Intravenous flat-detector CT angiography in acute ischemic stroke management

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Abstract

Introduction In the settings of stroke, a non-invasive high-resolution imaging modality to visualize the arterial intracranial circulation in the interventional lab is a helpful mean to plan the endovascular recanalization procedure. We report our initial experience with intravenously enhanced flat-detector CT (IV FDCT) technology in the detection of obstructed intracranial arteries.
Methods Fourteen consecutive patients elected for endovascular stroke therapy underwent IV FDCT. The scans were intravenously enhanced and acquired in accordance with the previously calculated bolus arrival time. Images were processed on a commercially available workstation for reconstructions and 3D manipulation. Occlusion level and clot length, the quality of collateral vessels, and the patency of anterior and posterior communicating arteries were assessed.
Results IV FDCT was performed successfully in all the cases and allowed for clot location and length visualization,
assessment of communicating arteries patency, and evaluation of vessel collateral grade. Information obtained from this technique was considered useful for patients treated by endovascular approach. Retrospective review of the images by two independent readers was considered accurate and reproducible.
Conclusions IV FDCT technology provided accurate delineation of obstructed vessel segments in acute ischemic stroke disease. It gave a significant help in the interventional strategy. This new technology available in the operating room might provide a valuable tool in emerging endovascular stroke therapy.

Keywords Stroke · Flat detector · Computerized tomography

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Introduction

Acute stroke is a major cause of death, morbidity, and social health costs. More than 85% of strokes have an ischemic origin [1]. Intravenous thrombolytic therapy for acute stroke is now recommended for selected patients who may be treated within 3 h and even within 4.5 h of onset of ischemic stroke [2]. Intra-arterial thrombolysis is an option for treatment of selected patients suffering major stroke of <6 h duration, due to occlusion of proximal vessels or in patients who have contraindications to intravenous thrombolysis [3].

Imaging of the brain is recommended before initiating any specific therapy to treat acute ischemic stroke. Anatomical location, size, and extent of the obstruction, as well as the time window from the stroke ictus, are the compulsory informations to be obtained, and upon which the intravenous or intra-arterial therapy will be defined [4, 5].

In most instances, MR will initially be used to confirm the ischemic nature of the cerebral lesion and rule out hemorrhagic event, followed by additional morphological vessel depiction by magnetic resonance angiography (MRA). Nevertheless, in many cases worldwide, conventional CT scan is the sole available modality and computed tomography angiography (CTA) is becoming an increasingly accepted noninvasive technique [6–8] and is considered as the gold standard in the detection of obstruction of the major brain vessels as well as the collateral pial vessels that carry blood towards the distal aspect of the obstructed vessels [9].

Vascular imaging is necessary as a preliminary step for intra-arterial administration of pharmacological agent or endovascular interventions. So far, the interventional X-ray technology was solely used for image guidance in the thrombolytic stroke therapy and mechanical clot retrieval, not providing assessment of the vessel portions located distally to the obstruction spot. Accurate and timely availability of high-resolution intracranial CT and CTA enhances assessment of spatial clot locations as well as helps in the definition of the most optimal patient treatment strategy [10–13]. The aim of our study was to investigate applicability of the IV FDCT technique in detecting the occlusion localization, the extent of the vascular obliteration by measurement of the clot length as well as the description of distal aspect of the brain circulation, located beyond the clot.

Materials and methods

After review of the protocol by our local ethics committee, informed consent was collected for all patients or their relatives before the endovascular procedures. Between March 2009 and December 2009, 14 patients (5 female, 9 men, average age of 69 years, presenting with acute stroke symptoms; NIHSS from 7 to 27, mean 19) with brain ischemia confirmed by magnetic resonance imaging (MRI) were referred for interventional treatment. Intracranial vessels had been explored by MRA. No patients had conventional CTA performed prior to arrival to the interventional unit. Mean time interval before endovascular therapy (Stroke Onset-Femoral puncture) was 4.2 h. The patients were scanned with IV FDCT for the purpose of accurate intracranial vessel assessment and clot location depiction.

