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ORIGINAL INVESTIGATION

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Mid-esophageal bicaval versus short-axis view of interatrial septum in two-dimensional transesophageal echocardiography for diagnosis and measurement of atrial septal pouches

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Background: Recent studies suggest that the left-sided septal pouch (SP) may increase the risk of cryptogenic stroke and act as an arrhythmogenic substrate. The aim of this study was to compare two transesophageal echocardiography (TEE) projections of the interventricular septum: mid-esophageal bicaval and short-axis views toward evaluating their ability to detect SPs.

Materials and methods: A total of 146 patients with both bicaval and short-axis TEE views were included in this study. The presence of SPs was determined, and they were evaluated for morphology.

Results: Irrespective of TEE projection view, the left SP was detected in 74 cases (50.7%), right SP in 16 cases (11.0%), and double in one case (0.7%). Agreement between both projections occurred in 119 cases (81.5%) with a weighted kappa coefficient of 0.68 (good agreement). We detected more left SPs from the bicaval view compared to the short-axis view; however, the observed difference was statistically insignificant (72 vs 59, $P = .13$). The detection of right SPs was higher in the short-axis view, but also statistically insignificant (9 vs 13, $P = .38$). Bland–Altman analysis revealed a significant difference in the left SP depth with higher values in the bicaval than short-axis view (systematic difference = 1.17 mm, LoA: −4.88–7.22 mm, $P = .02$, ICC = 0.58).

Conclusions: The mid-esophageal bicaval view should be preferable over mid-esophageal short-axis view of interatrial septum for the diagnosis and measurement of the left SP.

KEYWORDS
atrial fibrillation, cryptogenic stroke, interatrial septum, left-sided septal pouch, patent foramen ovale, septal pouch

1 | INTRODUCTION

The atrial septal pouch (SP) is a diverticulum within the interatrial septum that can be located on either the left or right side of the septum.[1,2] Cases of coexisting left and right SPs in the same patient (double SP) have also been described.[2] The pouches are formed as a result of incomplete fusions of the patent foramen ovale (PFO) channel. The estimated prevalence of left, right, and double SPs in structurally normal autopsied human hearts is 41.5%, 5.5%, and 5.5%, respectively, with the concomitant PFO channel frequency of

TABLE 1 Clinical characteristic of included patients (N = 146)

Ejection fraction (%; mean ± SD)	63.9 ± 9.7%
Body mass index (BMI, kg/m^2; mean ± SD)	26.2 ± 3.9
Arterial hypertension (%)	30.1%
Atrial fibrillation (%)	7.5%
Coronary artery disease (%)	14.4%
Congestive heart failure (%)	3.4%
Diabetes mellitus (%)	8.9%
Ever-smoker (%)	14.4%
Hyperlipidemia (%)	28.8%
Peripheral artery disease (%)	2.7%
Transient ischemic attack (%)	6.8%
Stroke (%)	47.9%

N = number of patients; SD = standard deviation.

25.0%.[2] Shortly, after the SP concept came to light, over a dozen case reports observed that SPs located on the left side of the interatrial septum may be the site of origin for thrombus formation and the source of ischemic strokes.[3–8] The anatomy of left-sided SP may promote blood stasis.[2] The association between left-sided SP and increased risk of cryptogenic stroke was confirmed in some preliminary epidemiologic retrospective studies.[9,10] Recent studies have further suggested that the left-sided SP may act as an arrhythmogenic substrate and thereby trigger atrial fibrillation.[11] Taken together, this data highlight the need for clinical evaluation of left-sided SPs, especially in the patients with the cryptogenic stroke. Right-sided SP seems to have no further clinical relevance.[2,12]

The SPs are visualized by cardiac computed tomography or transesophageal echocardiography (TEE).[11,13,14] Two TEE projections are commonly used for interatrial septum visualization and assessment: mid-esophageal bicaval view and mid-esophageal short-axis view; however, little is known about their relative accuracy for detecting SPs.[15] Therefore, the aim of this technically oriented study was to compare these two TEE projections' ability to detect and assess SPs.

