Stroke

CLINICAL AND POPULATION SCIENCES

Detection of Cardioembolic Sources With Nongated Cardiac Computed Tomography Angiography in Acute Stroke: Results From the ENCLOSE Study

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BACKGROUND: Identifying cardioembolic sources in patients with acute ischemic stroke is important for the choice of secondary prevention strategies. We prospectively investigated the yield of admission (spectral) nongated cardiac computed tomography angiography (CTA) to detect cardioembolic sources in stroke.

METHODS: Participants of the ENCLOSE study (Improved Prediction of Recurrent Stroke and Detection of Small Volume Stroke) with transient ischemic attack or acute ischemic stroke with assessable nongated head-to-heart CTA at the University Medical Center Utrecht were included between June 2017 and March 2022. The presence of cardiac thrombus on cardiac CTA was based on a Likert scale and dichotomized into certainly or probably absent versus possibly, probably, or certainly present. The diagnostic certainty of cardiac thrombus was evaluated again on spectral computed tomography reconstructions. The likelihood of a cardioembolic source was determined post hoc by an expert panel in patients with cardiac thrombus on CTA. Parametric and nonparametric tests were used to compare the outcome groups.

RESULTS: Forty four (12%) of 370 included patients had a cardiac thrombus on admission CTA: 35 (9%) in the left atrial appendage and 14 (4%) in the left ventricle. Patients with cardiac thrombus had more severe strokes (median National Institutes of Health Stroke Scale score, 10 versus 4; P=0.006), had higher clot burden (median clot burden score, 9 versus 10; P=0.004), and underwent endovascular treatment more often (43% versus 20%; P<0.001) than patients without cardiac thrombus. Left atrial appendage thrombus was present in 28% and 6% of the patients with and without atrial fibrillation, respectively (P<0.001). The diagnostic certainty for left atrial appendage thrombus was higher for spectral iodine maps compared with the conventional CTA (P<0.001). The presence of cardiac thrombus on CTA increased the likelihood of a cardioembolic source according to the expert panel (P<0.001).

CONCLUSIONS: Extending the stroke CTA to cover the heart increases the chance of detecting cardiac thrombi and helps to identify cardioembolic sources in the acute stage of ischemic stroke with more certainty. Spectral iodine maps provide additional value for detecting left atrial appendage thrombus.

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Key Words: angiography ▪ atrial fibrillation ▪ heart ▪ humans ▪ iodine ▪ stroke

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Nonstandard Abbreviations and Acronyms

AF	atrial fibrillation
AIS	acute ischemic stroke
ASPECTS	Alberta Stroke Program Early CT Score
CT	computed tomography
CTA	computed tomography angiography
CTP	computed tomography perfusion
DOAC	direct oral anticoagulant
ENCLOSE	Improved Prediction of Recurrent Stroke and Detection of Small Volume Stroke
LAA	left atrial appendage
LV	left ventricle
NCCT	noncontrast computed tomography
TEE	transesophageal echocardiography
TIA	transient ischemic attack
TOAST	Trial of ORG 10172 in Acute Stroke Treatment
VKA	vitamin K antagonist

The recurrence risk in patients with transient ischemic attack (TIA) or acute ischemic stroke (AIS) depends on the etiology.[1] Around one-third of AIS cases are caused by cardioembolism, requiring a different strategy for secondary prevention than an atherosclerotic cause of stroke.[2] In a quarter of the cases, the etiology of the stroke remains unknown (ie, cryptogenic stroke). Occult atrial fibrillation (AF) might explain some cryptogenic strokes, and these patients may need anticoagulant therapy instead of oral antiplatelet therapy.[3] Identifying these patients remains difficult with current cardiologic investigations including ECG, telemetry, Holter, loop recorder, and transthoracic echocardiography or transesophageal echocardiography (TEE).[4,5] Echocardiography is often performed days later, which may influence the chance of detecting cardiac thrombus after intravenous thrombolysis. TEE has a higher sensitivity than transthoracic echocardiography for left atrial appendage (LAA) thrombus but a lower sensitivity for left ventricular (LV) thrombus and is semi-invasive, time-consuming, and patient unfriendly.[6] Computed tomography angiography (CTA) may be a noninvasive alternative with superior visualization of the LAA and LV.

Patients with AIS routinely undergo CTA from head to the aortic arch to visualize the intracranial and extracranial arteries. The heart and aorta are not routinely covered with CTA although both are potential causes of stroke.[7] Studies have demonstrated that integrating cardiac CTA into the admission stroke imaging protocol is a promising alternative to echocardiography, but these studies were small, heterogeneous, and retrospective.[8] In addition, a previous study showed that dual-energy computed tomography (CT) has additional value compared with conventional single source CT.[9] With spectral or dual-energy CT high and low energy data are acquired with different approaches, enabling reconstruction of spectral images, including virtual monoenergetic images, iodine maps, and effective atomic number (Z effective) maps.[10,11] In a previous study, iodine maps helped to distinguish between cardiac thrombus and slow flow in the LAA.[9] Large prospective studies are needed to confirm the additional value of implementing spectral cardiac CTA into the admission stroke imaging protocol. With the ENCLOSE study (Improved Prediction of Recurrent Stroke and Detection of Small Volume Stroke), we investigated the yield of admission spectral nongated cardiac CTA for identifying cardioembolic sources of stroke in a consecutive series of patients with AIS.

