Review

Value of multi-detector computed tomography in delineation of the normal cardiac conduction system and related anatomic structures

S.H. Zidan, S.M. Shehata

Diagnostic Radiology Department, Zagazig University, Egypt

ABSTRACT

The cardiac conduction system is responsible for rhythmic myocardial stimulation for physiologic contraction of the heart.

Aim of the work: To assess the value of MDCT in outlining anatomic landmarks and variants of conductive system, therefore provides crucial information used in clinical practice.

Patients and methods: Thirty adult patients (18 males, 12 females) (mean age: 51.5 years) underwent elective retrospective ECG gated cardiac angiography using 128 MDCT.

Results: MDCT enables accurate delineation of conduction system components such as SANa, AVNa, CT, BB, CTI, Koch triangle, LAI and PVs.

Conclusion: MDCT has a fundamental role in demarcating potential arrhythmogenic structures before ablation procedures.

© 2016 The Egyptian Society of Radiology and Nuclear Medicine. Production and hosting by Elsevier. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Contents

1. Introduction .......................................................... 1334
2. Patients and methods .................................................. 1334
  2.1. Study design and population ....................................... 1334
3. Technique of cardiac imaging ......................................... 1334
  3.1. Patient preparation ................................................ 1334
  3.2. Scan preparation ................................................ 1334
4. Image acquisition ..................................................... 1335
  4.1. Timing bolus scan .............................................. 1335
  4.2. Angiographic scan .............................................. 1335

Abbreviations: AF, atrial fibrillation; AVN, atrioventricular node; AVNa, atrioventricular nodal artery; BB, Bachmann’s bundle; CS, coronary sinus; CT, crista terminalis; CTI, cavotricuspid isthmus; LAA, left atrial appendage; LCx, left circumflex artery; LIPV, left inferior pulmonary vein; MDCT, multi detector computed tomography; RCA, right coronary artery; RFCA, radio frequency catheter ablation; RIPV, right inferior pulmonary vein; RMPV, right middle pulmonary vein; RSPV, right superior pulmonary vein; SAN, sinoatrial node; SANa, sinoatrial nodal artery; SI, septal isthmus; STV, septal leaflet of tricuspid valve; VR, volume rendered; LAI, left atrial isthmus.

Peer review under responsibility of The Egyptian Society of Radiology and Nuclear Medicine.

* Corresponding author.
E-mail addresses: sayed_zidan69@hotmail.com (S.H. Zidan), samarshehata2003@gmail.com (S.M. Shehata).
1. Introduction

The conduction system is a population of myocytes that is responsible for generation of the cardiac electrical impulse and their conduction from the atrial to the ventricular chambers. The function of the cardiac conduction system is to ensure rhythmic myocardial stimulation thus leading to physiological contraction of the heart. Multiple anatomic and electrophysiological studies have provided strong background on the cardiac conduction system and its electrical connection structures [1–3].

Owing to the recent technologic advances in Multi detector CT (MDCT), it is emerging as a successful tool for noninvasive imaging of the cardiac anatomy with high resolution. It allows us to perform a virtual dissection of the cardiovascular system. Furthermore, MDCT has a fundamental role in anatomically delineating and outlining the cardiac sites related to the conduction system thus providing the electrophysiologist with an anatomic road map to facilitate the pacing and ablation procedures [1,2,4].

The cardiac conduction system is composed of the sinoatrial node (SAN), the atrioventricular node (AVN), the HIS bundle, the right and left bundle branches, the fascicles and the Purkinje fibers [5,6]. In addition to multiple related anatomic landmarks and variants, the right SAN artery, right atrial cavitricuspid isthmus, Koch triangle, AVN artery, interatrial muscle bundles, and pulmonary veins are included. The atrial components, the sub epicardial SAN and the sub-endocardial AVN are in contact with the atrial myocardium [5,7].

The rapid development of interventionalal procedures for the treatment of arrhythmias such as radiofrequency catheter ablation technique to precisely destruct minute arrhythmogenic tissues, has returned the interest in cardiac anatomy. Since anatomic variation of the cardiac conduction system landmarks and associated structures is common, it is necessary to be aware of these normal variants, especially prior to interventional procedures [8].

The purpose of our study was to assess the value of MDCT in outlining the anatomic landmarks and variants of the conductive system and therefore provide crucial information used in clinical practice.

2. Patients and methods

2.1. Study design and population

This study was prospectively conducted during the period from June 2014 to April 2016 at diagnostic radiology and cardiology departments, and included 30 cases (18 males and 12 females), ranging in age between 35 and 65 years old, with a mean age of 51.5 years. Patients were either self-referred or referred by a physician to our institute for elective multidetector CT coronary angiography.

