Computed Tomography Angiography in the Assessment of Patients With Stroke/TIA

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Abstract

Rapid advance in medical technology has resulted in the availability of numerous tests and treatment strategies in the management of acute stroke. The increasingly evidence-based context of clinical medicine necessitates that clinicians use only appropriate tools to facilitate the diagnostic process and patient management. In this review, we seek to explore the use of computed tomography angiography (CTA) in the diagnosis and management of patients presenting with acute stroke (ischemic and hemorrhagic) or transient ischemic attack (TIA). We present evidence in favor of the use of CTA, highlight the disadvantages of this imaging modality, and present a heuristic model based on our experience at utilizing CTA for decision making in acute stroke and TIAs.

Keywords

intracranial hemorrhages, cerebrovascular disorders, ischemic attack, transient, cerebrovascular disorders, stroke, cerebrovascular disorders, stroke and cerebrovascular disease, clinical specialty, imaging, techniques

Introduction

Rapid advance in medical technology has resulted in an explosion of diagnostic tests and treatment strategies in the management of acute stroke. Each clinical scenario presents unique challenges related to risks and benefits of testing and therapy. The increasingly evidence-based context of clinical medicine necessitates that clinicians use only appropriate tools to facilitate the diagnostic process and patient management.

At a time when medical practice is increasingly limited by scarce resources, careful consideration must be given to how diagnostic tests and resultant treatment strategies affect clinical outcomes. Physicians build heuristic decision models based on their experience and use these in decision making. In this review, we seek to explore the use of computed tomography angiography (CTA) in the diagnosis and management of patients presenting with acute stroke (ischemic and hemorrhagic) or transient ischemic attack (TIA). We intend to present evidence in favor of the use of CTA, highlight the disadvantages of this imaging modality, and present a heuristic model based on our experience at utilizing CTA for decision making in acute stroke and TIAs. Technical details and specific imaging protocols with CTA do not fall within the ambit of this review.

An acute stroke-imaging tool needs to answer 4 critical questions when patients present with symptoms¹:

Is there hemorrhage?

Is there an intravascular thrombus that is amenable to lysis?

Is there a core of irreversibly infarcted brain tissue?

Is there a penumbra of severely ischemic but potentially salvageable tissue?

Computed tomography angiography is a very good tool to answer question 2, does a fairly good job of answering question 3, and provides reasonable surrogate evidence for the existence of a penumbra (question 4). In addition, in conjunction with noncontrast CT (NCCT), it also provides additional information on hemorrhage growth in patients who present with acute intracerebral hemorrhage (ICH).

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Figure 1. Computed tomography angiography (CTA) showing a patient with a clearly delineated left middle cerebral artery M1 segment occlusion.

What Information Does CTA Provide in Patients Presenting With Acute Ischemic Stroke That Helps in Clinical Decision Making?

Presence of Occlusion

Intravenous (IV) tissue plasminogen activator (tPA) has limited clinical impact^{2,3} restricted to a small subgroup of patients with a number needed to treat of 3 to 8. Numerous angiographic studies have shown that a large proportion of patients with acute ischemic stroke (19%-39%) have no identifiable occlusion.⁴ The presence of an intracranial occlusion clearly identifies a subgroup of patients who have severe stroke deficits on presentation and who do not have a good prognosis unless treated with thrombolytic therapy.⁴⁻⁶ Computed tomography angiography is a rapid, easily available imaging tool for detecting intracranial occlusions in patients presenting with acute ischemic stroke, thereby guiding therapy (Figure 1).

