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CARDIOVASCULAR IMAGING

ORIGINAL ARTICLE

Assessment of the coronary venous system by using cardiac CT

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PURPOSE
We aimed to investigate the coronary venous system and its variations by using dual source computed tomography (CT).

MATERIALS AND METHODS
Retrospective assessment was carried out on 339 patients who underwent coronary CT angiography using 128-slice dual source CT for suspected coronary artery disease. The examinations were performed according to routine imaging protocols used to evaluate coronary arteries. The coronary venous system was evaluated in each case using maximum intensity projection and volume rendering technique multiplanar reformation reconstructions. In each patient, the presence and calibration of normal anatomy, as well as the variations of the coronary sinus, middle cardiac vein, small cardiac vein, posterior cardiac vein, great cardiac vein, anterior interventricular vein, posterolateral vein, left marginal vein, and anterolateral vein were recorded.

RESULTS
The coronary sinus, middle cardiac vein, great cardiac vein, and anterior interventricular vein were visualized in all of the patients. In all cases, one of the lateral or posterolateral veins of appropriate localization and diameter for cardiac resynchronization therapy was detected. The posterior cardiac vein was visualized in 87% of the cases, the left marginal vein in 87.9%, and the small cardiac vein in 20%. There was no significant difference in the diameters or visibilities of the coronary veins in terms of age.

CONCLUSION
The coronary venous system and its tributaries may be examined in detail using CT angiography examination performed according to the routine coronary CT angiography protocol used for dual source CT. Dual source CT may be a valuable tool for evaluation of the coronary veins prior to invasive procedures that are directed at the coronary venous system.

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Multidetector computed tomography (MDCT) angiography noninvasively assesses normal anatomy in addition to variations of the vascular structures and their relationship with adjacent anatomical structures. Images can be accurately, rapidly, and thoroughly interpreted due to the ability of this technique to capture fine axial images and make use of multiplanar reconstructions, interactive maximum intensity projection images, and volume rendering technique (1–4). In recent years, ECG-gated MDCT has become an important noninvasive tool and has been increasingly used to evaluate coronary arteries (5–8). This method enables assessment of the coronary venous system and other cardiac structures, in addition to the coronary arteries (5).

The coronary venous system is a commonly used route of entry to the heart and is used in treatment modalities for arrhythmias and heart failure (9, 10). In addition to cardiac pacing, this route may also be used for percutaneous venous interventional procedures, such as transcoronary venous ablation, percutaneous mitral annuloplasty, and retrograde cardioplegia perfusion (11, 12). The aim of cardiac resynchronization therapy is to restore the synchronization between right and left ventricles. For this purpose, a pacing lead is positioned in one of the branches of the great cardiac vein via the coronary sinus. A thorough knowledge of the venous anatomy prior to the procedure will ease the intervention process and increase the success rate. Catheter-based venous angiography is an invasive method with the potential for serious complications. Even when this method is used, the anatomy could not always be visualized (12). Even experienced centers have a failure rate of 5%–12% (13). Coronary computed tomography (CT) angiography is used in clinical practice to evaluate coronary artery anomalies, coronary artery stenosis, and the potencies of previous stents and bypass grafts (5–8). However, the coronary venous system can also be assessed using the same technique. Only a small number of previous studies have used 4-, 16-, and 64-slice MDCT (14–17).

The aim of our study was to assess a normal coronary venous system, its variations, and anomalies using a 128-slice dual source CT retrospectively.

Materials and methods

Each patient was informed and gave written consent prior to examination and procedure. All procedures performed were in accordance with the ethical standards of the Declaration of Helsinki developed by World Medical Association.

Study population

The study population was composed of 357 consecutive patients who had undergone coronary CT angiography between January 2009 and November 2011. All of the patients had undergone this test for suspected coronary artery disease. Subjects with a poor image quality (n=18) due to an inability to their hold breath and artifacts were excluded from the study. The remaining 339 patients (74 females and 265 males; mean age, 54±11.4 years; range, 25–85 years) constituted the study group.

Patients with a heart rate above 80 beats per minute (bpm) despite beta blockade, patients who were unable to hold their breath, patients with a creatinine level above 1.5 mg/dL, patients with an allergy to the contrast material, pregnant patients, patients with unstable cardiac arrhythmias were excluded from the study.

Dual source CT protocol

ECG-gated MDCT (Somatom Definition, 128-slice Dual Source CT, Siemens Medical Systems, Erlangen, Germany) was performed. The patients with a heart rate above 80 bpm were administered metoprolol tartrate intravenously (Beloc ampule 5 mg/5mL, AstraZeneca, İstanbul, Turkey) (5–15 mg). They were instructed on breath-holding exercises. The examination was performed with the patient in supine position and holding his/her breath. Contrast material of 75–90 mm^3 (Ultravist 370 mg/mL, Schering, Berlin, Germany) was given via the antecubital vein at a rate of 5–6 mm/s. Afterwards, 50-cc bolus of intravenous saline solution was given at a rate of 5 cc/s. The region of interest was located relative to the ascending aorta 1 cm distal to the tracheal bifurcation. The scan was automatically started 2 s after the threshold level reached 150 Hounsfield unit (HU). Contrast administration was controlled using bolus tracking. ECG-gated MDCT was performed according to the following protocol: detector collimation, 32×0.6 mm; gantry rotation time, 330 ms (temporal resolution, 83 ms); slice acquisition, 64×0.6 mm; pitch, 0.2–0.42 adapted to the heart rate; tube voltage, 120 kV; tube current, 390–438 mAs per rotation. The scanning duration was approximately 5.8–10.2 s, depending on the cardiac dimensions and the pitch, and took place during a single breath hold in the craniocaudal direction.

