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Dual-Enhanced Cardiac CT for Detection of Left Atrial Appendage Thrombus in Patients With Stroke

A Prospective Comparison Study With Transesophageal Echocardiography

Jin Hur, MD; Young Jin Kim, MD; Hye-Jeong Lee, MD; Ji Eun Nam, MD; Jong-Won Ha, MD; Ji Hoe Heo, MD; Hyuk-Jae Chang, MD; Hua Sun Kim, MD; Yoo Jin Hong, MD; Hee Yeong Kim, MD; Kyu Ok Choe, MD; Byoung Wook Choi, MD, PhD

***Background and Purpose*—**A noninvasive method with high reliability and accuracy comparable to transesophageal echocardiography for identification of left atrial appendage thrombus would be of significant clinical value. The aim of this study was to assess the diagnostic performance of a dual-enhanced cardiac CT protocol for detection of left atrial appendage thrombi and for differentiation between thrombus and circulatory stasis in patients with stroke.

***Methods*—**We studied 83 consecutive patients with stroke (56 men and 27 women; mean age, 62.6 years) who had high risk factors for thrombus formation and had undergone both dual-source CT and transesophageal echocardiography within a 3-day period. CT was performed with prospective electrocardiographic gating, and scanning began 180 seconds after the test bolus.

***Results*—**Among the 83 patients, a total of 13 thrombi combined with spontaneous echo contrast and 14 spontaneous echo contrasts were detected by transesophageal echocardiography. All 13 thrombi combined with spontaneous echo contrast were correctly diagnosed on CT. Using transesophageal echocardiography as the reference standard, the overall sensitivity and specificity of CT for the detection of thrombi and circulatory stasis in the left atrial appendage were 96% (95% CI, 78% to 99%), and 100% (95% CI, 92% to 100%), respectively. On CT, the mean left atrial appendage/ascending aorta Hounsfield unit ratios were significantly different between thrombus and circulatory stasis (0.15 Hounsfield unit versus 0.27 Hounsfield unit, $P=0.001$). The mean effective radiation dose was 3.11 mSv.

***Conclusions*—**Dual-enhanced cardiac CT with prospective electrocardiographic gating is a noninvasive and sensitive modality for detecting left atrial appendage thrombus with an acceptable radiation dose. **(*Stroke*. 2011;42:2471-2477.)**

Key Words: dual-source cardiac computed tomography (DSCT) ■ stroke ■ thrombus ■ transesophageal echocardiography

Investigation of potential embolic sources is an important diagnostic step in managing patients with acute ischemic stroke or transient ischemic attack, especially when the mechanism is considered to be embolic. Cardiogenic emboli have been estimated to be the causative factor in 20% to 40% of all stroke cases.[1–3]

Currently, transesophageal echocardiography (TEE) has emerged as the most sensitive technique for the detection of intracardiac thrombi and is believed to be the single best modality for patients with suspected intracardiac thrombi.[4–6] Although TEE is widely available, it is a semi-invasive test, usually performed under conscious sedation.

A noninvasive method with high reliability and accuracy comparable to TEE for the identification of left atrial appendage (LAA) thrombus would be of significant clinical value. Recent advances in multidetector CT, including improvements in temporal and spatial resolution, now allow accurate and consistent imaging of cardiac structure, including left atrial and LAA anatomy. CT is a sensitive modality for the detection of intracardiac thrombus, which is seen as a filling defect on CT.[7–10] However, spontaneous echo contrast (SEC), as seen by ultrasound, is caused by circulatory stasis in the LAA in patients with atrial fibrillation and can also appear as an apparent filling defect on CT images, thereby mimicking a thrombus. Therefore, it may be difficult to differentiate between a filling defect due to a thrombus and 1 that is due to circulatory stasis secondary to using an early-enhanced CT scan. A previous study reported that an additional delayed-

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From the Department of Radiology (J.H., Y.J.K., H.-J.L., J.E.N., H.S.K., Y.J.H., H.Y.K., K.O.C., B.W.C.), Department of Cardiovascular Radiology, Research Institute of Radiological Science, Yonsei University College of Medicine, Seoul, South Korea; the Division of Cardiology (J.-W.H., H.-J.C.), Yonsei Cardiovascular Center, Yonsei University College of Medicine, Seoul, South Korea; and the Department of Neurology (J.H.H.), Severance Hospital, Yonsei University College of Medicine, Seoul, South Korea.

Correspondence to Byoung Wook Choi, MD, PhD, Department of Radiology, Research Institute of Radiological Science, Severance Hospital, Yonsei University College of Medicine, 250 Seongsanno, Seodaemun-gu, Seoul 120-752, South Korea. E-mail bchoi@yuhs.ac

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enhanced scan was necessary for differentiating thrombus from circulatory stasis, which might also cause an apparent filling defect and mimic a thrombus on early-enhanced CT images.[10] However, a limitation of 2-phase cardiac CT (CCT) is higher radiation exposure due to the additional delayed-enhanced scan.