We included adult patients of both sex with normal heart rate, expected to have coronary artery disease. The exclusion criteria were as follows: arrhythmias or irregular heart rate, inability to comply with the protocol requirements (renal insufficiency: creatinine level >1.6 mg/dl, inability to sustain a breath hold for 10–12 s, pregnant or lactating females), calcium score exceeding maximum score and a known case of thyroid dysfunction. Four patients were further excluded due to poor image quality from motion or respiratory artifact.

All patients were subjected to contrast-enhanced retrospective ECG gated CT coronary angiography using 128 MSCT Philips ingenuity machine.

3. Technique of cardiac imaging

3.1. Patient preparation

All patients were instructed to fast for 4–6 h prior to the examination with no discontinuity of their medications. No atropine or caffeine for 12 h before the study. Reassurance of the patients was done and all steps of the study were explained in detail to each patient.

To evaluate patients ability of breath-withholding for relatively long time, they were required to perform a deep inspiration and to continue to hold their breath for 12 s without pushing (Valsalva maneuver). During this trial, the patient was observed for compliance and the electrocardiogram for significant changes.

Beta blockers were administrated if resting heart rate before the scan is more than 65 bpm. 100–200 mg metoprolol was administrated orally 60 min before scanning (unless contraindicated). Ideally the heart rate variation should be within 5 bpm during the scan.

3.2. Scan preparation

- ECG leads were fixed at the mid of the right and left clavicles. The third one is fixed at the left costal margin after skin preparation of the patient to ensure good skin contact and avoid scar areas. Turn on the ECG machine, and ensure good connection to the gantry and leads.
- Contrast material:

A bolus of 100 ml of non-ionic contrast of nonionic contrast media, 350–370 mg of iodine per milliliter (Ultravist
(which was pre heated before injection by putting it under the axilla for half an hour) was prepared for injection through 18-gauge cannula into the right antecubital vein with a flow rate of 5 ml/s using a programmed dual head power injector pump. A 50 ml saline chaser bolus was used to wash out the contrast from the right side of the heart for better visualization of the coronary arteries and reducing the streak artifact at SVC.

4. Image acquisition

The patient is positioned supine comfortably on the CT couch, and three scans were taken: Scanogram, timing bolus scan, and angiographic scan.

The imaging of the coronary arteries extends from the level of the carina down to about 1 cm below diaphragm. The center of the field of view is 2 cm to the left of the dorsal spine on the AP scout and at the level of the hilum on the lateral scout (Table 1).

4.1. Timing bolus scan

We gave 20 cc of contrast at 5 cc/s followed by 20 cc saline chaser. After a delay of about 5 s from the start of injection, time was estimated for the contrast to reach the great vessels of the chest, being variable according to the site of the cannula, rate of injection, body built and heart rate.

Series of axial images at the aortic were acquired with 2 s interval between subsequent images. Time-attenuation curves were generated, and we reviewed these images to determine the time of peak test bolus induced enhancement, then we add 9 s to it as a pre-scan delay. When the density within the descending aorta reached 120–140 HU, image acquisition was begun. The axial images taken are of low radiation dose with a 120 kV and 40 mA (not of diagnostic value), to reduce the radiation exposure.

4.2. Angiographic scan

The contrast-enhanced retrospective ECG gated scan was obtained within one single breath-hold. The distance between the level of the carina and the base of the heart was covered in approximately 10–12 s (Table 2).

5. Post procedural assessment

The patient is kept under observation for 15 min after the procedure to check the vital signs (pulse and blood pressure).

6. Image reconstruction

A systematic review of axial images was done to evaluate the quality of the study and analyze the cardiac and thoracic anatomy. The obtained axial images were reconstructed using different reconstruction techniques on an advanced Philips workstation. A slice thickness of 0.6 mm reconstructions was used.

6.1. Image interpretation

Cases were revised and interpreted by 2 radiologists using axial images (as source images), and reconstructed images (including MPR (curved and oblique), MIP and volume rendering techniques).

7. Statistical analysis

Data were checked, entered and analyzed using SPSS version 20 for data processing. Data were expressed as number and percentage for qualitative variables and mean ± standard deviation (SD) for quantitative one. Data were summarized using the arithmetic mean, and the standard deviation (SD). The comparison was done using the Student’s t-test and Chi-square test ($X^2$).

8. Results

Among the thirty patients involved in our study SAN artery was traced in all cases with normal anatomy, and no anatomical variants are detected at the studied group.

In our study, SAN artery arises from RCA in 20 patients (66.7%) (12 males and 8 females) while in the other 10 patients (33.3%) (6 males and 4 females) it arises from LCx artery.

We found in 17 cases (56.7%) SAN arteries approach the SAN by passing posterior to the SVC (retrocaval), while in the other 13 cases (43.3%) SAN arteries approach the SAN by passing anterior to the SVC (precaval). There was not statistical significant difference between males and females regarding the side of origin of SAN artery.

We also found that the mean distance between RCA ostium and origin of RT SAN artery was 16.5 ± 6.85 mm, range: 2–33 mm while the mean distance between LCx ostium and origin of LT SAN artery was 12.87 ± 5 mm, range: 6–23 mm (Table 3).