Image reconstruction and analysis

The reconstructions were made during all cardiac phases at 50-ms intervals at a slice thickness of 0.75 mm and a reconstruction increment of 0.5 mm. The best systolic and diastolic frames were chosen and transferred to the work station (multi-modality workplace) for advanced analysis. The images were then assessed in consensus by two five-year-experienced radiologists. All of the patient images were assessed using multiplanar reconstructions volume rendering technique and maximum intensity projection to evaluate the coronary venous system.

Visibility of the coronary veins was graded visually using a five-point scale for each coronary vein (grade 0, not visible [lack of vein]; grade 1, visible with discontinuity; grade 2, visible with irregular borders; grade 3, visible as a smoothly bordered vascular structure; grade 4, well-contrasted vessel, clearly visible throughout the entire segment).

For analysis, the visibility, number, anomalies, and variations of the veins were first assessed in the coronary sinus, small cardiac vein, middle cardiac vein, posterior cardiac vein, lateral veins, great cardiac vein, anterior interventricular vein, and the vein of Marshall. Beginning from the coronary sinus, the diameters of all of the veins were measured from outer wall to outer wall at the level of the ostium. The presence or absence of Thebesian valves was detected.

Description and nomenclature of coronary venous system

The coronary sinus is the main part of coronary venous system, beginning from the coronary sinus ostium at the right atrial junction and coursing up to the branching point of the vein of Marshall (or valve of Vieussen if the vein of Marshall is absent). It is designated as the great cardiac vein beyond the vein of Marshall or Vieussen valve. The main branches of the coronary sinus are the middle cardiac vein, small cardiac vein, posterior cardiac vein, and lateral vein. The anterior interventricular vein is the continuation of the great cardiac vein.

The coronary sinus is the largest vein of the coronary venous system. It originates from the great cardiac vein and drains into the right atrium via the coronary sinus ostium at the atrioventricular sulcus. Its ostium is located at the posteroseptal right atrium (Figs. 1–5).

The great cardiac vein originates from the anterior interventricular vein, courses next to the left anterior descending artery, and ends as the coronary sinus at the ostium of the vein of Marshall (Figs. 1, 2b, 3, 4, 5a, 6a).

The middle cardiac vein, also called the inferior or posterior interventricular vein, originates from the apex of the heart at the diaphragmatic level; it then courses via the posterior interventricular groove and is drained into the coronary sinus (Figs. 1a, 1b, 2, 3, 5).

The posterior cardiac vein, also called the posterior vein of left ventricle, courses along the diaphragmatic aspect of the left ventricle. It originates either from the posterior or lateral part of left ventricle and is drained into the coronary sinus. Its lateral tributaries are appropriate for left ventricular pacing (Figs. 1b, 2b, 2c, 3–5).

The lateral veins, also referred to as the left marginal veins, are three lateral veins: the posterolateral vein, the lateral vein, and the anterolateral vein. These veins are the target veins for the left ventricular lead implantation. The posterolateral vein courses between the posterior cardiac vein and the lateral vein and generally drains into the coronary sinus. The lateral vein courses along the lateral border of the left ventricle and ends in the coronary sinus or great cardiac vein. The anterolateral vein courses between the lateral vein and anterior interventricular vein and ends in the great cardiac vein (Figs. 1, 2b, 4, 5a, 6a).

The anterior interventricular vein, also referred to as the anterior vein, originates from the apex of the heart, courses via the interventricular groove and ends at the beginning of the great cardiac vein (Figs. 1c, 1d, 4, 6).

The vein of Marshall, also referred to as the oblique vein of the left atrium, is a tiny vessel with a mean diameter of 1 mm. It obliquely courses behind the left atrium and ends at the junction of the great cardiac vein and coronary sinus (Figs. 1b, 1c, 5).

Statistical analysis

The prevalence, median values, and mean values of the data were calculated. A commercially available software (Statistical Package for Social Sciences, version 13.0, SPSS Inc., Chicago, Illinois, USA) was used for the statistical analyses.

Results

The coronary venous system map was imaged in all patients. The image quality was optimal in 86.7% (294/339) of patients, whereas 13% (45/339) suffered from cardiac triggering artifacts and insufficient breath holding, causing suboptimal image quality.