In clinical practice, different contrast injection protocols such as biphasic or triphasic protocols were used for coronary artery CT angiography without standardization. However, the main focus of those injection protocols was to optimize contrast opacification of coronary arteries at the same time as using lesser amounts of contrast materials and having lesser streaky artifacts.[11] Therefore, we developed a new dual-enhanced single-phase CCT protocol using prospective electrocardiographic gating for evaluation of intracardiac thrombus and for the differentiation between a thrombus and circulatory stasis. This protocol used double injection of the contrast agent, and the scan was performed only once in the late phase, 180 seconds, after giving the first contrast bolus.

The aim of this study was to assess the diagnostic performance of a new dual-enhanced single-phase CCT protocol using prospective electrocardiographic gating for detection of LAA thrombi and for differentiation between thrombus and circulatory stasis in patients with stroke using TEE as the reference standard.

Methods

Patient Selection

Our Institutional Review Board approved this study, and patients provided informed consent. From March 2010 to October 2010, 351 consecutive patients were admitted to our hospital for a recent stroke (onset within the previous 7 days). Of these patients, 102 patients who had high risk factors for thrombus formation were prospectively enrolled in this study. High risk factors for thrombus formation were defined as follows: (1) persistent atrial fibrillation (AF) confirmed by electrocardiography[12,13]; (2) valve disease assessed by echocardiography,[14–16] including mitral stenosis (at least moderate in severity), previous mitral valve surgery (valve replacement or repair), or severe aortic regurgitation; (3) left ventricular dysfunction[17] defined as severe systolic dysfunction (ejection fraction <30%) or cardiomyopathy with moderate systolic dysfunction (ejection fraction <40%); or (4) history of AF documented by 12-lead electrocardiography before the index TEE examination.[18] TEE was performed within 2 weeks (mean time, 6.8 days; time range, within 5 to 13 days) of the initial stroke, except in patients with decreased consciousness (n=3), impending brain herniation (n=1), poor systemic conditions (n=3), tracheal intubation (n=2), or failure in introducing the esophageal transducer (n=1). Nine patients who had contrast agent allergy (n=2), renal dysfunction (n=3), or failed to provide an informed consent (n=4) were excluded.

The remaining 83 patients with high risk factors for thrombus formation were included. TEE and CT examinations were performed within a 3-day period (mean, 2.3 days) to determine the cardioembolic source. All patients underwent brain CT (n=62) or brain MRI (n=81) to confirm and characterize the stroke type and to exclude hemorrhage and other pathology. The patients consisted of 56 men and 27 women with ages from 36 to 83 years (mean age, 62.6 years). Baseline clinical characteristics, including systemic hypertension, hyperlipidemia, diabetes mellitus, and smoking habits, were determined from medical records and routine laboratory data.

Subtypes of ischemic stroke were classified according to the Trial of Org 10172 in Acute Stroke Treatment classification system.[19] The stroke subtypes of 83 patients were the following: stroke of undetermined etiology (n=37 [45%]), large-artery atherosclerosis (n=23 [28%]), cardioembolism (n=21 [25%]), and small-vessel occlusion (n=2 [2%]).

CCT Examination

CCT scans were performed with a second-generation dual-source CT scanner (Somatom Definition Flash; Siemens Medical Solutions, Erlangen, Germany) in the craniocaudal direction during a single breath-hold. Scanning was performed with the second injection of contrast agent, 180 seconds after injection of the first bolus of contrast agent.

No β-blockers were used in any of the enrollees for regulation of heart rate, because the CT was performed to evaluate the intracardiac structure and not the coronary arteries. The mean heart rate was 65±13 beats per minute (range, 53 to 89 beats/minute) during the CT examination.

A test bolus technique was used before image acquisition in each patient. For test bolus scans (first bolus), 50 mL noniodinated contrast agent, iodixanol (320 iodine mg/mL, Visipaque; GE Healthcare, Cork, UK), was administered using a power injector (Envision CT, Medrad) at a rate of 5 mL/s through an 18-gauge needle placed into the right antecubital vein. After contrast agent administration, 50 mL saline was administered at a flow rate of 5 mL/s through the same venous access. A region of interest was plotted inside the ascending aorta and a bolus geometry curve was acquired. Curve diagrams were analyzed immediately after acquisition, and the time to maximum enhancement was measured to determine the optimal scan delay.

Using prospective electrocardiographic gating, the scan was started 180 seconds later, after the end of the test bolus scan. The second bolus, composed of 70 mL of nonionic contrast agent, iodixanol (320 iodine mg/mL, Visipaque; GE Healthcare), followed by a 50-mL saline solution, was administered intravenously at a rate of 5 mL/s using a power injector (Envision CT; Medrad). The scan parameters were as follows: detector collimation, 2×64×0.6 mm; slice acquisition, 2×128×0.6 mm by means of a z-flying focal spot; gantry rotation time, 280 ms; tube voltage, 100 to 120 kV; tube current, 280 to 380 mAs; and pitch, 0.2 to 0.43 adapted to the heart rate. All prospectively electrocardiographic-triggered studies were centered at 70% of the R-R interval.