All the patients were fully sedated and intubated prior to both IV FDCT completion and the endovascular procedure. The head of the patient was positioned in the system at the isocenter, and a propeller scan was applied. The IV FDCT acquisition protocol and post-processing is embedded on the FD20 Allura interventional angio system (Philips Healthcare, Best, The Netherlands). Intravenous injection of non-ionic (370 mg I/ml) contrast material (Iopamiron 370, Iopamidol, Bayer-Schering, Germany) was performed through a central venous approach, using the femoral vein with a 4-French pigtail catheter advanced in the inferior vena cava. In order to calculate the contrast bolus arrival time at the cerebral level, 10 ml of the contrast media were injected at a rate of 5 ml/s. A conventional angiographic run at one frame per second in the frontal projection was performed at the neck level. The first subtracted image showing the contrast opacification of the cervical arterial vessels was used as the reference image to calculate the bolus arrival time. The total volume of injected contrast material during the acquisition was 80 ml at the rate of 5 ml/s. Clinical and angiographic data were prospectively collected and archived on the PACS of our institution.

The imaging system consisted in a motorized rotational movement (so-called propeller scan) of a C-armin in the plane perpendicular to the longitudinal table axis, which acquired 620 fluoroscopic frames in a circular motion at a frame rate of 30 frames per second, total rotation time of 20 s, over an angle of 240° (±120°) with a rotation speed of 22°/s, using a 1,024×1,024 pixel matrix detector with a 22-cm maximum field of view. The acquisition started in accordance to the delay of the bolus arrival previously calculated. During the propeller acquisition movement, the dataset was transferred automatically via a real-time digital link to the 3D workstation (XtraVision, Philips Healthcare, The Netherlands) for processing. The 3D volume, displayed in a 256^3 pixel matrix as a default reconstruction size was available after 1.5 min. Different types of image post-processing (beam hardening and scatter corrections) were applied in order to achieve maximum spatial and contrast resolution qualities.

Additional reconstructions could be performed with variable volume matrixes or dimensions of reconstructed volume (512^3 spatial resolution matrix as a maximum). Once displayed on the 3D monitor, the reconstructed results could be rotated, zoomed, and panned and, furthermore, displayed in different volume rendering formats as well as display modes (MPR or single slice view). Before the intervention, to determine the best endovascular treatment, the IV FDCT were reviewed dynamically under MIP and MPR modes by the operator to evaluate the localization of the vessel occlusion site, the clot length, the collateral circulation, the presence and size of communicating arteries. MIP thickness could vary from 1 up 100 mm according to the physician's wish (in most instances, a 3 to 5-mm thickness allowed for clear visualization of the target vessel).

For the purpose of this study, images have been retrospectively and independently reviewed on a dedicated workstation (Xtravision, Philips Healthcare, The Netherlands) by two physicians, respectively, a board certified neuroradiologist, and a neuroradiology fellow. The evaluation criteria were:

localization of the vessel occlusion site, measurement of the clot length, evaluation of collateral circulation grade, and anterior and posterior communicating arteries presence. For the localization of the vessel occlusion site, we analyzed the various level of occlusion according to a previously published classification [14].

For the measurement of the clot length, the IV CBCT were reviewed dynamically under MIP, MPR, and VR modes, and clot length were measured independently by the two reviewers with the measurement tools of the workstation. For the purpose of the statistical analysis, a semi-quantitative estimation of the clot length was given with ranges from 0 to 1 cm, 1 to 2 cm, 2 to 3 cm, and more than 3 cm. In the cases of anterior circulation stroke (9/14 cases), collateral circulation was scored following previously published scales of angiographic assessment of pial collaterals [15, 16]

A score of 1 was assigned if collaterals reconstituted the distal portion of the occluded vessel segment, a score of 2 was assigned if collaterals reconstituted vessels in the proximal portion of the segment adjacent to the occluded vessel, a score of 3 was assigned if collaterals reconstituted vessels in the distal portion of the segment adjacent to the occluded vessel, a score of 4 was assigned if collaterals reconstituted vessels two segments distal to the occluded vessel, a score of 5 was assigned if there was little or no significant reconstitution of the territory of the occluded vessel.

Presence or absence of communicating arteries was reviewed. When present, the size of the artery was quoted as below or above 1 mm. Three grades were possible: 0= artery not visible, 1=patent communicating artery with a diameter under 1 mm, 2=patent communicating artery with a diameter above 1 mm.

