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ORIGINAL ARTICLE

Interatrial shunt: diagnosis of patent foramen ovale and atrial septal defect with 64-row coronary computed tomography angiography

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Abstract
Purpose. The aim of this study was to investigate the frequency with which interatrial shunts are found during routine coronary computed tomography (CT) angiography and to describe imaging characterizations of patent foramen ovale (PFO), atrial septal defect (ASD), and atrial septal aneurysm (ASA).
Materials and methods. A total of 1081 adult patients were evaluated retrospectively for interatrial shunting; 77 were excluded from the study. CT diagnosis of PFO was defined as (1) a channel-like appearance of the interatrial septum (IAS) and (2) a contrast agent jet flow from the left atrium (LA) to the right atrium (RA). ASD was defined as (1) the IAS resembling a membrane with a hole and (2) a contrast jet flow between the two atria. ASA was identified by detecting a minimum 10-mm protrusion of the LA beyond the IAS into the RA.
Results. Among 1004 patients, 86 patients (8.6%) were diagnosed to have PFO. Another 23 patients (2.3%) had a hole in the IAS and were diagnosed as having ASD: 21 with an ostium secundum-type ASD and 2 with the sinus venosus type. ASA accompanied ASD in three patients.
Conclusion. Electrocardiography-gated CT using the saline-chaser contrast injection technique that is routinely used for coronary arterial imaging can be used to detect interatrial shunts. The technique can also serve as a method for differentiating PFO, ASD, and ASA.

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Introduction

Advances in multidetector computed tomography (MDCT) technique have allowed us to obtain detailed images of the heart. In addition to the coronary arteries, the myocardium, septa, valves, and other cardiac structures can be studied; and cardiac function can be evaluated. Structures that have been hardly evaluated due to poor image quality previously on computed tomography (CT)—such as the interatrial septum (IAS)—can now be imaged as a part of a routine cardiac CT evaluation because of the increase in spatial and temporal resolution.

Contrast agent injection with a saline chaser is a commonly employed technique during coronary CT angiography. It washes out the right side of the heart, allowing assessment of the anatomy of the left side of the heart and the IAS. Contrast between the right and left atria increases with this technique, and even a small left-to-right shunt can be detected as leakage or a jet of contrast material from the left atrium (LA), appearing as a contrast change in the right atrium (RA). Demonstration of a left-to-right patent foramen ovale (PFO) shunt is possible, and no provocative test is required.[1]

Atrial septal defect (ASD) is the commonest form of congenital heart disease that presents during adulthood. ASDs and atrial septal aneurysms (ASA) may both manifest with arrhythmias, stroke-thromboembolic events, and pulmonary arterial hypertension in adult population.[2,3] Correct diagnosis of PFO, ASD, and ASA during routine cardiac CT angiography evaluations may be important, and radiologists should be familiar with imaging findings of the IAS in PFO and the various types of ASD and ASA.

In approximately 70% of population, the primum and secundum septa of the IAS fuse shortly after birth. In the rest of the population, septal fusion fails or is incomplete.[4] If the foramen ovale is covered but not sealed, the resulting condition is a PFO. This means a potential channel existing between the atria that might open due to a reversal of the interatrial pressure gradient. PFO is common in the general population, with prevalence estimates of 25%–35% in autopsy series.[4] The incidence decreases gradually with increasing age.[4,5] Contrast-enhanced transesophageal echocardiography (TEE) with the Valsalva maneuver is the accepted reference standard method for the diagnosis and documentation of PFO.[6] However, TEE is an invasive method and occasionally nondiagnostic, and sedation causes problems with the Valsalva maneuver. For this reason, TEE is not a convenient modality for determining the prevalence of PFO in wide asymptomatic populations. Moreover, TEE has certain patient contraindications, including a history of dysphagia, active esophageal disorder, esophageal varices, and/or recent esophageal surgery.[7]

If the septum fails to develop properly and a true interatrial communication persists, it is described as an ASD. Four types of congenital ASD are described corresponding to defects in different regions of the IAS.[2]