Images were reconstructed with a slice thickness of 0.6 mm and a reconstruction increment of 0.4 mm using a soft-tissue convolution kernel (B36f). Radiation exposure was estimated from the dose-length product. The calculated mean radiation dose was 3.11 mSv (dose-length product range, 58 to 411 mGy*cm) depending on the scan range and the patient's body weight.

TEE Examination

TEE was performed with a 5- to 7-MHz multiplane probe positioned at the appropriate level within the esophagus. For each patient, all images were recorded on digital video in real time for display and evaluation. Multiple standard tomographic planes were imaged, and LAA-emptying velocity, the presence of left artery or LAA thrombi, and the severity of left artery SEC were determined. SEC was characterized by dynamic clouds of echoes curling slowly in a circular or spiral shape within the LAA cavity. The severity of SEC was divided into 4 grades based on appearance and density using a 5-MHz transducer, as follows: none, the absence of this phenomenon; mild, minimal echogenicity only detectable with optimal gain settings transiently during the cardiac cycle; moderate, dense swirling pattern during the entire cardiac cycle; and severe, intense echodensity and very slow swirling patterns in the LAA, usually with a similar density in the main cavity.

Image Analysis

Two experienced radiologists prospectively and independently reviewed the CT images of the 83 patients. Disagreement was resolved by a joint reading. Each reader was blinded to the results of other examinations and clinical data.

On CT, we defined a thrombus as a filling defect that appeared as an oval or round shape on CT images. Circulatory stasis was defined

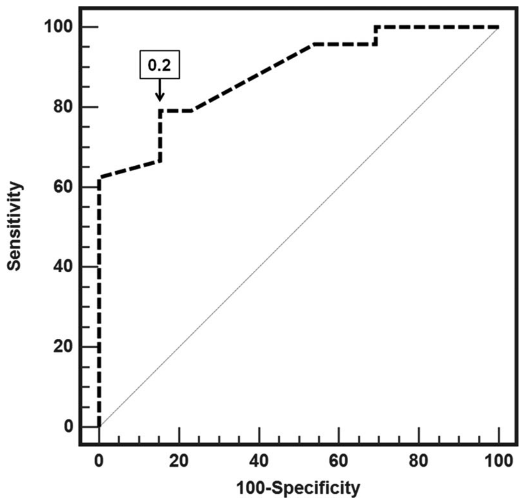

Figure 1. Receiver operating characteristic (ROC) curve using the Hounsfield unit (HU) ratios. The best cutoff value for separating thrombus from circulatory stasis was 0.2 (sensitivity, 80%; specificity, 85%, area under the ROC curve [AUC]=0.885).

as a filling defect that appeared as a triangular shape in the LAA with homogeneous attenuation on CT images.

For quantitative analysis, we calculated the LAA/ascending aorta (AA) Hounsfield unit (HU) ratio on CT images for thrombus and SEC. For that purpose, regions of interest of approximately 10 mm^2 (range, 5 to 18 mm^2) were placed inside the filling defect in the LAA seen on CT images and the AA of the same slice to generate an LAA/AA HU ratio. CT density was independently measured at 2 different selected points in HU by 2 radiologists and the mean LAA/AA HU ratio was used for analysis. Receiver operating characteristic curves were constructed using the HU ratios and the best cutoff value was determined for the differentiation between thrombus and circulatory stasis. Retrospective analysis demonstrated that the best cutoff threshold value for separating thrombus from circulatory stasis was 0.2 (Figure 1).

Two experienced cardiologists prospectively and independently reviewed the TEE images of the 83 patients and graded the severity of SEC. Disagreement was resolved by a joint reading. On TEE, thrombus was defined as a well-circumscribed, uniformly consistent, echo-reflective mass of different texture from the LAA wall.

Statistical Analysis

Categorical baseline characteristics were expressed as numbers and percentages and were compared between patients with and without thrombus or SEC by means of the χ^2 test. Continuous variables were expressed as mean and SD and were compared with the Student *t* test for independent samples.

For all imaging modalities, we recorded the number of the detected thrombi and SEC and characterized the diagnoses made by the reviewers as true-positive, true-negative, false-positive, or false-negative. Using TEE as the reference standard, sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of CT for detecting LAA thrombi and SEC were calculated; 95% CIs were calculated using the method of exact binomial tail areas.[20] The agreement between the detection of thrombi and SEC with CT and TEE was assessed with κ statistics. The statistical significance of differences in mean LAA/AA HU between thrombus and SEC as measured by CT was assessed using the Student *t* test. The statistical significance of differences in mean LAA/AA HU of thrombus and SEC according to different grades determined by TEE was assessed using 1-way analysis of variance with the Scheffe method. The correlation between LAA/AA HU ratio and LAA-emptying velocity determined by TEE was assessed. Pearson correlation was used to determine the correlation of mean CT density ratio values between the 2 observers. Probability values <0.05 were considered statistically significant. All statistical analyses were performed with SPSS software (Version 18.0; Statistical Package for the Social Sciences, Chicago, IL).

