

Coronary sinus ostium: the key structure in the heart's anatomy from the electrophysiologist's point of view

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Abstract There are no research studies that comprehensively analyze, with computed tomography, the coronary sinus (CS) ostium with respect to its importance for some electrophysiological procedures paying special attention to the Thebesian valve (ThebV). Our aim was to evaluate the characteristic features of the CS anatomy, which can be useful for electrophysiologists using multislice computed tomography (MSCT). An additional aim was to create a tomographic classification of ThebV types. Included into the study were 150 patients (aged 59.7 ± 11.4 ; 105M) (43 with heart failure). Due to the suspicion of coronary artery disease, 64-slice MSCT (Toshiba, Aquilion 64) was performed in all patients. All measurements and the search for the ThebV were performed on multiplanar reconstructions in axial projection at 0.5-mm slice thickness. The average diameter of CS ostium was 14.2 ± 3.5 mm and the angle of entrance of the CS to the right atrium was $112^\circ \pm 11^\circ$. Seven variants of the ThebV were introduced and six of them were confirmed in this group. The following frequency of variants of ThebV was confirmed: E, 11.3%; D,

10.6%; A1, 8.7%; A2, 7.4%; C, 6.0%; B2, 2.0%. A statistically significant correlation between age and the size of CS ostium was found ($r = 0.25$; $p < 0.05$). It is possible to visualize and evaluate the CS including measurements and ThebV evaluation in MSCT. Six anatomical variants of the valve were found. MSCT can potentially provide valuable knowledge before the CS cannulation.

Keywords Coronary sinus · Thebesian valve · Right atrium · Cardiac resynchronization · Heart failure

Introduction

The coronary sinus (CS) receives most veins of the heart, which empty into the right atrium (RA) [1, 2]. Three elements of the CS ostium are related to successful cannulation during left ventricle lead implantation or catheter ablation [3–6]: the size of the CS ostium, the entrance from the RA, and the presence of Thebesian valve (ThebV)—the valve of the CS, which is a semicircular fold of the lining membrane of the atrium at the orifice of the CS [2, 7].

The latest developments in multislice computed tomography (MSCT) have shown that the role of this examination is still increasing [8]. According to the Appropriateness Criteria for cardiac computed tomography and cardiac magnetic resonance imaging, an evaluation of intra- and extra-cardiac structures including coronary vein mapping before CRT implantation as well as evaluation of pulmonary vein anatomy prior to invasive radiofrequency ablation received the highest grading—A [8]. Still, there is no research that comprehensively analyzes the CS ostium in MSCT in respect to its importance for some electrophysiological procedures paying special attention to the ThebV. The only such existing study is the post-mortem

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research of Mak et al. [9], where authors examined 75 autopsied human hearts to characterize the ThebV at the CS ostium, including the shape, composition, percent coverage, and attachment points.

The aim of this study was to evaluate the characteristic features of the CS anatomy, which can potentially be useful for electrophysiologists using MSCT. An additional aim was to create tomographic classification of ThebV types.

Materials and methods

One hundred and fifty patients (aged 59.7 ± 11.4 ; 105M), including 43 with heart failure, were qualified for the study. The study protocol was approved by the local ethics committee and informed consent was obtained from each patient. In each case, 64-slice computed tomography was performed due to the suspicion of coronary artery disease (CAD). Patients were excluded from the study if they presented with any of the following clinical entities: atrial fibrillation (permanent or persistent), frequent cardiac extrasystoles, renal insufficiency (serum creatinine >1.3 mg/dl), hyperthyreosis, a known allergy to non-ionic contrast agents, or a previously implanted pacemaker with unipolar leads. Characteristic of the included patients according to their left ventricular systolic function is presented in Table 1.

MSCT protocol

A 64-MSCT of the heart was performed using an Aquilion 64 scanner (Toshiba Medical Systems, Japan). Scanning with retrospective ECG-gating was performed using a 64-MSCT with a collimated slice thickness of 0.5 mm during a breath-hold. The helical pitch was 12.8 (best

