

Electrocardiography-gated dual-source computed tomography in the detection of atrial septal aneurysm

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Abstract. The aim of the current study was to investigate the atrial septal aneurysm (ASA) incidence rate and describe its morphologic features by dual-source computed tomography (DSCT). A total of 8,626 patients (4,284 men and 4,342 women) who underwent DSCT examinations were enrolled. The presence of ASA was defined as the protrusion of the complete or partial interatrial septum with a maximum vertical distance (MVD) from the atrial septum plane of >10 mm during a cardiac cycle and a diameter of the aneurysm base of >15 mm. The MVD and direction of the protrusion, as well as other abnormalities, were recorded. The ASA patients were classified by both gender and directions of protrusion into four groups, including the right atrium (RA) and left atrium (LA) groups in males and females, respectively. Values across groups were compared using the independent-sample t-test and differences in qualitative variables were assessed with the χ^2 test. Of the 8,626 patients, 51 (0.6%) were diagnosed with ASA (mean age, 62 ± 10 years), including 23 (0.5%) males and 28 (0.6%) females. There were no significant differences in the age ($t = -1.37$, $P > 0.05$) and incidence rate ($\chi^2 = 0.43$, $P > 0.05$) between the male and female groups. However, there were significant differences in the mean ages ($t = -2.20$, $P < 0.05$) and the gender proportions ($\chi^2 = 7.39$, $P < 0.05$) of patients in the RA and LA groups. In the two male groups, no significant differences were observed in the diameters of the ASA bases

and MVD in the RA and LA groups. In the female groups, the differences in the MVD of protrusion in RA and LA groups were non-significant, whereas the diameters of the base of ASA demonstrated significant differences ($t = 2.27$, $P < 0.05$). In conclusion, the ASA incidence rate was 0.6%, and electrocardiography-gated DSCT scan served as an alternative diagnostic technique for the detection of ASA. It is essential for radiologists to recognize this clinical entity and to minimize misdiagnoses and missed diagnoses

Introduction

Atrial septal aneurysm (ASA) is a rare cardiac malformation characterized by an integral or localized protrusion of the septum into the right atrium (RA), left atrium (LA) or both. The reported incidence varies between 0.2 and 10.0% (1-3), depending on diverse diagnostic criteria [maximum vertical distance (MVD) of protrusion, >5 mm in children and 6-15 mm in adults] (2-4) and the assessment methods involved, including autopsy, transthoracic echocardiography (TTE) or transesophageal echocardiography (TEE). ASA is routinely evaluated by echocardiography (4,5).

For over a decade, electrocardiography (ECG)-gated multi-detector computed tomography (MDCT) has gained popularity as a noninvasive imaging method in the evaluation of heart disease (3). With the advent of 4-detector computed tomography (CT) and further advancements in 16- and 64-detector CT, the MDCT imaging has rapidly improved, which contributes to significantly reduced gantry rotation durations and elevated image resolutions. Dual source CT (DSCT) coronary angiography has emerged as an important novel modality for the non-invasive assessment of heart disease. DSCT imaging is characterized by higher temporal resolution (83 msec for DSCT and 75 msec for 128-section DSCT) with simultaneous data acquisition by two sets of X-ray tubes and detectors, which facilitates better evaluation of lesions and without the need to control heart rate in most situations (6). With the growing population of patients with suspected coronary artery disease undergoing CT coronary angiography with DSCT, increased comorbidity findings arise in CT coronary angiography images. However, misdiagnosis of comorbidities, such as ASA, remains common among radiologists. Furthermore, only a limited number of studies regarding the CT features of ASA are available in the literature (3,7,8).

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Abbreviations: ASA, atrial septal aneurysm; MVD, maximum vertical distance; TTE, transthoracic echocardiography; TEE, transesophageal echocardiography; MDCT, multidetector computed tomography; DSCT, dual-source computed tomography; MPR, multiplanar reconstruction; PFO, patent foramen ovale

Key words: atrial septum, aneurysm, multidetector computed tomography, coronary angiography

Therefore, in the present study, the aim was to evaluate the incidence rate of ASA in a large cohort of patients with suspected coronary artery disease and to address the morphologic characteristics of ASA by DSCT imaging.