Table 1. Clinical Characteristics of 83 Patients With Stroke

	No. of Patients (%)		
Characteristics	LAA-Filling Defect (n=27)	No Thrombus (n=56)	*P*
Age, mean±1 SD, y	62±10	64±12	0.937
Male	17 (64)	39 (70)	0.439
Hypertension	18 (68)	30 (54)	0.329
Hyperlipidemia	4 (15)	6 (11)	0.593
Diabetes mellitus	7 (26)	13 (23)	0.788
Smoking	7 (26)	15 (27)	0.934
Old CVA	4 (15)	6 (11)	0.593
Embolic source risk factors			
Persistent atrial fibrillation*	21 (78)	28 (50)	0.017
Severe left ventricular dysfunction			
Systolic dysfunction (EF <30%)*	4 (15)	10 (18)	0.730
Cardiomyopathy†	0	3 (5)	0.323
Valvular heart disease			
Mitral valve prosthesis or repair*	5 (19)	11 (20)	0.904
Mitral stenosis (≥moderate severity)*	0	2 (4)	0.223
Aortic regurgitation (severe)*	0	0	
Previous documented AF*	0	4 (7)	0.496

All study participant demographic data divided by normal or filling defects on LAA on CT findings including clinical variables and embolic source risk factors. LAA filling defects include 13 thrombi and 14 spontaneous echo contrast.

LAA indicates left atrial appendage; CVA, cerebrovascular accident; EF, ejection fraction; AF, atrial fibrillation; SD, standard deviation.

*Predefined high risk factors for thrombus formation.

†Dilated cardiomyopathy combined with systolic dysfunction.

Results

Twenty-eight patients (34%) had AF during CCT and TEE examinations. However, the image quality of all of the CCT and TEE examinations was considered acceptable for the evaluation of intracardiac abnormalities.

The clinical characteristics of the 83 patients are summarized in Table 1. Clinical characteristics were not significantly different between patients with and without thrombus or SEC, except for those in AF. AF was more commonly observed in patients with thrombus or SEC on TEE. On TEE, there were a total of 13 thrombi combined with SEC and 14 SEC without thrombus. One thrombus was located in the left atrium and 12 were located in the LAA. CT detected 26 filling defects in the left atrium or LAA. Of these 26 lesions, 13 filling defects were diagnosed as thrombi combined with circulatory stasis and 13 as circulatory stasis without thrombus (Figures 2 and 3). All 13 thrombi coexistent with SEC were clearly detected by CT. One mild SEC diagnosed on TEE was missed by CT. Using TEE as the reference standard,

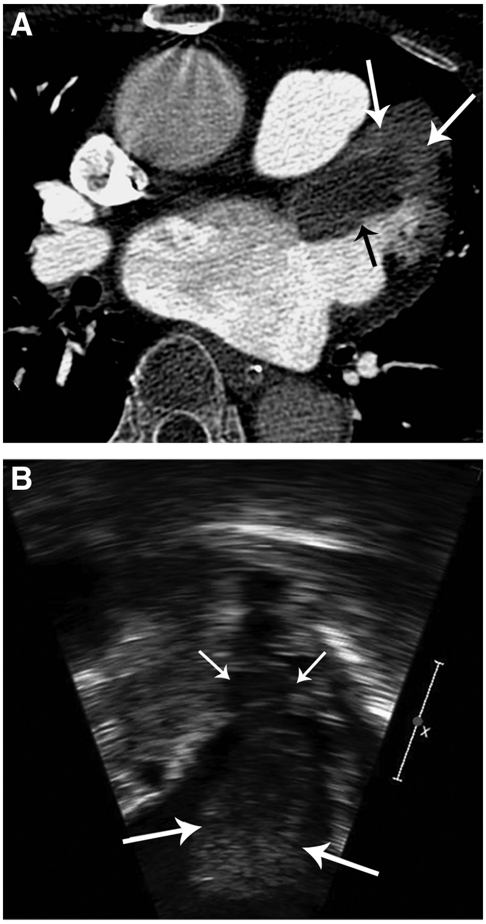

Figure 2. Cardiac CT (CCT) and transesophageal echocardiography (TEE) images from a 62-year-old woman with stroke and a left atrial appendage (LAA) thrombus. **A**, CT demonstrated an oval-shaped filling defect in the LAA (small arrow) with circulatory stasis (large arrows) just distal to the thrombus. A filling defect just distal to the thrombus caused by circulatory stasis showed higher attenuation density than thrombus. **B**, TEE image obtained 1 day after CCT. TEE demonstrated a thrombus (large arrow) with spontaneous echo contrast (SEC) just distal to the thrombus (small arrows).