Extent of Thrombus

In addition to providing information on the presence of an occlusion, CTA also helps in estimating the extent of occlusion in the arterial tree (the thrombus burden). Recanalization rates in patients with proximal occlusions are significantly lower with IV tPA when compared to endovascular therapy.^{7,8} Among 388 patients with proximal occlusions in the CTA database at our center, 127 patients underwent further imaging to assess recanalization of which only 27 (21.3%) patients had acute recanalization. Recanalization was assessed first using angio images of a conventional cerebral angiogram in patients going to the angiosuite for endovascular therapy or on

Figure 2. Clot burden score demonstrating the extent of clot on computed tomography angiography (CTA) in the anterior circulation in patients with acute ischemic stroke. *Int J Stroke* 2008;3(4):230-236. (To obtain permission from Copyright © 1999-2010 John Wiley & Sons, Inc. All Rights Reserved.)

transcranial doppler within 2 hours of IV tPA. By occlusion subtype, the rates of recanalization were distal internal carotid artery (ICA) (4.4%); M1-middle cerebral artery (MCA) (32.3%); M2-MCA (30.8%); and basilar artery (4%).⁹ Early recanalization is a powerful independent predictor of good clinical outcome.¹⁰ Given the low rates of recanalization with IV tPA in proximal occlusions, vascular imaging using CTA could potentially be useful in triaging patients for appropriate recanalization therapy. Computed tomography angiography can be used to assess the extent of thrombus in the arterial tree using a clot burden score¹¹ ([CBS]; Figure 2). With increasing CBS values (ie, less thrombus burden), patients are significantly more likely to have an independent functional outcome and less likely to die. In addition, final infarct sizes are smaller and hemorrhagic transformation rates lower.¹¹ Higher CBSs (smaller clots) were associated with higher recanalization rates in a recent study by Tan and colleagues.¹²

Thrombus extent can also be quantitated by measuring the length of a thrombus in the arterial tree. In a recent study, Riedel et al have shown that of 138 patients who presented with acute middle cerebral artery stroke and treated with IV tPA, no recanalization was noted in any patient with a thrombus length greater than 8 mm. Thrombus length in this study was measured as length of arterial hyperdensities in admission NCCT images with 2.5-mm slice width.¹³ We have developed a technique of measuring thrombus length directly using CTA. Our study also shows that thrombus length measured on baseline CTA determines recanalization with IV tPA in patients

Figure 3. Residual flow through a left M1 middle cerebral artery segment with anterograde filling of M2 segment pial arteries. Dynamic computed tomography angiography (CTA) will be able to give a better estimate of anterograde or retrograde flow.

presenting with acute anterior circulation occlusions. Thrombus length 0 to 5 mm demonstrated a recanalization rate of 42.8% and no patient with a thrombus length >20 mm recanalized with IV tPA.¹⁴

Residual flow through a thrombus is associated with less tissue damage in coronary angiography¹⁵ and higher rates of arterial recanalization in strokes treated with IV tPA.^{16,17} Increased surface area on thrombus for fibrinolysis to act could potentially be responsible for this. In a recently published series from our center, an intracranial nonocclusive thrombus (iNOT) was differentiated from fully occlusive thrombus or atherosclerotic stenosis using CTA.¹⁸ We have also shown that presence of residual flow detected using CTA (Figure 3) is associated with better clinical outcomes in patients with acute ischemic strokes.¹⁹

Willisian and leptomeningeal collaterals (LMCs) are responsible for preserving blood flow distal to the site of occlusion in patients with acute ischemic strokes. Evidence clearly shows that good LMC status is associated with smaller final infarct volumes and better clinical outcomes in patients with acute ischemic strokes.²⁰⁻²² Computed tomography angiography provides a quick and reliable method of assessment of Willisian and LMCs.^{23,24} Dynamic CTA using new generation 320 slice scanners with “z-”axis coverage of 16 cm is able to provide time-resolved images of retrograde filling of pial arteries.²⁵ We have described a method of scoring LMCs based on the extent of opacification of pial arteries distal to a M₁ MCA+/- intracranial ICA occlusion on CTA.²² The regional leptomeningeal score is a semiquantitative system of scoring based on the major anatomical regions of the anterior circulation and comparable to the ASPECTS scoring method of head CTs²⁶ (Figure 4A and B). We have demonstrated a strong correlation between the regional LMC (rLMC) score at baseline and both radiological and clinical outcomes.²² Our results as well as other previous studies show LMC status to be an important determinant of final infarct

core and highlight the importance of using CTA in assessing collaterals in patients presenting with acute ischemic stroke.^{20,27}