- Ostium secundum ASD is a defect in the mid-portion of the IAS involving the region of the fossa ovalis. It comprises 50%–70% of the ASDs, with female patients constituting 65%–75% of those with secundum ASDs.[8]
- Ostium primum ASD is a defect at the base of the IAS adjacent to the atrioventricular valves. It is within the spectrum of endocardial cushion defects. It accounts for 15%–30% of ASDs.[9]
- Sinus venosus ASD accounts for 4%–10% of all ASDs.[2,10] The interatrial communication lies outside the fossa ovalis, in the wall that separates the LA from the inferior or superior vena cava. The superior sinus venosus-type defect is the most common, occurring in the upper atrial septum, and is generally continuous with the superior vena cava. Partial anomalous pulmonary venous return (PAPVR) is associated with the superior sinus venosus-type ASD in 80%–90% of the patients especially in the pediatric group.[11] The inferior sinus venosus-type defect occurs at the junction of the RA and inferior vena cava.[10]
- Coronary sinus ASD (unroofed coronary sinus) accounts for <1% of ASDs. There is partial or complete absence of the wall between the coronary sinus and the LA.[12]

The ASA, an uncommon congenital anomaly, is defined as a 10- to 15-mm localized or diffuse protrusion of the IAS into the right or left atrium, or both.[13,14] ASA might be an isolated structural defect but is generally reported to be related to interatrial shunting.[14]

The aim of this study was to investigate the frequency of interatrial shunts incidentally detected during routine coronary CT angiography. We also describe the imaging characterization of PFO, ASD, and ASA using 64-row MDCT in a wide adult population.

Materials and methods

Patients

A total of 1081 adult patients (822 men, 259 women, age range 24–90 years) who underwent coronary CT angiography for evaluation of suspected or known coronary artery disease with 64-row MDCT from January 2008 to February 2010 were evaluated retrospectively for interatrial shunting. As lower contrast difference between the two atria interferes with the optimal evaluation of interatrial shunting, 45 patients were excluded from the study for having a contrast difference below 100 Hounsfield units (HU). Another 32 patients were excluded because of poor image quality due to factors such as respiratory artifacts. All of patients included had a contrast difference > 100 HU between the two atria, and CT was performed to evaluate suspected or known coronary artery disease.

CT scan protocol and image reconstruction

Coronary CT angiography was performed using a 64-section scanner (Philips Brilliance 64; Philips Medical System, Best, The Netherlands). In patients with a heart rate >70 beats/min, an oral β-blocker (100 mg metoprolol) was administered 1 h before the examination to reduce the heart rate. The acquisition protocol included a gantry rotation time of 330 ms, a collimation width of 0.625 mm, thickness 0.67 mm, increment 0.33, a tube voltage of 120 kV, and a current of 600–1050 mAs. To trigger the start of the scan, a real-time bolus tracking technique was used, and scanning was triggered at a threshold level of 120 HU in the descending aorta. Contrast enhancement was achieved with 100 ml of iomeprol (400 mg I/ml) (Iomeron; Bracco, Milan, Italy) injected at 5 ml/s followed by an injection of 60 ml of saline at 5 ml/s. A retrospective electrocardiography (ECG)-

gated volumetric data set was acquired during a single breath-hold.

Using a CT angiography algorithm, diastolic axial images were reconstructed on the basis of a relative-delay strategy at 75%. If artifacts appeared, additional image data sets were obtained for various points of the cardiac cycle, and the data set with the minimum artifact was selected for further analysis. All the reconstructed data sets were transferred to an offline three-dimensional workstation (Philips Extended Brilliance Workspace; Philips Medical Systems). Two- and four-chamber axial and coronal oblique maximum intensity projection (MIP) images were evaluated in consensus by two radiologists (K.A., D.K., 10 and 7 years of experience in CT interpretation, respectively).

CT criteria for PFO, ASD, and ASA

The CT diagnosis of PFO was defined as the presence of both of the following findings: a channel-like appearance of the IAS and a contrast agent jet flow from the contrast agent-filled LA to the saline-filled RA (Fig. 1a). ASD was defined as presence of both of the following findings: IAS resembling a membrane with a hole (Fig. 1b) and a contrast jet flow between the two atria.[15,16] ASA was defined as the presence of at least a 10-mm protrusion of the LA beyond the IAS into the RA (Fig. 1c).

