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Cardiac computed tomography compared with two-dimensional transesophageal echocardiography for the detection and assessment of atrial septal pouches

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Abstract

The aim of this study is to compare the two-dimensional transesophageal echocardiography (2D-TEE) with multi-slice computed tomography (MSCT) and with autopsied material to evaluate the ability and precision of the imaging methods for the detection and assessment of septal pouch (SP). One hundred and fifty patients that underwent both 2D-TEE and MSCT and 50 autopsied human hearts were investigated. In MSCT, the interatrial septum was classified as a left SP in 37.3%, right SP in 3.3%, and patent foramen ovale (PFO) channel in 3.3%. In 2D-TEE, the interatrial septum was classified as a left SP in 39.3%, right SP in 11.3%, double SP in 4.7%, and PFO channel in 2.0%. The weighted kappa coefficient between MSCT and 2D-TEE in assessing the septum morphology was 0.59. The prevalence of the left SP is lower when it is evaluated by MSCT or 2D-TEE than by anatomical study, but this difference is insignificant (37.3% vs. 44.0%, p = 0.40, and 39.3% vs. 44.0%, p = 0.56, respectively). The prevalence of left SPs is lower when detected by MSCT or 2D-TEE than during autopsy, but the difference is statistically insignificant (37.3% vs. 44.0%, p = 0.40, and 39.3% vs. 44.0%, p = 0.56, respectively). Both 2D-TEE and MSCT are comparable techniques for detecting left-sided SPs with the insignificant lower prevalence of detecting left-sided SPs compared to autopsied material. However, TEE with the contrast seems to be superior over MSCT due to the possibility of unambiguous PFO channel detection. Therefore, TEE with contrast should be preferred over MSCT in the identification of left-sided SPs.

Keywords Septal pouch · Left atrium · Interatrial septum · Patent foramen ovale · Cryptogenic stroke · MSCT

Introduction

The atrial septal pouch (SP) is a new anatomical entity within the human interatrial septum [1, 2]. A SP is a kangaroo pouch-like structure (diverticulum) that occurs when the patent foramen ovale (PFO) channel is absent but the septum primum and septum secundum are partially fused, with no connection between both atria. The diverticulum may be located either on the left or right side of the interatrial septum; left and right SPs may also coexist in the same heart (double SP) [1]. 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). The high prevalence of SPs (over 50% of the healthy population) indicates that the pouch is not a pathology, but rather is an element of normal human anatomy [1, 3–5]. However, the left-sided SP, as an element of human morphology, may play a significant clinical role in the pathogenesis of cerebrovascular accidents and atrial fibrillation. The anatomy of left-sided SP may promote blood stasis and thrombus formation increasing the risk of cryptogenic stroke [5–10]. Moreover, the SP may be a trigger for atrial fibrillation, as

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recently it was proven that the presence of the left-sided SP is associated with the increased risk of atrial fibrillation [9]. Due to the potential clinical relevance of the left-sided SP, its routine evaluation should not be neglected, particularly in patients with cryptogenic stroke, for whom the SP should be thoroughly investigated [10].

The SP can be visualized in vivo using two methods, two-dimensional transesophageal echocardiography (2D-TEE) and contrast-enhanced electrocardiogram-gated multi-slice computed tomography (MSCT) of the heart, but nothing is known about the accuracy of these two methods in detecting SPs [5, 9, 11]. Recent studies have also shown that the TEE with the three-dimensional (3D) modality may be superior over 2D examination [12].

Therefore, the aim of this technically oriented study is to compare 2D-TEE, MSCT, and matched autopsied material to evaluate the ability and precision of these imaging methods to detect and assess SPs.

Methods

This study was approved by the Bioethical Committee of Jagiellonian University Medical College, Cracow, Poland (No 122.6120.37.2016). The Bioethical Committee waived the need for informed consent from all individuals and donors included in this study. The study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki. The methods were carried out in accordance with the approved guidelines. The datasets generated during and analyzed during the current study are available from the corresponding author on reasonable request.