mode) and the rotation time was 0.4 s. The average tube voltage was 135 kV at 380 mA, which was strictly dependent on the patient's body mass index (BMI). A pre-selected region of interest was used in this examination. In each case, the start of the scan was exactly the same as that for a routine arterial imaging. All reconstructions were created in the optimal phase for coronary arteries, and three high-quality reconstructions were created in each. We used 65 beats per minute as the cut-off for heart rate (HR). If the HR was higher, metoprolol succinate (Betaloc, AstraZeneca, Sweden) at a dose of 5–10 mg was administered intravenously if not contraindicated. If the expected HR slowing was not achieved, the patient was excluded from the study. On average, 100 ml of non-ionic contrast agent (Ioperamid, Ultravist 370, Schering, Germany, or Iomeprol 400, Bracco Int., Germany) was administered to each patient during the examination at an average rate of 5.0 ml/s. Contrast was given in three phases: 90 ml of contrast agent (average), then 24 ml of contrast agent and 16 ml of saline flush (60/40%) and finally 30 ml of saline [10].

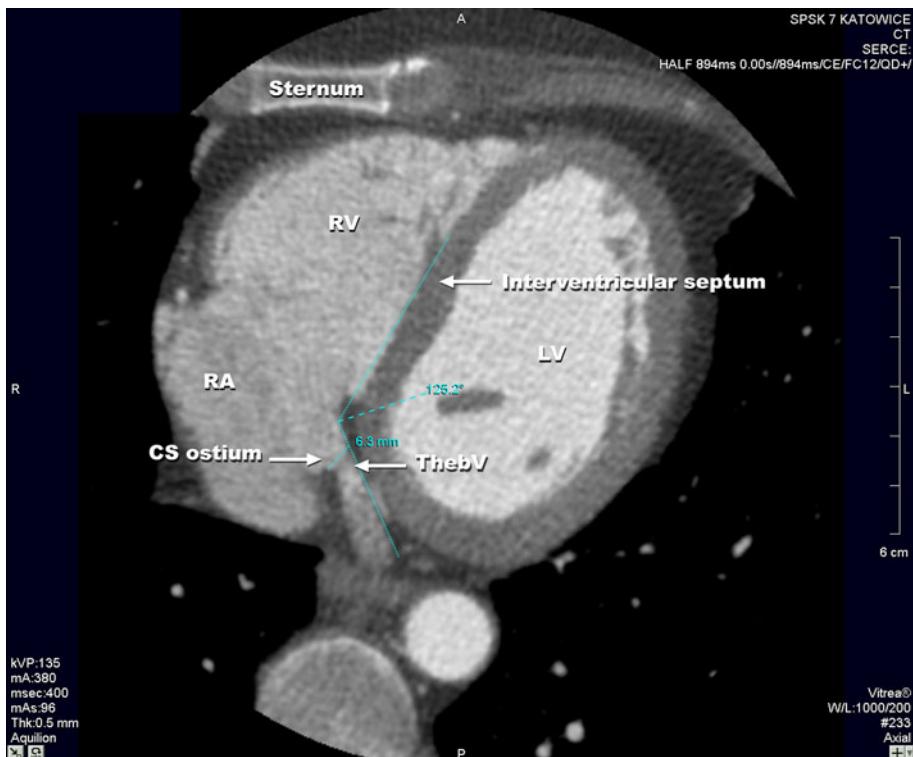
Measurements

Measurements and the search for the ThebV including grading were performed using the Vitrea 2 workstation (Vital Images, USA; software version 3.9.0.0). All data were evaluated by two experienced MSCT investigators. In a subset of 15 patients, intra- and inter-observer agreement was evaluated. From the three highest-quality reconstructions, the optimal one was chosen. To keep the results comparable, all measurements were performed in the axial plane on MPRs (Fig. 1). Additional information about anatomy is also presented for this figure. Our earlier experiences with visualization of the coronary venous

Table 1 Characteristics of the included patients

	EF < 40% (n = 43)	EF = 41–60% (n = 28)	EF > 60% (n = 79)	Whole group (n = 150)
Age	59.53 ± 13.32	58.26 ± 9.86	60.27 ± 10.82	59.69 ± 11.39
Sex (males, %)	84	89	55.69	70
CS ostium diameter (mm)	13.27 ± 3.22	14.79 ± 3.82	14.46 ± 3.41	14.18 ± 3.47
Thebesian valve present in (%)	27.27	53.57	53.16	46
Angle of entrance (°)	110.15 ± 11.39	113.95 ± 12.14	112.84 ± 11.07	112.28 ± 11.38
Hemodynamic parameters				
Ejection fraction (%)	31.06 ± 6.09	52.57 ± 5.46	68.52 ± 5.63	54.81 ± 17.19
End-diastolic volume (ml)	229.09 ± 68.48	162.96 ± 44.92	137.09 ± 32.47	168.29 ± 61.87
End-systolic volume (ml)	158.86 ± 51.14	78.03 ± 26.61	44.16 ± 14.63	84.16 ± 58.96
Stroke volume (ml)	70.23 ± 23.43	84.63 ± 22.39	94.33 ± 20.96	85.25 ± 24.34
Cardiac output (l/min)	4.25 ± 1.45	5.66 ± 2.36	5.55 ± 1.24	5.19 ± 1.66
Myocardial mass (g)	183.56 ± 51.13	172.39 ± 56.91	147.63 ± 44.08	162.86 ± 51.12