Neurovascular Anatomy

Neurointerventionists need information not only on the site of occlusion but also on the anatomy of the arch of aorta and proximal extracranial neck vessels to plan an intra-arterial procedure. Computed tomography angiography provides high-resolution images of the arch of aorta and neck vessels that help in planning endovascular procedures and could potentially reduce procedural time.²⁸ In addition, site of thrombus within the arterial tree also determines the choice of endovascular technique. Device profiles of present generation devices are tailored to the target artery with each device available in different sizes.^{29,30} Small pial arteries can however only be accessed by microcatheters and chemical thrombolysis with intra-arterial (IA) tPA. Increasingly, neurointerventional practice is now based on achieving recanalization using multiple devices and techniques tailored to the needs of a specific situation and the use of CTA helps in this decision-making process.

Computed Tomography Angiography Source Images

Hypoattenuation on CTA source image is an indicator of reduced cerebral blood volume in the area of ischemia (Figure 5). These hypoattenuation characteristics are not as time dependent as hypoattenuation due to ischemia on NCCT.³¹ Areas of hypoattenuation on CTA source image correlate well with lesions on diffusion-weighted image (DWI) and are therefore a marker of core or irreversibly infarcted brain tissue at presentation.^{31,32} Numerous studies have also shown that CTA source image improves the prediction of final infarct size and clinical outcome when compared to NCCT, more so in patients presenting ultra early (<90 minutes from stroke symptom onset; Simerpreet Bal, MD, et al., May 1, 2011, personal communication). With new generation scanners, a distinction has to be made between CTA source image acquired during the arterial phase and images acquired during the venous phase. Computed tomography angiography source images acquired during the arterial phase are flow weighted and indicate brain region with reduced cerebral blood flow when compared to images acquired during the venous phase which are more blood volume weighted and hence better approximate irreversibly infarcted brain tissue.³³ This distinction is addressed adequately with new generation scanners with whole brain coverage, which provide whole brain perfusion images along with time-resolved CTA images of the intracranial circulation. The utility of CTA source images may become questionable with the availability of new generation scanners.^{25,34} Until then, CTA source images have a role in delineating irreversibly infarcted brain tissue in patients presenting with acute ischemic stroke.

Figure 4. A, Regional leptomeningeal collateral score on computed tomography angiography (CTA). “Excellent Collaterals”: imaging shows a right proximal M1 MCA occlusion with excellent leptomeningeal collaterals including retrograde opacification of the pial arteries until the distal end of the thrombus. Regional leptomeningeal score (rLMC score) is 19. B, Regional leptomeningeal collateral score on computed tomography angiography (CTA). “Poor Collaterals”: imaging shows evidence of carotid “T” occlusion with cross filling of the ipsilateral A2 via an anterior communicating artery.

What Information Does CTA Provide in Patients Presenting With Minor Stroke and TIA That Helps in Clinical Decision Making?

Minor stroke and TIA is the largest group of cerebrovascular disease patients. Over 80% of all patients with stroke may fall into this category.³⁵ Up to 30% of disabling strokes are heralded by nondisabling TIAs and minor strokes, usually within the prior 7 days.^{36,37} After a TIA or minor stroke, there is a 10% to 20% risk of a subsequent stroke within 90 days.³⁸⁻⁴⁰ There is growing evidence to show that the presence of intracranial stenosis and occlusion in patients with minor stroke and TIA detected using CTA predicts the risk of recurrent stroke and clinical outcome at 90 days.⁴¹⁻⁴³ By identifying intracranial occlusions and stenosis, CTA can therefore be used

as a risk-stratification tool acutely in patients presenting with minor strokes and TIAs.