In our study the SAN artery was best demonstrated on phase 75% of the cardiac cycle whether arising from RCA (14/20) or LCx (8/10) (Fig. 1).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Scan parameters for cardiac angiographic acquisition.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scan parameters</td>
<td>Value</td>
</tr>
<tr>
<td>kV</td>
<td>120 kV</td>
</tr>
<tr>
<td>Tube current</td>
<td>800–1000 mAs</td>
</tr>
<tr>
<td>FOV</td>
<td>220 mm</td>
</tr>
<tr>
<td>Matrix</td>
<td>512</td>
</tr>
<tr>
<td>Slice thickness</td>
<td>0.6–0.8</td>
</tr>
<tr>
<td>Increment</td>
<td>-0.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Scan parameters of the scanogram.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scan parameters</td>
<td>Value</td>
</tr>
<tr>
<td>kV</td>
<td>120 kV</td>
</tr>
<tr>
<td>Tube current</td>
<td>30 mA</td>
</tr>
<tr>
<td>FOV</td>
<td>220 mm</td>
</tr>
<tr>
<td>Matrix</td>
<td>512</td>
</tr>
</tbody>
</table>
The SAN artery arising from RCA could be demonstrated in axial and sagittal planes in all cases and in coronal plane in 90% (18/20) of cases, while SAN artery arising from LCx could be demonstrated in axial and coronal planes in all cases and in sagittal plane in 90% (9/10) of cases. Curved planar image was the best in demonstrating a long segment of the vessel.

Concerning the AVN artery, it was traced in all cases with normal anatomy, and no anatomical variants was detected among the studied group. 86.7% (26/30) of AVN arteries originate from RCA and 13.3% (4/30) originate from LCx. The Best cardiac cycle Phase for demonstrating AVN Artery arising from either RCA or LCx was phase 75% (22/30) followed by phase 70% (4/30) (Fig. 2).

In the studied group the AVN artery arising from RCA could be demonstrated in axial and sagittal planes in all cases and in coronal plane in 88% (23/26) of cases, while the AVN artery arising from LCx could be demonstrated in axial and coronal planes in all cases and in sagittal plane in 75% (3/4) of cases.

Regarding the cavotricuspid isthmus, it was demonstrated at all cases and we found a highly statistical significant difference between cavotricuspid isthmus measurement in midsystolic and middiastolic phases (see Table 4).

Concerning the left atrial isthmus, there was not statistically significant difference between males and females regarding lt. atrial isthmus measurement (Table 5).

As regards the pulmonary veins, we found the typical pattern at 20 cases with typical 4 pulmonary veins and 4 well differentiated ostia draining into the left atrium (right and left superior and inferior pulmonary veins), while the other ten cases showed multiple anatomical variants in the form of Conjoined left pulmonary veins in 16.7% of cases (5/30), right supernumerary middle pulmonary vein in (10%) of cases (3/30), and both left conjoined and right supernumerary pulmonary vein in 6.7% of cases (2/30).

We measured the diameters and calculate the mean and standard deviation of each pulmonary vein ostium as well as the length of trunk of each pulmonary vein and tabulate them in Table 6.

We can demonstrate most of cardiac conduction structures by coronary CT angiography but we were unable to delineate some anatomic structures. Finally we summarized the applicability of CT angiography in demonstration

### Table 3
Origin, mode of termination and Distance from the ostium of the supplying vessel of SAN artery in the studied group.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Frequency (30)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Origin</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCA</td>
<td>Total</td>
<td>20</td>
</tr>
<tr>
<td>Male</td>
<td>12</td>
<td>40</td>
</tr>
<tr>
<td>Female</td>
<td>8</td>
<td>26.7</td>
</tr>
<tr>
<td>LCX</td>
<td>Total</td>
<td>10</td>
</tr>
<tr>
<td>Male</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>Female</td>
<td>4</td>
<td>13.3</td>
</tr>
<tr>
<td><strong>Mode of termination</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precaval</td>
<td>13</td>
<td>43.3</td>
</tr>
<tr>
<td>Retrocaval</td>
<td>17</td>
<td>56.7</td>
</tr>
<tr>
<td><strong>Distance from parent Vs ostium</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance b/w RCA ostium, origin of RT SAN artery</td>
<td>16.5 ± 6.85 mm</td>
<td>2–33 mm</td>
</tr>
<tr>
<td>Distance b/w LCx ostium, origin of LT SAN artery</td>
<td>12.87 ± 5 mm</td>
<td>6–23 mm</td>
</tr>
</tbody>
</table>

Fig. 1. Bar chart for the best demonstrative cardiac cycle phase of SAN artery of the studied group.