2 | METHODS

2.1 | Study population

A total of 393 consecutive patients (52.9% females) were identified and analyzed retrospectively in this study. All patients underwent TEE with contrast administration between August 2013 and August 2017 for PFO channel detection. The mean age for the whole population was 40.1 ± 13.7 years. Patients with diagnosed PFO channel and atrial septal defect (n = 229), as well as patients without high quality two TEE projections of interatrial septum (mid-position,

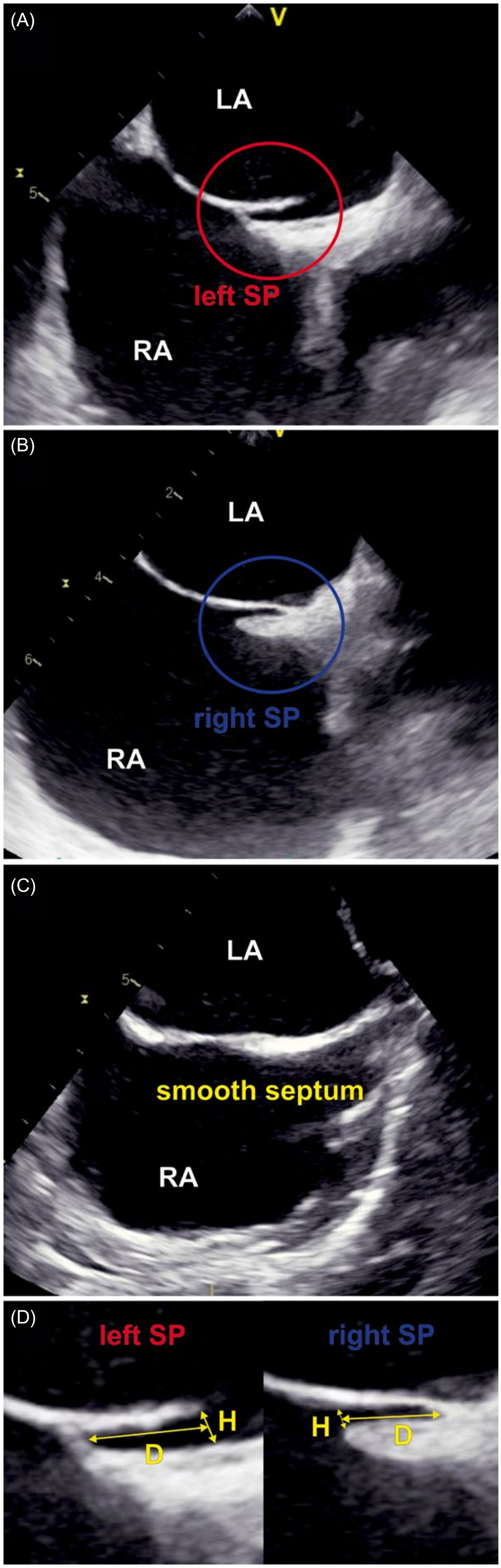

FIGURE 1 Mid-esophageal bicaval view of interatrial septum in two-dimensional transesophageal echocardiography. A. Left septal pouch (SP); B. right SP; C. smooth septum; and D. enlarged pictures of left and right SP with marked measurements. D = SP depth; H = SP ostium height; LA = left atrium; RA = right atrium

