European Radiology (2019) 29:4930–4936
https://doi.org/10.1007/s00330-019-06041-x

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A "one-stop-shop" 4D CTA protocol using 320-row CT for advanced imaging in acute ischemic stroke: a technical note

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Received: 17 September 2018 / Revised: 24 December 2018 / Accepted: 24 January 2019 / Published online: 15 February 2019

Abstract

This technical note describes a novel CT scan protocol that includes a non-enhanced CT, dynamic CTA, and perfusion of the whole brain and CTA of the carotid arteries using a 320-row area detector CT scanner, with a unique contrast injection and acceptable radiation exposure dose in patients presenting with acute ischemic stroke. The acquisition parameters and reconstruction parameters will be discussed including the use of model-based iterative reconstruction (MBIR), time summing (tMIP), and subtraction techniques to optimize the results of this protocol.

Key Points

- *Scanning on a 320-row area detector CT can achieve both brain perfusion with dynamic angiography and reconstructed arterial and venous CTA, and supra aortic trunk angiography, in a single acquisition.*
- *It provides, in a single exam, a full diagnostic workup, i.e., all the acquisitions that are needed to make a quick decision, with reasonable exposure to ionizing radiation and reduced amount of medium contrast, in case of acute ischemic stroke presentation.*

Keywords Computed tomography angiography · Stroke · Perfusion · Image reconstruction

Abbreviations

CTA	Computed tomography angiography
CTP	Computed tomography perfusion
DLP	Dose length product
FIRST	Forward-projected model-based iterative reconstruction solution
LCD	Low contrast detectability
MBIR	Model-based iterative reconstruction
MRI	Magnetic resonance imaging
MTT	Mean transit time
NECT	Non-enhanced computed tomography
NIHSS	National Institute of Health Stroke Score
rCBF	Relative cerebral blood flow
rCBV	Relative cerebral blood volume
ROI	Region of interest
SAT	Supra aortic trunk
tMIP	Time maximum intensity projection
TTP	Time to peak

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Introduction

Dynamic CT angiography (CTA) scanning is often used in imaging acute ischemic stroke, to manage treatment decisions and potential for endovascular therapy. Wide-area detector computed tomography has recently brought the possibility both to interpose a supra aortic trunk (SAT) CTA during the acquisition of a whole brain CT perfusion (CTP) and at the same time to extract 4D dynamic angiography from the perfusion data [1, 2]. Advanced model-based iterative reconstruction (MBIR) [3], subtraction, and time summing reconstructions (time maximum intensity projection tMIP) are applied to

these acquisitions to increase diagnostic accuracy. The goal of this technical note is to describe the parameters of this acquisition, and its reconstructions, to show the value of this "one-stop-shop" protocol with a unique contrast medium injection, and an acceptable radiation exposure dose.

Technical features: details and discussion

Description of the "one-stop-shop" acquisition protocol

Acquisitions (Fig. 1) were performed on a 320-row area detector CT Aquilion ONE Genesis (Canon Medical Systems) and postprocessing performed on the Vitrea Workstation (Canon Medical Systems). Main acquisitions were performed using the following parameters: 320 × 0.5 mm collimation, 220 mm field of view, 80 kV tube voltage, 0.75 s rotation time. A non-enhanced cerebral helical CT (NECT) scan is performed first (300 mA, 12.5 s total acquisition time). A test bolus is necessary to optimize the dynamic acquisitions (to reduce the number of phases before the arrival of contrast medium) and to determine the time for the SAT acquisition in a pure arterial phase (Fig. 1a). The test bolus scan is performed using 15 mL of contrast medium (Iomeprol 400, Bracco Imaging) at 5 mL/s followed by 30 mL of saline solution at 5 mL/s using double lumen injector. The acquisition consists of a 2-mm scan every second (maximum 19, no more than 35 s total acquisition time, 4 × 0.5 mm collimation, 100 mA, 1 s rotation time), located 2 cm below the skull base. From the test bolus scan, the time of first optimal opacification of cervical vessels is determined. Then, the timing of the whole scan is adapted, subtracting 3 s to this delay to determine the start time of the CTA acquisitions (Fig. 2b and d). Due to an algorithm requirement, this delay between the mask (non-contrast scan) and the rest of the acquisitions should not be more than 7 s to compute correct perfusion maps. The main scan consists of a mask scan (150 m1, 0.75 s total acquisition time) at $T = 7$ s, then the CTA acquisitions start at the time derived from the test bolus scan (selected opacification minus 3 s, but less than or equal to 7 s from T) with an injection of 60 mL contrast medium at 5 mL/s followed by 50 mL of saline flush solution at 5 mL/s. CTA acquisitions are composed as follows: First, a continuous acquisition for 4D angiography is performed (200 mA, 13.5 s total acquisition time). Then, with a rapid table motion (2 s), a 16 cm volume acquisition centered on the supra aortic trunk level is performed (300 mA, 0.75 s total acquisition time). The table moves back to the skull and seven intermittent arterial phases (each 2 s) and five venous phases (each 5 s) are acquired as volumes (200 mA, rotation, 12 + 20 s total acquisition time, Fig. 1c). The duration of the continuous acquisition for 4D angiography and the number/frequency of intermittent arterial phases and venous phases can be modified if needed, based on the patients cardiac output to capture the optimal contrast bolus peak and outflow.