Interobserver reliability was assessed using a Kappa test (MedCalc for Windows, version 9.3.2.0; MedCalcSoftware, Mariakerke, Belgium). Data from the first observer were used for the statistical analysis.

Results

On a 6-month period, 14 patients (5 female, 9 men, average age of 69 years, presenting with severe acute stroke symptoms; NIHSS from 7 to 27, mean 19) were referred for interventional treatment. Mean time interval before endovascular therapy (stroke onset-femoral puncture) was 4.2 h.

Indication for endovascular treatment of intracranial arterial occlusion was: patient out of the time delay for IV thrombolysis, $n=8$; contraindication to IV thrombolysis, $n=3$; and combined IV+IA thrombolysis, $n=3$.

IV FDCT was successfully performed in all the 14 patients. Thirteen datasets were rated as good in quality,

and one dataset was slightly blurred secondary to movement artifacts. There were no complications related to the venous access site and no contrast injection related complications. The mean delay between the bolus injection moment and the arrival at the intracranial level was 14 s. In all the cases, the occlusion site was clearly depicted. The informations collected were considered useful in treatment planning for all the patients. In all cases, the visualization of the vascular bed distal to the arterial occlusion was considered by the physician performing the endovascular treatment as an adjunct for anatomic characterization and selection of the devices for mechanical revascularisation. The techniques and devices used for the treatment of the arterial occlusion were: Mechanical Clot retrieval with Solitaire FR device (EV3, Aliso Viejo, CA, USA) $n=8$, thromboaspiration (6F Fargo catheter Balt, Montmorency, France) $n=2$, clot disruption by angioplasty $n=5$, intracranial stenting $n=2$; stenting at the cervical level was also used in $n=4$ cases.

The retrospective review results are summarized in Table 1 and demonstrate complete concordance for the information regarding the level of occlusion and estimation of the collateral circulation. Patency and size of communicating arteries were evaluated with $k=0.83$, and for evaluation of the clot length, k was 0.79 demonstrating good interobserver reliability.

Representative cases

Case 1. A 72-year-old man presented with a left middle cerebral artery occlusion at 2.45 h with an NIHSS score of 17. The patient was treated by intravenous thrombolysis with rTPA (0.9 mg/kg) after a brain MRI demonstrated a deep MCA infarct. After 1 h, as the clinical score did not improve and the Doppler examination confirmed the persistence of the occlusion, the patient was referred for endovascular treatment. Under general anesthesia and intubation, an IV FDCT following the described technique allowed for visualization of the MCA occlusion, the extent of the clot and estimation of the collateral leptomeningeal circulation (Fig. 1). The patient was treated by two successive deployments and retrieval of a Solitaire FR under proximal carotid balloon occlusion. Complete revascularization of the MCA territory was gained 1 h after the femoral puncture. At 90 days, the patient was mRS 1.

Case 2. A 71-year-old man with a history of high blood pressure, diabetes, and coronaropathy presented with a left internal carotid artery stroke (NIHSS score of 10) and was thrombolysed at 3.30 h after the beginning of symptoms. Brain MRI was

Table 1 Summary of patients, results of IV FPD CTA, and endovascular techniques

Patient	Sex	Age	Indication	Clot length	Localisation	Occlusion	Collateral circulation	Right PCom	LPCom	ACom	Treatment technique
1	F	86	Out of IV delay	50	ICA	4B	4	1	2	1	Solitaire
2	M	72	Combined IV/IA	20	MCA	3a	2	0	0	1	Solitaire
3	F	77	Contraindication to IV	12	BA	4B	–	1	0	1	Thromboaspiration
4	F	63	Contraindication to IV	20	MCA	3A	2	0	0	2	Solitaire and angioplasty
5	M	61	Out of IV delay	5	V4 SIN	4A	–	NA	NA	NA	Angioplasty and stenting
6	M	88	Contraindication to IV	15	VA-BA	4B	–	2	1	0	Thromboaspiration
7	M	65	Combined IV/IA	50	ICA	4A	1	0	0	2	Solitaire
8	F	80	Combined IV/IA	15	MCA	3A	2	2	2	2	Angioplasty
9	F	65	Out of IV delay	5	VA-BA	4A	–	2	2	NA	Solitaire
10	M	72	Out of IV delay	26	MCA	3a	4	0	2	1	Solitaire
11	M	73	Out of IV delay	20	ICA	4A	1	0	0	0	Angioplasty
12	M	50	Out of IV delay	>50	VA-BA	4B	–	1	0	0	Angioplasty/stent
13	M	56	Out of IV delay	>50	ICA	3A	2	0	2	2	Solitaire
14	M	49	Out of IV delay	25	MCA	3A	3	0	1	NA	Solitaire