Fig. 2. Bar chart for the best cardiac cycle phase for demonstration of AVN artery of the studied group.
of cardiac conduction system and related structures (the ability of our machine and protocol to delineate the examined structures) in Table 7.

9. Discussion

Multidetector cardiac CT imaging enables delineation of the variable course of the arterial blood supply, to the sinoatrial and atrioventricular node. Detection of the nodal arteries by MDCT helps to understand the tiny cardiac vascular anatomy which is crucial prior to interventional catheter-based or open surgical procedures performed near these important structures [1,8].

Using three-dimensional images allows estimation of the relation of the SAN artery to the superior border of inter atrial septum that may be close or remote. The risk of injury of SA node artery in superior transeptal approach done in mitral valve surgery is more when the artery ends retrocaval than when it ends precaval [9].

In our study, images were analyzed for the origin, number, anatomic course, and anatomic variants of the arteries to the SAN region. In accordance with Saremi [9] axial images were the optimal plane to visualize the course of sinaltrial nodal arteries. SAN artery arising from RCA could be demonstrated in axial and sagittal planes in all 20 cases, coronal plane in 18 cases (90% of Rt SAN artery cases), and curved planar image in all cases, while the SAN artery arising from LCx could be demonstrated in axial and coronal planes in all 10 cases, sagittal plane in 9 cases (90% of Ll SAN artery cases) and curved planar image in all cases. Curved planar images were the best for demonstrating a long segment of the vessel.

In our study, SAN artery arising from RCA was best demonstrated on phase 75% of the cardiac cycle in 14 cases (70% of cases), in 4 cases (20%) it was best demonstrated on phase 70%, while in 2 cases (10%) it was best demonstrated on phase 90%. Also, SAN artery arising from LCx was best demonstrated in 8 cases (80% of cases) on phase 75% of the cardiac cycle, in 1 case (10%) SAN artery was best demonstrated on phase 70%, and also in 1 case (10%) it was best demonstrated on phase 80%. This agrees with Seifarth et al. [10], who reported that the optimal diastolic reconstruction window is at phase 75% or 70% in patients with low and intermediate heart rates.

Several anatomic and angiographic studies have revealed some anatomical variations of the SAN artery, MDCT permits definitive localization of SAN and AVN arteries, all cases displayed normal anatomy of both SAN and AVN arteries, and all cases had single SAN artery arising from both RCA or LCx arteries. No variants regarding the origin of SAN artery cases) and curved planar image in all cases. In accordance with Saremi [9] axial images were the optimal plane to visualize the course of sinoatrial nodal arteries. SAN artery arising from RCA could be demonstrated in axial and sagittal planes in all 20 cases, coronal plane in 18 cases (90% of Rt SAN artery cases), and curved planar image in all cases, while the SAN artery arising from LCx could be demonstrated in axial and coronal planes in all 10 cases, sagittal plane in 9 cases (90% of Ll SAN artery cases) and curved planar image in all cases. Curved planar images were the best for demonstrating a long segment of the vessel.

In our study, SAN artery arising from RCA was best demonstrated on phase 75% of the cardiac cycle in 14 cases (70% of cases), in 4 cases (20%) it was best demonstrated on phase 70%, while in 2 cases (10%) it was best demonstrated on phase 90%. Also, SAN artery arising from LCx was best demonstrated in 8 cases (80% of cases) on phase 75% of the cardiac cycle, in 1 case (10%) SAN artery was best demonstrated on phase 70%, and also in 1 case (10%) it was best demonstrated on phase 80%. This agrees with Seifarth et al. [10], who reported that the optimal diastolic reconstruction window is at phase 75% or 70% in patients with low and intermediate heart rates.

Several anatomic and angiographic studies have revealed some anatomical variations of the SAN artery, MDCT permits definitive localization of SAN and AVN arteries, all cases displayed normal anatomy of both SAN and AVN arteries, and all cases had single SAN artery arising from RCA or LCx arteries. No variants regarding the origin of SAN were detected. The SAN artery was arising from RCA in 20 cases (66.7%), 12 of them were males (40%), 8 were females (26.7%), or from LCx in 10 cases (33.3%), 6 cases of them were males (20%), 4 were females (13.3%), no cases of dual or triple blood supply were detected. There is no statistical significant difference between males and females regarding the side of origin of SAN artery.
In partial agreement with our results, Saremi et al. [9] reported that a single sinoatrial nodal artery arose from the RCA in 65.7% of cases (Fig. 3) and from the LCX artery in 27.4% of cases (Fig. 4). A dual blood supply to the SAN was seen in six (5.9%) cases: one supply from the RCA and the other supply from the LCX artery with non-significant relation between the side of origin of SAN artery and patient’s sex.