Study population

A total of 150 consecutive patients (65.3% females) were identified and retrospectively analyzed in this study. All individuals were severe symptomatic aortic stenosis patients that underwent both 2D-TEE and MSCT of the heart as an element of classification for trans-catheter aortic valve implantation between January 2014 and March 2017. The mean time between the 2D-TEE and MSCT was 34.3 ± 40.9 days. The mean age for the whole population was 80.8 ± 6.9 (range 40–92) years, mean body mass index (BMI) 27.0 ± 4.7 kg/m^2, and mean ejection fraction $52.2 \pm 14.1\%$. The exclusion criteria for this study were: (1) previous cardiac surgery, (2) trans-septal puncture, (3) left atrial interventions, or (4) implanted cardiac devices. Clinical data for enrolled patients are presented in Table 1. Fifty autopsied hearts from sex-, age- and BMI-matched Caucasian individuals (65% females, p = 0.87) were also investigated. The mean donors age was 79.2 ± 9.2 (range 60–94) years (p = 0.2) and the mean BMI was 27.3 ± 6.2 kg/m^2 (p = 0.72).

Table 1 Clinical characteristic of enrolled patients (N = 150)

Left ventricle ejection fraction, median (IQR) [%]	61.0 (50.0–67.0)
Arterial hypertension (%)	90.0%
Atrial fibrillation (%)	38.0%
Chronic obstructive pulmonary disease (%)	12.0%
Coronary artery disease (%)	43.3%
Diabetes mellitus (%)	33.3%
Hyperlipidemia (%)	52.0%
New York Heart Association class $\geq$ III (%)	73.3%
Pacemaker (%)	12.0%
Peripheral artery disease (%)	9.3%
Transient ischemic attack or stroke (%)	13.3%

IQR interquartile range, *N* number of patients

Cardiac multi-slice computed tomography protocol

Before the cardiac MSCT examination procedure, every patient had their pulse checked in the case of the heart rate over 70 beats per minute, 10 or 40 mg of propranolol or 40 mg of verapamil was administered to the patient. The MSCT was performed using a 64-row dual-source scanner (Aquilion 64, Toshiba Medical Systems, Tokyo, Japan). The contrast-enhanced electrocardiogram-gated image acquisitions were performed during inspiratory breath hold. The imaging parameters for dual-source MSCT were a tube voltage of 100–120 kV and an effective tube current of 350–400 mA. The collimation and temporal resolution were $2 \times 32 \times 0.6$ mm and 165 ms, respectively. The arrival time of the contrast agent to the ascending aorta was determined at the level of the carina with the use of a test bolus method (volume of 15 ml of contrast agent, followed by 20 ml of saline). Contrast agent was injected at a dose of 1.0 ml/kg and a rate of 5.5 ml/s followed by 40 ml of saline at the same rate. The acquisition delay was the time of maximum density of the ascending aorta in the test bolus with an additional 6 s of delay. Images were reconstructed with a B26f and B46f kernel and an image matrix of 512×512 pixels. Multiphase reconstruction (from 10 to 100%) was performed. The post-processing and study evaluation were performed using a dedicated workstation (Aquarius, TeraRecon, San Mateo, United States).

Two-dimensional transesophageal echocardiography protocol

All 2D-TEE examinations were performed with a two-dimensional ultrasound system (Vivid E7, GE Healthcare, Boston, USA) with a 3.0–8.0 MHz transducer (6VT-D, GE Healthcare, Boston, USA). The interatrial septum

was assessed in mid-position views of 90°–120° (BiCaval view) and in mid-position views of 30°–50° (short-axis view) in all patients. TEE was performed without the Valsalva maneuver and without saline contrast administration. The post-processing and study evaluation were performed using a dedicated workstation (EchoPAC, GE Healthcare, Boston, USA).

Image interpretation

The MSCT scans were evaluated during the 70% phase using transverse projection and multiplane reconstruction, as needed. In all cases both atria were fully depicted and appropriately contrasted with sharp contours. There was a lack of artefacts that may interfere with interatrial septum assessment. The left SP was identified as the blind-ending pouch located on the left side of the interatrial septum, filled with the contrast agent, and when no jet flow of contrast agent thorough the interatrial septum and no second pouch on the opposite side of the septum were seen (Fig. 1a). Right SP was identified in the same manner, but on the right side of the septum (Fig. 1b). The PFO channel was identified when the jet flow of contrast agent was seen from the right to the left atrium through the interatrial septum. When the jet flow of contrast agent thorough the interatrial septum was not identified and the pouches could be seen on both sides of the septum, double SP was reported. In case of the absence of any of the aforementioned structures, the interatrial septum was classified as a "smooth septum".

In 2D-TEE, the interatrial septum was also classified as either a smooth septum, left SP (Fig. 1a), right SP (Fig. 1b), or double SP using the same morphological criteria as in the MSCT. The PFO channel was detected when the PFO channel was directly visible or the right-to-left shunting was demonstrated by color Doppler.