Analyses of the images were realized by two readers separately for the purpose of interobserver evaluation. Clot length was measured after multiplanar reformation. Occlusion level was analyzed according to the classification proposed by Qureshi. Collateral circulation was graded according to previously published angiographic scales. Communicating arteries were analyzed and evaluated as absent, diameter <1 mm, or diameter >1 mm

consistent with an ischemic stroke involving the lenticular and insular territory. One and a half hours after IV thrombolysis, the patient did not present any clinical improvement and was referred for endovascular treatment. The IV FDCT was consistent with a complete occlusion of the internal carotid artery up to the carotid termination (Fig. 2). Successful mechanical revascularization was achieved after multiple attempts of thromboaspiration (6F Fargo catheter Balt, Montmorency, France) and temporary flow restoration with Solitaire FR. The internal carotid artery and the carotid termination were patent at the end of the procedure. The whole procedure lasted for 4 h. Unfortunately, the patient subsequently died from a severe hemorrhagic transformation of the lenticular stroke.

Case 3. A 77-year-old woman suffered from sudden loss of consciousness, left hemiplegia, and right third nerve palsy. Initial CT scan was considered normal. The patient progressively improved during the night with regression of the left deficit but subsequently worsened to her initial status with clinical suspicion of basilar artery thrombosis.

IV FDCT confirmed the occlusion of the middle third of the basilar artery (Fig. 3). Visualization of the basilar tip was excellent. The treatment was performed by thromboaspiration of the clot (6F Fargo catheter). The patient improved and was discharged with mRS 3.

Discussion

The majority of patients presenting with acute stroke benefit from an MR exploration with excellent definition of the localization and extent of the parenchymal ischemic infarct, nonetheless owing to the MR technology, the description of the arterial occlusion is often poor. Accurate clot assessment, as well as the degree of collateral circulation, is considered crucial for determination of the patient treatment strategy and eventual outcome [5]. There is a potential clinical benefit in accomplishing the imaging acquisition in the interventional suite, at least in those patients who will require a subsequent endovascular therapy. The aim of our study was to evaluate the feasibility of CT-like intracranial angiography acquired with a C-arm-mounted flat-detector technology peri-procedurally in the operating room in stroke patients elected for intra-arterial therapy.

CTA is considered as the gold standard in the visualization of the intracranial arteries in a noninvasive way [10, 17]. One of the major advantages over conventional angiography is