In contrast to our study, Kawashima and Sasaki [11] found anatomical variation of SAN artery origin and reported that single SAN artery arose either from RCA (32%) or from LCx (14.2%), and dual blood supply from both RCA and LCx was reported in 50% of cases, while triple blood supply was reported in 3.8% of cases. Also Ozturk et al. [12] disagreed with our results and reported that the sinoatrial node was vascularized by a single artery in 96% of cases, and by 2 arteries in 4% of cases. It was arising from RCA in 55.4% of cases, from LCx in 39.4% of cases, from the aorta in 0.8% of cases and from bronchial artery in 0.4% of cases.

---

**Fig. 3.** (a) Curved planar image of the arterial supply of SA node (SAN artery) arising from proximal right coronary artery (RCA). Terminal segment of the SANa (green arrow) passes behind the superior vena cava (SVC) (retrocaval). (b) Volume rendered image demonstrates SAN artery (arrow) originating from RCA (arrow) and its course. SAN artery: sinoatrial nodal artery. RCA: right coronary artery (arrow). (c) Volume color coded image demonstrates SAN artery (arrow) origin from RCA (arrow) and course. (d) Axial CT image shows SA node (green arrow) (enhanced tissue along the crista terminalis).
The terminal portion of the SAN artery is not seen; however, enhancing SAN can be seen along the epicardial aspect of the crista terminalis (CT). The mode of termination of the SAN artery is classified as retrocaval, precaval, or pericaval in relation to the SVC. SAN arteries reaching the SAN via a retrocaval or pericaval course (especially those arising from the LCX artery) can be surgically traumatized during superior trans-septal incisions in mitral valve surgery [13].

In our study, the terminal sinoatrial nodal arteries approached the SAN anterior to the SVC (precaval) in 13 cases (43.3%), 8 of them were males (26.7%), 5 of them were females (16.7%), posterior to the SVC (retrocaval) in 17 cases (56.7%), 10 of them were males (33.3%), and 7 of them were females (23.3%), and this was relatively in agreement with Saremi et al. [9] who reported that the terminal sinoatrial nodal arteries approached the SAN anterior to the SVC in 42.6% of patients and posterior to the SVC in 47.5% of patients, and through multiple branches surrounding the SVC (pericaval) in 9.9% of patients, the latter mode of termination was more common in patients with a dual blood
supply to the SAN, and there was no significant difference between it and the precaval mode of termination. Also in relative agreement with our results Ozturk et al. [12] reported that SAN artery was precaval in 36% of cases, retrocaval in 48.2%, and pericaval in 15.8% of cases.

In our study, the distance between the RCA ostium and the origin of the right sinuatrial nodal artery ranged from 2 to 33 mm (mean, 16.5 ± 6.85 mm). The distance between the LCX artery ostium and the origin of the left sinuatrial nodal artery ranged from 6 to 23 mm (mean, 12.9 ± 5), and the mean value is in relative agreement with Saremi et al. [9], who reported that the distance between the RCA ostium and the origin of the right sinuatrial nodal artery ranged from 0 to 40 mm (mean, 16 mm ± 7). The distance between the LCX artery ostium and the origin of the left sinuatrial nodal artery ranged from 2 to 35 mm (mean, 12 mm ± 6).

Fig. 5. (a) Axial CT image shows the proximal part of AVN artery (green arrow) at Koch triangle; arising from distal RCA. (b) Sagittal CT image demonstrates the proximal part of AVN artery (green arrow) arising from distal RCA. (c) Coronal CT image shows proximal part of AVN artery (green arrow) arising from distal RCA.
Also Yildirim et al. [14] reported that a single SAN artery originated from the proximal 35 mm of the RCA in 91% of cases. In 4% of cases, the origin was from the proximal 40 mm of LCx artery. In 3% of cases, it originated directly from the RCA sinus and in 2%, the SAN artery originated as a branch from the conal branch of the RCA.

In a study performed by Ozturk et al. [12], the mean distance from the origin of right SAN artery RCA ostium was 16.2–62 mm. The mean distance from the origin of left SAN artery to LCx ostium was 19.3 mm (the range was 2–66 mm).

Regarding atrioventricular node artery (AVN artery), in our study, the AVN artery arises from RCA is best demonstrated on phase 75% of the cardiac cycle in 22 cases (84.6% of Rt. AVN artery cases). In 4 cases (15.4%) AVN artery is best demonstrated on phase 70%, whereas AVN artery arising from LCx is best demonstrated in 3 cases (75% of Lt AVN artery cases) on phase 75% of the cardiac cycle. In 1 case (25%) AVN artery is best demonstrated on phase 70%.

We observed that AVN artery arising from RCA (Fig. 5) could be demonstrated in axial and sagittal planes in all 26 cases, and coronal plane in 23 cases (88% of Rt AVN artery cases), while the AVN artery arising from LCx could be demonstrated in axial and coronal planes in all 4 cases, and sagittal plane in 3 cases (75% of Lt AVN artery cases).