All MSCT and 2D-TEE data sets were blindly reviewed and independently evaluated by two researchers (M.K.H. and A.K-O.). The same observers interpret 2D-TEEs and MSCTs. When two researchers could not reach consensus on the interatrial septum classification (in the same patient using the same imaging method), the images were re-evaluated with the third researcher (D.S. or W.P.) until consensus was reached by the three investigators.

All linear measurements were taken using virtual calipers. The maximum depth (D) and ostium height (H) of the pouches were measured in the multi-planar reconstruction for MSCT. The BiCaval 90°–120° view was used when measuring in 2D-TEE, which anatomically corresponds to the long axis of the SP [1]. The 2D-TEE measurements were performed in the 60–70% phase (diastole). As described before, we defined the SP depth (D) as the maximum distance from the pouch apex to its ostium. The ostium height (H) was defined for left-sided SPs as the maximum distance

between its free wall and left atrial wall and for right-sided SPs as the largest distance between the fossa ovalis floor and the left surface of the antero-superior rim. The SP volume was calculated using the formula: $V \: [ml] = 0.013 \times (D \: [mm]) + 0.038 \times (H \: [mm])$ [1]. All of the measurements were made by two independent researchers (M.K.H and A.K-O.) in order to reduce bias. The mean of the two measurements was calculated, with approximation to the tenth decimal place. The inter-observer variability was calculated. Randomly selected 20 2D-TEE and 20 MSCT were re-measured in blinded fashion by the same observer 1 week after the original assessment to calculate the intra-observer variability.

Autopsied material

The hearts were collected during routine forensic medical autopsies at the Department of Forensic Medicine Jagiellonian University Medical College from non-cardiac death persons. Specimens were dissected in the routine manner and fixed by immersion in 10% paraformaldehyde solution. The left, right, and double SPs, as well as the PFO channel, were identified. The linear measurements were obtained by two investigators using 0.03 mm precision electronic calipers (YATO, YT-7201, Poland). The maximum depth and ostium height of the pouches were measured, and the pouch volumes were calculated as described above.