Short-axis images perpendicular to the IAS were obtained using the four-chamber view as reference. The best image for locating the hole in the IAS was chosen, and the diameter of the defect was measured with the linear tool of the workstation. A similar method was used for measuring the protrusion in patients with an ASA.

Results

Among 1004 patients (68 men, 18 women; age range 24–75 years, mean 49.5 years), 86 (8.6%) demonstrated both a contrast jet flow from the LA to the RA and a channel-like appearance of the IAS; they were diagnosed to have PFO (Fig. 2). The contrast jet passed through the channel from the LA to the RA in all of these patients. Another 23 patients (2.3%) (18 men, 5 women; age range 25–70 years, mean 50.1 years) had a hole in the IAS and contrast jet flow from the LA to the RA; they were diagnosed to have ASD (Fig. 3). In the ASD group, the mean diameter of the hole in the IAS was measured at 5.7 mm (range 2–17 mm). Of the 23 patients with ASD, 21 had ostium secundum-type ASD and 2 had sinus venosus-type [one inferior sinus venosus type (Fig. 4) and one superior sinus venosus type (Fig. 5)]. The patients with sinus venosus-type ASD did not have any findings of PAPVR. Neither ostium primum or coronary sinus-type ASD was detected in any of the patients. ASA accompanied ASD in three patients (Fig. 6). The protrusion of the LA beyond the IAS into the RA was measured at 10 mm, 12 mm, and 15 mm, respectively, in these patients; and the diameters of the defect in the IAS were 3.0 mm, 3.0 mm, and 7.8 mm, respectively.

Discussion

A channel-like appearance of the IAS on CT images represents failure of fusion between the two embryonic septa and can be used as a finding for diagnosing PFO.[15] In the present study, we also accepted both channel-like appearance of the IAS and the presence of a contrast

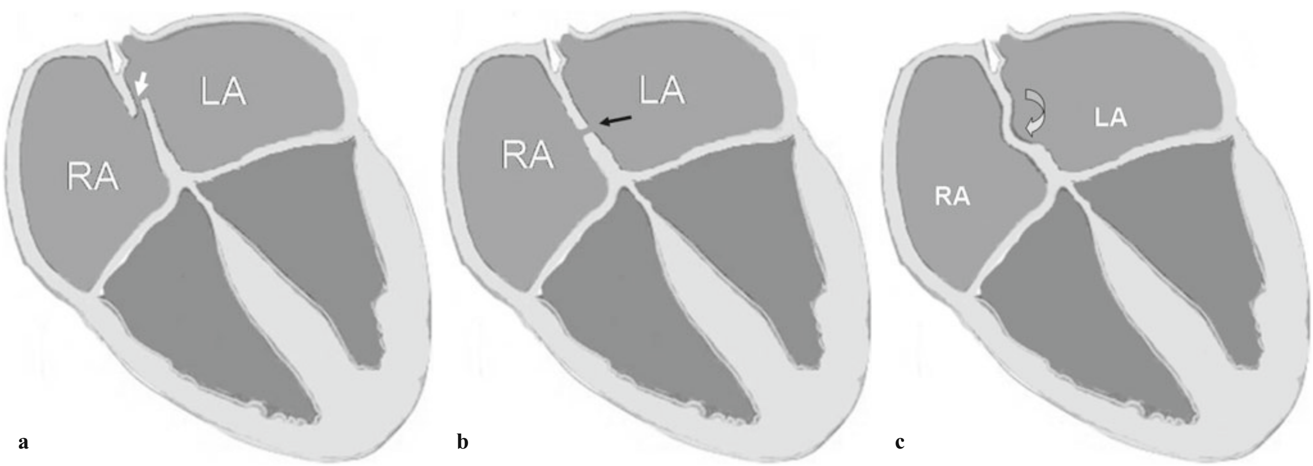

Fig. 1. Drawing of the heart. **a** *White arrow* indicates the channel-like appearance of the interatrial septum (IAS) in the presence of a patent foramen ovale (PFO). **b** *Black arrow* shows the defect of the IAS in the atrial septal defect (ASD). **c** *Curved arrow* demonstrates the protrusion of the left atrium (*LA*) beyond the IAS into the right atrium (*RA*)