In the current study, AVN artery arose from distal RCA in 26 cases (86.7%) (15 males (50%) and 11 females (36.7%)); while it arose from distal LCx in 4 cases (13.3%), 3 males (10%) and one female (3.3%). Also Saremi et al. [9] reported that the AVN artery arose from the distal RCA in 87.2% patients and from the distal LCx artery in 10.8% patients. A dual supply (co-dominant coronary system) originating from both the RCA and the LCX artery was observed in 2.0% patients, and that the relationship between the side of origin of the atrioventricular nodal artery and the sex of the patient was not significant.

Cavotricuspid isthmus (CTI) is the target of catheter-directed ablation procedures, which constitute the treatment of choice for atrial flutter, and MDCT can provide detailed information about the CTI and can enable evaluation of the variability of CTI anatomy in different cardiac phases [15] (Fig. 6).

For us it has been found that the CTI measurements at mid systolic phase were longer than those of mid diastolic phase, with about 19% shortening at mid diastole compared to mid systole. It ranged from 14.4 to 27.1 mm (mean length: 20.8 ± 3.7 mm) in mid diastolic phase of cardiac cycle, while in mid systolic phase it ranged from 18.2...
to 32.5 mm (mean length: 25.8 ± 4.3 mm). In partial agreement with our results, Saremi et al. [15] reported that the mid diastolic length of central isthmus ranged from 12 to 43 mm, mean length was 24 mm ± 4.3, and the mean length of central isthmus at ventricular systole was 28 mm ± 4.7. The longest CTI measurements were
observed at ventricular systole. Measurements showed an approximately 13% shortening at mid diastole compared with mid systole.

Radio-frequency catheter ablation (RFCA) of the distal pulmonary veins and posterior left atrium is increasingly being used by cardiac interventional electrophysiologists for management of atrial fibrillation, thus necessitates a pre-procedural understanding of the complex three-dimensional (3D) anatomy of the distal pulmonary veins and posterior left atrium [16–18].

The left atrial isthmus (the area between the margin of the mitral annulus and the orifice of the left inferior pulmonary vein) (Fig. 7) may be the source of recurrence after circumferential pulmonary vein catheter ablation for AF. Pre ablation CT easily helps in evaluation of the length, depth, and morphologic variants of this region [19]. CT images of the left atrial isthmus might influence the ablation results [20].

Becker [21] reported that the length of the left atrial isthmus is highly variable, ranging from 17 to 51 mm. In our study, the left atrial isthmus length ranged from 20 to 45 mm, mean length was 29.7 ± 5.3 mm, and also Chiang et al. [20], reported that the mean length of left atrial isthmus was 27.1 mm, and that the morphology of the isthmus was variable.

Cardiac computed tomography is an established imaging modality for assessment of the anatomy and variants of the pulmonary veins and the dimension of pulmonary veins ostia which is essential prior to radiofrequency catheter ablation (RFCA) [22].

In our study, classical four pulmonary veins with well differentiated four ostia draining into the left atrium are observed in 20 cases (66.7%) (Fig. 8). In 5 cases (16.7%), left conjoined PV is detected with Common ostium for the left superior and left inferior PVs and normal Rt superior and Rt inferior pulmonary veins ostia (Fig. 9).

In 3 cases (10%), right supernumerary additional middle right PV is detected with normal left superior and inferior pulmonary veins ostia (Fig. 10), while in 2 cases (6.6), both left conjoined and right supernumerary pulmonary veins are detected in the same case (Fig. 11).

In agreement with our results Porres et al. [23] reported that the pattern of typical four pulmonary veins and four well-differentiated ostia is seen in 60–70% of the population. Atypical anatomic patterns are found in approximately 38% of the population. The short left common trunk is the second most common normal anatomic pattern, occurring in 15% of the population. Anatomic variants on the right side are less common and tend to be more complex, with one or more accessory veins.

Based on anatomical study, Klimek-Piotrowska et al. [24] also reported that pattern of four classical PV ostia was observed in 70.8% of all cases. The most common variant was the classical pattern with additional middle right PV (19.2%), followed by the common ostium for the left superior and the inferior PVs (4.44%).

Fig. 9. (a) Volume rendered image (posterior epicardial view) shows the left conjoined pulmonary vein, right inferior pulmonary vein (RIPV) and right superior pulmonary vein (RSPV). (b) Endocardial VR image (endocardial view) demonstrates left conjoined pulmonary vein ostium measuring 41.3 × 21.7 mm.
In contrast to our results, Ikiz et al. [16] reported that the common arrangement, the unilateral common ostium, the unilateral additional vein, the additional vein on both side and the complex type were observed respectively in 73.2%, 17.9%, 5.4%, 1.8% and 1.8% of their study. Also Prasanna et al. [25] disagreed with us and reported that the most common drainage pattern was two pulmonary veins, each on right and left side, with two separate ostia. The next common drainage pattern on the right side was three pulmonary veins with three ostia (24%) and on the left side, they noticed a single pulmonary vein with a single ostium in 14% of specimens.