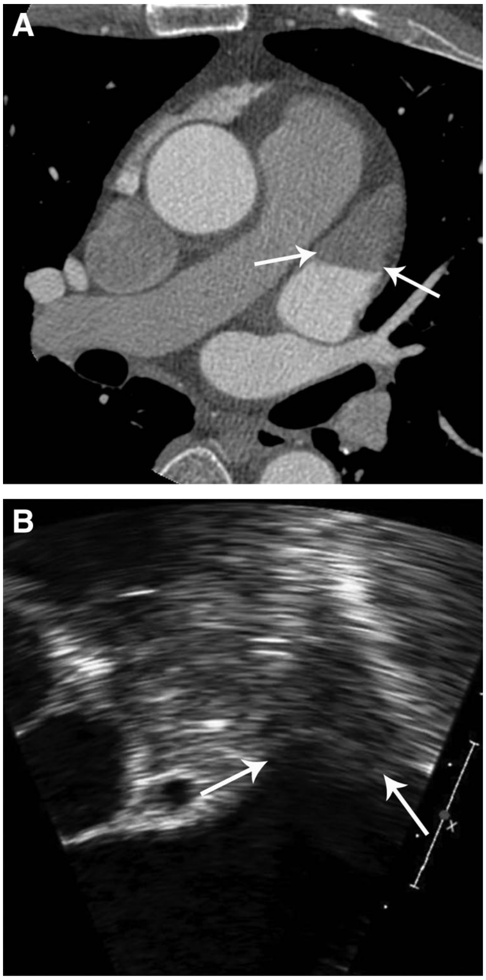

Figure 3. Cardiac CT (CCT) and transesophageal echocardiography (TEE) images from a 61-year-old man with stroke and spontaneous echo contrast (SEC). **A**, CT demonstrated triangular-shaped filling defects in the left atrial appendage (LAA; arrows) without an oval-shaped filling defect suggestive of thrombus. **B**, TEE image obtained 1 day after CCT. TEE demonstrated moderate SEC without any thrombus in the LAA (arrows).

the overall sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of CT for the detection of thrombi and circulatory stasis in the left atrium or LAA were 96% (95% CI, 78% to 99%), 100% (95% CI, 92% to 100%), 99% (95% CI, 93% to 100%), 100% (95% CI, 84% to 100%), and 98% (95% CI, 89% to 100%), respectively.

The concordance between detection of thrombus and SEC in the LAA with CT and TEE was high. Fifty-six patients had no thrombus or SEC on either CT or TEE; 13 patients had thrombus on both CT and TEE; 13 patients had SEC (without thrombus) on both CT and TEE; and 1 patient had SEC seen on TEE but not on CT (overall κ=0.975; Table 2). There were no patients with thrombus detected on TEE but not on CT. Of the 13 filling defects diagnosed correctly as thrombus by CT, combined circulatory stasis was categorized on TEE as severe SEC in 6 cases, moderate SEC in 4 cases, and mild SEC in 3 cases. Of the 13 filling defects diagnosed correctly as circulatory stasis without thrombus by CT, SEC was categorized on TEE as severe in 2 cases, moderate in 5 cases, and mild in 6 cases.

On CT, the mean LAA/AA HU ratios were 0.15±0.06 HU for thrombus, 0.27±0.09 HU for circulatory stasis, and 0.94±0.06 HU for normal (no thrombus or circulatory stasis). The mean LAA/AA HU ratios were significantly different between thrombus and circulatory stasis (P=0.001; Figure 4). However, the mean LAA/AA HU values for severe SEC

Table 2. Concordance Between CT and TEE for the Detection of Thrombus and SEC in the Left Atrial Appendage

	TEE		
CT Finding	Thrombus	SEC	No Thrombus
Thrombus*	13	0	0
Circulatory stasis†	0	13	0
No thrombus	0	1	56

TEE indicates transesophageal echocardiography; SEC, spontaneous echo contrast.

*Includes thrombus combined with circulatory stasis.

†Includes circulatory stasis without thrombus.