Materials and methods

Study population. A total of 8,626 patients (4,284 men and 4,342 women) with suspected coronary artery disease who underwent DSCT coronary angiography between December 2012 and October 2014 at the Affiliated Hospital of Xuzhou Medical College (Xuzhou, China) were enrolled into the present study. The entry criteria for inclusion were as follows: i) No allergy to iodine-containing contrast medium; ii) sufficient renal function; iii) hemodynamic stability; and iv) no pregnancy in women. The ASA patients were classified by sex (male or female) and the direction of protrusion to give four groups: Male right atrium (RA), male left atrium (LA), female RA and female LA groups.

The Ethics Committee of the Affiliated Hospital of Xuzhou Medical College approved the study protocol, and written informed consent was obtained from all patients.

Scanning protocol and image reconstruction. The patients were placed in supine position medial to the DSCT scanner (Somatom Definition; Siemens Healthineers, Erlangen, Germany) to ensure that the heart was covered by the smaller field of view of the second tube detector array. A bolus of 80 ml nonionic iodinated contrast agent (350 mg I/ml; GE Healthcare Co. Ltd., Shanghai, China) was injected at a velocity of 5 ml/sec, followed by an injection of 50 ml normal saline at the same velocity into an antecubital vein via an 18-gauge cannula. Image acquisition commenced 5 sec after the attainment of a predefined threshold of attenuation in the region of interest, which was allocated in the ascending aorta (signal attenuation threshold, 100 HU). The entire volume of the heart was covered during one breath holding within 15-20 sec, and ECG pulsing was recorded. Retrospective gating ensured that the data reconstruction was synchronous with the electrocardiographic signals. The parameters for the data acquisition in a craniocaudal direction are as follows: Rotation time of 0.33 sec, tube voltage of 120 kVp, effective tube current of 420 mAs, adapted pitch values of 0.20-0.43 (according to the heart rates of patients), slice thickness of 0.75 mm, a reconstruction increment of 0.4 mm, a medium soft-tissue convolution kernel (B26f) and an image matrix of 512x512 pixels.

Imaging analysis and measurements. ASA was diagnosed in patients with an MVD of protrusion from the atrial septum plane of >10 mm and a diameter of the aneurysm base of >15 mm (9). Data sets were evaluated with a 3-D workstation (Syngo MMWP VE30A; Siemens Healthineers, Erlangen, Germany), and analyzed by multiplanar reconstruction (MPR). The MVD and diameters of the aneurysm base were measured in the MPR. The following features were evaluated in the images: MVD of protrusion, diameter of the aneurysm base, direction of the maximal protrusion (into the right or left atrium, or even protruding with bilaterally equidistance during one cardiac cycle), other atrial septum-associated

morphological abnormalities, as well as thrombus attachment to the ASA.

Statistical analysis. Statistical analysis was performed with the SPSS software (version 16.0; SPSS, Inc., Chicago, IL, USA). The quantitative variables are presented as the means \pm standard deviation. Values across groups were compared using the independent-sample t-test, while differences in qualitative variables were assessed with the χ^2 . $P < 0.05$ was considered to indicate differences that were statistically significant.

Results

Clinical characteristics of patients with ASA. The clinical characterization of the ASA population is summarized in Table I and Figs. 1-3. Of the 8,626 subjects enrolled into the present study, 51 (0.6%) patients, including 23 males (0.5%) and 28 females (0.6%), were confirmed to suffer from ASA. Patients with ASA had a mean age of 62 ± 10 years, a median age of 64 years and an age range of 34-79 years. Atrial septal aneurysms bulged towards the right atrium in 33 patients and towards the left atrium in 17 patients. Interatrial shunting through the foramen in the wall of the aneurysm was identified in 1 patient (Fig. 4). In addition, ASA was concomitant with atrial fibrillation in 4 patients, and there was no thrombosis on the surface of the ASA.