In partial agreement with us multiple previous studies stated that a common ostium was most frequently found on the left-sided pulmonary veins, whereas an additional vein was most frequently found on the right side [23,24,26].

In our study left conjoined pulmonary vein was the second common pattern, in agreement with Porres et al. [23] and Lacomis et al. [27].

We also observed that the anatomic variants on the right side are less common and tend to be more complex. This was in disagreement with multiple previous studies which reported that the accessory middle right PV is the second most common variation immediately after the classical pattern in healthy individuals [23,24,26].

In our study, the mean ostial diameter of RSPV was 14.4 mm ± 2.1 mm (range: 11.2–20.1 mm). This agreed with an anatomical study performed by Klimek-Piotrowska et al. [24] who had reported that the mean ostial diameter of RSPV was 14.3 ± 2.9 mm. Also Gebhard et al. [22] reported that in normal individuals, the maximal

Fig. 10. (a) VR image (posterior epicardial view) from multi-detector CT shows three right and two left pulmonary veins draining into the Lt Atrium (Rt supernumerary pulmonary vein). (b) Endocardial VR image (endocardial view) shows right superior (RSPV), right middle (RMPV) and right inferior (RIPV) pulmonary veins ostia.

Fig. 11. Volume rendered image (posterior epicardial view) of the left atrium and pulmonary veins from multi-detector CT shows left conjoined and right supernumerary pulmonary veins draining into the left atrium. RIPV: Right Inferior Pulmonary Vein, RMPV: right middle Pulmonary Vein, RSPV: Right Superior Pulmonary Vein.

Also Prasanna et al. [25] disagreed with us and reported that the most common drainage pattern was two pulmonary veins, each on right and left side, with two separate ostia. The next common drainage pattern on the right side was three pulmonary veins with three ostia (24%) and on the left side, they noticed a single pulmonary vein with a single ostium in 14% of specimens.

In partial agreement with us multiple previous studies stated that a common ostium was most frequently found on the left-sided pulmonary veins, whereas an additional vein was most frequently found on the right side [23,24,26].

In our study left conjoined pulmonary vein was the second common pattern, in agreement with Porres et al. [23] and Lacomis et al. [27].

We also observed that the anatomic variants on the right side are less common and tend to be more complex. This was in disagreement with multiple previous studies which reported that the accessory middle right PV is the second most common variation immediately after the classical pattern in healthy individuals [23,24,26].

In our study, the mean ostial diameter of RSPV was 14.4 mm ± 2.1 mm (range: 11.2–20.1 mm). This agreed with an anatomical study performed by Klimek-Piotrowska et al. [24] who had reported that the mean ostial diameter of RSPV was 14.3 ± 2.9 mm. Also Gebhard et al. [22] reported that in normal individuals, the maximal
ostial diameter of RSPV was 21 ± 0.6 mm, and the minimum ostial diameter was 14.5 ± 0.5 mm.

We have found that the length of RSPV trunk (distance from ostium to the first order branch) ranged from 8.1 to 20 mm (mean = 14.1 ± 3.5 mm). Also Klimek-Piotrowska et al. [24] reported that the mean RSPV ostium to last tributary distance = 11.8 ± 4.0 mm.

In our study, the maximal ostial diameter of LSPV was 19.5 mm, and the minimum ostial diameter was 9.8 mm (mean = 13.5 ± 2.5 mm); Gebhard et al. [22] reported that the maximal ostial diameter of RSPV was 18.9 ± 0.4 mm, and the minimum ostial diameter was 11.9 ± 0.4 mm. Klimek-Piotrowska et al. [24] reported that the mean ostial diameter of LSPV was 13.8 ± 2.9 mm.

In our study the length of LSPV trunk ranged from 9.4 to 24 mm (mean = 16.5 mm). Klimek-Piotrowska et al. [24] reported that the mean LSPV ostium to last tributary distance = 15.1 ± 4.6 mm.

In our study, the maximal ostial diameter of RIPV was 19.1 mm, and the minimum ostial diameter was 9.6 mm (mean = 13.2 ± 2.1 mm). Gebhard et al. [22] reported that the maximal ostial diameter of RIPV was 19 ± 0.5 mm, and the minimum ostial diameter was 14.2 ± 0.4 mm. Klimek-Piotrowska et al. [24] reported that the mean ostial diameter of RIPV was 13.7 ± 3.3 mm.

In our study the length of RIPV trunk ranged from 6.1 to 20.3 mm (mean = 12.5 ± 3.5 mm). Klimek-Piotrowska et al. [24] reported that the mean RIPV ostium to last tributary distance = 11.0 ± 3.7 mm.

In our study, the maximal ostial diameter of LIPV was 18.1 mm, and the minimum ostial diameter was 8.1 mm (mean = 12.1 ± 2.3). Gebhard et al. [22] reported that the maximal ostial diameter of RSPV was 17.3 ± 0.4 mm, and the minimum ostial diameter was 10.8 ± 0.3 mm. Klimek-Piotrowska et al. [24] reported that the mean ostial diameter of LIPV was 13.3 ± 3.4 mm.