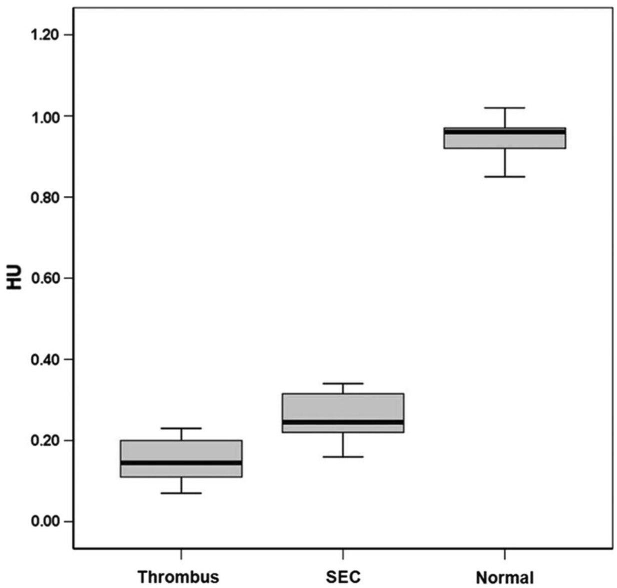

Figure 4. Box–whisker graph of CT density values (LAA/AA HU) of thrombus, spontaneous echo contrast, and normal groups. The lower and upper ends of the box represent the 25th and 75th percentiles, respectively, and the line across the box indicates the median. The whiskers range from the 5th to 95th percentile. LAA/AA indicates left atrial appendage/ascending aorta; HU, Hounsfield unit.

(0.20±0.03 HU), moderate SEC (0.25±0.08 HU), and mild SEC (0.34±0.11 HU) did not vary significantly among SEC grades determined by TEE ($P>0.05$). Receiver operating characteristic curve analysis of HU ratio measurements defined 0.2 as the best cutoff threshold value for separating thrombus from circulatory stasis. Using the cutoff value of 0.2, the overall sensitivity, specificity, positive predictive value, and negative predictive value of CT for the detection of thrombi in the left atrium or LAA were 85% (95% CI, 54% to 97%), 94% (95% CI, 84% to 97%), 73% (95% CI, 45% to 91%), and 97% (95% CI, 89% to 99%), respectively.

On TEE, the mean LAA-emptying velocities were 15.1±4.2 cm/s for thrombus, 22.2±6.5 cm/s for SEC, and 64.5±15.5 cm/s for normal (no thrombus or SEC). The mean LAA-emptying velocity was significantly different among the 3 groups ($P<0.001$). However, the mean LAA emptying velocity was not significantly different between thrombus and SEC ($P=0.462$). The LAA-emptying velocity was positively correlated with the mean LAA/AA HU values by CT ($r=0.841$).

There was good interobserver agreement for mean LAA/AA HU ratios for the thrombus, circulatory stasis, and normal groups ($r=0.897$, $r=0.861$, and $r=0.912$, respectively).

Discussion

This study was designed to examine the performance of the dual-enhanced single-phase CCT protocol in comparison with TEE for the detection of thrombus and differentiation between LAA thrombus and circulatory stasis in patients with stroke. This study demonstrates that the new protocol with prospective electrocardiographic gating is a noninvasive and sensitive modality for detecting LAA thrombus. Furthermore, this protocol can also differentiate between thrombus and circulatory stasis and has an acceptable radiation dose.

Thrombi of the left atrium (LA) and LAA are common sources of stroke, and because LA and LAA thrombi are treatable sources of embolism, the detection of thrombi may significantly affect patient management. Currently, TEE is considered the reference standard for the detection of intracardiac thrombus. However, TEE requires special skills for proper performance and interpretation. Additionally, it is a semi-invasive test, usually performed under conscious sedation.[4–6]

CT is a very sensitive modality for detection of intracardiac thrombus. However, CT can result in false-positive findings such as circulatory stasis, which is also seen as a filling defect on CT images. Therefore, CT is unable to visually distinguish 100% of circulatory stasis from definite thrombus, which results in reduced specificity.[7–9] Comparing TEE and CCT in 223 patients with AF, Kim et al[8] reported that the sensitivity, specificity, positive predictive value, and negative predictive value for the detection of severe SEC and thrombus using cardiac CT were 93%, 85%, 31%, and 99%, respectively. In our previous study[9] comparing 64-slice CCT and TEE in 101 patients, the sensitivity and specificity of 64-slice cardiac CT for the detection of thrombi in LAA were 100% and 96%. There were 4 false-positive filling defects on CT that were diagnosed as SEC by TEE. It is known that further assessment with delayed imaging of the LAA after 1 to 2 minutes can improve the specificity for distinguishing circulatory stasis from thrombus.[10] However, with this 2-phase protocol, the radiation exposure to the patients increased.

We developed a new dual-enhanced single-phase protocol using prospective electrocardiographic gating for detection of intracardiac thrombus and for simultaneously distinguishing thrombus from circulatory stasis. We used prospective electrocardiographic gating to reduce the radiation dose, and this protocol used double injection of the contrast agent. The scan was performed only 1 time on a delayed phase, 180 seconds, after giving the first contrast bolus. The double injection protocol was performed for differentiation between thrombus and circulatory stasis. Because it is difficult to differentiate LAA thrombus from circulatory stasis during the first pass of contrast, we hypothesized that a double injection of contrast might be able to delineate these 2 phenomena with more certainty because a thrombus and circulatory stasis would have a different attenuation density on delayed phase scanning due to the contrast enhancement of the first contrast bolus. To achieve a sufficient attenuation density difference between thrombus and circulatory stasis on the delayed phase scanning, we used 50 mL of contrast agent for first bolus injection.