Fig. 1 Case 1. A 72-year-old man with a left middle cerebral artery resistant to intravenous thrombolysis with rTPA. **a** Conventional DSA, AP view, late arterial phase demonstrate occlusion of the left MCA at M1 with collateral leptomeningeal circulation and retrograde reconstitution of the MCA segments up to the bifurcation. **b** IV FDCT MPR coronal view, is concordant with the angiogram, depicts the length of the occlusion and demonstrates presence of clot inside the branches of the bifurcation. **c** and **d** Conventional DSA and IV FDCT MPR lateral view. Excellent visualization of the bifurcation branches of the MCA distal to the occlusion
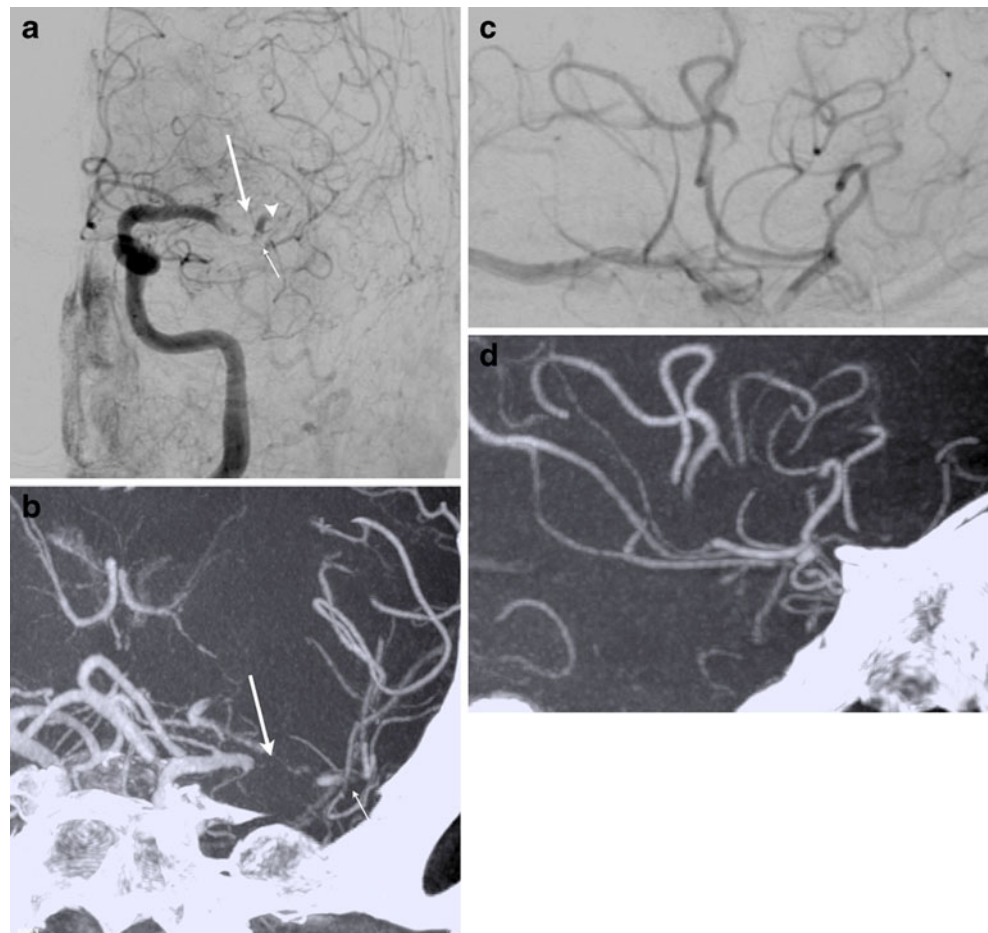
the visualization of the entire arterial brain circulation in the same acquisition, which provides detailed information on the anatomic extent of arterial circulation through the collateral pathways [17] (leptomeningeal circulation, anterior and posterior communicating artery patency and caliber). Accurate depiction of the clot location with a good visualization of the distal aspect of the obstructed artery beyond the clot are the mandatory prerequisites for neurovascular navigation planning in case of chemical or mechanical vessel recanalization. Quantification of the extent of vascular occlusion helps in the determination of the treatment strategy and in predicting eventual patient outcome [5, 17, 18]. The knowledge of pial collateral arterial supply before endovascular treatment is important as it can predict infarct volume and clinical outcome for patients with acute stroke undergoing thrombolysis independent of other predictive factors [15].

The visualization of the arterial bed distal to the occlusion, thus allowing delineation or estimation of the clot length (as depicted in cases 2 and 3) is one of the major advantage versus conventional DSA. This is related to the technique and the relative time length in the acquisition that allows complete filling of the collateral leptomenigeal supplies that are very nicely depicted.

The acquisition benefit from the advanced image post-processing available in the workstation, which is in real time connected to the acquisition system. The datasets can be dynamically manipulated and displayed in a multiplanar fashion (MPR reconstructions, curvilinear and maximal intensity projection are available) giving the ability to view vascular anatomy in any possible plane, which, versus DSA, provides information on localization and extent of vascular obstruction. In our experience, the use of this technique allowed for selection of the type of access and mechanical thrombectomy device we used for clot retrieval. The knowledge of the clot length helps selecting or combining the commonly used mechanical thrombectomy stent retrievers and aspiration catheters. The estimation of the collateral circulation might also predict the difficulty of the procedure and the prognosis [19].