Interleaving the SAT scan

Due to the 16 cm volume acquisition, the brain CTA and SAT CTA are not included in the same field of view, but 2 cm interlaced (Fig. 1e). Considering the construction of the

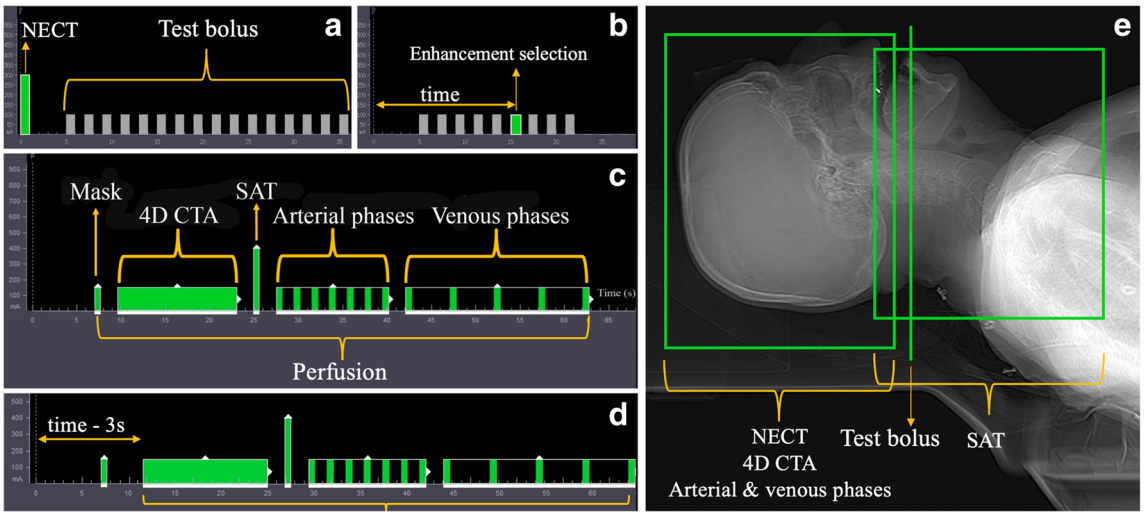

Fig. 1 Diagrams of the acquisition protocol and boxes placement. **a**–**d** Temporal diagrams. **a** Acquisition of NECT and test bolus scan. **b** Determining the time for the ideal arterial enhancement from the test bolus. **c** The exact timing of each acquisition during the "one-stop-shop" protocol on a timeline, with the intensity of the X-ray beam in mA (milliampere). **d** Displacement of the timing according to the results of the test bolus. **e** Acquisition boxes placement on a lateral topogram