Fig. 1 Anatomy of the heart including coronary sinus ostium and Thebesian valve together with measurements of the CS ostium size and angle of entrance (MPR, axial projection)



system showed that visualization of the CS on the sagittal and coronary planes is less useful. The following features of ThebV were analyzed in MSCT images:

- Place of divergence (where the valve is started):
 - interatrial septum
 - wall of the atrium
- Number of visible parts:
 - one part
 - two parts
- Diameter of the membrane (size of cover CS ostium):
 - Whole CS ostium is covered,
 - more than 50% is covered
 - less than 50% is covered

An example of visualization of CS ostium on three planes (axial, sagittal, and coronary) is also presented (Fig. 2). Cardiac hemodynamic parameters were evaluated by using semi-automatic software in the Vitrea 2 workstation.

Statistical analysis

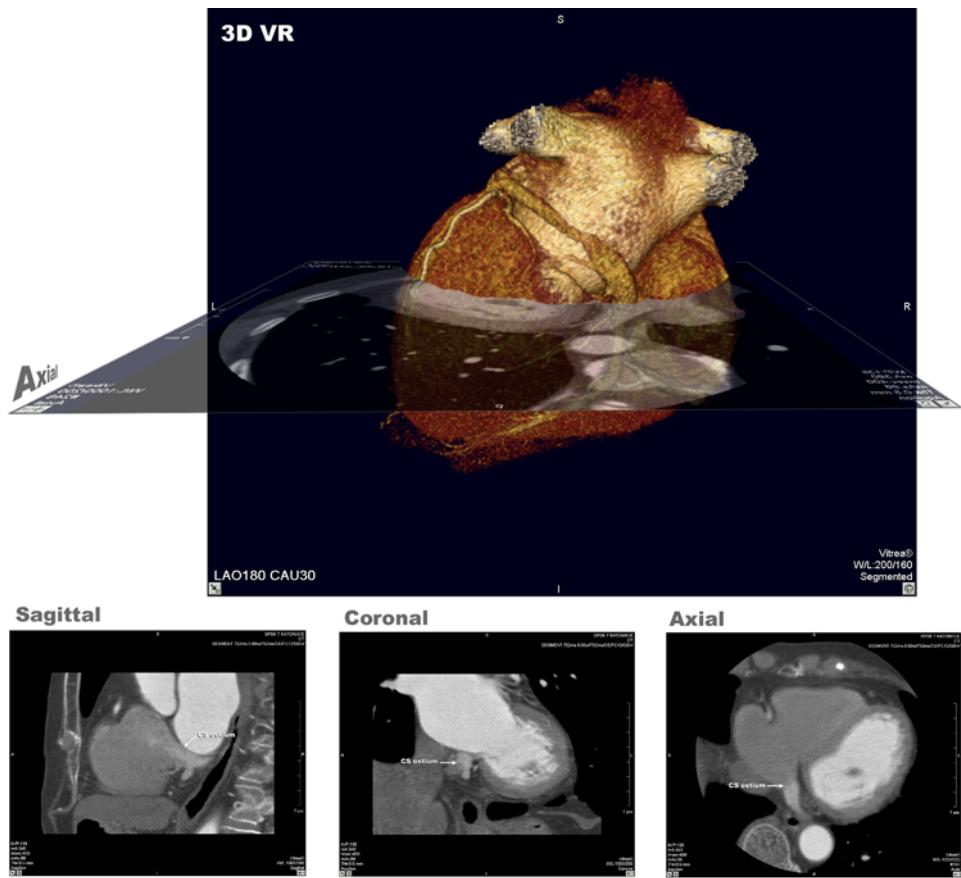
Continuous data are presented as mean values and corresponding standard deviations. Shapiro-Wilk test was used to check for normality. For the statistical comparison of diameters, Student's *t* test was used and a *p* value < 0.05 was considered statistically significant.