Comparison of the RA and LA groups. One ASA patient was excluded from the present study due to bilaterally equidistant protrusions during one cardiac cycle. The characteristics of the RA and LA groups are summarized in Table II. No significant differences were observed between males and females with respect to the age and incidence rate in ASA patients ($t = -1.37$, $P > 0.05$; $\chi^2 = 0.43$, $P > 0.05$). By contrast, patients in the LA group had a significantly higher age compared with those in the RA group ($t = -2.20$, $P < 0.05$). Furthermore, a significantly greater number of female patients were included in the RA group compared with the LA group ($P < 0.05$).

Comparison of male and female groups. In the male groups, the differences in the ASA base diameter and the MVD of protrusion between the RA and LA group were not statistically significant. In the female groups, the difference in the MVD between the RA and LA were also non-significant, whereas the diameter of the ASA base in the RA group was significantly higher compared with the LA group ($t = 2.27$, $P < 0.05$).

Discussion

The etiology of ASA remains controversial, with certain aneurysms considered to be a primary or congenital malformation, or secondary to the elevation of interatrial pressure gradients, which bulges the septum into the lower pressure side (3,10). Thus, ASA may be putatively attributable to an abnormal structure of the interatrial septum or modifications of the normal interatrial pressure gradients, or both. In addition, the septal bulging may be static or dynamic (4,5), bulging into the right atrium, the left atrium or both atria.

The reported prevalence of ASA in human adults varies widely among studies due to distinctions of imaging method

Table I. Clinical characteristics of patients with ASA.

Characteristics	Males	Females
No. of ASA patients (n)	23	28
Age (years) ^a	60±12	64±8
Direction of the maximal protrusions		
RA	10	23
LA	12	5
Bilateral	1	0
Comorbidities		
PFO	0	1
AF	2	2
Intra-atrial thrombi	0	0

^aExpressed as the mean ± standard deviation. ASA, atrial septal aneurysm; RA, right atrium; LA, left atrium; ASD, atrial septal defect; PFO, patent foramen ovale; AF, atrial fibrillation.

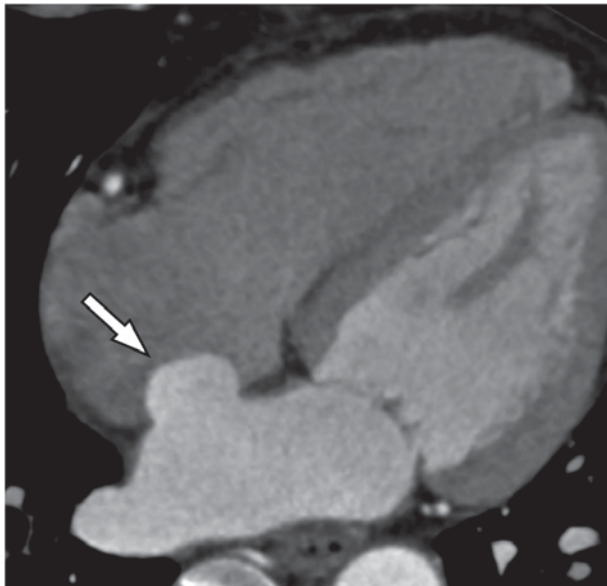


Figure 1. Dual-source computed tomography with electrocardiography-gating in the axial multiplanar reconstruction view at 76% of the electrocardiogram R-R intervals (heart rate), demonstrating protrusion of interatrial septum into the right atrium (white arrow).

selections and absence of a ‘gold standard’ for the definition of true ASA. The diagnostic criteria used in different studies vary, with an aneurysm protruding >10 mm beyond the plane of the atrial septum (4,9,11,12), or an aneurysm with an MVD of >7.5 mm (1) or >15 mm (13) commonly required for ASA diagnosis. In the present study, ASA was defined as a protrusion beyond the plane of the atrial septum with an MVD of >10 mm. Previously, the prevalence of ASA has been reported to range between 0.2 and 4% using TTE, and between 2 and 8% using TEE (9). To the best of our knowledge, only one previous study (3) has employed MDCT as the diagnostic device in ASA assessment, with a reported incidence of 1.33%. In the present study, the ASA incidence rate was 0.6%, with