We have found that the length of LIPV trunk ranged from 7.8 to 21.2 mm (mean = 13.7 ± 3.7 mm). Klimek-Piotrowska et al. [24] had reported that the mean LIPV ostium to last tributary distance was 13.5 ± 4 mm.

In our study, the maximal ostial diameter of right supernumerary middle PV was 11.4 mm, and the minimum ostial diameter was 8.6 mm (mean = 9.4 ± 1.1). Gebhard et al. [22] reported lower values where the maximal ostial diameter of RSPV was 7.7 ± 0.5 mm, and the minimum ostial diameter was 6.3 ± 0.5 mm. Klimek-Piotrowska et al. [24] reported that the mean ostial diameter of additional right pulmonary vein was 8.2 ± 4.1 mm.

In our study the length of supernumerary RMPV trunk ranged from 6.5 to 12.4 mm (mean = 10 mm), while Klimek-Piotrowska et al. [24] stated that the mean additional right PV ostium to last tributary distance was 7.8 ± 3.2 mm.

In our study, the mean ostial diameter of left conjoined pulmonary vein was 21.4 mm (range: 16.3–26.5 mm). Klimek-Piotrowska et al. [24] reported that the mean ostial diameter of left conjoined pulmonary vein was 19.6 ± 6.7 mm.

We have found, in agreement with Porres et al. [23] that the diameters of the superior pulmonary veins are generally larger than those of the inferior pulmonary veins.

In our study the mean maximum widths of the crista terminalis (Fig 12) at the precaval bundle and sagittal band were 2.71 mm ± 0.6 and 2.73 mm ± 0.79, respectively. This

![Fig 12](image_url)
agreed with Saremi [28] who had reported that the mean maximum widths for the precaval band and sagittal band were 2.67 mm ± 0.89 and 2.76 mm ± 0.78, respectively.

The Bachmann bundle (BB) forms the largest anatomic and preferential interatrial electrical connection structure. Its role of this interatrial band is to ensure rapid inter-atrial conduction, leading to physiologic synchronous contraction of both atria. Abnormalities of BB are associated with abnormal atrial activation, atrial disease, and atrial fibrillation. Ischemic damage of the BB is considered a potential cause of interatrial conduction block (IAB) [29].

We have located the BB in 86.66% (26/30) of our patients (Fig 13). The BB showed a variation in size and thickness with a mean length of 12.7 mm ± 2.83 (range 4.6–18.8 mm), a mean anteroposterior diameter of 4.25 mm ± 1.02 (range 1.4–8.98 mm), and a mean superoinferior diameter of 5.67 mm ± 1.66 (range 2.9–17.6 mm). In agreement with us Saremi et al. [28] had reported that BB was visualized in 90.2% of all healthy patients and recorded a mean length of 13.8 mm ± 2.95 (range 3.9–20 mm), a mean anteroposterior diameter of 4.59 mm ± 1.07 (range 1.7–9.3 mm), and a mean

Fig. 13. (a–c) Serial axial CT scan (from above downwards) demonstrates the Bachmann’s bundle (BB) (green arrow) (anterosuperior interatrial connection). RA: right atrium, RAA: right atrial appendage, LA: left atrium.
superoinferior diameter of 6.10 mm ± 1.85 (range 2.4–18.3 mm) for the healthy group.

In the present study, we faced some limitations. First, the study population was small and therefore further studies are required to validate the present results in a larger population. The second limitation was that cardiac angiography is still limited by technical problems with regard to motion and respiratory artifacts which may affect the image quality. The third limitation was that we did not use GTN so the small vessels (SANa & AVNa) were hardly seen; we consider that it would be beneficial to give GTN just before the examination for better tracing of the small vessels. The last limitation was that we could not correlate our findings with cardiac catheterization to confirm our results.

Finally MDCT can be considered a useful tool for noninvasive, thin-section imaging of the coronary blood vessels and cardiac anatomy. We have found that apart from enhanced sinoatrial node (SAN) along the crista terminalis, the major components of the cardiac conduction system including the atrioventricular node (AVN), the HIS bundle, and the right and left bundle branches are too small to be directly visualized by MDCT; that may be beyond the capability of the machine or our protocol. However, their related anatomic landmarks and variants that are of special interest to electrophysiologists such as the SAN artery, the cavitricuspid isthmus, Koch triangle, AVN artery, Bachmann bundle, left atrial isthmus, crista terminalis and pulmonary veins can be reliably demonstrated by MDCT. We stated that MDCT has an imperative role in demarcating potential arrhythmogenic structures to be furtherly examined at serial upcoming studies.

Conflict of interest

The authors declare that there are no conflict of interests.

References