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 ± SD. 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 MSCT and 2D-TEE. The qualitative variables were compared using the χ^2 test of proportions for categorical variables. The weighted kappa coefficient was used to assess agreement in terms of the interatrial septum types observed in the same patients using the analyzed techniques. For a relative measure of inter-reliability, the intra-class correlation coefficient (ICC) was calculated. Agreement between techniques was plotted using the Bland–Altman method. To examine the diagnostic accuracy value of the MSCT, the sensitivity, specificity, positive and negative predictive values (PPV and NPV), accuracy, and positive and negative likelihood ratios (LR+ and LR−) were calculated. 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 almost perfect agreement [13]. Correlation coefficients were calculated to measure any statistical dependence between the parameters
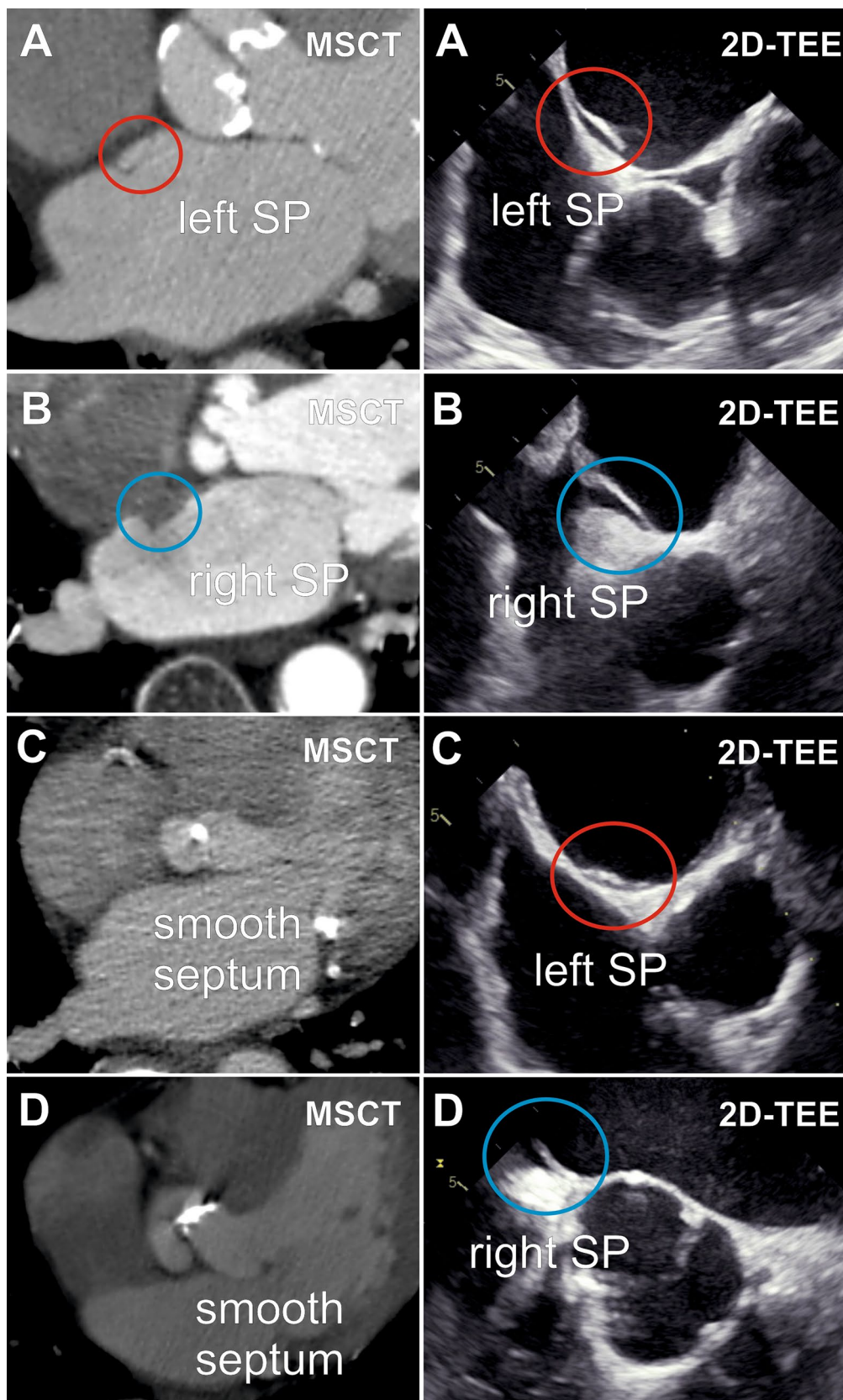
Fig. 1 Interatrial septum structures in MSCT and transesophageal echocardiography (2D-TEE) in the same patients. Left SP (**a**). Right SP (**b**). Left SP in 2D-TEE and smooth septum in MSCT (**c**). Right SP in 2D-TEE and smooth septum in MSCT (**d**)

of the measured hearts. To detect a simple correlation (r = 0.25), for 80% power with a 5% significance level (two-tailed; α = 0.05; β = 0.2) the required minimal sample size was calculated to be approximately 123 cases. Statistical analyses were conducted using STATISTICA v12 (StatSoft Inc., Tulsa, OK, USA). A p-value of < 0.05 was considered statistically significant.

Results

The lack of agreement in the interatrial septum classification between two independent observers was noted only in 4 2D-TEE and 5 MSCT cases and the consensus was reached with third researcher in all of these cases.

In MSCT, the interatrial septum was classified as a left SP in 56 cases (37.3%), right SP in 5 (3.3%) and PFO channel in 5 (3.3%); no double SPs were identified by MSCT. In 2D-TEE, the interatrial septum was classified as a left SP in 59 cases (39.3%), right SP in 17 (11.3%), double SP in 7 (4.7%), and PFO channel in 3 (2.0%). The smooth septum was noted more often in MSCT (84 cases, 56.0%) than in 2D-TEE (64 cases, 42.7%) (p = 0.02). The comparison of the results of the classification using both methods is shown in Table 2. The weighted kappa coefficient between the MSCT and 2D-TEE in assessing the interatrial septum morphology was 0.59 (good agreement). Agreement between MSCT and 2D-TEE in the classification of the septum occurred in 110 cases (73.3%); in the remaining 26.7% of patients, discrepancies between methods were noted. The discrepancies included: left SP in 2D-TEE: smooth septum in MSCT (11 cases, 27.5% of all discrepancies) (Fig. 1c); right SP in 2D-TEE: smooth septum in MSCT (11 cases, 27.5%) (Fig. 1d); double SP in 2D-TEE: left SP in MSCT (5 cases, 12.5%); and smooth septum in 2D-TEE: left SP in MSCT (4 cases, 10%). Mutual recognition of the PFO channel was 0% and was co-classified as a left (5 cases), right (1 case), or double SP (1 case), but never as a smooth septum. 2D-TEE was more accurate than MSCT for detecting right (p = 0.01) and double SPs (p = 0.01). No statistically significant

differences were observed between 2D-TEE and MSCT in the number of detected left SPs (59 vs. 56, p = 0.72); the difference was larger when considering left-sided SP, but was still statistically insignificant (66 vs. 56, p = 0.24).

