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Left atrial volume assessed by ECG-gated computed tomography: Variations according to age, gender and time during the cardiac cycle

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KEYWORDS
Cardiac-gated computed tomography (CT);
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Left atrial enlargement

Abstract
Purpose: The purpose of this study was to retrospectively assess the accuracy of the maximal left atrial volume (LAV_{max}) measured at 75% of the cardiac cycle compared to the 40% measurements and to evaluate this volume according to age and gender.
Patients and method: A total of 150 patients with a mean age of 50 ± 17 (SD) years (range: 21—79 years) were analyzed. There were 78 men and 72 women. LAV_{max} were measured from retrospective triphasic cardiac-gated multi-detector computed tomography (MDCT) data at the 40% (LAV_{40}) and 75% (LAV_{75}) of the RR cycle phases by a semi-automatic method.
Results: $LAV_{40}$was $50.7 \pm 14\,mL/m^2$ and LAV_{75} was $42.5 \pm 13\,mL/m^2$. The difference was statistically significant. Considering the reference range of LAV_{max} reported in the literature, 33% of the patients had enlarged LA with LAV_{40} and only 17% with LAV_{75}. These volumes were positively influenced by age but not by gender. The relationship between LAV_{75} and LAV_{40} was: $LAV_{75} = 0.908\ LAV_{40} - 3.486$ ($r^2 = 0.92$) or $LAV_{40} = 1.1 \times LAV_{75} + 3.8$ ($r^2 = 0.92$).
Conclusion: LAV_{max} measured at the 75% of the cardiac cycle phase significantly underestimates actual LAV leading to reconsider normal values. LAV_{40} can be computed from the measured value of LAV_{75} obtained on prospective ECG-gated MDCT.

Abbreviations: LAV max, maximal left atrial volume; LA, left atrium; MDCT, multidetector computed tomography; ES, end systolic; LAA, left atrial appendage; PV, pulmonary veins.

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Left atrial (LA) enlargement is related to risk of cerebral stroke in men and is a prognostic variable for cardiovascular diseases as a major predictor of death in both genders [1—3]. It is also recognized as an independent prognostic factor of cardiovascular mortality and morbidity [1,4] mainly for its role as marker of atrial fibrillation and heart failure. Recently, it has been shown that indexed volumetric measurement of the left atrium (LA) is more accurate and a more robust marker of adverse events than 2 dimensional measurements (LA area or diameter) [5]. LA volume varies during the cardiac cycle with a maximal LA volume (LAV_{max}) at the end systolic phase (30—40% of the RR cycle) just before the mitral valve opening and a minimal LA volume (LAV_{min}) at the end diastolic phase (90-0% of the RR cycle) just after the mitral valve closure [6].

LAV_{max} and LAV_{min} may be accurately measured using retrospective ECG-gated multi-detector computed tomography (MDCT) [7]. In the literature, the reference value of the LAV max using a retrospective cardiac-gated MSCT is 54 mL/m^2 measured at 40% of the RR cycle. Nowadays to minimize the patient's radiation exposure, prospective ECG-gated MDCT is widely used [8]. However, the drawback of this technique is the single acquisition at 70—80% of the R—R cycle. Therefore, at this time of the cardiac cycle (70—80%), the LAV_{max} could be underestimated.

The objective of this study was to retrospectively assess the accuracy of the LAV_{max} measured at 75% of the cardiac cycle compared to the measure performed at 40% and to study the correlation of this parameter according to age and gender.

Methods

Study design and population

All patients referred for cardiac MDCT examinations performed between January 2009 and August 2011 were eligible for the study. Cardiac CT examinations were indicated according international guidelines [9]. The study was conducted according to the ethical principles stated in the Declaration of Helsinki and in adherence with applicable guidelines for good clinical practice. All patients received clear and adapted information about cardiac CT and possible events before inclusion.

A total of 2505 consecutive cardiac CT were performed during the period of inclusion. Patients over 18 year-old with sinus rhythm and no history of atrial fibrillation (AF) symptoms were included consecutively; sinus rhythm was determined by electrocardiogram monitoring before CT on evidence of the presence of '*P*' waves and a regular RR interval. Cardiac CT examinations presenting mild or poor quality of the images and/or coronary calcium score > 1000 were secondary excluded considering that in this condition, coronary analyze could be limited (local protocol agreement). We also excluded the patients with age under 18 years, patent allergy to iodinated contrast medium, renal insufficiency (serum creatinine under 1.5 mg/dL), and pregnancy.

To avoid confusion bias on LA function parameter measurements, we did not include patients who had affections which may influence LA emptying and filling and lead to blood stasis in LA [10]: significant mitral stenosis, mitral replacement or severe aortic regurgitation assessed by echocardiography, significant left ventricular systolic failure (LV ejection fraction < 45%) measured by echocardiography or assessed by cardiac CT, and/or diastolic (documented by echocardiography) dysfunctions [11] and patients with documented paroxysmal or chronic atrial fibrillation (AF) by electrocardiography or echocardiography.

Patients in early post-myocardial infarction period, specifically in large anterior myocardial infarctions were also excluded. A physical examination and a study of the clinical database of the patient were systematically carried out before cardiac-CT to check all these points. Stratification by decade was performed to obtain 25 patients in each age group, from 20 to 80 years, for both genders.

The final study population consisted of 150 patients (78 men and 72 women) with a mean age of 50 ± 17 (SD) years (range: 21—79 years).

Imaging method

All cardiac CT examinations were performed using a 64-section CT scan (LightSpeed VCT, GE Healthcare, Milwaukee, WI, USA). Sublingual nitroglycerin was given to the patient as premedication if systolic blood pressure was above 110 mmHg. Patients with known preserved left ventricular systolic function were also given 2.5 to 7.5 mg of atenolol intravenously before the CT scan, with an objective of a heart rate below 65 beats/min (bpm).

With the patient in the supine position, image acquisition was obtained during a single breath-hold at end-inspiratory suspension, in the cranio-caudal direction, with retrospective electrocardiographic gating. Image acquisition was obtained using a triphasic injection of iodine-based contrast medium: 80 mL of an intravenous contrast agent (iomeprol 400 mg/mL, Iomeron® 400, Bracco SA, Milan, Italy) injected through an antecubital vein at 4.5 mL/s followed by 40 mL (50%) injected at 4 mL/s and 30 mL of isotonic saline solution injected at 3 mL/s. Imaging was acquired by using a real-time bolus tracking technique in which the region of interest (ROI) was placed at the ascending aorta waiting to reach a trigger threshold of 100 HU. Scanning parameters were as follows: gantry rotation time of 350 ms, detector collimation of 64 × 0.625 mm, table feed adapted to cardiac frequency and tube voltage of 100 kVp to 120 kVp at a current of 500 mA to 750 mA depending on patient weight. The average scanning time was 5 to 8 seconds. Ten data sets of non-overlapped transversal images were reconstructed retrospectively at every 10% of the R—R interval with slice thickness of 0.6 mm. With ''automated tube current modulation'', the current is less than 400 mA between 90% and 30% of the cardiac cycle, and is between 600 mA to 750 mA during the rest of the cycle with a progressive transition between the two phases.

Image analysis

All examinations were analyzed retrospectively using specific semi-automated software (Advantage TM version 4.2, CardioQ Analysis II, GE Healthcare). The detection of the LA endocardial borders and the quantification of the LA volumes were done by applying the three-dimensional segmentation technique (Fig. 1). A cine-loop was used to define

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