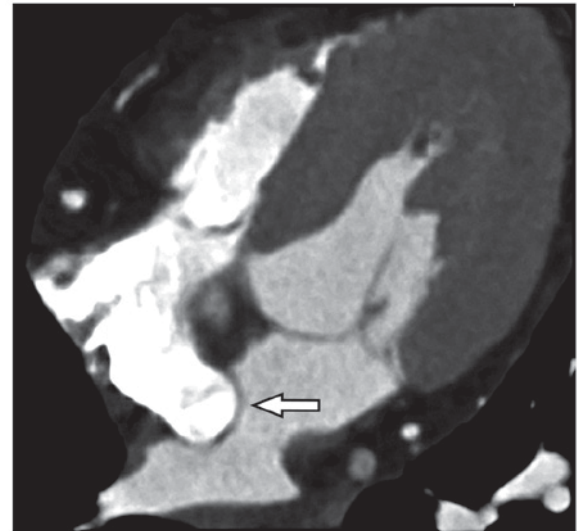


Figure 2. Dual-source computed tomography with electrocardiography-gating in axial multiplanar reconstruction view at 33% of the electrocardiogram R-R intervals (heart rate), revealing protrusion of the interatrial septum into the left atrium (white arrow).

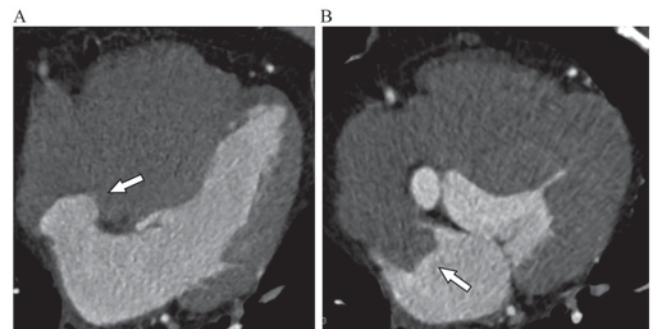


Figure 3. Dual-source computed tomography images of the same patient at (A) 71% of the electrocardiogram R-R intervals (heart rate) showing protrusion of the interatrial septum into the right atrium, and (B) at 33% of the electrocardiogram R-R intervals (heart rate) presenting protrusion into the left atrium (white arrows).

no marked difference observed between the two genders. The direction of the MVD into the left atrium was predominantly observed in elderly patients. It is possible that these patients are more predisposed to valvular diseases or other maladies as a result of elevated pressure in the right atrium. Furthermore, the direction of the MVD into the right atrium was more frequently observed in female patients.

ASA reportedly occurs as a discrete cardiac malformation or, more frequently, in concomitance with other cardiac anomalies, particularly atrial septal defects and patent foramen ovale (PFO) (3-5). ASA in adults is also associated with atrial fibrillation, mitral valve prolapse and migraines with aura (1,4,9,12). In the current study, no thrombosis was detected on the surface of the ASA, and ASA was comorbid with PFO in only 1 patient.

Although ASA is usually identified by chance, this abnormality may lead to severe clinical outcomes. ASA has been demonstrated to be an independent predictor of an embolic event in multivariate analyses (5,13), while the prevalence

Table II. Characteristics of patients with ASA predominantly protruding into the right or left atrium.

Characteristics	Direction of MVD	
	RA	LA
No. of patients (n)	33	17
Age (years)	60±11	66±7
Diameter of the base of ASA (mm)		
Males	25.39±10.14	19.90±4.45
Females	25.78±7.82	17.50±4.59
MVD of protrusion (mm)		
Males	11.70±2.12	10.98±2.01
Females	11.51±2.00	11.66±1.57

Data are expressed as the mean ± standard deviation. ASA, atrial septal aneurysm; MVD, maximum vertical distance; RA, right atrium; LA, left atrium.