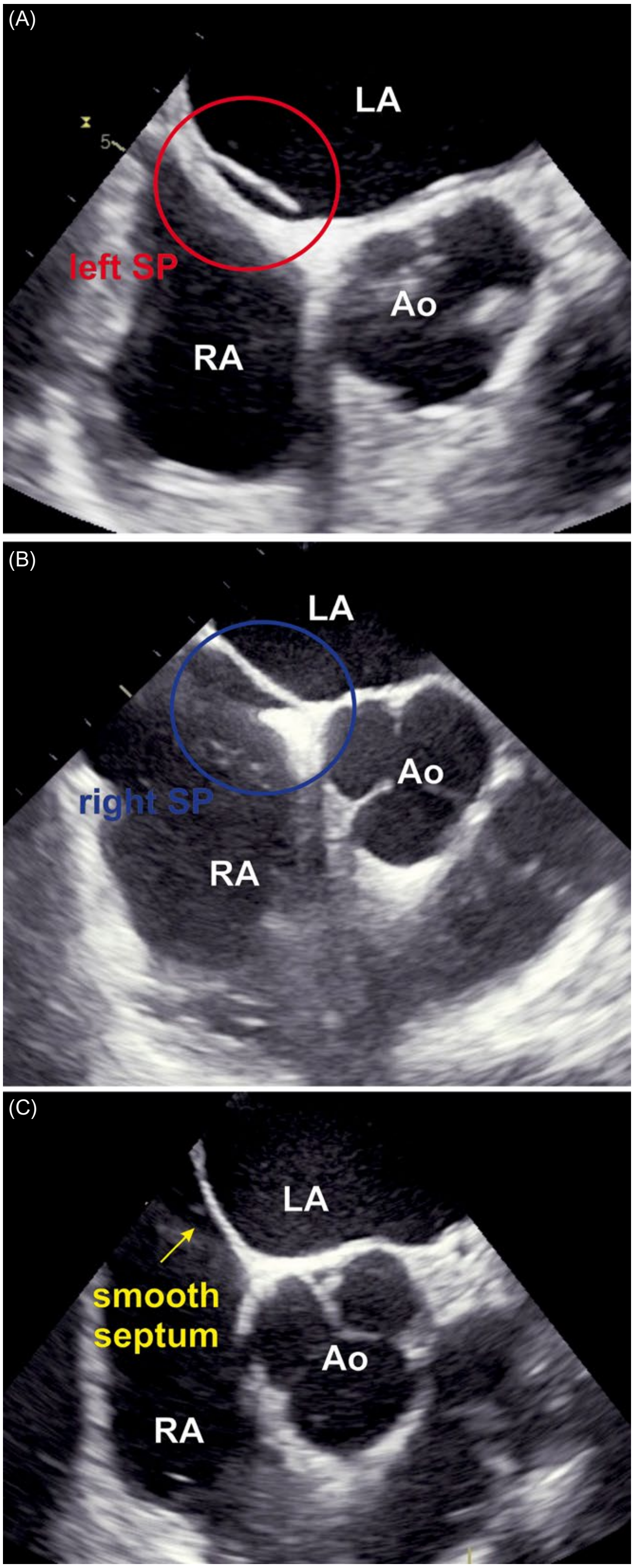

FIGURE 2 Mid-esophageal short-axis view of interatrial septum in two-dimensional transesophageal echocardiography. A. Left septal pouch (SP); B. right SP; and C. smooth septum. Ao = aortic valve; LA = left atrium; RA = right atrium

90–120 degrees, bicaval and mid-position, 30–50 degrees, short-axis view; n = 18), were excluded from further analysis. Finally, a total of 146 patients with two projections (48.6% females, mean age of 43.7 ± 10.7 years) were selected for inclusion in this study. Table 1 presents clinical characteristic of included patients.

2.2 | Image interpretation

All TEE datasets were reviewed blindly and independently evaluated by two researchers. When the two researchers were unable to reach a consensus on the interatrial septum classification of the same patient, the images were re-evaluated by the third researcher and discussed until a consensus was reached by all three investigators. Initially, PFO channel was detected by the presence of microbubbles in the left atrium after agitated saline injections and the Valsalva maneuver. In addition, the presence of atrial septal defects was evaluated using standard criteria.[15] The presence of a PFO channel or atrial septal defect was further confirmed by the original echocardiography report.

The interatrial septum was classified as a left SP, a right SP, a double SP, or a smooth septum. A left SP was defined as a blindly ended diverticulum on the left side of the interatrial septum, that is, exclusively connected to the left atrium with no visible connection between the atria through the interatrial septum (Figures 1A and 2A). A right SP was identified using the same criteria, but on the right side of the septum (Figures 1B and 2B). Double SP was noted when two pouches on both sides of the septum coexist in the same heart. The term "left-sided SP" describes a pouch located on the left side of the interatrial septum (left and double), while the "right-sided SP" is used when the pouch is present on the right side of the septum (right and double). Smooth septum indicates no PFO channel, SP, or other structures (Figures 1C and 2C).[2,16]

All linear measurements were taken using virtual calipers. The maximum depth (D) and ostium height (H) of the pouches were measured in the diastole at rest as previously described by Hołda et al[2] (Figure 1D). The SP volume was calculated using the formula: $V\ [mL] = 0.013 \times (D\ [mm]) + 0.038 \times (H\ [mm])$.[2] Toward reducing bias, all measurements were made by two independent researchers and the inter-observer variability was calculated. The mean of the two measurements was calculated with an approximation to the tenth decimal place. Toward assessing intra-observer variability, a randomly selected set of fifteen TEE was remeasured by the same blinded observer 1 week after the original assessment.