METHODS

Data Availability

Source data will not be made available, since no patient approval was obtained for sharing anonymized data. However, detailed analytic methods and study materials will be available to other researchers upon reasonable request.

Study Design

Patients were selected from the ENCLOSE study (https://www.clinicaltrials.gov; unique identifier: NCT04019483)—a prospective observational cohort study in the University Medical Center Utrecht and Amsterdam University Medical Center, the Netherlands. The rationale and design of ENCLOSE have been described before.[12] In short, consecutive patients with TIA or AIS who underwent noncontrast CT (NCCT), CT perfusion (CTP), and CTA were included between June 2017 and March 2022. This study was reported according to Strengthening the Reporting of Observational Studies in Epidemiology guidelines for reporting observational studies.[13]

Patient Selection

All patients with suspected TIA or AIS undergo nongated head-to-heart CTA as part of standard care at the University Medical Center Utrecht. Inclusion criteria for ENCLOSE were age ≥18 years, clinical diagnosis of TIA or AIS, and admission CT within 9 hours from symptom onset or last seen well. Patients without an assessable cardiac CTA were excluded.

Ethics Approval and Data Availability

The ENCLOSE study was approved by the Medical Ethics Committee of the University Medical Center Utrecht. Written informed consent was obtained from the patient or the legal representative.

Data Collection

Demographics, medical history, stroke characteristics, and use of antiplatelet, direct oral anticoagulant (DOAC), or vitamin K antagonist (VKA; dichotomized into <2 and ≥2 international normalized ratio) were registered. Stroke etiology was determined by the treating neurologist with the TOAST (Trial of ORG 10172 in Acute Stroke Treatment) classification.[14] Evaluation of cardioembolic sources such as echocardiography was performed in case of cryptogenic stroke or suspected cardioembolic source.

Imaging Acquisition

In the acute stage, all patients underwent NCCT, CTP, and nongated head-to-heart CTA (Brilliance iCT-256, IQon Spectral CT, or Spectral CT 7500; Philips Healthcare, Best, the Netherlands) without increasing the iodine contrast agent dose used for standard stroke head-to-arch CTA. The CT parameters have been described before.[12] For spectral CT, extra 1-mm spectral CTA maps (monoenergetic 40 keV maps, iodine maps, and Z effective) were reconstructed.

Imaging Analysis

The quality of the cardiac CTA was graded with a 5-point Likert scale—very poor (nondiagnostic)—poor—moderate—good—excellent—based on the level of noise, motion artifacts, and cardiac blood pool attenuation.[15] Possible findings related to cardioembolic sources of stroke were evaluated on the nongated cardiac CTA including left atrial abnormalities (thrombus, patent foramen ovale, atrial septum defect, atrial septum aneurysm, and LAA morphology), ventricular abnormalities (thrombus, ventricular septum defect, myocardial ischemia, cardiomyopathy, LV aneurysm, and cardiac tumor), aortic or mitral valve abnormalities (noncalcified thickening, calcifications, prosthetic valve, and endocarditis), coronary artery calcifications, and abnormalities of the ascending aorta and aortic arch (dissection and plaque characteristics). Thrombus was distinguished from slow flow and was defined as a homogeneous, hypodense filling defect with a clear border and low CT value (<100 HU) on standard CTA.[16] The presence of cardiac thrombus was based on a 5-point Likert scale and dichotomized into certainly absent or probably absent versus possibly, probably or certainly present. LAA morphologies were categorized as chicken wing, windsock, cauliflower, or cactus.[17] Myocardial ischemia was assessed on cardiac CTA with the 5-point Likert scale and was defined as subendocardial curvilinear low attenuation. Coronary calcifications were graded on a 4-point scale: absent, mild (minimal calcification), moderate (moderate calcification, up to 2 vessels), and severe (severe calcification in 1 vessel or moderate in all 3 vessels). Ascending aorta and aortic arch plaques were characterized by evaluating low attenuation plaque (<30 HU) as an indicator of a lipid-rich core, irregular surface, and ulceration (>2 mm).

Early ischemic changes on brain NCCT and perfusion defects on CTP were graded with the Alberta Stroke Program Early CT Score (ASPECTS).[18] Early ischemic changes in the posterior circulation were graded with the posterior circulation ASPECTS.[19] ASPECTS and posterior circulation ASPECTS range from 0 to 10, and 1 or 2 points were subtracted for every ASPECTS or posterior circulation ASPECTS area involved. The presence of old infarcts was also assessed on NCCT. Anterior circulation occlusions were graded with the clot burden score and posterior circulation occlusions with the Basilar Artery on CTA score.[20,21] Both scores range from 0 to 10, and 1 or 2 points were subtracted for every occluded vessel segment.