Presence of extracranial large artery disease is an important determinant of recurrent stroke risk in patients with minor stroke.⁴² In pooled data from 3886 patients with clinically defined TIA who were investigated while in secondary care, the addition of imaging parameters that included stenosis of at least 50% on carotid imaging (2 points) and abnormal DWI (2 points) in the ABCD3 imaging (ABCD3-I) score (0-13 points) improved risk stratification significantly. *C* statistics for the ABCD3-I score were higher than that for the ABCD2 score: 0.90 at 2 days, ($P = .035$), 0.92 at 7 days ($P = .001$), 0.85 at 28 days ($P = .028$), and 0.79 at 90 days ($P = .073$).⁴⁴ This and other previous data show the importance of detecting extracranial carotid disease in patients presenting

Figure 5. A, Computed tomography angiography (CTA) source images in all 3 planes windowed for optimal imaging of hypoattenuation of contrast. B, Computed tomography angiography (CTA) source image showing hypoattenuation of contrast in the right middle cerebral artery territory in a patient who presents with an acute ischemic stroke and left hemiplegia with hemineglect.

with minor strokes and TIA. Computed tomography angiography is a reliable, accurate, and quick method of detecting carotid disease in patients who present to the emergency department (ED) with symptoms suggestive of minor stroke or TIA.²⁸ In a recent study on patients with minor stroke and TIA, costs resulting from strategies employing duplex ultrasonography (US), CTA, contrast material-enhanced magnetic resonance (MR) angiography, and various combinations of these modalities were modeled in a decision tree and Markov model. The authors concluded that in patients with a high-risk profile, a high probability of carotid artery disease or

those who can undergo surgery without delay, immediate CTA followed by surgery for 50% to 99% stenosis is indicated.⁴⁵

Computed tomography angiography also helps in predicting functional outcomes after minor strokes and TIAs. In a study from our center, a composite CT-based “at-risk” metric, defined by acute stroke on NCCT, circle of Willis intracranial vessel occlusion or $\geq 50\%$ stenosis, extracranial occlusion or $\geq 50\%$ stenosis was associated with poorer outcome, thereby suggesting that CTA can be used for prognostication and risk stratification after minor strokes and TIAs.⁴²

Figure 6. Computed tomography angiography (CTA) arch to vertex in a patient with a tapering occlusion of the right internal carotid artery at the skull base due to dissection.

What Additional Diagnostic Information Does CTA Provide in Patients Referred to the Stroke Service From the ED?

In addition to its utility in diagnosis, risk stratification, prognostication, and making treatment decisions in patients presenting with major or minor acute ischemic strokes or TIAs, CTA when done acutely in the ED also provides a wealth of additional information about pertinent cerebrovascular diseases.

As mentioned earlier, CTA is a reliable tool to diagnose extracranial large artery disease. In carotid disease, CTA has been used to evaluate extracranial carotid plaque characteristics and the presence of an intraluminal thrombus.⁴⁶ In a large retrospective study, the presence of intraluminal thrombus detected on CTA was found to be highly predictive of the symptomatic side in carotid disease when compared to a smooth plaque surface or extensive calcification, thus suggesting certain plaque characteristics that could predict an unstable plaque with a tendency for recurrent thromboemboli.⁴⁷ In another study, carotid wall enhancement using CTA

indicated symptomatic carotid disease. The authors postulated that the sign could potentially be used in risk stratification of carotid plaque characteristics.⁴⁸ Though other imaging techniques like MR imaging (MRI) and high-definition dual source CT scanners with spectral imaging may provide far greater detail about plaque characteristics,^{49,50} CTA is at present the only imaging tool that is readily available to clinicians in an emergency setting.