In our study, the new CCT protocol showed high sensitivity (96%) and high specificity (100%) in thrombus and circulatory stasis detection in the LA/LAA in patients with stroke as compared with TEE. We had 1 false-negative finding on CT, which was diagnosed as mild SEC on TEE. Because of the time interval between the 2 modalities, the presence or severity of atrial fibrillation could affect this result. However, 13 thrombi and moderate/severe SEC were all correctly detected on CT. Additionally, using this protocol, the mean LAA/AA HU ratios were significantly different between thrombus and circulatory stasis ($P=0.001$). These results suggest that the new CCT protocol is not only useful for the detection of thrombus, but also useful for differentiation between thrombus and circulatory stasis. However, when we used the best cutoff value of 0.2 HU ratios and calculated the overall sensitivity and specificity of CT for the detection of thrombi, CT showed lower sensitivity (85%) and specificity (94%) compared with visual analysis. This result suggests that quantitative analysis using LAA/AA HU ratios is insufficient for accurate differentiation between thrombus and circulatory stasis.

LAA dysfunction, which is associated with AF in many cases, is also commonly accompanied by SEC.[21,22] It is known that LA and LAA SEC are caused by local blood stasis, which is associated with a high incidence of thrombus formation and thromboembolic events.[23,24] Fatkin et al[24] demonstrated that significant LAA dysfunction is similarly associated with LAA thrombus formation and the degree of LAA SEC is negatively associated with LAA-emptying velocities. In our study, the mean LAA-emptying velocity was significantly different among the thrombus, SEC, and normal groups ($P<0.001$). However, the mean LAA-emptying velocity was not significantly different between the thrombus and SEC groups ($P=0.462$).

We evaluated whether any quantitative value on CT can predict LAA function. For that purpose, we calculated the mean LAA/AA HU ratios on CT images. We hypothesized that by using a quantitative measurement of HU within the LAA relative to a reference point, we would be able to evaluate LAA function by CT. Our data revealed that the mean LAA/AA HU ratios were strongly correlated with the LAA-emptying velocity measured by TEE ($r=0.841$). However, our quantitative analysis showed that CT, as compared with TEE, could not differentiate the severity of SEC. This finding suggests that LAA/AA HU values can indirectly predict the function of the LA and LAA but are insufficient for accurate characterization of the SEC severity in the LA and LAA.

TEE is not only the imaging method of choice for the detection of LAA thrombus or SEC, but is also able to detect cardioembolic sources such as patent foramen ovale, valvular vegetations, or mobile thrombi in the aorta. In addition, in contrast to CT, TEE can be performed in patients with renal dysfunction or an allergy to contrast media. However, TEE is a semi-invasive test. Furthermore, evaluation of SEC and thrombus involves individual judgment that is reader-dependent. Therefore, in clinical practice, a less invasive modality that is capable of assessing for intracardiac thrombus in the setting of embolic stroke is desirable. For that purpose, we believe that CCT with the new protocol we describe in this study can be used as an alternative modality for detecting thrombus in selected patients with stroke, because it has high diagnostic accuracy for the detection of intracardiac thrombus, can distinguish SEC from thrombus, and is a noninvasive and reproducible modality.

Our study had several limitations. First, we did not perform the 2 examinations on the same day. All examinations to evaluate for intracardiac thrombus were performed within a 3-day period. Second, because of the double injection of contrast agent, we used a total of 120 mL of contrast agent, which is a much larger than is usually used for current CCT protocol. However, we believe this amount is acceptable for patients with normal renal function. In our study, the mean blood urea nitrogen and creatinine of the 83 patients with stroke were 15.3 mg/dL (range, 7.4 to 19.8 mg/dL) and 0.91 mg/dL (range, 0.67 to 1.19 mg/dL), respectively. There were no renal complications after the CT examinations. A further limitation was radiation exposure. To reduce the radiation dose, we used a prospective electrocardiographic gating technique and the calculated mean radiation dose was 3.11 mSv. In patients with stroke, when brain CT and CCT are applied to the same patients, the radiation exposure could be increased. Although a small amount of radiation exposure is inevitable, we believe that this protocol provides a means of detecting and ruling out potential intracardiac thrombus in selected patients with stroke and has an acceptable radiation dose.

Conclusions

Dual-enhanced single-scan CCT with prospective electrocardiographic gating is a noninvasive and sensitive modality for detecting LAA thrombus and has an acceptable radiation dose. Furthermore, this protocol can also differentiate between thrombus and circulatory stasis. Therefore, we believe that the new CCT protocol using prospective electrocardiographic gating may be clinically useful for detecting and ruling out intracardiac thrombus in patients at risk for cardioembolic stroke and may pose an alternative diagnostic tool to TEE.

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Disclosures

None.