The coronary sinus, middle cardiac vein, great cardiac vein, and anterior interventricular vein were visualized in all cases (100%). The posterior cardiac vein was visualized in 87%, and the left marginal veins were visualized in 87.9% (Table 1). Two left marginal veins were shown in 40/339 (11.8%), and three left marginal veins were shown in three cases. The posterior cardiac vein were two in number in 90/339 (26.5%) and three or more in 14 cases. The ostial diameters of the coronary sinus and its branches are given in Fig. 7. Although the diameters of the middle cardiac vein, great cardiac vein, and coronary sinus show individual variability, the anterior interventricular vein diameter is similar in nearly all of the cases. There was considerable variability in the diameter and number of the posterior cardiac vein and lateral veins.

The small cardiac vein was observed as a very small vein in 20% (68/339) of cases, 29.2% (19/65) of which directly drained into the middle cardiac vein. Two cases had aneurysms at the proximal part of the middle cardiac vein, and the small cardiac vein was draining into this aneurysmal lumen (Fig. 2a, 2b). A dual middle cardiac vein was present in nine of the 339 patients (2.6%) (Fig. 2c).

The Thebesian valve was detected as a hypodense, thin leaflet at the ostium of the coronary sinus in 245 of 339 patients (72.2%). There was a prominent density difference between the right atrium and the coronary sinus in all cases with the Thebesian valves (Figs. 2c, 3).

In one case, an isolated posterior cardiac vein was observed, which was directly drained into the left atrium (Fig. 4). In another case, an isolated anterior interventricular vein was identified draining into the left atrium (Fig. 6). The vein of Marshall was present in 10.6% (36/339) of the patients (Figs. 1b, 1c, 5).

No significant differences were observed between the diameters or visibilities of the veins in terms of age.

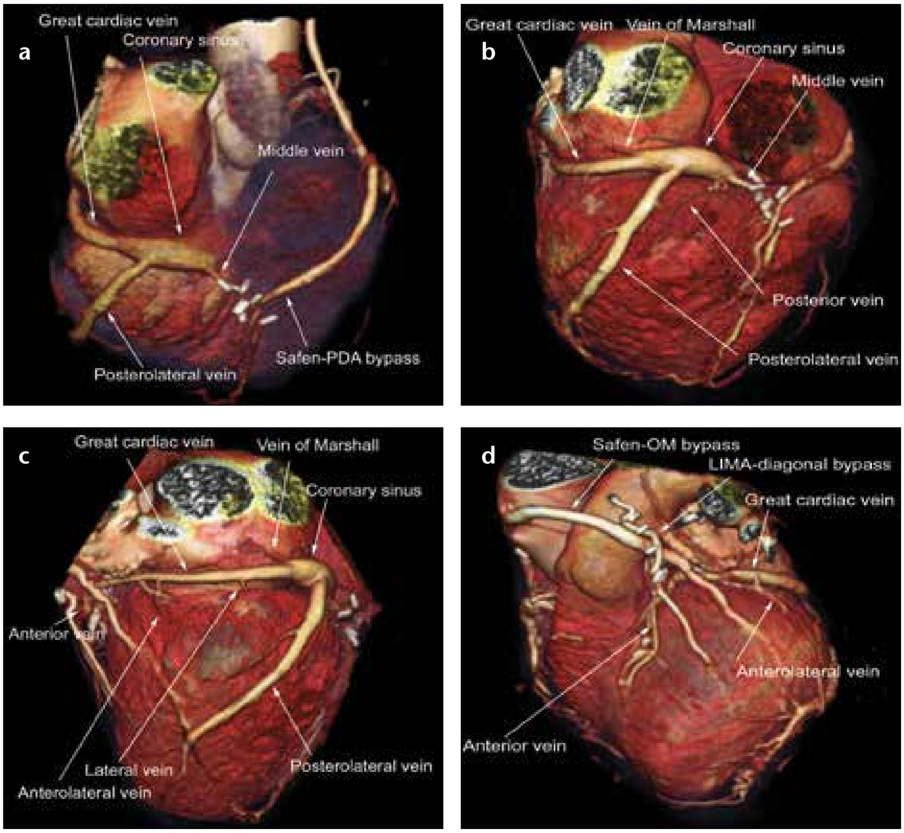

Figure 1. a–d. Volume-rendered images show the coronary sinus and its tributaries. The target veins for cardiac resynchronization therapy are observed in images of the posterosuperior **(a)**, posterior **(b)**, posterolateral **(c)**, and anterolateral **(d)** walls of the heart. The anterolateral vein, lateral veins, and posterior cardiac vein have a thin caliber and are not suitable for cardiac resynchronization therapy. The posterolateral vein is dominant and suitable for cardiac resynchronization therapy. The proximal vein of Marshall is obliterated and of a thin caliber.