Results

The average diameter of the CS ostium was 14.2 ± 3.5 mm and the angle of entrance of the CS to the RA was $112.3^\circ \pm 11.4^\circ$. Different types of ThebV were found in 69/150 patients (46%). Patients were divided into two groups: with and without ThebV. Average diameter of the CS ostium in the group with valve present was 14.6 ± 3.7 and 13.8 ± 3.3 mm in group without valve (*p* = 0.17; NS). Average angle of entrance of the CS to the RA was $112.4^\circ \pm 12.1^\circ$ and in $112.1^\circ \pm 10.8^\circ$ group without valve (*p* = 0.17; NS).

Knowledge about heart anatomy and exact analysis of MSCT data allowed us to create seven variants of the ThebV. This was the basis upon which the classification of the types of ThebV in MSCT was created (Fig. 3). Six variants of the valve were confirmed in this study. The following frequency of different variants was found: E, 11.3%; D, 10.6%; A1, 8.7%; A2, 7.4%; C, 6.0%; B2, 2.0%. Expected variant B1 was not found in the examined group. The occurrence of some types of ThebV differed within groups according to the left ventricular ejection fraction. Type C (100% of cases) and D (81% of cases) were found almost exclusively in subjects with normal LVEF, whereas type A1 was unique in subjects with most compromised LVEF (one out of 13 cases; 8%). Other types were present nearly uniformly. Valve of Vieussens, a valve in the great cardiac vein, was not visualized in none of the included patients.

Fig. 2 Examples of visualization of CS ostium on three projections in MPRs. Additional 3D simulation is shown, reference position of MPR axial projection on 3D posterior view of the heart



The data about CS anatomy were correlated with demographic and hemodynamic data. Correlation coefficients are presented in Table 2. Statistically significant correlations between age and the size of CS ostium: $r = 0.25$; $p < 0.05$ as well as ejection fraction and the size of CS ostium: $r = 0.18$; $p < 0.05$ were found (Figs. 4, 5).