In comparison to 2D-TEE as the reference standard, the accuracy of MSCT in the detection of left SPs was 83.3%, with a sensitivity of 76.3% and specificity of 87.9% (PPV = 80.4%, NPV = 85.1%; LR+ = 6.31; LR− = 0.27). The accuracy of MSCT in the detection of left-sided SPs was 85.3%, sensitivity 75.8%, and specificity 92.9% (PPV = 89.3%, NPV = 83.0%; LR+ = 10.6; LR− = 0.26). For right SPs, the MSCT accuracy was 92.0% with the low sensitivity of 29.4% and high specificity of 100% (PPV = 100%, NPV = 91.7%).

In autopsied material, the left SP was present in 44.0%, right in 14.0%, and double SP in 6.0% of all cases; the PFO channel was present in 12.0%. The prevalence of left SPs is lower when detected by MSCT or 2D-TEE than by anatomical study, but the difference is statistically insignificant (37.3% vs. 44.0%, p = 0.40, and 39.3% vs. 44.0%, p = 0.56, respectively). The detection rates of right and double SPs were significantly lower when detected by MSCT (3.3% vs. 14.0%, p = 0.01 and 0% vs. 6.0%, p = 0.00 respectively) than by anatomical study. The same differences between 2D-TEE and autopsied material measurements were still present, but statistically insignificant (11.3% vs. 14.0%, p = 0.61 for right SP and 4.7% vs. 6.0%, p = 0.71 for double SP).

Bland–Altman plots comparing the MSCT and 2D-TEE measurements of left-sided SPs that were detected by both MSCT and 2D-TEE (n = 50) are presented in Fig. 2. For left-sided SP depth, the systematic difference was − 0.56 mm, limits of agreement (LoA), which varied from − 9.31 to 8.18 mm (Fig. 2a, p = 0.52, ICC = 0.35). For left-sided SP ostium height, the systematic difference was − 0.92 mm, whereas the LoA were − 3.61 to 1.77 mm (Fig. 2b, p = 0.00, ICC = 0.27). The systematic difference for left-sided SP volume was − 0.04 mm and the LoA were − 0.21 to 0.13 mm (Fig. 2c, p = 0.00, ICC = 0.31). When comparing the sizes of right SPs (n = 5), no differences were noted in right SP depth and ostium height (systematic difference =

Table 2 Comparison of the classification of the interatrial septum morphological type in 2D-TEE and MSCT (n = 150)

	2D-TEE smooth septum	2D-TEE left SP	2D-TEE right SP	2D-TEE double SP	2D-TEE PFO channel	Total
MSCT smooth septum	60	11	11	1	1	84
MSCT left SP	4	45	0	5	2	56
MSCT right SP	0	0	5	0	0	5
MSCT double SP	0	0	0	0	0	0
MSCT PFO channel	0	3	1	1	0	5
Total	64	59	17	7	3	150

2D-TEE two-dimensional transesophageal echocardiography, *SP* septal pouch, *PFO* patent foramen ovale, *MSCT* multi-slice computed tomography