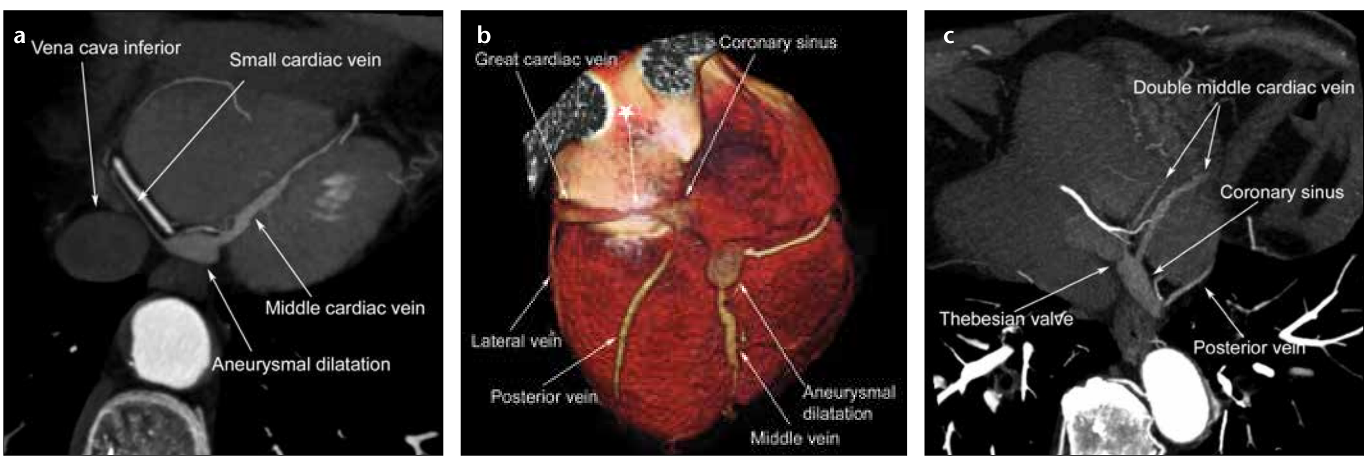

Figure 2. a–c. Maximum intensity projection **(a, c)** and volume rendering technique **(b)** images of the middle cardiac vein variations. The images in **(a)** and **(b)** belong to the same patient, whereas the image in **(c)** is from a different patient There is an aneurysmal dilatation in the proximal part of the middle cardiac vein **(a)**. The coronary sinus has a small diameter due to aortic compression (**b**, *star*). Dual middle cardiac vein drained into the coronary sinus are shown; the small cardiac vein is observed draining into the middle cardiac vein, along with the Thebesian valve, coronary sinus, and posterior cardiac vein **(c)**.

Discussion

The results of our study suggest that ECG-gated 128-slice dual source CT performed with conventional imaging technique and used to visualize coronary arteries is capable of acquiring high-quality images of the coronary venous system. Using dual source CT, the coronary venous system and its branches, variants, and anomalies may be detected noninvasively. The venous diameters, courses, and relationships to other cardiac structures may be examined in detail using multiplanar reconstructions and volume rendering technique images. The main problem faced when evaluating the coronary venous system using ECG-gated MDCT is to select the optimal phase for reconstruction (18, 19).

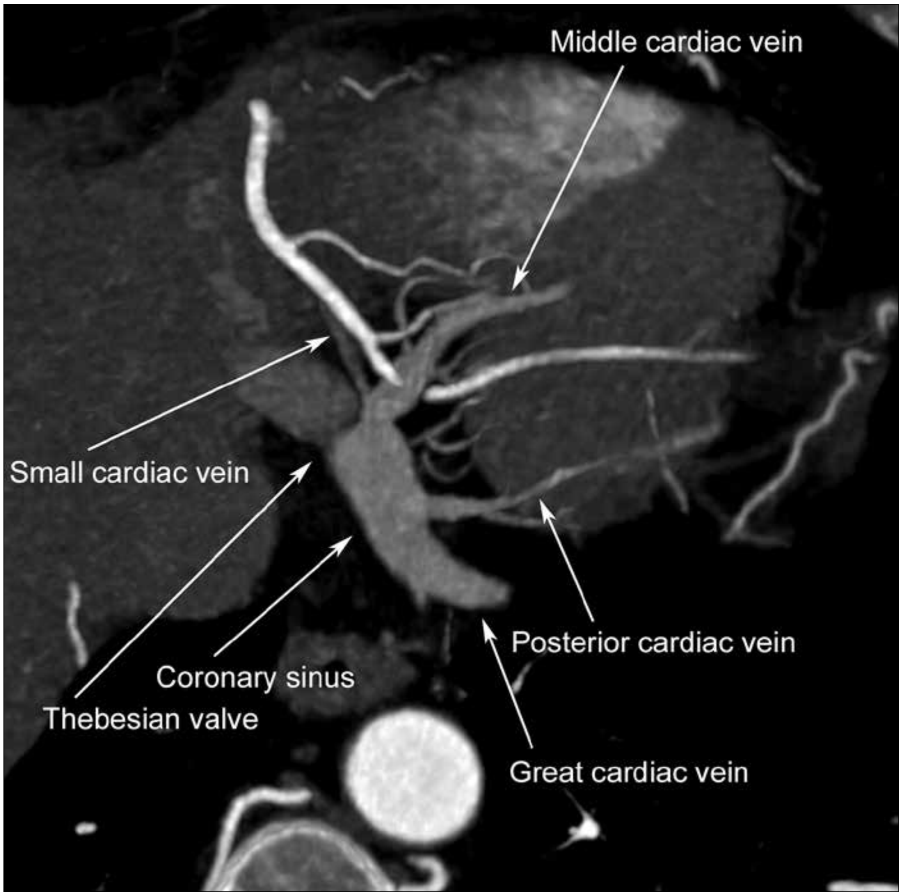

Figure 3. Axial maximum intensity projection image shows the Thebesian valve and the coronary sinus and its tributaries.