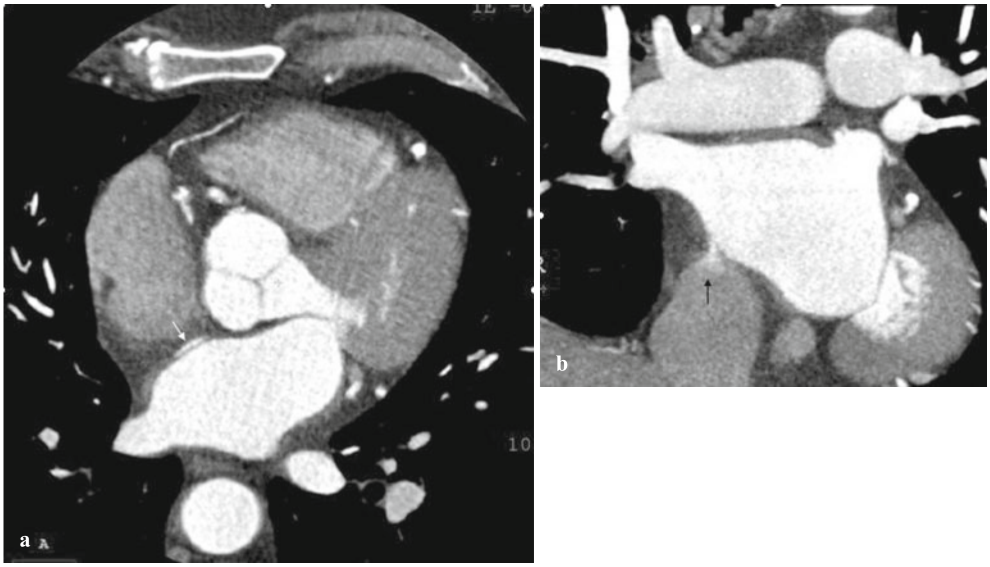

Fig. 2. A 57-year-old woman had a PFO. Axial (**a**) and coronal oblique (**b**) 1.9-mm maximum intensity projection (MIP) reformatted images demonstrate a channel-like appearance of the IAS (*white arrow*) and a subtle contrast jet from the LA to the RA (*black arrow*)

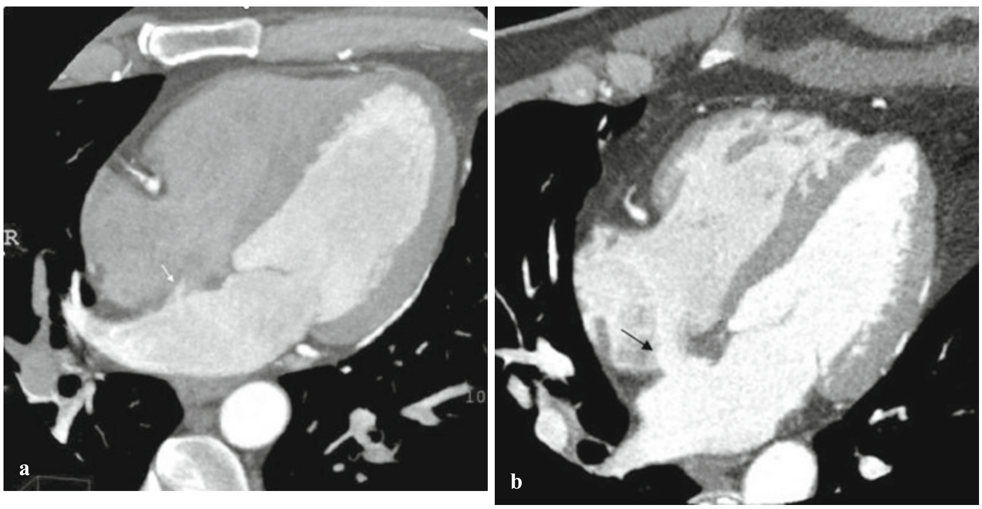

Fig. 3. Two patients had an ostium secundum-type ASD. **a** Four-chamber 4.6-mm MIP reformatted image shows a 3.5-mm defect in the region of the fossa ovalis in the IAS in a 39-year-old man (*white arrow*). **b** Four-chamber 3.1-mm MIP reformatted image demonstrates a 10.8-mm defect (*black arrow*) in the IAS in a 45-year-old man