Fig. 2 Bland–Altman plots comparing MSCT and transesophageal echocardiography (2D-TEE) left SP measurements. Comparison of mean left SP depth (**a**) ostium height (**b**) and volume (**c**) determined by MSCT and 2D-TEE
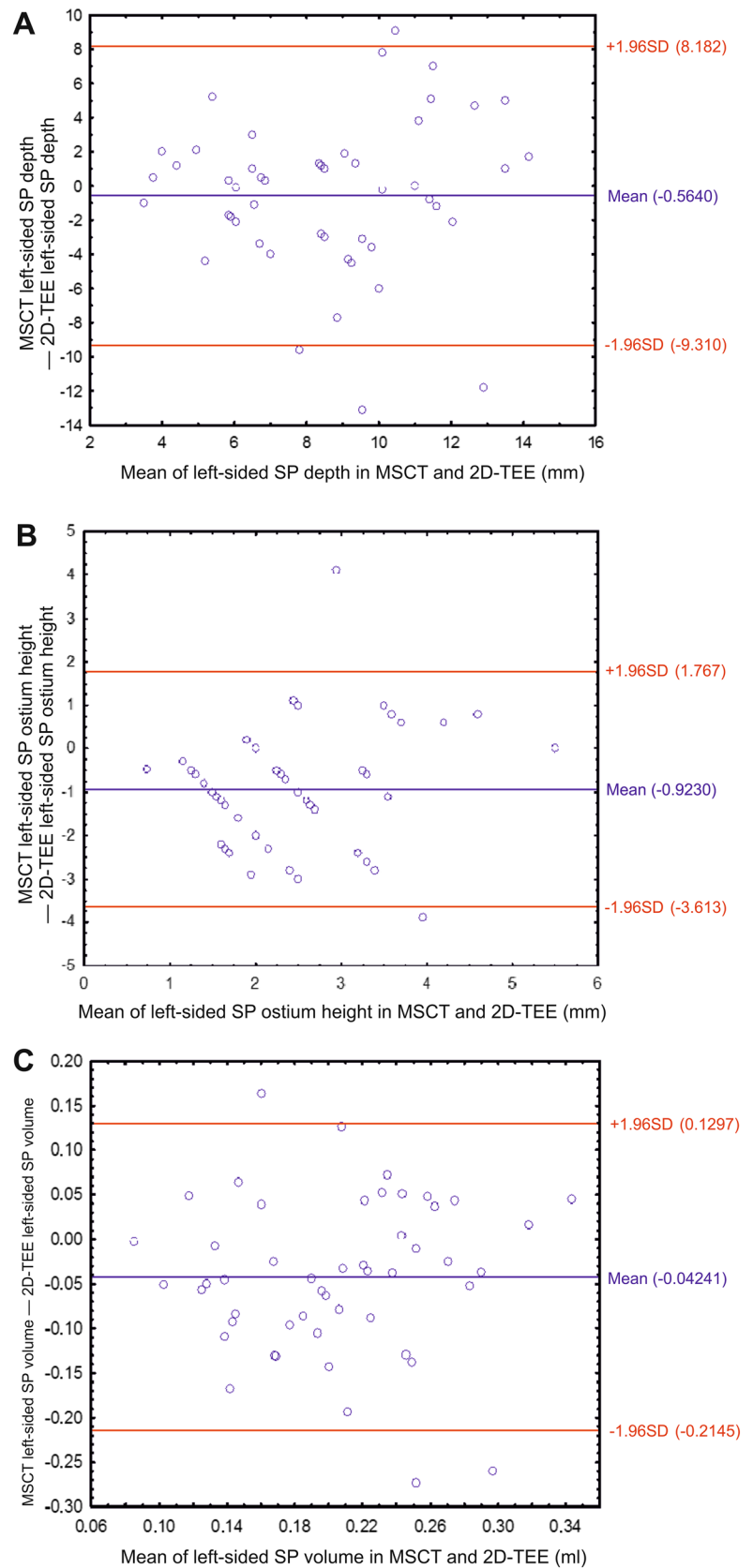
1.62 mm, LoA were − 4.0 to 7.24 mm, p = 0.11, and systematic difference = 0.6 mm, LoA were − 1.35 to 2.54 mm, p = 0.34, respectively), but the calculated volume differed significantly (systematic difference = 0.04 ml, LoA were − 0.0002 to 0.09 ml, p = 0.04).

The mean values of all measurements of left and right SPs, as well as the comparison between the cadaveric material and MSCT and 2D-TEE, are shown in Table 3. Figure 3 shows the comparison of left-sided SP dimensions in all three data sets. There were no significant differences in the size of left-sided SPs measured in 2D-TEE that were detected by both MSCT and 2D-TEE and those that were detected only by 2D-TEE (p > 0.05). The calculated inter- and intra-observer variability showed almost perfect agreement for all sets of measurements (ICC > 0.8).

In all study groups, there were no differences in the interatrial septum classification between sexes (p > 0.05). Also, there were no significant differences in age or BMI between patients with particular interatrial structures and those without them (p > 0.05). No correlations were found between the BMI and any of the measured parameters in all study groups.

Discussion

The most widely used imaging method to evaluate the interatrial septum is TEE, which remains the preferred initial diagnostic modality for the detection and diagnosis of atrial septal defects and the PFO channel [14]. 2D-TEE is also a commonly used clinical and research tool for those focusing on SPs [5, 7, 12]. The MSCT is likewise used to identify and characterize SPs, but mainly for research purposes [9, 15, 16].