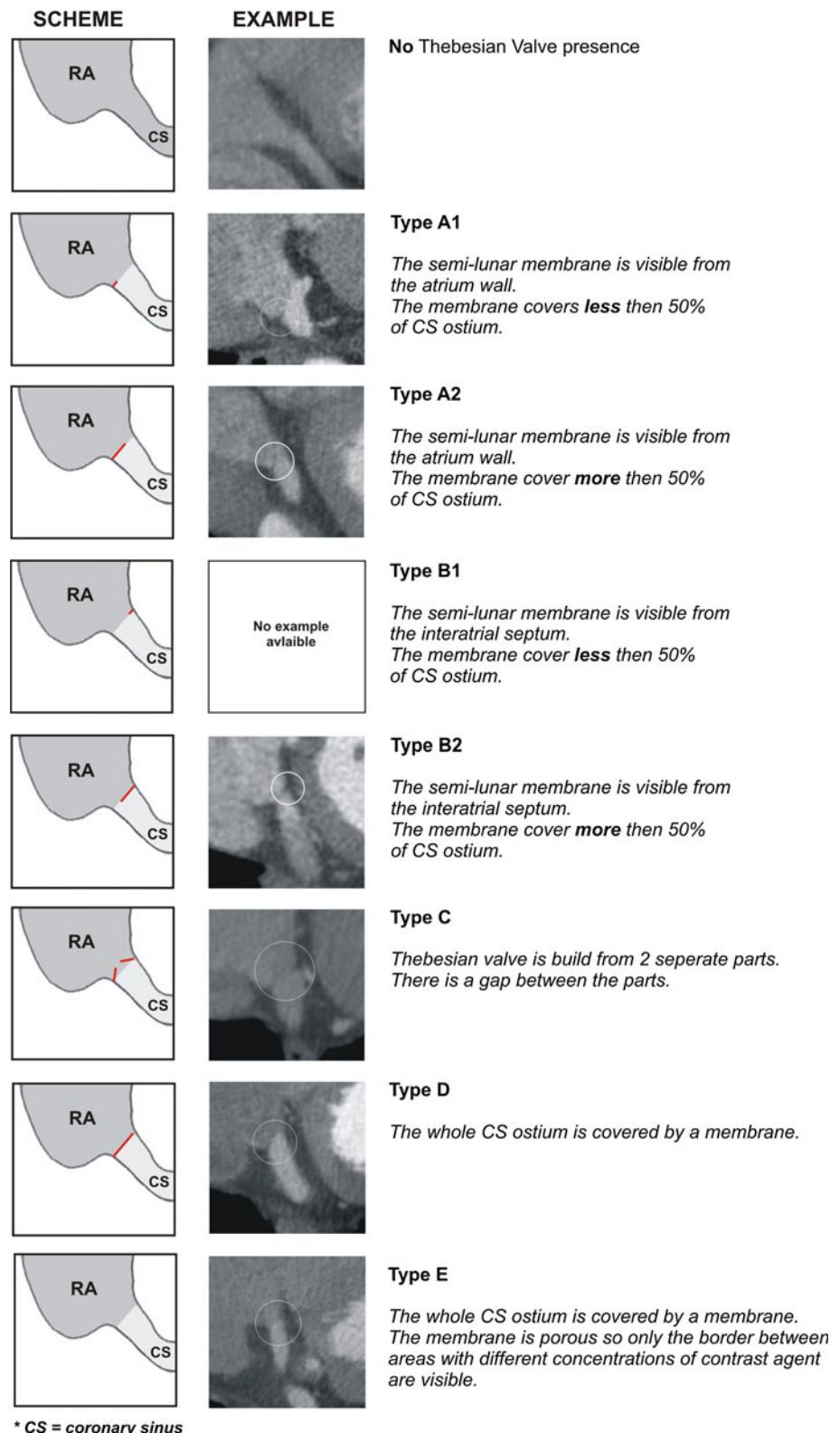
Discussion

The CS ostium is an anatomical heart's structure important for left ventricle lead implantation before cardiac resynchronization [11]. MSCT is an excellent tool for non-invasive imaging vessels of the heart [12, 13]. An examination of the CS in MSCT can be performed during routine evaluation of the coronary arteries. Recent studies have proven that it is possible to visualize the coronary venous system in MSCT [14–18]. In the Appropriateness Criteria, MSCT for non-invasive coronary vein mapping prior to the placement of a biventricular pacemaker is marked highly recommended [8]. However, the method still waits for a common use. In our earlier study we created a user-friendly approach that might be helpful in the coronary venous system visualization in a way similar to the intra-operative fluoroscopy [17].

In the present study, a quantitative analysis of the CS ostium with special attention being paid to the ThebV was performed together with an attempt to classify the types of this valve. From the implanting physician's point of view, an accurate assessment of the CS ostium, taking measurements of the size of the ostium (which is a key element for cannulation) and a determination of the angle of the entrance to the CS, is of special importance [17]. Also, the presence of any form of ThebV would seem to be of importance. The presence of this valve can make a cannulation significantly more difficult, and sometimes even impossible, as noted by Shinbane et al. [19].

Other authors have shown indirect visualization of ThebV. Anh et al. [20], who performed a study in which 100 patients undergoing CRT devices, visualized the CS ostium using a fiber-optic endocardial catheter. They found the ThebV in 54% of patients (similar to our results). More frequently (61%), the valve was positioned at the inferior or posterior (33%) area of the CS ostium. In 6% of cases, the valve covered more than 70% of the ostium. A prospective evaluation of the anatomy of the coronary venous system using 16-row CT was performed by Christiaens et al. [14]. According to their study, in 36% of patients, the presence of the ThebV was confirmed. The average diameter in the antero-posterior was 12.2 ± 3.6 mm. We

Fig. 3 Types of the Thebesian valves introduced in presented study, schemes and examples (MPR, axial projection)



* CS = coronary sinus

obtained similar results: the frequency of ThebV presence was 46% and the average size was 14.2 ± 3.5 . The somewhat higher frequency in our study may be related to the use of a higher-resolution CT scanner (64 slices vs. 16).