The 3 spectral CT reconstructions (monoenergetic 40 keV map, iodine map, and Z-effective map) were assessed after the standard CTA image assessment for change in diagnostic certainty for the presence of LAA or LV thrombus.

Cardiac imaging assessments were done by a senior radiology resident with 10 years of cardiac imaging experience (R.A.P.T.) and a radiologist specialized in cardiovascular and neurovascular imaging with 20 years of experience (B.K.V.). The first 24 patients were assessed by both observers to align evaluation methods. The brain imaging assessments were done by a radiologist specialized in stroke imaging with 15 years of experience (J.W.D.). The observers were blinded for clinical data.

Outcome Measures

The primary outcome was the presence of cardiac thrombus on admission nongated cardiac CTA.

The secondary outcome was the diagnostic certainty of cardiac thrombus evaluated on the spectral CT reconstructions.

The tertiary outcome was the likelihood of a cardioembolic source of the stroke determined by a panel of experts. A reference standard for the detection of a cardioembolic source of the stroke does not exist, in which case a panel diagnosis can serve as the reference standard.[22] The advantage of a panel diagnosis is that it closely reflects decision-making in clinical practice. A panel of experts, including 2 radiologists (J.W.D. and B.K.V.) and 2 cardiologists (M.J.C. and M.G.) with, respectively, 20 and 8 years of experience, was consulted. After patient discharge, all available clinical and imaging data from patients with a cardiac thrombus were presented by a neutral member (F.K.) with the aim to reach a consensus diagnosis by discussion. The panel rated the likelihood of a cardioembolic source of the stroke with 4 categories: certainly absent, possibly present, probably present, and certainly present. The panel also decided whether referral to the cardiologist was indicated. Staged unblinding, exposing the clinical and imaging data in 2 phases to the panel, was used to avoid incorporation bias. In each phase, the panel needed to reach consensus on the diagnosis and referral. In phase 1, the clinical characteristics, the admission ECG, and the admission NCCT, CTP, and CTA without the cardioaortic part were presented to the panel. In phase 2, directly following the decision in phase 1, the additional admission nongated cardiac CTA was presented. The difference in the determined likelihood of a cardioembolic source of the stroke between phase 1 and 2 served as outcome.

Another outcome was AF, which was the history of AF (previously known paroxysmal, persistent, or permanent AF) or newly detected AF with ECG, telemetry, or Holter during admission or 90-day follow-up.

Other outcomes included echocardiography findings within 90 days after the index event, changes in oral anticoagulant medication, 90-day recurrence, and functional outcome, which was determined with the modified Rankin Scale 90 days after the stroke by a trained research nurse (Supplemental Results).

Statistical Analysis

Frequencies and means or medians were reported for baseline characteristics and findings on admission nongated cardiac CTA (descriptive analysis). Complete case analysis was performed because few missing values were expected.

Parametric and nonparametric tests were used to compare the groups with and without the primary outcome. The secondary and tertiary outcomes were analyzed with the χ^2 test. A *P* value <0.05 was considered statistically significant. The analyses were performed with R: a language and environment for statistical computing, version 3.5.1 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Descriptive Analysis

Of the 389 patients who participated in ENCLOSE, 370 (68 with TIA and 302 with AIS) were included with an assessable cardiac CTA (Figure 1). The LV was not fully displayed in 17 patients. Mean age was 67±14 years, and 61% were male (Table 1). The quality of the admission nongated cardiac CTA was poor in 34 (9%), moderate in 74 (20%), good in 161 (44%), and excellent in 101 (27%) patients (Table S1). Poor and moderate quality of the CTA was mainly due to limited cardiac blood pool attenuation. In 44 (12%) patients, a possible, probable, or certain cardiac thrombus was detected: 35 (9%) had a thrombus in the LAA (none in the LA) and 14 (4%) in the LV, of which 5 (1%) in both. One additional patient had a thrombus in an LV assist device (not counted as a primary outcome). Cardiac thrombus was found in 7 (10%) of the 68 TIA patients; this proportion did not differ from the AIS group (13%; *P*=0.647). Possible, probable, or certain myocardial ischemia was present in 97 (27%) patients. Other relevant findings (Table S1) included moderate-to-severe coronary calcification (n=189; 51%), aortic dissection (n=7; 2%), ascending aorta plaque (n=61; 17%), and aortic arch plaque (n=157; 43%). In, respectively, the ascending aorta and aortic arch plaques, 5% versus 6% had a low attenuation plaque; 10% versus 41%, an irregular surface; and 2% versus 9%, an ulceration.