In this study, 2D-TEE was found to be superior to MSCT in detecting left (also left-sided) and right SPs. Moreover, the differences in the occurrences of left, right, and double SPs between 2D-TEE and autopsied sex-, age-, and BMI-matched material were statistically insignificant. The use of 3D-TEE may even increase the qualitative and quantitative ability of the SP assessment: Elsayed et al. showed that the

3D modality is superior to 2D-TEE in the number of detected SPs. Also, 3D-TEE can measure the SP ostium width by providing an enface view of the left-sided SP, which could not be performed in 2D-TEE. Furthermore, the SP measurements were significantly greater when measured using the 3D modality than those measured using 2D-TEE [12].

Using MSCT, with 2D-TEE as the reference standard, 26.7% of patients would have received an inappropriate classification of the septum; also, the number of detected left-sided SPs would be 15.6% lower and the number of right SPs would be as much as 70.5% lower. Although the number of detected left-sided SPs in MSCT is lower, the difference between MSCT and 2D-TEE is statistically insignificant; also, there is no significant difference in the number of detected left-sided SPs between MSCT and cadaveric material. The sensitivity (75.8%) and specificity (92.9%) of MSCT for detecting left-sided SP is relatively good and acceptable, and thus the MSCT may be a useful tool for detecting left-sided SPs. In contrast, the MSCT should not be used to detect right-sided SPs, as the sensitivity of this technique is unacceptably low for this structure. The low contrast of blood in the right atrium significantly hinders the evaluation of the right-sided interatrial septum structures, which results in the low detection of right and double SPs in MSCT.

In current study, the detection of the PFO channel was poor and the level of its co-identification was around 0%. It cannot be excluded that some of the identified SPs are in fact PFO channels with functionally closed or unsuccessfully visualized channels. Both MSCT and 2D-TEE are poor techniques to detect the PFO channel. Being aware of this limitation, we deliberately decided to conduct our research on relatively old patients (80.8 ± 6.9 years old). In our previous study, we discovered that, along with age, the PFO valve fuses with the left side of the interatrial septum and forms SPs. This leads to a higher prevalence of the PFO channel in younger patients, compared to the elderly, and thus a higher prevalence of SP and smooth septum in older patients than in young patients [1]; by choosing the elderly population for

Table 3 Comparison of the measurements (mean ± SD) performed in MSCT, 2D-TEE with the measurements on cadaveric material

	MSCT	2D-TEE	Cadaveric	p-value MSCT versus cadaver	p-value 2D-TEE versus cadaver
Left SP depth (mm)	8.94 ± 3.56	8.15 ± 3.57	8.77 ± 7.16	0.17	0.75
Left SP ostium height (mm)	2.79 ± 1.15	2.0 ± 1.27	5.34 ± 1.56	**0.00**	**0.00**
Left SP volume (ml)	0.22 ± 0.08	0.18 ± 0.07	0.32 ± 0.12	**0.00**	**0.00**
Right SP depth (mm)	5.38 ± 2.25	5.98 ± 2.96	5.36 ± 2.32	0.89	0.63
Right SP ostium height (mm)	3.5 ± 1.05	2.54 ± 1.44	4.44 ± 1.25	0.21	**0.00**
Right SP volume (ml)	0.20 ± 0.06	0.17 ± 0.08	0.24 ± 0.06	0.32	**0.03**