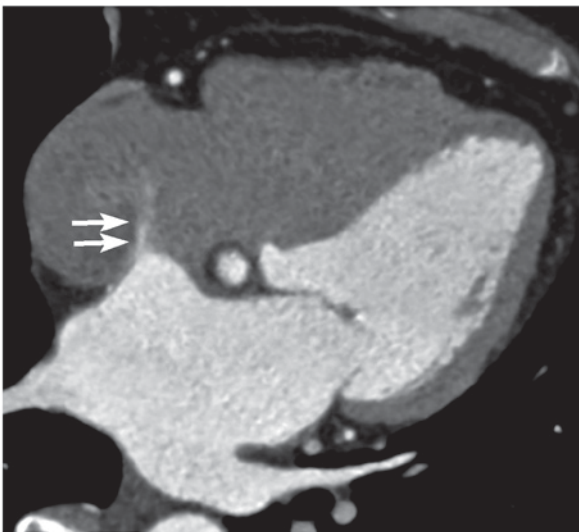


Figure 4. Dual-source computed tomography with electrocardiography-gating in axial multiplanar reconstruction view at 78% of the electrocardiogram R-R intervals (heart rate), revealing interatrial shunting through the foramen in the wall of the atrial septal aneurysm (white arrows).

of ASA in patients with cerebral ischemia was 27.7% and it was the only potential cardiac source of embolism in patients <45 years of age (13). However, ASA was not significantly associated with ischemic stroke unless concomitant with PFO, particularly in patients aged <55 years (14-16). In addition, patients suffering from stroke comorbid with PFO and ASA were at a high risk of recurrent stroke (17).

To date, TEE and TTE are routine approaches used for the diagnosis of ASA. Owing to its proximity to the atria, TEE is superior to TTE in the imaging of atrial abnormalities (4). Furthermore, it is difficult to differentiate between ASA with thrombotic attachment and motion-induced artifacts, as well as bulging of the fossa ovalis (4). In the case of suboptimal echocardiography, however, ECG-gated cardiac

MDCT scanning may provide an alternative modality for such diagnoses. The current spatial and temporal resolution of 64-MDCT of the heart is approximately 0.4x0.4x0.4 mm³ voxel and 165 msec, which facilitate the visualization of the delicate intracardiac structures, such as septal membranes. Further technological advances of the improved temporal resolution of DSCT (83 msec) may potentiate ECG-gated cardiac CT in the evaluation of intracardiac abnormalities (8). This technique can readily recognize such clinical entities and minimize the misdiagnosis of tumors, as well as avoid subsequent investigations. In addition, echocardiography exempts the patients from ionizing radiation and iodinated contrast media used in CT scanning, which is particularly preferable when examining infants and children. Since the imaging examinations in the present study were intended for suspected coronary artery disease, all the patients were subjected to CT coronary angiography and the simultaneous diagnosis of ASA, without modifications of the doses of ionizing radiation and iodinated contrast media. With the innovation of DSCT technology in MDCT, the ionizing radiation and contrast media dosage can be minimized in conformance with a weight-based low-dose protocol (18). Additionally, DSCT facilitates high temporal resolution in patients with high heart rates or arrhythmias without the administration of β -blockers.

Although ASA is a well recognizable cardiac malformation, this abnormality remains commonly neglected among radiologists. Despite the popularity of echocardiography for ASA diagnosis, DSCT imaging, particularly when coupled with ECG gating, may benefit the precise visualization of the anatomical details of the atrial septum. Given the association of ASA with intracardiac shunting and thromboembolic complications, it is advisable for radiologists to recognize this clinical entity and minimize the probabilities of misdiagnosis of ASA as a cardiac tumor.

In conclusion, the present study demonstrated that DSCT may serve as a novel diagnostic technique for the detection of interatrial septal abnormalities. DSCT enables ASA and associated heart anomalies to be accurately visualized.

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Availability of data and materials

The datasets used and/or analyzed during the present study are available from the corresponding author on reasonable request.

Authors' contributions

KX, LXX and ZXL conceived and designed the study. XLZ, QX, LL, CFH, SGH and JYL collected and processed the data. LXX and ZXL wrote the paper. KX, LXX and ZXL reviewed and edited the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The present study was approved by the Ethical Committee of the Affiliated Hospital of Xuzhou Medical College, Xuzhou, China (approval number xyfylw2012016). All patients provided written informed consent for participation in the present study.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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