Cardiac Thrombus

Patients with a cardiac thrombus on CTA were older (mean, 71 versus 64; *P*=0.046), had higher National Institutes of Health Stroke Scale score (median, 10 versus 4; *P*=0.006), had lower CTP ASPECTS score (median, 7 versus 10; *P*=0.004), had lower clot burden score (median, 9 versus 10; *P*=0.004), and underwent endovascular treatment more often (43% versus 20%; *P*<0.001) compared with patients without a cardiac thrombus (Table 1). Patients with cardiac thrombus more often had a medical history of myocardial infarction (25% versus 11%; *P*=0.007), AF (43% versus 13%; *P*<0.001), and VKA use (27% versus 6%; *P*<0.001) compared with patients without a cardiac thrombus. The results were comparable for the 35 patients with LAA thrombus (Table S2). Seventeen (49%) of these 35 patients had a history of AF, and 13 (37%) used oral anticoagulation: 9, a VKA and 4, a DOAC (Table S3). Six (17%) of the 35 patients with LAA thrombus had a TIA at baseline, 3 with a history of AF (2 with VKA and 1 with DOAC use) and 1 with AF during follow-up. Of the 309 patients without a history of AF, 18 (6%) had LAA thrombus (Table S3). In addition, of the 301 patients who did not use oral anticoagulation, 22 (7%) had LAA thrombus, whereas 13 (19%) of the 69 patients with anticoagulation use had LAA thrombus. LAA morphology differed between patients with and without AF (Table S4). Patients with LV thrombus more often had an LV aneurysm (29% versus 2%; *P*<0.001), previous myocardial ischemia (77% versus 26%; *P*<0.001), and dilated cardiomyopathy (43% versus 5%; *P*<0.001) compared with patients without an LV thrombus (Table S5).

Spectral CT

Spectral cardiac CTA acquisitions were acquired in 271 (73%) patients (Table S6). The observers mostly found no difference in usefulness of the 3 spectral reconstructions, but they found iodine maps more useful in patients with cardiac thrombus than in patients without cardiac thrombus (50% versus 17%, respectively; *P*<0.001). In addition, the diagnostic certainty for LAA thrombus was higher for iodine maps (Table S7) compared with the conventional CTA (*P*<0.001). Example cases are shown in Figures 2 and 3.

Panel Diagnosis

All patients (n=44) with possible to certain presence of cardiac thrombus on CTA were presented to the expert panel. The likelihood of a cardioembolic source of the stroke significantly increased after the cardiac CTA was presented to the panel (Table 2; *P*<0.001).

DISCUSSION

The main findings of this prospective study included detection of cardiac thrombi with admission nongated head-to-heart CTA in 12% of the patients with TIA or AIS. A medical history of myocardial infarction, AF, or VKA use were associated with the presence of cardiac thrombus on CTA. Spectral iodine maps improved the diagnostic certainty of LAA thrombus. Presence of any cardiac thrombus was associated with higher stroke severity and a higher clot burden resulting in a higher rate of endovascular treatment and a higher 90-day modified Rankin Scale score. According to an expert panel, the additional information provided by the admission nongated cardiac CTA helped significantly to diagnose cardioembolic stroke.