Statistically significant values (p < 0.05) are highlighted in bold

2D-TEE two-dimensional transesophageal echocardiography, *SP* septal pouch, *MSCT* multi-slice computed tomography
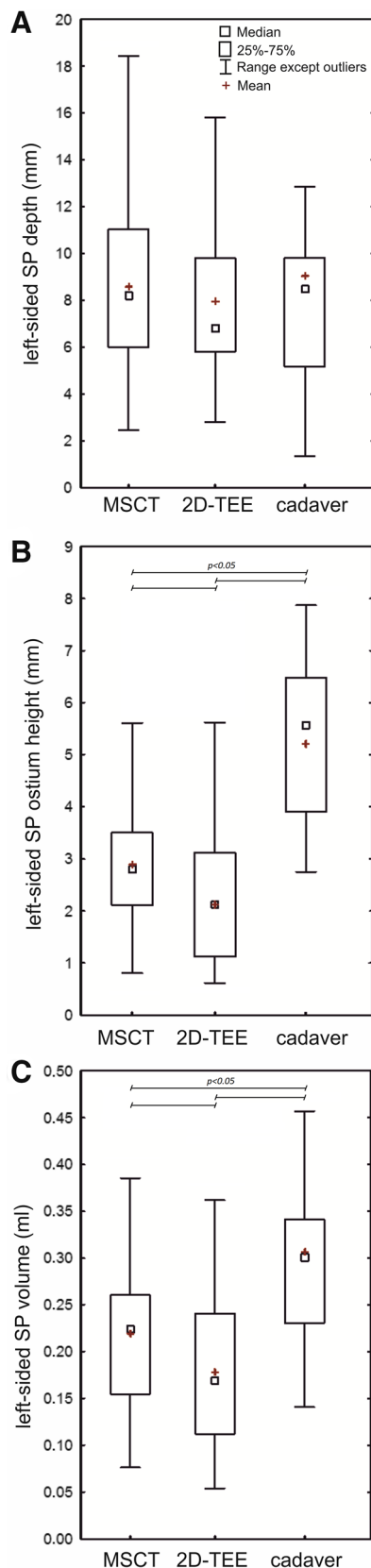
Fig. 3 Box–whisker plots presenting the left-sided SP depth (**a**), ostium height (**b**) and volume (**c**) measured in MSCT, transesophageal echocardiography (2D-TEE) and cadaveric material

this study, we significantly reduced this bias. Another limitation of this study is that no saline contrast administration with maneuvers to transiently increase right atrial pressure was used, which are the best available technique to visualize the right-to-left shunting in TEE, increasing the sensitivity of PFO channel detection [14]. As the 2D-TEE in the current study was performed without contrast administration this might have affected the detection of PFO channel. The prevalence of the PFO channel in our age- and sex-matched autopsied material was 12.0% and in fact the comparable prevalence should be expected also in the patients included in this study. The possibility of the contrast use once again places TEE over MSCT for properly detecting interatrial septum structures, where in the MSCT no additional tools and modalities may be implemented.

Looking at the dimensions of the left-sided SP, the ostium height and thus the calculated volume are significantly smaller when measured in 2D-TEE than when measured in MSCT (Figs. 1, 2). There is also a significant difference between those parameters measured in both MSCT and 2D-TEE when compared with cadaveric material (Table 3). An explanation of this difference may be that MSCT is performed during inspiratory breath hold, which may influence the size of the SP. Also, the presence of the blood and its positive pressure inside the atrial cavity may affect the SP ostium dimensions, making them significantly smaller in imaging studies than when they are assessed post-mortem. No differences were observed in the SP depth between the MSCT, 2D-TEE, and cadaver measurements. Unfortunately, there is a lack of knowledge whether all left-sided SPs or the pouches about a certain size should be recognized as a stroke risk factor. However, measurements of SPs may have clinical relevance and be a useful diagnostic tool in the future. The SP depth is the most conservative dimension that could be compared between the methods in the same patient and should be used as a preferable parameter to define the SP size.

This study has several other limitations. Firstly, it is a retrospective, single-center imaging study. The spatial resolution of 64-row MSCT is great, but may still be inadequate to show very small structures; however, the 64-row MSCT is probably the most commonly available imaging modality in cardiologic centers and therefore it was used in this study. Due to a relatively small number of patients with the co-detected right SPs (n = 5), the results of the analysis of its dimensions may be faulty. In this study the TEE was performed without intravenous contrast administration which might have affected the detection of PFO channel. Furthermore, no 3D modality was used for TEE, because the 3D reconstruction of the interatrial septum was available only in small number of patients from our cohort. Also, this is a technically oriented study which aimed to compare two methods of imaging. Therefore, no clinical data of patients

were collected during follow-up and analyzed, so we cannot draw any conclusions about the possible clinical significance of the SPs. Moreover, clinical data for autopsied patients were not fully available and thus not analyzed in this study. Finally, autopsied hearts and clinical imaging sets are not from the same patients but were matched which may also have impact on current study results.

Conclusions

In conclusion, both 2D-TEE and MSCT of the heart are comparable techniques for detecting left-sided SPs with the insignificant lower prevalence of detecting left-sided pouches compared to the matched autopsied material. However, TEE with the contrast modality seems to be superior over the MSCT due to the possibility of unambiguous PFO channel detection. Therefore, TEE with saline contrast administration should be preferred over MSCT in the identification of SPs. The MSCT should not be used for detecting and evaluating right-sided SPs. The SP depth is the most conservative dimension and should be used for specifying SP size.

Compliance with ethical standards

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