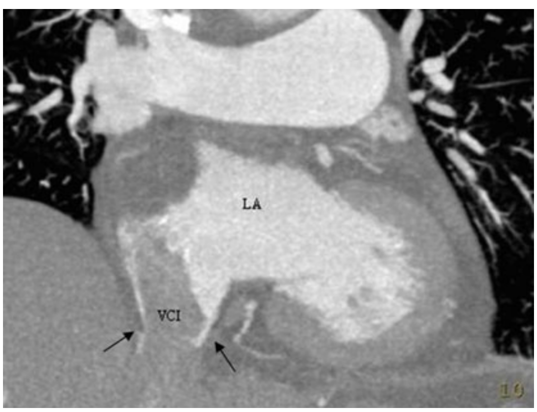

Fig. 4. A 60-year-old woman had an inferior sinus venous-type ASD. Coronal oblique 4.5-mm MIP reformatted image clearly shows a contrast jet (*black arrows*) passing from the LA to the junction of the RA and the inferior vena cava (*VCI*)

Fig. 5. A 51-year-old man had a superior sinus venous-type ASD. Axial oblique 2.5-mm MIP reformatted images demonstrates the contrast jet (*white arrow*) from the left atrium (*LA*) to the superior vena cava (*VCS*) outlining its anterior wall. *RA*, right atrium

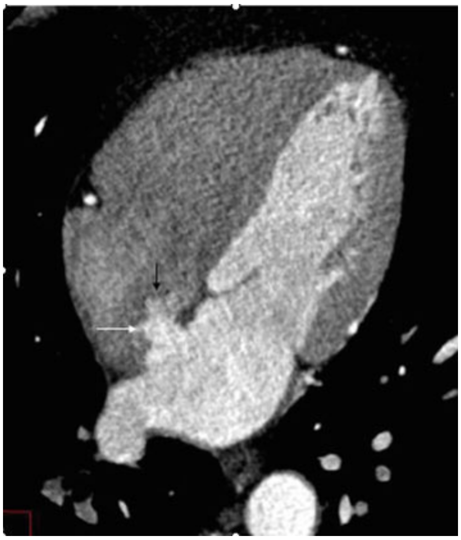

Fig. 6. A 57-year-old man had an atrial septal aneurysm (ASA). Long-axis, four-chamber 0.7-mm MIP reformatted image shows an ASA protruding 15 mm beyond the IAS into the RA (*white arrow*). A contrast jet (*black arrow*) consistent with ASD is also seen

jet flow between the two atria as diagnostic criteria for PFO.

The prevalence of a left-to-right shunt through a PFO is not well known. Based on autopsy series and clinical studies, the incidence of PFO in approximately 20%–35% of the population.[4,17] In an echocardiographic study, the PFO incidence in patients aged 70–79 years was approximately half that of patients aged 40–49 years but is still significant (6.15%).[18] The mean age of the patients with PFO was 49.5 years, and the frequency was calculated to be 8.6% in our study, which is well correlated with the study of Fisher et al.[18] In a study by Kim et al., 29 of 1363 patients demonstrated contrast jet flow; using echocardiography, 15 were diagnosed to have PFO and 5 were diagnosed to have ASD. The age distribution of the patients was not described in this study.[16] Although the frequency we detected seems to be higher than that found by Kim et al., we believe this might be a consequence of different age distribution of patients in the two studies.