There are several types of coronary venous system imaging, each of which has its own advantages and disadvantages (12, 20–23). The conventional method used to evaluate coronary venous system is invasive retrograde cardiac venography. However, this technique requires cannulation and balloon occlusion of the coronary sinus, followed by cineangiographic imaging of the cardiac veins and their tributaries by injecting contrast into the coronary sinus and its branches in at least two positions. The disadvantages include coronary sinus trauma due to balloon occlusion, a longer imaging time, and the fact that a high volume of contrast material may be needed in this technique (12). It is also possible to evaluate the coronary venous system using electron-beam CT. However, a considerable number of patients may not be adequately assessed by this modality because not all parts of the heart come under examination, and the image quality is suboptimal (22, 24). Another noninvasive imaging method is magnetic resonance imaging (MRI). Chiribiri et al. (21) assessed coronary venous system using MRI in a 23-patient study. In this study, the posterior cardiac vein, left margin-

Table 1. Anatomical observations obtained from the studies that evaluated coronary venous system by means of noninvasive methods

	Mao et al. (22)	Chiribiri et al. (21)	Jongbloed et al. (15)	Mlynarski et al. (20)	Malagò et al. (23)	Present study
Imaging technique	EBCT	MRI	16-slice CT	64-slice CT	64-slice CT	Dual source CT
Study population (n)	231	23	38[a]	199	301	339
Coronary sinus	100%	100%	100%	100%	100%	100%
Great cardiac vein	100%	100%	NE	NE	100%	100%
Middle cardiac vein	100%	96%	100%	100%	100%	100%
Anterior interventricular vein	100%	65%	NE	80.4%	100%	100%
Left marginal vein	78%	70%	57%	80.4%	84%	87.9%
Posterior cardiac vein	81%	78%	86%	62.3%	82%	87%
Small cardiac vein	NE	52%	46%	NE	18.9%	20%
Marshall vein	6%	0%	36%	NE	10.9%	10.6%
Thebesian valve	NE	NE	NE	NE	77%	72%

[a]10 patients with heart failure were not evaluated.
CT, computed tomography; EBCT, electron-beam computed tomography; MRI, magnetic resonance imaging; NE, not evaluated.

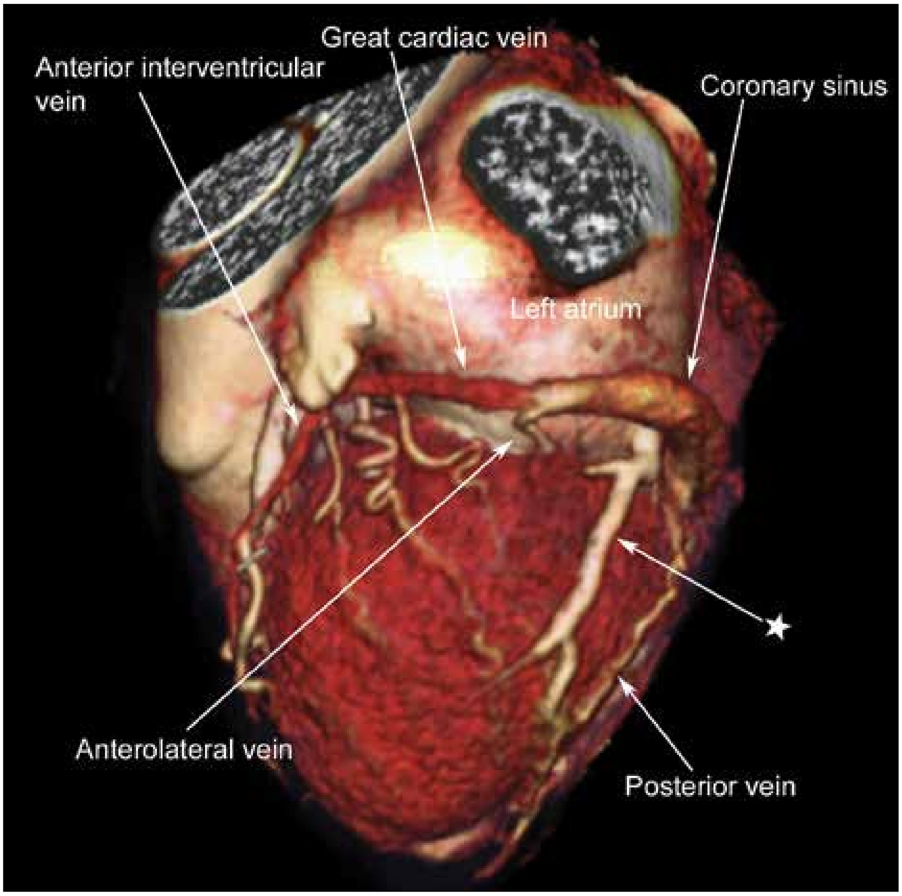

Figure 4. In the anterolateral volume rendering technique image of heart, the posterolateral vein is abnormally drained into the left atrium instead of the great cardiac vein (*star*). The posterior cardiac vein is thin and tortuous.