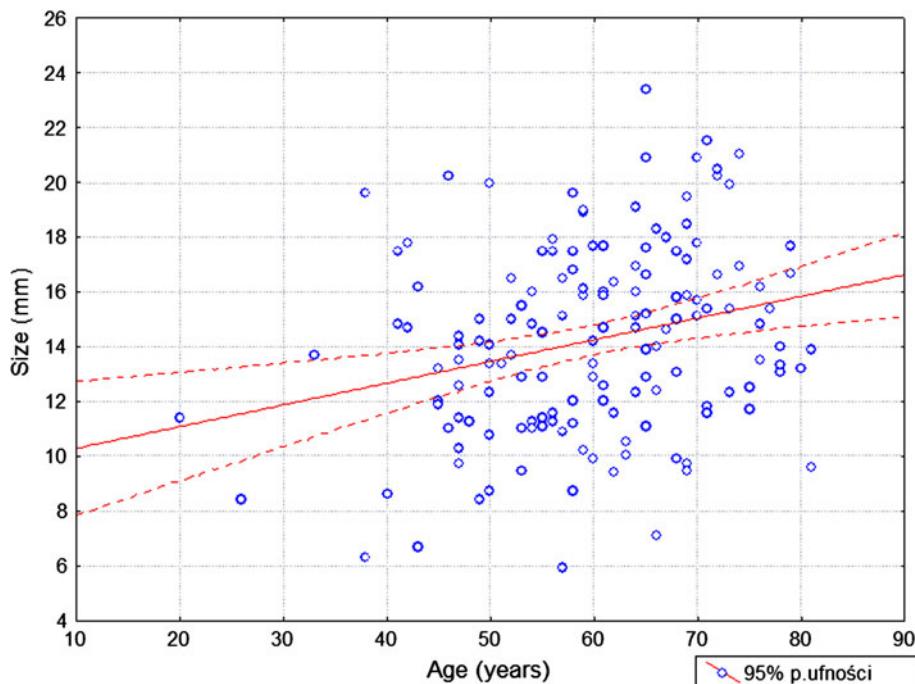
There have also been some post-mortem studies searching for the presence of the ThebV. Up to now, the biggest analysis was presented by Mak et al. [9]. Authors analyzed 75 randomly selected autopsied human hearts.

Table 2 Correlation coefficients between the coronary sinus dimensions and the demographics and hemodynamic data

CS coronary sinus

	CS ostium diameter (mm)	CS angle of entrance (°)
Age (years)	0.25 statistical	0.09
Ejection fraction (%)	0.18 statistical	0.07
End-diastolic volume (ml)	-0.11	-0.03
End-systolic volume (ml)	-0.15	-0.08
Stroke volume (ml)	0.09	0.13
Cardiac output (l/min)	0.13	0.10
Myocardial mass (g)	0.01	-0.05

Fig. 4 Correlation between age and the size of CS ostium ($r = 0.25$; $p < 0.05$)



ThebV was found in 73% of the hearts examined. Average transverse dimension was significantly shorter (7.3 ± 2.8 mm) in hearts with ThebV present when compared to the group without the valve (9.4 ± 2.9 mm). Differences in dimensions can be caused by the fact that Mak et al. [9] examined autopsied hearts that have been preserved with formalin, which can influence the dimensions.

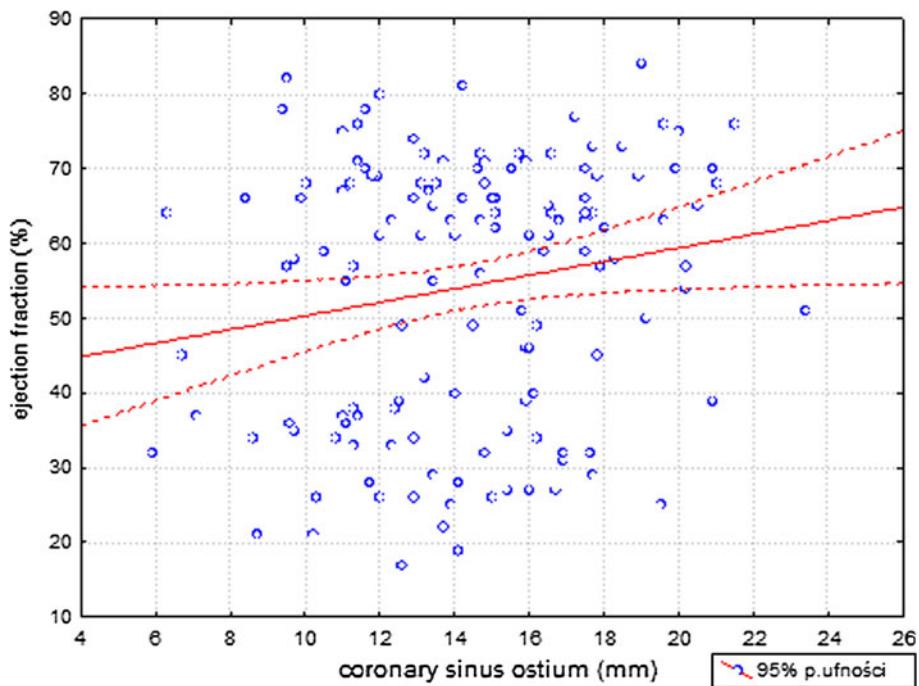
In a study of 50 human CSs of the heart, Silver and Rowley [1] showed that ThebV covered the ostium in 41% of cases, including 20% that were totally covered and in 26% of hearts with increased weight. We also performed analyses based on the mass of the heart calculated by MSCT, however, no association with cardiac mass was found. In contrast, El-Masarany et al. [21] obtained different results. In their study, the ThebV was present in 87.5% (35/40)—in those cases it was a thin semi-lunar fold. In 4/40 patients (10%), the valve was in the form of a narrow circular rim surrounding the ostium. The valve was absent in only one case. There are differences between the research. Nevertheless, this indicates