2.3 | Statistical analysis

Categorical results are presented as numbers and percentages. The Shapiro-Wilk test was performed to determine if the quantitative data were normally distributed. Quantitative results are presented as mean ± standard deviation. Student's t test was used to test for significant differences between continuous variables and the paired t test was used to compare the measurements of the structures between two different TEE projections. The qualitative variables were compared using the chi-square test of proportions for categorical variables. The weighted kappa coefficient was used to

TABLE 2 Comparison of the classification of the interatrial septum morphological type in mid-esophageal bicaval and mid-esophageal short-axis transesophageal echocardiography (TEE) views (n = 146)

Classification	TEE bicaval smooth septum	TEE bicaval left SP	TEE bicaval right SP	TEE bicaval double SP	Total
TEE short-axis smooth septum	55	15	3	0	73
TEE short-axis left SP	2	57	0	0	59
TEE short-axis right SP	7	0	6	0	13
TEE short-axis double SP	0	0	0	1	1
Total	64	72	9	1	146

SP = septal pouch.

TABLE 3 Comparison of septal pouches (SPs) measurements (mean ± standard deviation) performed mid-esophageal bicaval and mid-esophageal short-axis views of interatrial septum in two-dimensional transesophageal echocardiography

	Bicaval view	Short-axis view	*P*-value
Left SP depth (mm)	9.2 ± 3.8	8.0 ± 3.1	.062
Left SP ostium height (mm)	1.6 ± 0.8	1.6 ± 0.8	.805
Left SP volume (mL)	0.18 ± 0.07	0.17 ± 0.06	.236
Right SP depth (mm)	6.2 ± 1.6	5.5 ± 2.2	.411
Right SP ostium height (mm)	1.7 ± 0.8	2.6 ± 1.3	.076
Right SP volume (mL)	0.15 ± 0.05	0.17 ± 0.07	.363

assess agreement in terms of the interatrial septum types observed in the same patients but imaging in two different projections. For a relative measure of inter-reliability, the intra-class correlation coefficient (ICC) was calculated. Agreement between projections was plotted using the Bland–Altman method. The ICC was used to assess the inter- and intra-observer variability. An ICC value of 0.7–0.8 indicated a strong agreement; a value > 0.8 indicated an excellent agreement. Statistical analyses were conducted using STATISTICA v13.1 (StatSoft Inc., Tulsa, OK, USA). A *P*-value of less than 0.05 was considered statistically significant.

3 | RESULTS

The lack of agreement in the interatrial septum classification between two independent observers was noted in seven cases, and a consensus was reached with a third researcher in all cases. Irrespective of TEE projection, the left SP was detected in 74 cases (50.7%), right SP in 16 cases (11.0%), and double in one case (0.7%).

A comparison of the results of the interatrial septum classification from both projections is shown in Table 2. The weighted kappa coefficient between the bicaval and short-axis views in assessing the interatrial septum morphology was 0.68, which indicates good agreement.[17] Agreement between projections in the classification of the septum occurred in 119 cases (81.5%). In the remaining 18.5% of patients, observed discrepancies between projections included the following: smooth septum in short-axis : left SP in bicaval (15 cases, 55.6% of all discrepancies); right SP in short-axis : smooth septum in bicaval (seven cases, 25.9%); smooth septum in short-axis : right SP in bicaval (three cases, 11.1%); and left SP in short-axis : smooth septum in bicaval (two cases, 7.4%). We found that 77.0% (57 of 74) of all detected left SPs were detected by both views while only 35.7% (6 of 16) of right SPs were detected in both projections. We were able to detect more left SPs in bicaval view compared to short-axis view; however, the observed difference was statistically insignificant (72 vs 59, *P* = .13). On the other hand, the number of detected right SPs was higher in short-axis view, but still statistically insignificant (9 vs 13, *P* = .38).

The mean values of all measurements of left and right SPs are shown in Table 3. There were no significant differences found in the mean size of left or right SPs measured in bicaval or short-axis view (*P* > .05). The calculated inter- and intra-observer variability showed almost perfect agreement for all sets of measurements within the same view (ICC > 0.8).