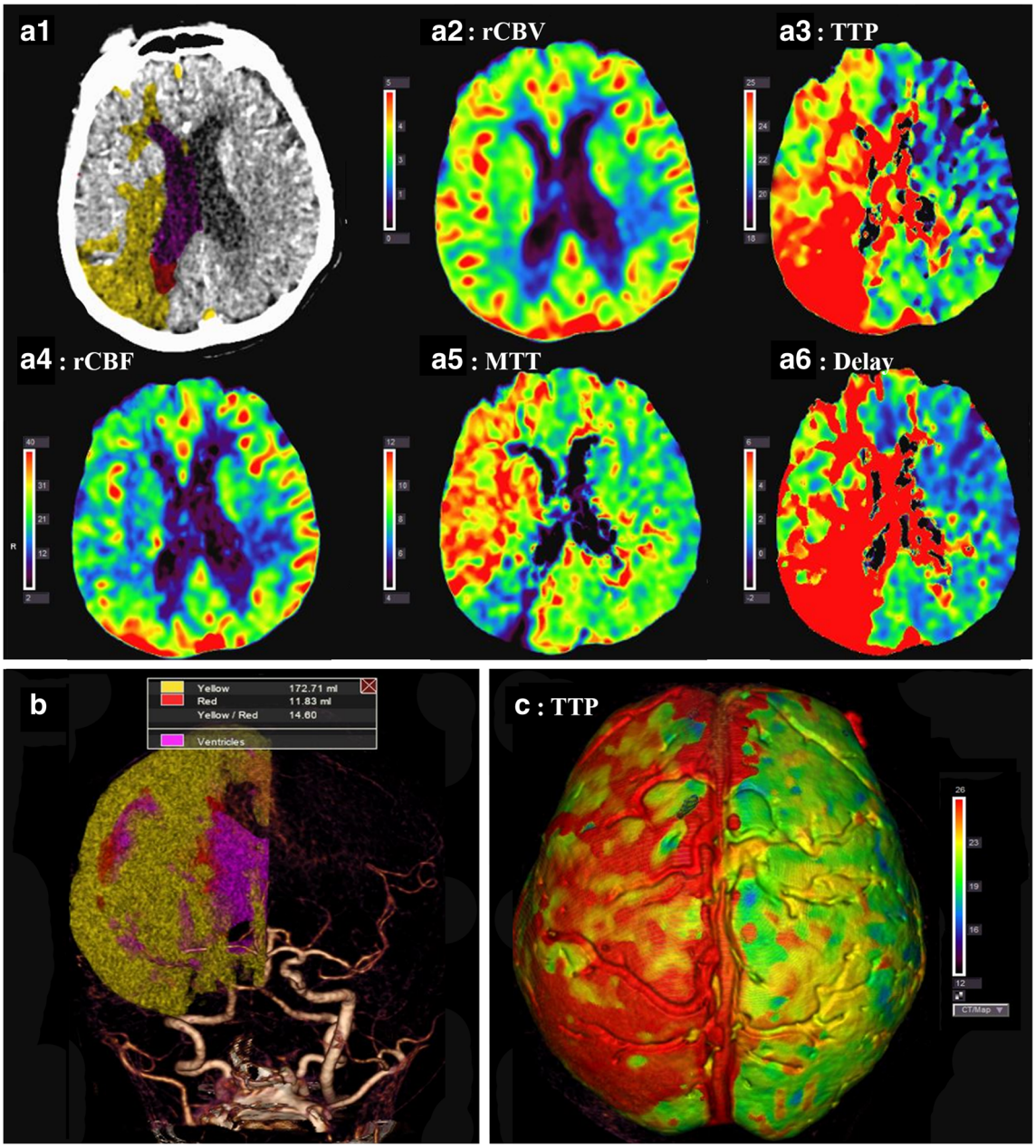

Fig. 2 CTP results. Note the restricted infarct core of the right posterior junctional area (about 11 mL) and a penumbra of the right carotid artery territory, predominating in the posterior territory of the right sylvian artery and internal carotid artery junctional territories. **a** Axial reconstructions from CTP and parametric perfusion maps. **a1** Brain perfusion summary map: automatic measurement of infarct size and characteristics. For areas marked as yellow, the software uses a relative value where TTP is increased, in seconds, compared to the reference hemisphere. For areas marked as red, the software uses a relative value where CBV is decreased, in percent, compared to the reference hemisphere. Yellow indicates areas where TTP is above the threshold of 6.8 s. Red indicates areas where CBV is below the threshold of − 41%. These thresholds can be adapted by the user. When the software displays the summary map, it uses the TTP value to attempt to determine the unaffected hemisphere as a reference for perfusion normalization. **a2** rCBV. **a3** TTP. **a4** rCBF. **a5** MTT. **a6** Delay. **b** Subtracted vessels in VRT superimposed with ischemic core in red and penumbra in yellow in VRT, ventricular volume can be display in purple. **c** TTP in VRT (superior view)