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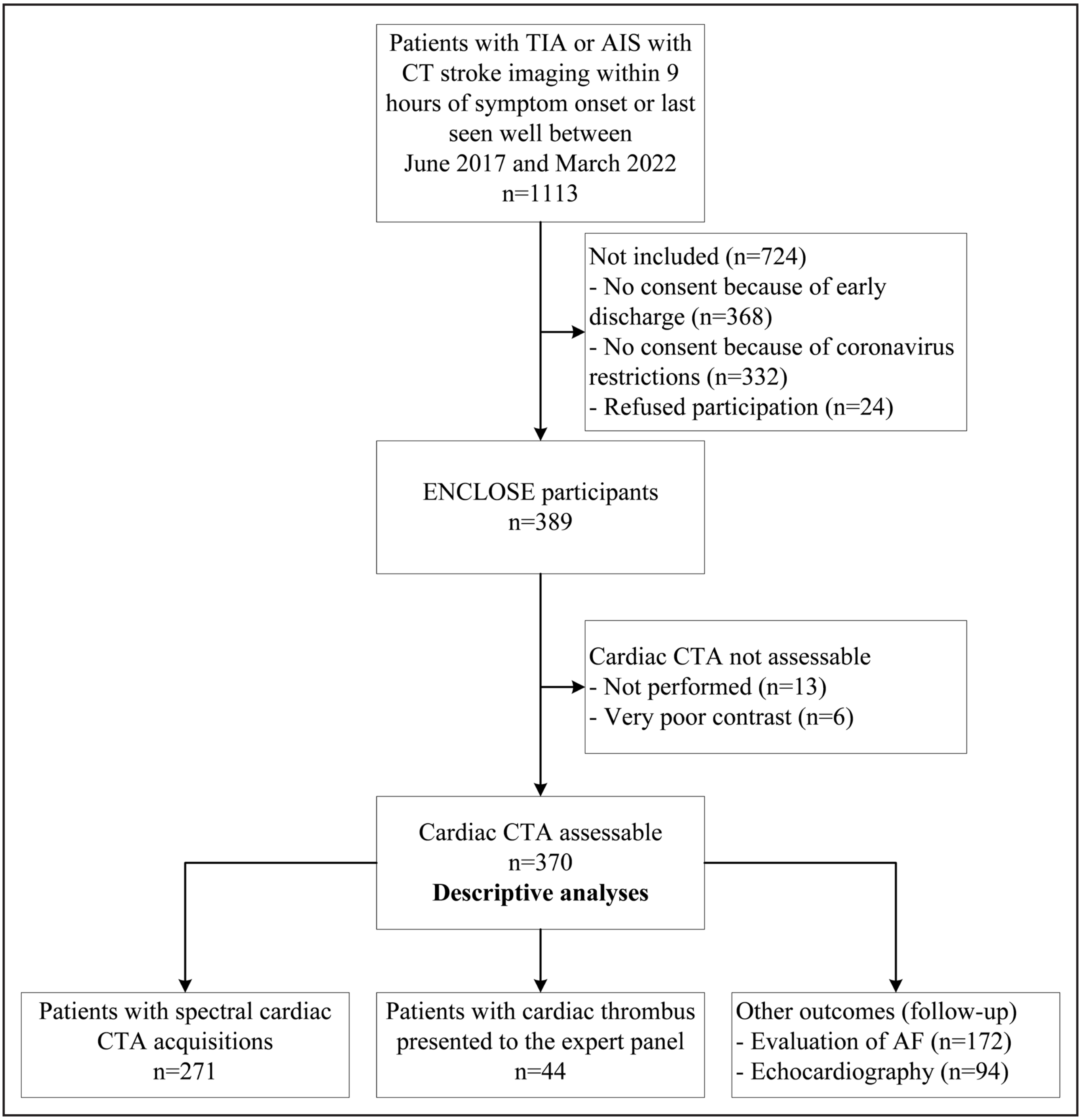

Figure 1. Flowchart of patient selection.

AF indicates atrial fibrillation; AIS, acute ischemic stroke; CT, computed tomography; CTA, computed tomography angiography; ENCLOSE, Improved Prediction of Recurrent Stroke and Detection of Small Volume Stroke; and TIA, transient ischemic attack

Clinical Perspective

Early detection of a cardioembolic source of stroke can help to initiate proper prophylactic treatment. In our study, 6% of the patients without AF and 7% of the patients without oral anticoagulation had LAA thrombus, and most patients either started or continued with a DOAC or a VKA after a thrombus was detected. About one-third of the patients with LAA thrombus and a history of AF did not use oral anticoagulation. Almost one-fifth of the patients with oral anticoagulation use had LAA thrombus. The use of VKA was associated with the presence of LAA thrombus, which could not be fully explained by low international normalized ratio values (<2). Conversely, DOAC use was not associated with LAA thrombus, which is compatible with previous studies that showed that DOAC use is more effective for preventing stroke or systemic embolism than VKA use in patients with AF.[23] Taken together, our results may impact both patients with and without known AF or oral anticoagulation use, but prevention strategies and prediction of recurrence need further evaluation.

Table 1. Patient Characteristics Stratified by Cardiac Thrombus on Admission Nongated Cardiac CT Angiography