Bland–Altman plots comparing the short-axis and bicaval measurements of left SPs that were detected in both views (n = 57) are presented in Figure 3. For left SP depth, the systematic difference was 1.17 mm, limits of agreement (LoA), which varied from −4.88 mm to 7.22 mm (Figure 3A; *P* = .02, ICC = 0.58). The difference between views was statistically significant with higher left SP depth in bicaval (9.3 ± 3.9 mm) than in short-axis (8.1 ± 3.1 mm) view. For left SP ostium height, the systematic difference was 0.05 mm, whereas the LoA were −1.35 to 1.46 mm (Figure 3B; *P* = .74, ICC = 0.65). The systematic difference for left SP volume was 0.02 mm, and the LoA were −0.08 to 0.12 mm (Figure 3C; *P* = .06, ICC = 0.67).

There were no statistically significant differences in left SP sizes when comparing those co-detected in two views (n = 57) and detected only in bicaval view (n = 15) (depth: 9.3 ± 3.9 vs 8.7 ± 3.5 mm, *P* = .54; ostium height: 1.7 ± 0.9 vs 1.2 ± 0.7 mm, *P* = .06; volume: 0.19 ± 0.07 vs 0.16 ± 0.06, *P* = .17). Due to small number of co-detected right SPs (n = 6), agreement analyses of their morphometry were not performed.

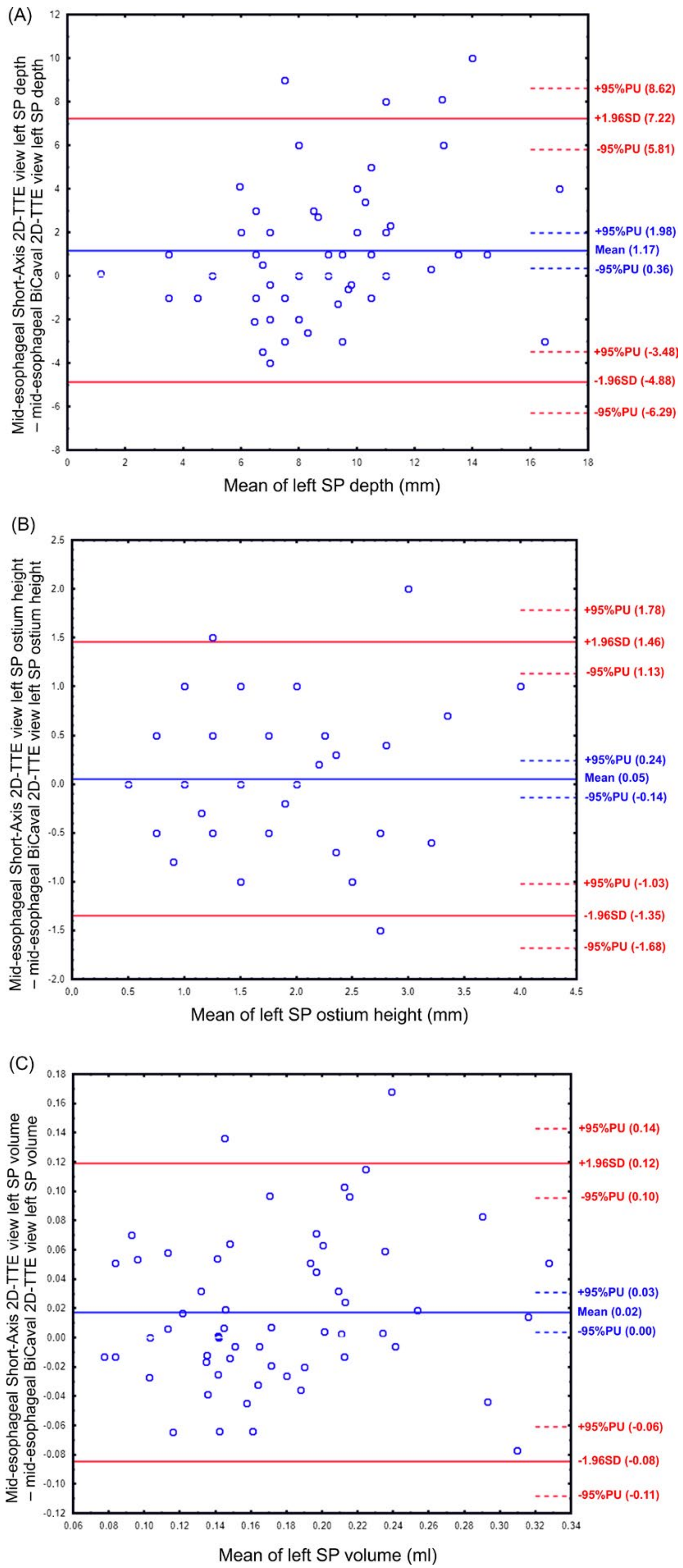

FIGURE 3 Bland–Altman plots comparing left septal pouch (SP) measurements in mid-esophageal bicaval and mid-esophageal short-axis two-dimensional transesophageal echocardiography views (2DTEE). Comparison of mean left SP depth (A) ostium height (B) and volume (C)