protocol, the SAT scan can be acquired between 23 and 30 s from the injection. In this cohort, SAT scans were placed at a mean of 28.21 s (standard error (SE) 0.43; range (min to max) 24 to 30 s). No suboptimal enhancement on SAT scans was noticed, and venous contaminations represented less than 20% of the acquisitions but did not impact the reading. As a comparison, in 20 consecutive standard SAT CTA acquisitions (Table 1), SAT was placed at a mean of 24.28 s from the injection (SE 0.68; range 17 to 31 s), and it is to note that these last SAT acquisitions took a mean of 5.1 s (SE 0.06).

Table 1 Comparison of "one-stop-shop" and conventional CTA and CTP protocols. Note that the new protocol includes, in an equal time and with a smaller amount of contrast medium, all examinations that are provided by the standard CTA and CTP protocols, while adding with the test bolus the guarantee of a pure arterial phase when acquiring the SAT images, and the possibility to have a dynamic 4DCTA to explore cerebral vasculature

Protocol	"One-stop-shop"	"Standard" CTA	"Standard" CTP
NECT scan	X	X	X
Mask scan	X	Optional	X
Time of injection	Test bolus scan	Enhancement of cervical vessels (manual/ROI)	Enhancement of cervical vessels (manual/ROI)
4D scan	X	–	–
SAT scan	Volume	Helical	–
Arterial scan	Continuous then intermittent (7 phases)	Main acquisition (from aortic arch to vertex)	Intermittent (13 phases)
Venous scan	Intermittent (5 phases)	Optional	Intermittent (5 phases)
Total acquisition time (maximum)	93 s	48 s	56 s
Total amount of contrast medium	75 mL	60 mL	60 mL

Dosimetry

Radiation dose was calculated using 20 consecutive patients who underwent the "one-stop-shop" 4D CTA protocol. Dose length product (DLP) was recorded for each patient: NECT 629.51 mGy cm (SE 22.13; range 501 to 738 mGy cm; 20.59% of the total exam dose), test bolus 23.25 mGy cm (3.05; range 16 to 30 mGy cm; 0.77%), mask 62.87 mGy cm (SE 0.03; range 62 to 63 mGy cm; 2.1%), mean number of control slices 9 (SE 1.22; range 6 to 18 slices) with 2.5 mGy cm fixed dose per slice, dynamic CTA 1463.41 mGy cm (SE 0.79; range 1456 to 1464 mGy cm; 47.95%), SAT 125.74 mGy cm (SE 0.06; range 125 to 126 mGy cm; 4.12%), arterial phases 440.09 mGy cm (SE 0.21; range 438 to 440 mGy cm; 14.42%), venous phases 308.06 mGy cm (SE 6.28; range 251 to 314 mGy cm; 10.09%), yielding a total 3052.93 mGy cm (SE 19.47; range 2716 to 3230 mGy cm). To add a comparison, in our center on the same scanner, another protocol including a NECT, injection for CTP acquisition, reconstruction of an arterial phase from the CTP, then venous acquisitions, and reinjection for a SAT acquisition yielded for 20 consecutive scans a total of 2914 mGy cm (SE 71.65; range 1918 to 3595 mGy cm) ($p = 0.07$), and added about 40 to 50 mL contrast medium.