Characteristic, n (%)	Total, N=353	Thrombus*, n=44 (12)	No thrombus, n=309 (88)	*P* value
Age, y; mean±SD	67±14	71±14	67±14	0.046
Male sex	214 (61)	28 (64)	186 (60)	0.662
Admission NIHSS, median (Q1–Q3)	4 (1–12)	10 (3–17)	4 (1–10)	0.006
Intravenous thrombolysis	127 (36)	16 (36)	111 (36)	0.954
Endovascular treatment	80 (23)	19 (43)	61 (20)	<0.001
TOAST classification				<0.001
Large vessel disease	73 (21)	6 (14)	67 (22)	
Cardioembolism	84 (24)	27 (61)	57 (18)	
Small vessel disease	54 (15)	3 (7)	51 (17)	
Other	47 (13)	2 (5)	45 (15)	
Undetermined	95 (27)	6 (14)	89 (29)	
Medical history				
Ischemic stroke	46 (13)	9 (20)	37 (12)	0.118
TIA	51 (14)	3 (7)	48 (16)	0.124
Myocardial infarction	44 (12)	11 (25)	33 (11)	0.007
Angina pectoris	10 (3)	1 (2)	9 (3)	0.811
AF	58 (16)	19 (43)	39 (13)	<0.001
Coronary intervention	17 (5)	2 (5)	15 (5)	0.929
Coronary surgery	22 (6)	3 (7)	19 (6)	0.864
Peripheral artery disease	12 (3)	2 (5)	10 (3)	0.654
Malignancy	69 (20)	6 (14)	63 (20)	0.291
Hypertension	181 (51)	22 (50)	159 (51)	0.857
Hyperlipidemia	112 (32)	15 (34)	97 (31)	0.719
Diabetes type 2	52 (15)	6 (14)	46 (15)	0.827
Smoking				0.294
Current smoking	75 (24)	9 (24)	66 (24)	
Previous smoking	106 (34)	9 (24)	97 (35)	
Never smoked	132 (42)	20 (53)	112 (41)	
Drug use				
Antiplatelet	108 (31)	14 (32)	94 (30)	0.851
VKA	29 (8)	12 (27)	17 (6)	<0.001
International normalized ratio ≥2	18 (64)	7 (58)	11 (69)	0.569
DOAC	36 (10)	4 (9)	32 (10)	0.795
Antihypertensive medication	181 (51)	26 (59)	155 (50)	0.268
Lipid-lowering medication	126 (36)	18 (41)	108 (35)	0.440
Antidiabetic medication	48 (14)	5 (11)	43 (14)	0.644
Brain CT findings				
NCCT ASPECTS, median (Q1–Q3)	10 (10–10)	10 (9–10)	10 (10–10)	0.136
NCCT pc-ASPECTS	10 (10–10)	10 (10–10)	10 (10–10)	0.799
NCCT old infarcts	143 (41)	18 (41)	125 (40)	0.954
CTP ASPECTS	10 (6–10)	7 (4–10)	10 (6–10)	0.004
CTP pc-ASPECTS	10 (10–10)	10 (10–10)	10 (10–10)	0.682
Clot burden score	10 (9–10)	9 (7–10)	10 (9–10)	0.004
BATMAN score	10 (10–10)	10 (10–10)	10 (10–10)	0.541

AF indicates atrial fibrillation; ASPECTS, Alberta Stroke Program Early CT Score; BATMAN, Basilar Artery on Computed Tomography Angiography; CT, computed tomography; CTP, computed tomography perfusion; DOAC, direct oral anticoagulant; NCCT, noncontrast computed tomography; NIHSS, National Institutes of Health Stroke Scale; pc-ASPECTS, posterior circulation Alberta Stroke Program Early CT Score; TIA, transient ischemic attack; TOAST, Trial of ORG 10172 in Acute Stroke Treatment; and VKA, vitamin K antagonist.

*Possible to certain presence.