Computed tomography angiography has also been used in identifying disease of the arch of aorta and thrombus in the left atrial appendage. In a recent study, the sensitivity of CTA in detecting grades 1 to 4 aortic arch atheroma was 53% and the specificity was 89%. For high-grade atheroma, the specificity improved to 99%, but the sensitivity decreased to 23%. The high negative predictive value suggests that CTA may be a useful screening tool to exclude high-grade atheromas.⁵¹ Cardiac CTA has been used to detect left atrial thrombus in patients with stroke. With transesophageal echocardiography as the reference standard, the overall sensitivity, specificity, and accuracy of 64-section cardiac CTA for detecting thrombi in a recent study were 100% (95% confidence interval [CI]: 63%, 100%), 95% (90%-99%), and 96% (92%, 100%), respectively.⁵² Though not yet routinely used in evaluation of acute stroke/TIA patients, CTA can in future be used fruitfully to detect cardiac thrombus as a potential stroke etiology. This would entail imaging from the left atrium upward to the vertex, a technique that can also provide additional information about the presence of major pulmonary emboli too.

Computed tomography angiography can also help in diagnosing dissections of intracranial arteries, major arteries of the neck, and of the proximal aorta with diagnostic and therapeutic implications in patients presenting with symptoms suggestive of stroke or TIA (Figure 6). Computed tomography angiography is also useful in diagnosing intracranial vasculitis or vasculopathies, though catheter angiography and biopsy are still the gold standards^{53,54} (Figure 7). It is also a reliable noninvasive tool for monitoring the evolution over time of intracranial vasculopathy and stenosis.

What Information Does CTA Provide in Patients Presenting With Acute Hemorrhagic Stroke That Helps in Clinical Decision Making?

Computed tomography angiography can quickly and accurately identify intracranial aneurysms, arteriovenous malformations, dural arteriovenous fistulas, and other vascular anomalies in patients presenting acutely with ICH, thus allowing for appropriate endovascular or surgical treatment. The probability of finding these secondary causes of ICH ranges from 15% in adults to as high as 65% in patients younger than

Figure 7. Computed tomography angiography (CTA) showing irregularity of the pial arteries in a patient with a suspected intracranial vasculopathy.

40 years.⁵⁵⁻⁵⁷ Age <46 years, lobar or infratentorial location of hemorrhage, female sex, and absence of known hypertension or impaired coagulation on admission identifies a subgroup of patients in whom the probability of detecting these secondary causes are high.⁵⁷

The “spot sign” in CTA (Figure 8) indicates the presence of active contrast extravasation and is probably an indicator of ongoing bleeding within an ICH.^{58,59} Several studies have shown that the spot sign is an accurate and powerful predictor of hematoma expansion, mortality, and poor outcome in patients with primary ICH.⁵⁹⁻⁶¹ A positive spot sign is a serpiginous and/or linear-shaped contrast density located within the margin of a parenchymal hematoma and not present in the NCCT. It must not have any anatomical continuity with vasculature adjacent to the hemorrhage. In addition, the spot sign must have an attenuation characteristic >120 Hounsfield units. These prespecified criteria help in distinguishing a spot sign from spot sign mimics such as choroidal calcifications, tumors, Moyamoya disease, aneurysms, and microarteriovenous malformations (AVMs).⁶²⁻⁶⁵ Since the presence of a spot sign indicates active bleeding and hemorrhage growth, the sign is now being used in 2 large randomized control trials designed to identify appropriate patients for early hemostatic therapy using recombinant factor VIIa (STOP-IT and SPOTLIGHT Trials) and if validated in these trials, could become a powerful triage tool in the selection of patients with primary ICH for hemostatic therapy.

Computed tomography angiography also helps in identifying possible venous sinus thrombosis though care has to be taken in interpreting the images for the presence of this abnormality only if the images are sufficiently in the venous phase,²⁸ although a CT venogram is the more ideal test in this setting.

Figure 8. Computed tomography angiography (CTA) showing a “spot sign” in a patient with a left capsule ganglionic primary intracerebral hemorrhage extending into the corona radiata.

What are the Drawbacks Associated With the Use of CTA in Patients Presenting With Acute Ischemic or Hemorrhagic Stroke or TIA?