the huge anatomical variability of the coronary venous system.

Our paper is the first in which a heart failure subgroup ($EF < 40\%$) was examined. It might be of special importance since this group is a potential target for cardiac resynchronization. In this group, the prevalence of the ThebV occurrence appeared significantly lower when compared to groups with preserved (41–60%) or normal (>60%) ejection fraction. However, there were no significant differences in the angle of entrance or the CS diameter between the groups. Prevalence of the ThebV in heart failure patients is probably caused by atrial enlargement and stretch of the CS as well as the ThebV.

Another important result of our paper is the introduction of a new classification of the ThebV variants, which can potentially be useful in clinical practice, especially considering the fact that only MSCT or EBCT can reliably visualize this anatomical structure. Knowledge of the type of the ThebVs can facilitate the success of cannulation. However, this requires further research.

Fig. 5 Correlation between ejection fraction and the size of CS ostium ($r = 0.18$; $p < 0.05$)



We suppose that in case of a lack of the success in the first implantation of a left ventricle lead, one should consider performing MSCT. However, before qualification one has to recall the limitations of tomography as a tool in examinations (including slow HR <75 , without AF and other arrhythmias, lack of renal insufficiency, all of which are affected by the type of scanner being used). If an MSCT was performed earlier on individual patients, one should return to the raw data, and reconstruct and analyze the data, with special attention being paid to the presence of the ThebV. Its presence should not lead to a priori abandoning the procedure. Rather, accurate preparation for the implantation, including the proper curve of the stylet, might be inevitable. There are no clinical data showing how the presence of ThebV influences the success CS cannulation, the only report being Shinbane et al. [19], where prominent ThebV was the reason of the epicardial left ventricle lead implantation.

Limitations of the study

There are several issues regarding the clinical utility of the examined technique. First, most of them are related to the MSCT as a method itself. Excluding patients with arrhythmias is a limitation, especially since they are very common among patients with heart failure. Second, the dose of radiation, as well as the amount of contrast agent used during examination, is also substantial. In the examined cohort were included relatively young patients and

most were men. The angle of entrance determination can also be subject to bias based on inter-individual variation in heart position relative to the axial imaging plane. Last but not least, many patients may require a beta-blocker use for HR reduction, which may be poorly tolerated and require continuous HR and blood pressure monitoring.

The shape of ThebV is very difficult to describe; classification of ThebV presented in this paper is only a proposal, and without anatomopathological confirmation. The valve can occur in many types, can be fibrous or fibromuscular, and since it is very thick, it can be easily detected on MSCT scans. It can also be fenestrated or very thin, so the resolution of current MSCT scanners does not provide sufficient quality to characterize it. This can be a reason that the presence of ThebV in 46% of the subjects in our research may be lower than the true prevalence of the population.

Therefore, further research is necessary to evaluate the importance of the type of ThebV, and especially which (types) can potentially create problems during implantation. Successful CS cannulation is based more on the operator's skills and experience than on the MSCT findings. However, pre-procedural MSCT would change the procedure and/or treatment strategy.

Conclusions

It is possible to visualize and evaluate the CS including measurements and the ThebV evaluation in MSCT. Six

variants of the ThebV were found, based on a new tomographic classification. The MSCT can potentially provide clinically valuable knowledge before CS cannulation.

Conflict of interest There are no conflicts of interest for any of the authors.

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