Table 2. Comparison of ostial diameters (in mm) of coronary sinus and its branches in studies with noninvasive methods

	Mao et al. (22)	Chiribiri et al. (21)	Malagò et al. (23)	Present study
Imaging technique	EBCT	MRI	64 slice CT	Dual source CT
Study population (n)	231	23	301	339
Coronary sinus	10.5±2.4	11±3.6	8.7	9.5±2.1
Great cardiac vein	NE	8.6±3	7.3	8.3±1.7
Middle cardiac vein	4.6±1.5	6±1.9	5.5	4.3±1.2
Anterior interventricular vein	2.7±0.7	4.6±1.1	2.2	2.9±0.7
Left marginal vein	3.1±0.9	4.5±1.5	2.3	2.2±0.9
Posterior cardiac vein	3.2±1.3	4.1±1.2	2.4	2.4±1

CT, computed tomography; EBCT, electron-beam computed tomography; MRI, magnetic resonance imaging; NE, not evaluated.
Data are given as mean±SD or mean.

al vein, and anterior interventricular vein were infrequently visualized; the vein of Marshall was not visualized in any patient. In addition, compared to other methods, the diameters of the coronary sinus and its branches were measured to be higher (21).

In recent years, the cardiac venous system has been increasingly involved in cardiac therapeutic interventions. One of the coronary veins needs to be cannulated for cardiac resynchronization therapy implantation. Radiofrequency ablation and myoblast transplantation are performed via the venous system. Performing MDCT has been recommended to noninvasively evaluate the coronary vein map before attempting biventricular pacemaker implantation (25).

The coronary venous system shows great variability (26, 27). There are few studies with limited sample sizes that imaged the coronary venous system noninvasively using MDCT. Abbara et al. (16) reported in their study that they detected no lateral vein in 7.4% of cases and no posterior vein in 20.4% of 54 patients. However, either the posterior vein or lateral vein was identified in all of the cases. In another study, Mlynarski et al. (20) identified the posterior vein in 47.2% and the anterolateral vein in 34.7% of cases. They detected a lateral-posterior vein that was appropriate for cardiac resynchronization therapy. This study did not assess the Thebesian veins or other coronary venous structures. Malagò et al. (23) detected the coronary sinus, great cardiac vein, anterior interventricular vein, and middle cardiac vein using 64-slice CT in all patients in a large study of 301 subjects. We also observed all the veins mentioned above. Malagò et al. (23) also detected the posterior cardiac vein in 82% of the subjects and the left marginal veins in 84% of the subjects. Either the lateral vein or the posterior cardiac vein of an appropriate size and location for cardiac resynchronization therapy was always detected (23).

Previous studies have been conducted using 4-, 8-, 16-, and 64-slice CT scanners. To our knowledge, our present study is the largest study to be carried out to date using a 128-slice dual source CT. Comparison of the ostial diameters of the coronary sinus and its branches and anatomical observations that can be used to evaluate the coronary venous system using noninvasive methods are given in Tables 1 and 2.

In two of our patients, we detected a saccular aneurysm in the middle cardiac vein. In one of them, the small cardiac vein was draining into the aneurysmal segment. The middle cardiac veins were assessed according to the presence of aneurysms in the CT study; a dilatation two times that of the normal vein diameter was accepted to indicate a fusiform aneurysm. Although fusiform aneurysm was detected in 10% of the patients (11), we assessed the subjects only in terms of saccular

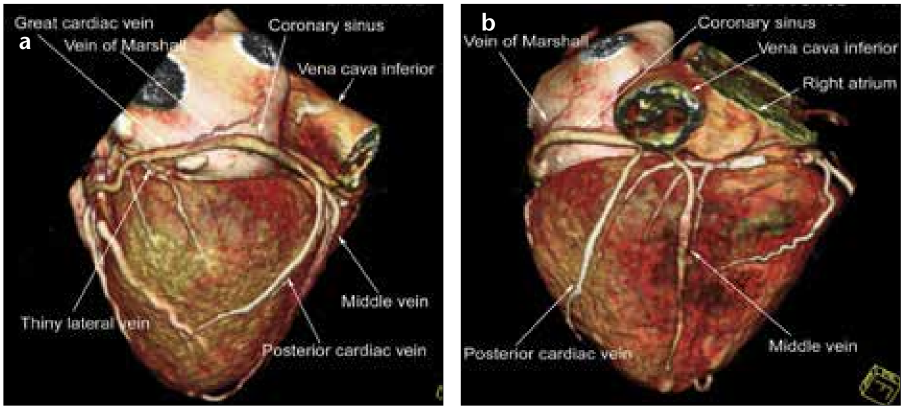

Figure 5. a, b. A thin lateral vein of insufficient caliber for cardiac resynchronization therapy is observed and drains into the lateral wall of the heart in volume rendering technique images of the posterior and lateral wall of the heart. The oblique vein of Marshall is also observed **(a)**. The posterior cardiac vein on the posterior aspect of the heart is observed to be suitable for cardiac resynchronization therapy **(b)**.