Early investigations reported a PFO as a valve that closed on the LA side of the IAS due to the relatively higher left-sided pressure through which a right-to-left shunt could occur only at a moment of elevated RA pressure.[19] Some authors have reported that the prevalence is much higher than generally acknowledged and that in the presence of a PFO any left-sided cardiac lesions that increases LA size and pressure may induce a left-to-right interatrial shunt through this channel.[20–22] Some authors also have suggested that the determinant of shunt direction is not the LA pressure itself but the pressure difference between the two atria.[15] The pressure difference between the LA and the RA is largest around the v wave, which corresponds to end-systole, isovolumetric relaxation, and early diastole. Findings suggest that interatrial shunts could be adequately detected on routine cardiac CT images reconstructed at end-systole or mid-diastole.[15] In most of our patients we evaluated the images that were reconstructed on the basis of a relative-delay strategy at 75%, corresponding to the mid-diastolic phase of the cardiac cycle.

MDCT imaging requires the patient to be placed in the supine position, whereas TEE is performed with the patient seated, which facilitates shunt occurrence.[23] Although routine cardiac CT during the resting state[15] can depict a PFO, CT has limitations for use in detecting PFO because it does not show the functional aspects of a PFO that differentiate clinically important cases. Also PFOs with high membrane mobility and right-to-left shunting at rest are more closely associated with cryptogenic stroke.[24] The position-induced increase in right-to-left shunts is well known, especially in platypnea-orthodeoxia syndrome, where desaturation occurs when the individual assumes an erect or upright position.[25] Future studies may use cine-CT imaging during the Valsalva maneuver to detect right-to-left shunting.[15]

Atrial septal defect is the commonest asymptomatic congenital heart disease detected in adults. Approximately 50%–70% of ASDs are ostium secundum type. In our study, 21 of the 23 ASDs (91.3%) we detected were this type. Although ostium primum type ASD is the second commonest form of ASD, we detected none in any of the patients in our study. As the ostium primum type ASDs tend to be large and are in the spectrum of endocardial cushion defects,[2] they are usually symptomatic and diagnosed at younger age groups, which is a feature suggesting that age is the reason for not finding any ostium primum-type ASDs in our adult patient group.

Atrial septal aneurysm might be an isolated structural defect but is generally reported to be related to interatrial shunting. Mügge et al. reported that ASA was an isolated structural defect in 32% of patients and was associated with interatrial shunting in 54% of patients.[14] Although large PFOs are more commonly reported with ASA,[2,14] all three patients with ASA in our study group had an ASD. The IAS did not represent the channel-like appearance of PFO in these three patients and had holes of 3.0 mm, 3.0 mm and 7.8 mm. Therefore, we decided to categorize these patients as having ASD rather than large PFOs.

Our study has several limitations. First, we could not evaluate the sensitivity and specificity of CT for diagnosing a PFO or ASD due to its retrospective study design. The study population was selected based on CT findings: demonstration of a contrast jet between the atria and the appearance of the IAS. We believe that the contrast jet is the essential criterion for IAS. Thus, patients with a channel-like appearance of the IAS but without a clear contrast jet from LA to RA were excluded from this study, and the distinction between PFO and ASD was made depending on the visual assessment of the IAS.

Second, we mostly used CT images reconstructed at mid-diastole (at 75% of the R-R interval). This is generally the phase in which coronary arteries are well visualized with minimum motion artifacts. We did not examine the effect of the cardiac cycle on the detection rate of IAS. As stated previously, patients with a channel-like appearance of the IAS but without contrast agent jet were excluded from the study. But the amount, grade and direction of the interatrial shunt might depend on the pressure differences between the two atria during the cardiac cycle. This should be analyzed with further studies designed to interpret the images in different phases of the cardiac cycle.

Third, we do not have echocardiographic confirmation of our CT findings. This might be considered the major limitation of our study. However, many of the studies in the literature emphasize the fact that the sensitivity of transthoracic echocardiography is low in regard to detecting PFO. Even TEE and CT do not have optimum correlation depending on the facts that were particularly reviewed in this article.

Conclusion

Electrocardiography-gated CT using the saline-chaser contrast injection technique that is routinely used for coronary arterial imaging may be useful to diagnose an IAS. The criterion for the diagnosis is the presence of a contrast jet from the LA to the RA. Also, visual assessment of the IAS might serve as a method for differentiating PFO and ASD.

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