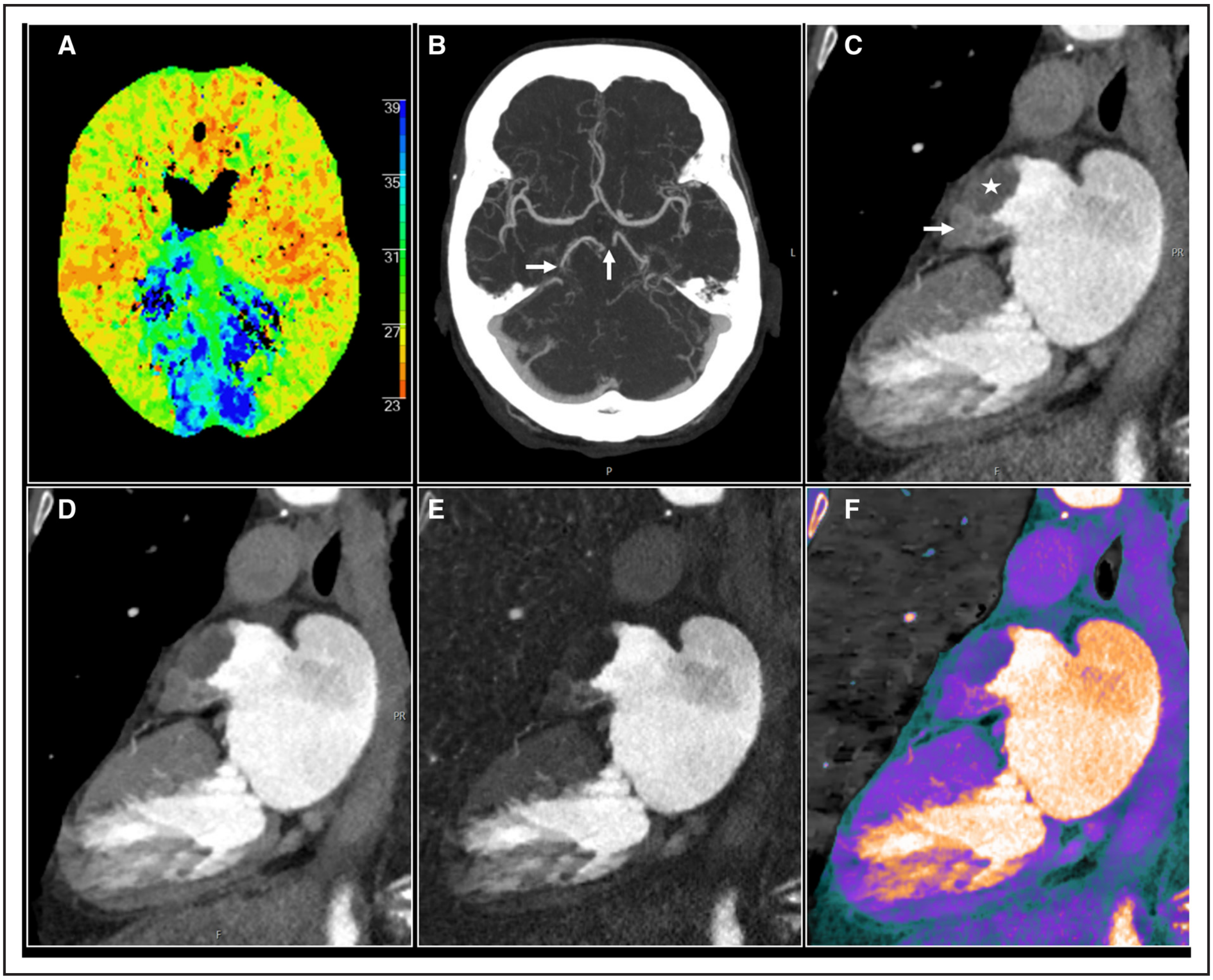

Figure 2. A 71-year-old male patient with loss of consciousness (E1M2V1; National Institutes of Health Stroke Scale score, 36), previous myocardial infarction without anticoagulant or antiplatelet medication, and atrial fibrillation de novo.
Computed tomography (CT) perfusion showed bioccipital and right thalamic perfusion defects (**A**). CT angiography showed left P1 and right P2 segment occlusions of the posterior cerebral arteries (arrows in **B**) and thrombus (star) combined with slow-flow phenomenon (arrow) in the left atrial appendage on sagittal reconstruction (**C**). The thrombus is homogeneous (attenuation, 51±14 HU) versus inhomogeneous slow flow (attenuation, 131±23 HU). Spectral CT reconstructions include monoenergetic 40 keV (**D**), iodine map (**E**), and Z effective (**F**). The iodine concentration (**E**) is 0.25±0.6 mg/mL in the thrombus versus 2.56±1 mg/mL in the slow flow.

Admission nongated cardiac CTA also helps detect other cardiac abnormalities such as LV aneurysm, myocardial ischemia, and cardiomyopathy, which are also associated with LV thrombus formation. Plaque in the ascending aorta or aortic arch may be the cause of stroke in patients with cryptogenic stroke.[24] A previous study demonstrated that the detection rate of aortic plaque is higher for CTA compared with TEE.[25] We found more plaque, with more low attenuation plaque (lipid-rich core), irregular surface, or ulceration, in the aortic arch than in the ascending aorta. These plaque characteristics are associated with an increased risk of stroke.[26] These results show that admission nongated cardiac CTA can also help to identify aortic embolic sources of AIS. Extending the CTA coverage may reveal abnormalities in the lung, such as aspiration/lobar pneumonia or pulmonary nodules, but this was beyond the scope of this study.[27]

Technical Perspective

Current guidelines recommend transthoracic echocardiography or TEE for the detection of cardiac thrombi, although the sensitivity is limited, TEE is semi-invasive, and both do not outperform CTA.[4,8] We investigated nongated cardiac CTA, whereby the standard head-aortic arch stroke CTA was extended to cover the whole heart in <5 s of extra scan time, without extra iodine contrast material and with an acceptable increase of the radiation dose of 2 mSv. The yield of cardiac CTA was higher than echocardiography in our study and in a recent ECG-gated CTA study.[28] To minimize motion artifacts, cardiac CTA is usually acquired with ECG gating but requires a separate scan costing extra iodine contrast agent, radiation dose, and time in a situation where time is brain in AIS compared with nongated CTA.[29] A disadvantage of nongated CTA could be that

