65)
Chronic renal failure, n (%)	4 (12)
Chronic obstructive pulmonary disease, n (%)	4 (12)
Prior stroke, n (%)	3 (9)
Prosthesis type	
Mitral, n (%)	34 (100)
Mechanical prostheses, n (%)	34 (100)
- Bileaflet, n (%)	31 (91)
- Monoleaflet, n (%)	3 (9)
Time since valve surgery, months	139 [80–240]
History of redo valve replacement, n (%)	6 (18)
History of percutaneous leak closure, n (%)	5 (15)
Presenting symptoms	
HF, n (%)	20 (59)
Hemolytic anemia, n (%)	1 (3)
HF and hemolytic anemia, n (%)	13 (38)
NYHA class ≥III, n (%)	16 (47)
LV ejection fraction, %	57±5

HF, heart failure; LV, left ventricular; NYHA, New York Heart Association; PVL, paravalvular leak.

of the dehiscence were all confirmed at the time of the surgery in each patient (100%). Percutaneous closure of mitral PVLs was performed in 13 high-risk surgical patients with advanced heart failure and severe paravalvular MR. The site of the dehiscence was also all confirmed at the time of the procedure in each patient (100%).

Discussion

This single-center study showed that RT-3DTEE is more effective than 2DTEE for establishing the number, location, size and shape of mitral PVLs.

Mitral PVLs are a well-recognized complication of mechanical or bioprosthetic surgical valve replacement, with a reported incidence of 7–17%.^{2–4} Most PVLs are small and clinically benign; however, larger PVLs can manifest as heart failure or hemolysis, necessitating either surgical or percutaneous repair.⁹

Echocardiography has an important role in the diagnosis of the PVL. RT-3DTEE can address the shortcomings of 2DTEE and demonstrate the exact number, sites, size, and shape of the PVLs.^{23,25} We had considerable difficulty in detecting more than 1 PVL with 2DTEE. However, with the help of RT-3DTEE it was relatively easy to detect all PVLs.

According to some authors,^{16,23,31,32} mitral PVLs occur more frequently at the anterolateral and posteromedial segments of the mitral valve annulus. In our study, the most common locations were septal and lateral. These discrepant finding could be in part related to the surgical technique and the implanted prosthesis, because the vast majority of surgeries were performed in the same center. On the other hand, we have also observed that there is not an absolute concordance between

Table 3. Characteristics of the Mitral PVLs in the Study Patients

	2DTEE	RT-3DTEE	P value
Number of patients with 1, 2 and ≥3 PVLs			0.01
1, n (%)	26 (100)	16 (61)	
2, n (%)	–	7 (27)	
≥3, n (%)	–	3 (12)	
PVL location			NS
Septal, n (%)	10 (38)	13 (35)	
Posterior, n (%)	2 (8)	5 (13)	
Lateral, n (%)	8 (31)	11 (30)	
Anterior, n (%)	4 (15)	8 (22)	
Not specified, n (%)	2 (8)	–	
Severity of paravalvular MR			NS
Severe, n (%)	17 (65)	16 (61)	
Moderate, n (%)	6 (23)	7 (27)	
Mild, n (%)	3 (12)	3 (12)	
Median PVL size, mm (range)	–	7 (3–36) long×4 (2–10) wide	
ERO area of the PVL, cm² (range)	–	0.36 (0.15–2.10)	
Mild regurgitation, cm ² (range)	–	0.18 (0.16–0.26)	
Moderate regurgitation, cm ² (range)	–	0.29 (0.17–0.51)	
Severe regurgitation, cm ² (range)	–	0.78 (0.24–2.10)	
Vena contracta, mm (range)	5 (3–8)	4 (2–10)	NS
PVL morphology			
Oval, n (%)	–	20 (54)	
Round, n (%)	–	13 (35)	
Crescent, n (%)	–	3 (8)	
Highly irregular, n (%)	–	1 (3)	

NS, P>0.05. MR, mitral regurgitation; 2DTEE, 2-dimensional TEE; RT-3DTEE, real-time 3-dimensional TEE. Other abbreviations as in Tables 1,2.

locations given by 2DTEE and RT-3DTEE, because in 10 (38%) there was not an exact match for the location. This happened in patients in whom the location of the PVL could not be established with 2DTEE and in patients with more than 1 PVL.

Although the morphology of the PVL is very complex, most reported leaks are either oval or crescent-shaped with irregular borders.³³ In our study, oval-round and crescent-shaped PVLs comprised 97% of all PVLs. Note that the PVL shape is essential for the selection of the percutaneous treatment and the most adequate device in each case. The oval or crescent morphology of many PVLs makes it difficult to find a specific device that adapts to these defects. For this reason, a number of devices not specifically designed for this task have been used to treat PVLs, including atrial septal defect occluders, patent foramen ovale occluders, duct occluders, and muscular ventricular septal defect occluders.^{34–36} PVL size and location are other important factors in determining the most appropriate treatment and the most adequate device in each case. Also, RT-3DTEE now plays an important role during the closure procedure in the hemodynamics room, because it guides the operator during the different stages of the intervention, including the choice of site for atrial transeptal puncture, guiding the catheter and the device to the leak and immediate assessment of the results of the closure.^{37–39}

We did not find significant differences in the degree of paravalvular MR evaluated by 2DTEE and RT-3DTEE. Only in 1 patient with a very eccentric regurgitant jet was the paravalvular MR assessed as severe by 2DTEE and as moderate by RT-3DTEE. Note that quantification of the severity of paravalvular MR in cases of multiple PVLs and/or eccentric jets is a real challenge. Color-Doppler in 3D echocardiography can be acquired together with a full volume,^{40,41} which is particularly useful in these complex cases.⁴² Also, other imaging techniques, such as computed tomography, could be useful for providing further information.¹²

Therefore, 2DTEE can be used for the diagnosis and quantification of paravalvular MR, but it is not sufficient for determining the characteristics and anatomical shape of the PVLs. RT-3DTEE provides excellent visualization of the mitral prosthesis⁴³ and has become the technique of choice for the assessment of PVLs. However, RT-3DTEE presents some limits. It depends critically on the quality of the image, which requires a learning process in order to optimize its acquisition.

Study Limitations

First, this was a single-center study with a not very large population. Only patients with a prosthetic mitral valve were included. The assessment of prosthetic aortic valve by RT-3DTEE is to some extent more limited than assessment of prosthetic mitral valve. Also, although we obtained high-resolution echocardiographic images, the mean frame rate was not very high. Finally, there is no gold standard for the localization of PVLs, such as fluoroscopy or surgical findings, to conclude that RT-3DTEE is superior to 2DTEE. However, in the patients who underwent surgery or percutaneous mitral PVL closure, the location and dimensions of the dehiscence were consistent with the RT-3DTEE findings.

Conclusions

RT-3DTEE permits detailed description of PVL characteristics compared with 2DTEE. This new technology may be very important in clinical decision-making and may contribute to the success of the potential corrective techniques.

Disclosures

None.

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