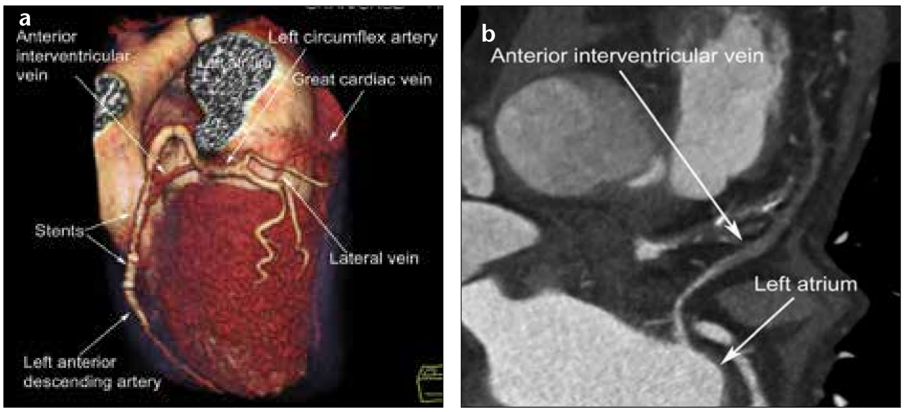

Figure 6. a, b. Volume rendering technique **(a)** and maximum intensity projection **(b)** images of the anterior interventricular vein show an abnormal termination. No connection is observed between the anterior interventricular vein and great cardiac vein. The anterior interventricular vein is drained to the level of the left atrial appendix **(a, b)**. Additionally, there are sequential stents and stenosis in the left anterior descending artery **(a)**.

aneurysm. Saccular aneurysms have not previously been reported in these studies (11, 23). Double middle cardiac vein was found in 9/339 cases (2.65%) in our study. The prevalence of double middle cardiac vein has been reported at 1.99% in the literature (23). We detected the small cardiac vein in 20% of our cases. The small cardiac vein rate in CT studies has been reported to be 42.6% and 18.9% (16, 23).

The vein of Marshall has been used as a marker of the boundary between the coronary sinus and great cardiac vein (23, 26). There are frequently valves of Vieussens at this location. These valves may pose difficulty in directing and passing the catheter into the cardiac veins (28). It is hard to visualize the vein of Marshall compared to other veins in CT studies, requiring special care and thorough examination. The vein of Marshall is a thin 1-mm-diameter vein that is frequently obliterated by fibrosis. When obliterated, it may be visualized as a band. It was present at a rate of 10.6%. It has been reported in the literature at rates of 34% and 10.9% (15, 23).

The posterior cardiac vein generally drains into the coronary sinus (75%). However, it also ends in the great cardiac vein (26). We detected an isolated posterior cardiac vein draining into the left atrium in one patient. The anterior interventricular vein drains into the great cardiac vein in 99% of cases. It drains into the right atrium after an aberrant pathway in 1% of cases (11). In one patient, it was observed to drain into the left atrium with an abnormal termination. To our knowledge, however, no similar posterior cardiac vein and anterior interventricular vein have been reported in CT studies. The Thebesian valve, the first barrier to the coronary venous system, was detected in 72.2% of the patients in our study. The corresponding rates in CT studies in the literature have been found to be 77% and 36% (23, 29).

The cardiac resynchronization therapy is a treatment modality that is able to improve the quality of life and decrease mortality in selected cases. However, lateral vein lead implantation is a difficult task and may prove unsuccessful in 10%–15% of the cases. An important reason for this difficulty is due to the anatomy of the coronary venous system (30, 31). For biventricular pacing, the left ventricular lead is usually placed percutaneously in a branch of the coronary venous system (32). The lateral, anterolateral, and posterolateral veins are selected for hemodynamic benefit; however, anatomic barriers at the entrance of these veins (such as the Thebesian valve or the Vieussens valve) usually preclude lead implantation (29, 33).

The diameters of the coronary sinus and its branches are important for electrophysiological studies. A too-small coronary sinus diameter and a too-small or too-big target vein can cause cardiac resynchronization therapy to be unsuccessful (34). The coronary vein diameter for the smallest left ventricular lead must be greater than 1.5 mm (11).