Our protocol for reconstruction

An MBIR reconstruction (forward-projected model-based iterative reconstruction solution (FIRST)) is applied to the cerebral non-enhanced acquisition (low contrast detectability (LCD)) (Fig. 3a, b) [5] and to the SAT CTA (Fig. 3e) [3]. A series of volumes is reconstructed from the continuous 4D angiography acquisition, with a temporal resolution up to 0.05 s (Fig. 3c, d). The whole CTA acquisition (except for the SAT) permits the generation of perfusion maps, including relative cerebral blood volume (rCBV)/flow (rCBF), mean transit time (MTT), time to peak (TTP), and delay (in seconds, measuring the relative arrival time of contrast medium in the tissue). It provides similar physiological information to TTP, but is not dependent on the size or shape of the arterial time density curve (Fig. 2a) [6]. The brain perfusion summary map (Fig. 2, a1) displays color-coded regions, based on a derivative of the hemispherical comparisons of all the other maps, where perfusion values appear to be increased or decreased based on the contralateral hemisphere. Three of the best arterial and venous phases are respectively summed to generate arterial and venous tMIP volumes (Fig. 3f). The tMIP image reflects the maximum value of each voxel in the dynamic data for all time phases selected. All reconstructions are performed at 0.5-mm thickness and 0.5-mm interval.

Added value of the reconstructions for interpretation

FIRST brain LCD provides good detection of early ischemic changes and can be used for ASPECT scoring (Fig. 3b) [7]. By performing the CTA and SAT in a single protocol, radiation exposure [8] and amount of contrast material can be reduced. Economy of this radiation exposure permits us to add a 4D dynamic acquisition. Generally speaking, dynamic acquisitions allow a multiphase analysis, which other investigators report, depict a better scoring of the clot burden, a precise evaluation of arterial collaterals (Fig. 3c) and thrombus length, and accurate diagnostic of distal intra cranial internal carotid artery pseudo occlusion [9–11]. Including a mask, or non-contrast scan, to the dynamic scans allows subtraction of the skull from the 4D CTA for robust and quick 3D volume