4 | DISCUSSION

Results of our study show that in bicaval view detects more left-sided SPs compared to short-axis view. The opposite is observed for right-sided SP, which could be better visualized in short-axis view. Discrepancies between TEE projections were limited only to lack of pouch detection in one view (smooth septum) and its presence in a second view. Moreover, we found that in more than half of the discrepancies, the left SP is not diagnosed in short-axis view, when it is clearly visible in bicaval view, while opposite situation was found only in 2 cases (55.6% vs 7.4%, $P = .0002$). There were no cases with the diagnosis of the pouch on different sides of the septum in recorded TEE projections. Previous studies have focused on the clinical significance of left-sided SPs in stroke patients and have used TEE which usually does not provide information on the views using during inspection of the interatrial septum.[9,10,18] Using a singular or an inadequate view for interatrial septum examination that not cover relatively small area of the possible SP occurrence may be one of the cause why the reported prevalence of the SP is significantly lower in TEE (left-sided = 10.6% – 27.9%, right-sided = 1.4% – 12.3%, when PFO channel and ASD are excluded from the calculations; left-sided = 8.7% – 22.4%, right-sided = 1.1% – 9.3%, when PFO channel and ASD are not excluded)[9,10,14,18,19] when compared with anatomical studies (left-sided = 44.6%; right-sided = 8.8%, PFO not excluded).[1,2] We strongly recommend the use of more than one TEE view or angle for detection and diagnosis of SPs. Only one TEE view provides insufficient basis for the diagnosis of SP absence.

The existence of the SP is a relatively new discovery, and its clinical relevance is still under investigation. The left-sided SP is of special interest because of its possible involvement in thromboembolic events.[20] Still, nothing is known about whether all SPs should be considered suspicious or only those of a certain (large) size. Two dimensions of the SP are easily obtainable: depth and ostium height. Our study found no significant difference in the left SP ostium height. The measured depth of the left SP varies significantly between views, with greater depth in the bicaval view. The bicaval view best reflects the anatomy of the left-sided SP because it provides a view of the interatrial septum that is oriented in the same line with the long-axis of the pouch. Therefore, this projection should be preferable to measure left-sided pouch depth.

There is a theory of lifelong, continuous remodeling of the interatrial septum, according to which the PFO channel evolves into the pouches and then to smooth septum.[2] The PFO channel cannot coexist with the SP, but its morphology can mimic the presence of the pouch. Therefore, the presence of the PFO channel should be established before the diagnosis of the SP, preferably by the demonstration of right to left shunting across the channel.[15] This makes TEE with intravenous contrast administration the best technique for interatrial septum assessment and detection of SPs. A study by Elsayed et al[13] found that the three-dimensional TEE is superior over the two-dimensional TEE in the number of perceived SPs. When available, three-dimensional methodology should also be implemented for SP detection.

The current study is not without limitations. Firstly, this is a retrospective study and therefore, the presence of the SP was not confirmed by echocardiographers. However, the presence of the PFO channel was of the interests in all patients and as SPs result from incomplete PFO channel fusion, the area of possible SP occurrence was covered in all cases. Secondly, this is a technically oriented study and thus, clinical data were not analyzed. Therefore, we cannot draw any conclusions on clinical relevance of left- or right-sided SPs. Finally, our specific population of patients and their high prevalence of PFO channel occurrence (58.3%) prevent the application of this current study (prevalence of the pouches) to the whole population.

5 | CONCLUSION

Preferably, the diagnosis of SP presence should be confirmed on the basis of minimum two different TEE views. Mid-esophageal bicaval view should be preferable over mid-esophageal short-axis view of interatrial septum for diagnosis and measurements of left-sided SP.

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CONFLICT OF INTEREST

All authors have no potential conflict of interests.

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