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Abstract

脳卒中患者における左心耳内血栓検出のための二重造影心臓 CT ― 経食道心エコー法との前向き比較試験

Dual-Enhanced Cardiac CT for Detection of Left Atrial Appendage Thrombus in Patients With Stroke ― A Prospective Comparison Study With Transesophageal Echocardiography

Jin Hur, MD[1]; Young Jin Kim, MD[1]; Hye-Jeong Lee, MD[1]; Ji Eun Nam, MD[1]; Jong-Won Ha, MD[2]; Ji Hoe Heo, MD[3]; Hyuk-Jae Chang, MD[2]; Hua Sun Kim, MD[1]; Yoo Jin Hong, MD[1]; Hee Yeong Kim, MD[1]; Kyu Ok Choe, MD[1]; Byoung Wook Choi, MD, PhD[1]

[1] Department of Radiology, Department of Cardiovascular Radiology, Research Institute of Radiological Science, Yonsei University College of Medicine, Seoul, South Korea; [2] Division of Cardiology, Yonsei Cardiovascular Center, Yonsei University College of Medicine, Seoul, South Korea; and [3] Department of Neurology, Severance Hospital, Yonsei University College of Medicine, Seoul, South Korea

背景および目的：左心耳内血栓を同定するための，経食道心エコー法に匹敵する高い信頼性と精度を備えた非侵襲的方法は，臨床的に重要な価値があると考えられる。本研究の目的は，脳卒中患者の左心耳内血栓を検出し，血栓と血流うっ滞を識別するための二重造影心臓 CT プロトコル[注)]の診断性能を評価することであった。

方法：血栓形成の高い危険因子を有する脳卒中患者で，二重造影 CT と経食道心エコーの検査間隔が 3 日以内の連続患者 83 例（男性 56 例，女性 27 例，平均年齢 62.6 歳）を被験者とした。前向き心電図同期法を用いて CT を実施し，造影剤テストボーラス投与から 180 秒後に撮造を開始した。

結果：経食道心エコー法により，患者 83 例のうち合計 13 例に血栓ともやもやエコー，14 例にもやもやエコーが認められた。13 例の血栓ともやもやエコーはいずれも，CT 上で正しく診断された。経食道心エコー法を基準とした場合，CT による左心耳内血栓および血流うっ滞検出の全般的感度は 96％（95％ CI：78 ～ 99％），特異度は 100％（95％ CI：92 ～ 100％）であった。CT 上の左心耳と上行大動脈の Hounsfield 単位の平均値の比は，血栓と血流うっ滞で有意に異なっていた（それぞれ 0.15 Hounsfield 単位，0.27 Hounsfield 単位，$p = 0.001$）。平均実効線量は 3.11 mSv であった。

結論：前向き心電図同期法を用いた二重造影心臓 CT は，許容範囲内の線量で左心耳内血栓を検出できる高感度の非侵襲的撮像法である。

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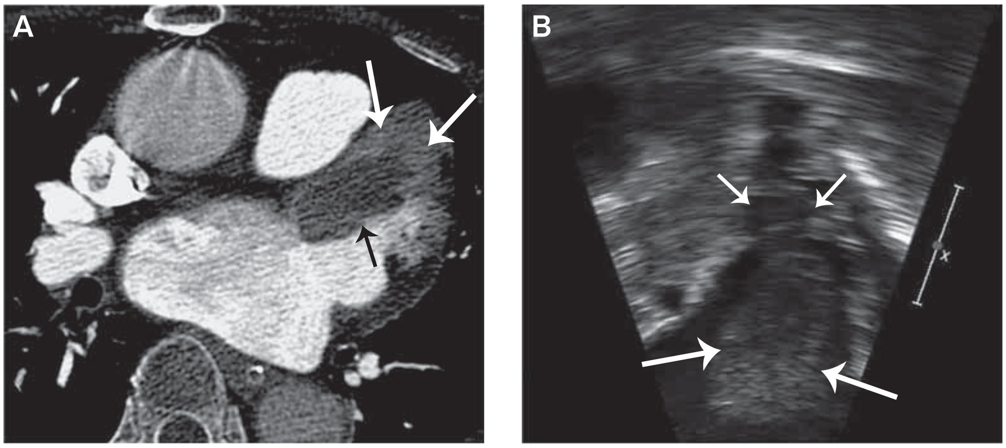

図 2 左心耳（LAA）内血栓を有する 62 歳の脳卒中女性患者の心臓 CT（CCT）画像および経食道心エコー（TEE）画像。A：CT では，LAA 内に楕円形の陰影欠損（小さい矢印）と，血栓遠位部に隣接して血流うっ滞（大きい矢印）が認められた。血栓遠位部に隣接する，血流うっ滞によって生じた陰影欠損は，血栓に比べて減衰濃度が大きかった。B：CCT の翌日に収集した TEE 画像。血栓（大きい矢印）と，血栓遠位部に隣接するもやもやエコー（SEC；小さい矢印）が認められる。

注：この手法では 180 秒間隔で造影剤が 2 回投与される。