Although in our series we did not encounter such a case, the relief of the arterial occlusion after IV thrombolysis and its confirmation by IV FDCT prior starting the endovascular procedure, would be extremely valuable.

The X-ray flat-detector technology provides for projection radiography, fluoroscopy, digital subtraction angiography, and volumetric CT capabilities in a single patient

Fig. 2 Case 2. A 71-year-old man with a left internal carotid artery stroke, with an NIHSS score of 10 and was thrombolysed at 3.30 h after the beginning of the symptoms. **a** Brain MRI TOF AP view, consistent with a complete occlusion of the internal carotid artery with no visualization of the cerebral branches. **b** Left internal carotid artery conventional DSA, AP view demonstrate occlusion ICA at the siphon. No collateral circulation is visible through the injection of this ax. **c** The IV FDCT is consistent with a complete occlusion of the internal carotid artery at the carotid termination with clear depiction of the clot extent and the collateral circulation through the anterior communicating artery (*white arrowhead*) and through leptomeningeal circulation with reconstitution of MCA segment (*thin white arrow*)
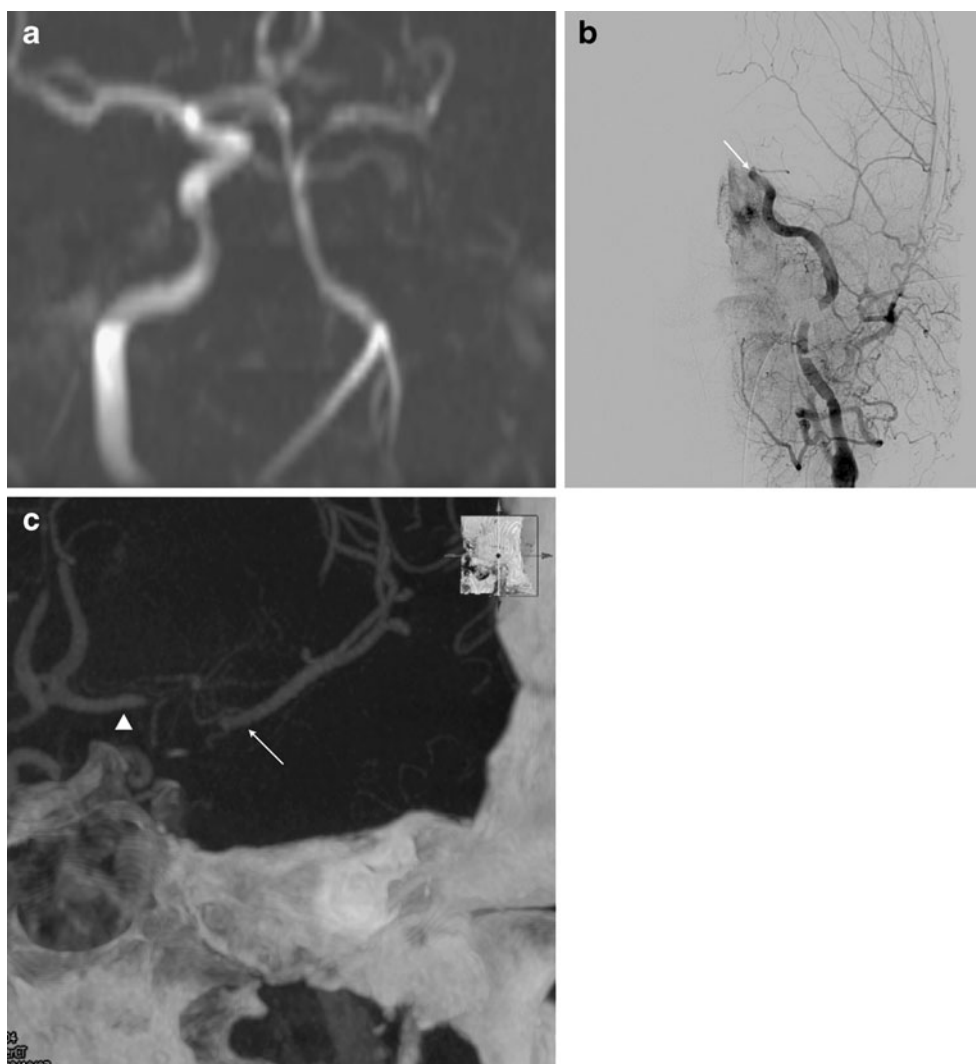
setup. The use of IV FDCT has been previously described in the literature on few patients [13], and its benefits were clearly emphasized [13, 20, 21].