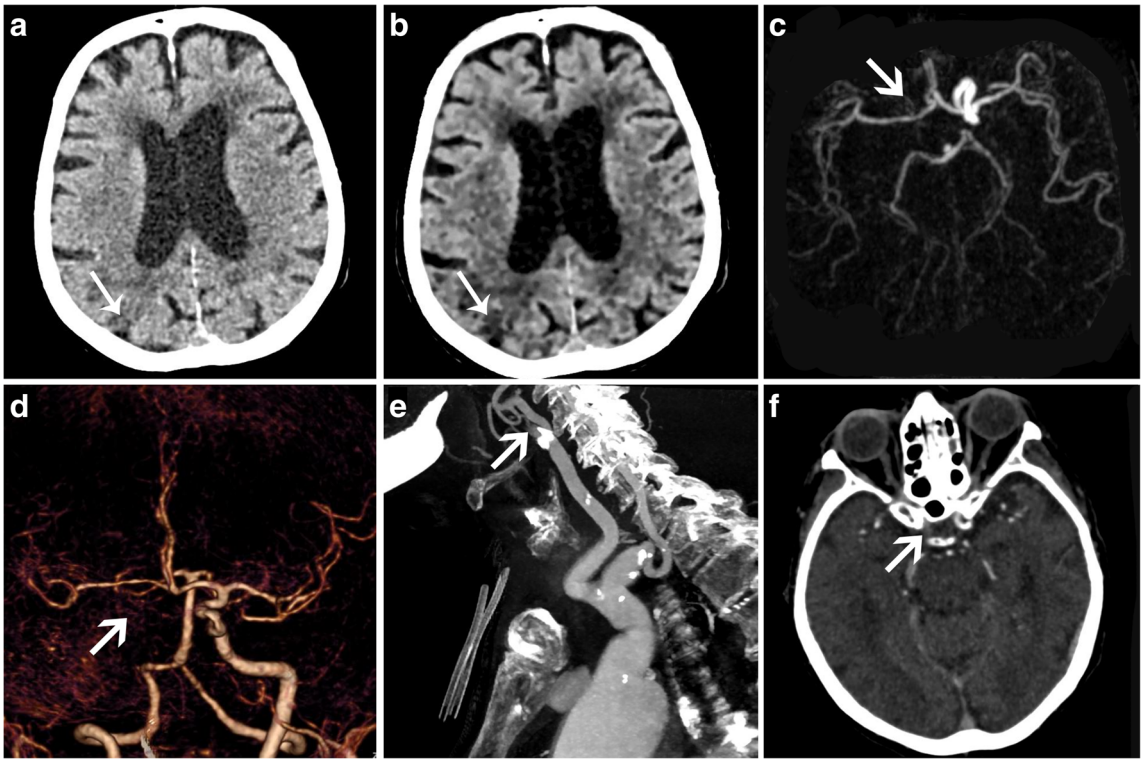

Fig. 3 Other reconstructions from the "one-stop-shop" protocol. Note the occlusion of the initial portion of the cervical internal carotid artery, with early direct collaterally brought by the circle of Wills via the Anterior Communicating Artery reinjecting the right carotid territory. ASPECTS 9/10. **a** Axial reconstruction from NECT using adaptive iterative dose reconstruction (AIDR) 3D [4]. **b** Axial reconstruction from NECT using FIRST LCD, note the better visualization of early ischemic changes of the right parietal lobe. **c** Axial MIP with subtracted vessels, of an arterial phase of the dynamic 4D CTA. **d** Anterior view in VRT with subtracted vessels, of the same arterial phase of the dynamic 4D CTA. **e** Sagittal reconstruction with FIRST in MIP of the SAT acquisition. **f** Axial reconstruction of arterial time-MIP reconstruction

rendering and visualization of the vessels in the brain. Registration algorithms provide optimal removal of the skull in scans with patient motion (Fig. 2b; Fig. 3c, d). tMIP reconstructions permit a standard analysis of an arterial and venous CTA. FIRST reconstruction of the SAT generates better angiographic contrast in cases of poor opacification [12]. The reconstruction time for the entire study is 5–6 min with the FIRST reconstructions of the non-enhanced brain scan and SAT, and the 4D CTA taking the most time.

Discussion

CTP performed on a second-generation 320-row area detector CT scanner provided similar image quality and visualization at acceptable radiation doses as conventional CTA (Fig. 4) [13, 14]. More appropriate patient management decisions can potentially be made with whole brain perfusion over limited coverage perfusion [15]. The diagnostic protocol in patients presenting with acute ischemic stroke is usually composed of a cerebral non-enhanced CT, a head and neck CTA, and a cerebral CTP when available. Usual protocols require two bolus injections of contrast medium (for CTA and CTP). Therefore, an intracranial artery occlusion cannot be seen before injection, and then, in most cases, a complementary CTP is performed. Reversal of the order of the CT stroke protocol had no significant influence on the quantitative parameters of CTP (CTA before or after CTP). It has been recently demonstrated that cerebral CTP acquisition could be interleaved with the neck CTA acquisition [1, 2], as the quantitative CTP values would remain unaffected by the time gap induced by performing the neck CTA within the CTP acquisition. With the recent extension of the delay of mechanical thrombectomy up to 16/24 h, AHA guidelines recommend CTP (or magnetic resonance imaging, MRI) in case of selected patients (class 1, level of proof A) [16–18]. Due to the essential construction of this protocol, the "classical" CTA acquisitions, i.e., arterial and venous, are reconstructed from the dynamic CTA acquisitions of this protocol. Teams that want to prove a vessel occlusion before performing CTP are encouraged to consider this protocol as a second advanced imaging in the same exploration, while adapting (low) the number of arterial and venous intermittent phase of the protocol. However, this would lead to a second injection of contrast medium and loss a part of its benefits (Table 1). In our practice, based on the management of acute ischemic stroke, this protocol