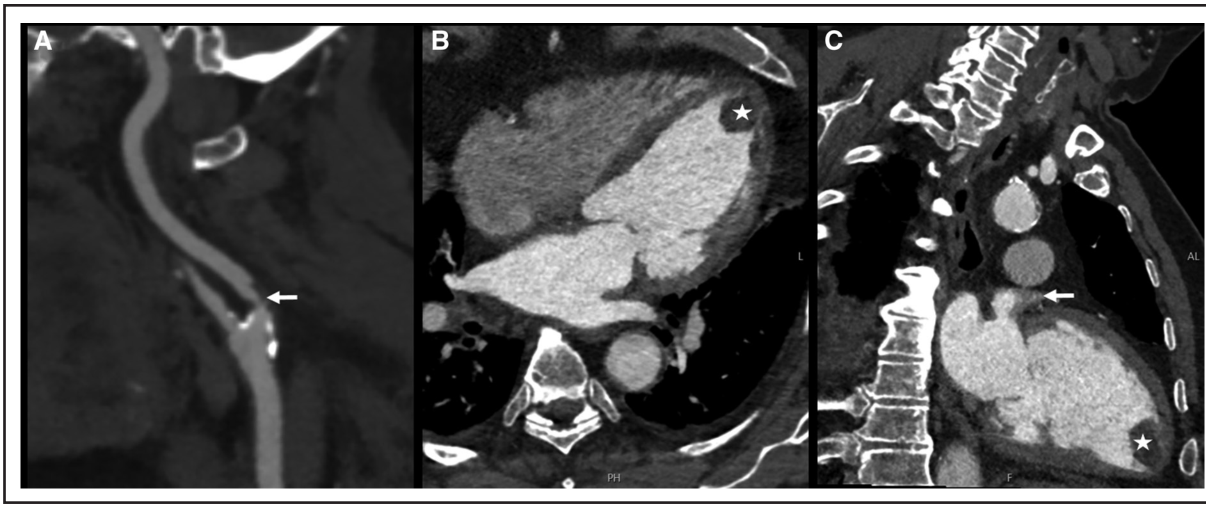

Figure 3. An 87-year-old male patient with sudden onset of aphasia and right-sided hemiparesis (National Institutes of Health Stroke Scale score, 13), a medical history of acetylsalicylic acid for cardiovascular risk management, and previous myocardial ischemia on his ECG.

The computed tomography angiography excluded arterial occlusions and showed a >70% stenosis of the left internal carotid artery (arrow in **A**) and thrombus in the left ventricular apex (star on 4-chamber [**B**] and 2-chamber views [**C**]). There was slow flow visible in the left atrial appendage (arrow in **C**) with an inhomogeneous aspect, an attenuation of 174±56 HU, and an iodine concentration of 6.58±1.4 mg/mL that was not suspect for thrombus. No atrial fibrillation was detected in the week between the stroke and his death.

metric measurements such as left atrial enlargement, which has been associated with stroke, are unreliable as compared with measurements on ECG-gated CTA.[30] We could not evaluate left atrial enlargement as the cardiac phase differed between scans. Whether the diagnostic value of nongated cardiac CTA is equivalent to ECG-gated CTA in AIS is unknown. Technical improvements of CT scanners allow faster acquisition times, which should improve image quality and reduce motion artifacts without increasing the radiation dose in nongated cardiac CTA.[29] Different scanner types including conventional scanners were used, and, therefore, our results seem largely generalizable to other centers.

Detecting LAA thrombi, and differentiation from slow flow effects, has often been researched. The combination of a dual-phase early and late CT, dual-enhancement single-phase CT, and spectral CT have shown that CT can accurately detect LAA thrombi without significantly increasing the radiation dose.[9,31,32] Our stroke CT protocol with a contrast bolus for CTP before CTA combines the dual-enhancement single-phase CTA concept that is routinely used to rule out LAA thrombus before pulmonary vein ablation in patients with AF, with additional information from the spectral energy reformats.[16] Our study showed that the iodine mapping was most useful for detecting LAA thrombi, which is in line with previous spectral CT studies where iodine concentration measurement helped to differentiate between thrombus and stasis of blood (slow flow).[9,33]

Table 2. Results From the Expert Panel Meetings Concerning Patients With Possible to Certain Presence of Cardiac Thrombus on Nongated Cardiac Computed Tomography Angiography

Panel diagnosis, n (%)	Phase 1 (n=44)	Phase 2 (n=44)	*P* value
Likelihood of cardioembolic cause			<0.001
Certainly not	0 (0)	0 (0)	
Possibly yes	20 (45)	6 (14)	
Probably yes	24 (55)	8 (18)	
Certainly yes	0 (0)	30 (68)	
Referral to cardiology	44 (100)	44 (100)	

Limitations

The time window of 9 hours was chosen before the extended treatment window trials were published. Many patients could not be included because of logistic reasons such as coronavirus restrictions and early discharge to home or to their referring hospital. Since logistic reasons were the main cause why patients could not be included, the risk of selection bias seems low.

The absence of a reference standard, knowing that TEE and transthoracic echocardiography do not outperform CTA, implied that we could not analyze sensitivity or specificity. Only patients with a possible to certain cardiac thrombus were presented to the expert panel, which could have influenced the decision-making but also represents the expected clinical pathway for future patients with stroke. The inclusion of patients without cardiac thrombus will probably not affect the results as the diagnostic certainty of a cardioembolic source of the stroke is not expected to change in case of a negative cardiac CTA. In addition, staged unblinding helped to avoid incorporation bias.

In conclusion, extending the stroke CTA to cover the heart enables detection of cardiac thrombi and helps to identify cardioembolic sources in acute stroke with more certainty. Spectral iodine maps provide additional diagnostic value for detecting LAA thrombus. Future studies should investigate the impact of admission cardiac CTA on prevention strategies and etiology of stroke recurrence.

ARTICLE INFORMATION

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Disclosures

None.

Supplemental Material

Checklist
Supplemental Results
Tables S1–S7

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