The contrast resolution of the FDCT is less favorable to that of conventional CT. Experimental measurements showed that the contrast resolution of FDCT reconstructions was sufficient to visualize a phantom with 5-HU contrast inserts of 9 mm at a dose of 50 mGy. CT scans at an identical dose could visualize inserts of the same size with 3-HU contrast. However, the spatial resolution of the FDCT with the resolution power of 30 line pairs per centimeter at 10% modulation transfer function is, by far, superior to the spatial resolution of MSCT (15 line pairs per centimeter) [22]. Furthermore, the differences in image quality can be explained by the finer element size of the flat X-ray detectors, the larger contribution of scatter, the slightly lower detector quantum efficiency, more optimal use of X-ray dose in CT using a bowtie filter, and the limited size of the detector in the radial direction. The quality of secondary reconstructions of rotational acquisitions obtained with a

reasonable quantity of contrast medium appeared satisfactory and reproducible to the observers. A high-resolution IV FDCT scan of the brain exposes the patient to 49 mGy (computed tomography dose index (CTDI) weighted). Measured CTDI dose for the standard FDCT at 120 kV is 45 mGy, and for FDCTA at 80 kV, it is 49 mGy, both with a 48-cm detector field of view [23]. This is equal to the dose recommended by the International Electrotechnical Commission for a diagnostic conventional CT examination of the brain, and this dose even remains lower to the dose received for a conventional CTA.

We could not perform direct comparison with CTA image quality because all our patients had benefited from an MR prior to their admission in the operating room. Thus, one of the improvement of the evaluation of this technique would be to compare it to the results of CTA. Moreover, the possibility to assess the whole cerebral blood volume and to have evaluation of the cerebral perfusion is one of the further goal of the development of the technique as preliminary study have already reported it [24]. Our study