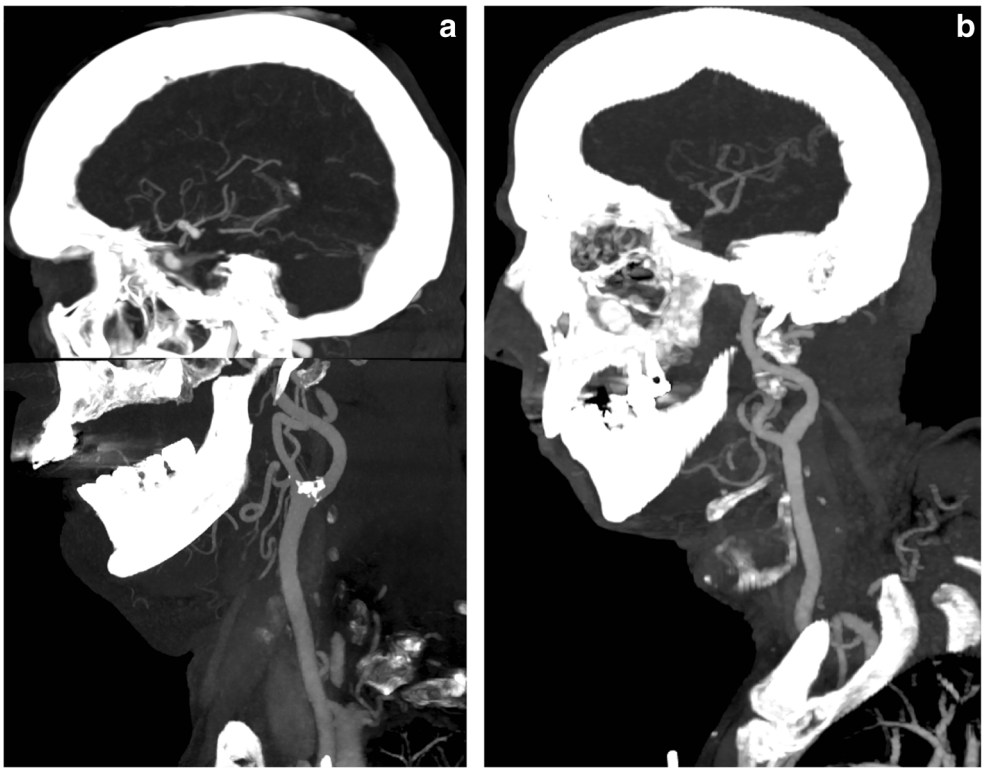

Fig. 4 Image comparison of "one-stop-shop" and "standard" CTA protocol. **a** Images from the "one-stop-shop" protocol: time-MIP of arterial phases in sagittal MIP overlapped on the SAT acquisition (sagittal MIP). **b** Sagittal MIP of "conventional" CTA acquisition. Note that for the new protocol, the acquisitions are not in the same field of view

is implemented routinely for patients with an acute stroke clinical presentation with NIHSS > 6, the absence of blood on NECT, time to onset of symptoms < 24 h, or without a precise time to onset with contra-indication to MRI. The routine perfusion examination can be discussed but brought to our experience supported by the literature, with the use of an entire coverage of the brain on the *Z*-axis, a good depiction of small infarcts (when only CTA analysis could miss the distal clot, i.e., M3 or M4 segment of middle cerebral artery occlusion), and the use of this technique (CTP) leads to adapted selection of these patients for endovascular or thrombolytic therapy (Fig. 4). In our center, this protocol has been implemented for 18 months with 300 patients examined. There are about 1500 comparable area detector CT scanners of the same brand worldwide, including about 300 in Europe. Another constructor (General Electric Healthcare) also has developed area detector CT scanner, with a similar overall number of scanners, and this market is growing more and more. Even though MRI remains essential due to its diagnostic power in acute ischemic stroke presentation, low or no access to this modality should not have consequences on the patient care [19]. This "one-stop-shop" protocol may improve patient selection in case of acute ischemic stroke CT imaging, providing a full diagnostic workup, i.e., all the acquisitions that are needed to make a quick decision, in a single exam with acceptable radiation exposure and reduced amount of medium contrast. This new scanning technique is only possible with area detector CT scanners and thus has limited applicability in sites without this technology; however, the number of sites with these CT scanners is increasing.

Acknowledgments The authors thank the radiology technicians Mr. Leprêtre Alexis and Ms. Montier Corinne for their implication in the study.

Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Prof. Ben Salem Douraied.

Conflict of interest One of the authors (Haioun Karim) who provided us technical data about the new acquisition is an employee of Canon Medical Systems France. The other authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Statistics and biometry One of the authors has significant statistical expertise (JO) but no complex statistical methods were necessary for this paper.

Informed consent Written informed consent was waived by the Institutional Review Board.

Ethical approval Institutional Review Board approval was obtained.

Methodology
- Observational
- Performed at one institution

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