We acquired the best images of the coronary venous system during the systolic phase. Coronary venous flow has a phasic pattern throughout the cardiac cycle (35). The coronary sinus takes blood from the ventricular veins during systole. It contracts at the atrial systole, emptying blood into the right atrium (36). Therefore, the diameters of the coronary veins are greater during late systole than during mid-diastole. However, no significant difference has been observed between the two phases in terms of vein diameters (37). Moreover, it is easier to assess the coronary venous system branches in the systolic phase images compared to the diastolic phase images (38). Therefore, the coronary veins are more easily evaluated in the systolic phase images in CT angiography imaging.

We excluded 18 subjects from the study due to poor image quality caused by an inability to hold their breath and artifacts. We continued our study with 339 subjects. In some subjects the coronary veins were nonopacified, and

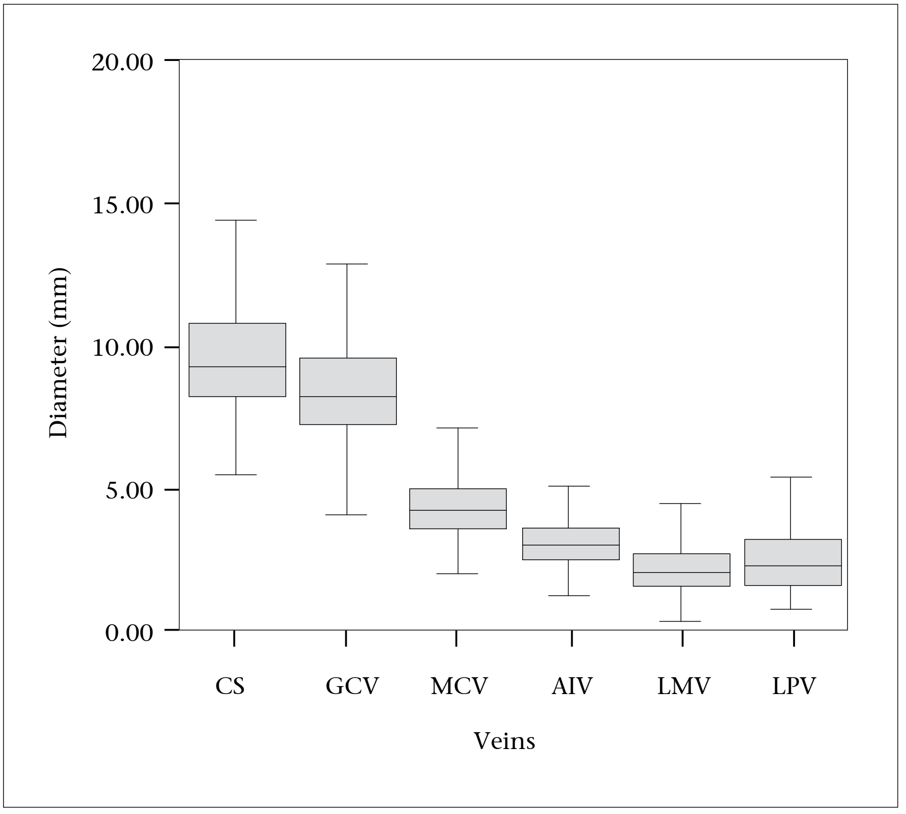

Figure 7. Box plot graph shows diameters of coronary sinus and its branches at ostial level. AIV, anterior interventricular vein; CS, coronary sinus; GCV, great cardiac vein; LMV, left marginal vein; LPV, left posterior vein; MCV, middle cardiac vein

in others, they contained only a small amount of contrast material. However, insufficiently enhanced or nonenhanced coronary veins were assessed using volume rendering, multiplanar reconstructions, and maximum intensity projection images. We did not exclude these subjects.

There are some limitations to our study. First, there were no patients with heart failure in this study. Imaging of the coronary veins using routine coronary CT angiography protocol may not always be feasible in heart failure patients due to heightened heart rate, cardiac arrhythmias, and an inability to hold breath because of respiratory symptoms. Beta blocker use is contraindicated in this patient population owing to the low ejection fraction. Another limitation is the exclusion of the patients with arrhythmia from the study, as arrhythmia is a common problem in patients with heart failure.

Our study protocol was designed for coronary arterial imaging; however, the trigger HU value was higher (150 HU), and the contrast injection and time to onset of scanning was longer. Therefore, although the scan time was short, the scan process began after adequate contrast had reached the coronary veins. Despite this adjustment, the veins other than the proximal coronary veins (coronary sinus, middle cardiac vein, small cardiac vein, and posterior vein) were not optimally visualized. However, thanks to the higher resolution relative to 8-, 16-, and 64-slice CT and the higher-resolution multiplanar reconstructions, maximum intensity projection volume rendering technique images, even small-caliber coronary veins were assessed.

In conclusion, the coronary venous system and its tributaries and variations may be examined in detail using CT angiography examination performed with routine coronary CT angiography protocol and dual source CT. Dual source CT may be a valuable tool to evaluate coronary veins prior to invasive procedures directed at the coronary venous system.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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