Fig. 3 Case 3. A 77-year-old woman with basilar artery occlusion. **a** Right vertebral artery angiogram AP view, demonstrate occlusion of the basilar trunk at its middle third. **b** IV FDCT MPR AP view is consistent with the occlusion of the middle third of the basilar artery and allows for clear visualization of the basilar tip and both P1 (*thin white arrows*). The right posterior communicating artery is visible (*white arrowhead*). C IV FDCT MPR axial view allows for clear visualization of both posterior communicating arteries (*white arrows*)
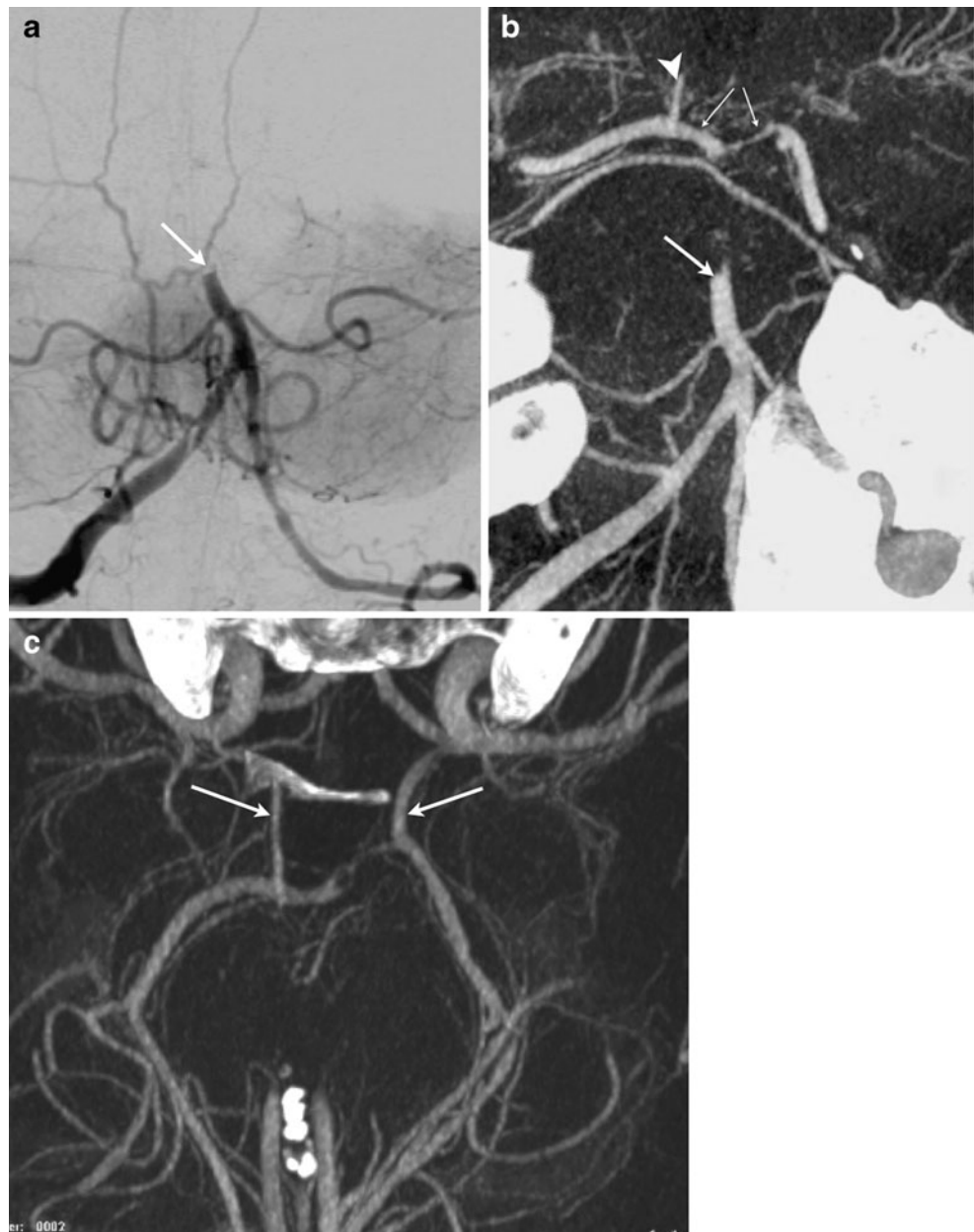
has limitations and the technique would benefit from various improvements.

In the performed cases, we used the inferior vena cava as the injection site. Preparing an additional femoral venous access is time-consuming and is relatively invasive. We used it in our early experience to ensure good performance and reproducibility as it provides a good iodine bolus compaction and steady contrast flow [25]. It did not increase much the time before starting treatment of the patient as the whole process of femoral access, image acquisition, and post-processing takes less than 10 min during which additional preparation of the patient is realized. However, the brachial approach, commonly used for the CTA, could be preferred

and we are progressively switching for this less invasive route in our current practice with similar image quality results on the cases performed. Also, the use of a dual-syringe power injector with saline injection flushing the contrast iodine could help us for bolus compaction and to lower the total of amount of contrast used.

The largest field of view used was 22×22 cm, which is sufficient to visualize the vessels from the distal cervical ICA up to the pericallosal artery, thus allowing a perfect visualization of the circle of Willis. With developing technology, it should be possible to increase the imaging coverage to 40 or 48 cm, in order to make possible the visualization of the entire intracranial circulation as well as the

cervical vessel tree. Further studies are necessary to reduce the contrast media load as well as the radiation dose [26].

Other potential clinical applications could benefit from this noninvasive imaging technique providing high spatial resolution—especially diagnostic imaging of cranial base tumors, brain arteriovenous malformation, or follow-up after aneurysm treatment by coiling or clipping.

Conclusion

The initial clinical results provide a high confidence and reproducibility rate for further utilization of this new technique in the interventional settings. The technique is used prior to or during interventional procedures with patient lying on the interventional table. The acquired IV FDCT scan provides an accurate delineation of the obstruction site, which might impact treatment strategy especially regarding the selection of the devices according to the level and the length of the occlusion.

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