Radiation

The mean radiation dose measured in millisievert (mSV) dose for an arch to vertex CTA is around 5.4 ± 2.2 mSV. This dose is further reduced if a center does circle of Willis CTA only (1.6 mSV). This compares favorably with a CT chest (7-11.3 mSV) and a CT abdomen (8-11.7 mSV).^{66,67} This dose also compares favorably with the annual exposure to radiation of the general population.⁶⁸ Computed tomography angiography in many centers is however accompanied by an NCCT (2.7 mSV) and a perfusion CT (3.3-6.7 mSV) that may result in a total radiation dose of up to 16 mSV.⁶⁹ This dose is approximately 5 to 6 times the estimated annual background effective radiation dose²⁸ for a person in the United States (3 mSV). Cancer mortality⁷⁰ due to radiation depends on the age of the patient with a lifetime attributable risk of cancer incidence from a 100 mSV exposure being 16.5 per 1000 at age 20, which reduces to 2.1 per 1000 at age 80. Multiple technical strategies to reduce the risk of radiation exposure are used, such as thinner slices with decreased tube current, altering table speed and pitch, and lowering kilo voltage peak.⁷¹ A comprehensive CT-based stroke protocol including perfusion imaging and/or delayed CTA would only be indicated in patients in whom the tests either would result in a significant change in management (aggressive revascularization procedure) or is part of a clinical trial with informed consent.

Risk of Contrast-Induced Nephropathy

Three factors have been associated with an increased risk of contrast-induced nephropathy: preexisting renal insufficiency, preexisting diabetes, and reduced intravascular volume.^{72,73} In a study from our center, 36 patients underwent baseline CTA and then proceeded to conventional angiography with a mean of 110 mL dose (range 34-231 mL), yet none developed radio-contrast nephropathy with no increase in serum creatinine noted on follow-up.⁷⁴ In a large prospective cohort study of patients presenting with stroke, the incidence of acute contrast nephropathy was 5% in those exposed to contrast when compared to 10% in the nonexposed group ($P = .003$). Administration of a contrast-enhanced CT protocol involving CTA/computerized tomography perfusion (CTP) and conventional angiography in selected patients did not appear to increase the incidence of contrast-induced nephropathy.⁷⁵ In a series of patients with ICH, the risk of nephropathy was 14% in those receiving no contrast, 5% in those receiving 1 contrast study, and 6% in those receiving more than 1 contrast study. Neither CTA nor any use of contrast predicted nephropathy in univariate or multivariate analysis.⁷⁶ With these and similar findings,⁷⁷ it is clear that if patients are hydrated sufficiently, the risk of contrast-induced nephropathy in patients presenting with acute stroke or TIA is minimal. Other strategies to reduce the risk include protocols designed to use the smallest amount of contrast possible for optimal imaging, denser contrast agents, and power injectors. At our center, acquisitions are obtained after a single bolus intravenous contrast injection of 90 to 120 mL nonionic contrast media into an antecubital vein at 3 to 5 mL/s, autotriggered by the appearance of contrast in a region of interest (ROI) manually placed in the ascending aorta.

Time Lost While Doing a CTA

Computed tomography angiogram is often used for triaging patients for appropriate therapy. Opponents of this approach point to the fact that vascular imaging may delay treatment.⁷⁸ The addition of CTA to an NCCT only adds approximately 5 minutes to the scanning time and can be safely completed emergently with a small dose of contrast.⁷⁴ In a recent study, Salottolo et al show that the use of multimodal imaging including vascular imaging and perfusion CT did not delay initiation of IV tPA.⁷⁹ Our experience has been that time spent on additional vascular imaging at baseline (4-5 minutes) has not delayed treatment and has helped in triaging patients for appropriate therapy.

The Problem of Expertise in Interpreting CTA

A learning curve is a well-known phenomenon in any field of knowledge. In a study on the processing and interpretation times of CTA and perfusion CT in patients with stroke, the time for CTA processing and interpretation by radiology residents was 2.3 ± 1.3 minutes. Neuroradiology fellows took

1.6 ± 0.4 minutes and consultant neuroradiologists took 1.5 ± 0.7 minutes, respectively. The time required for CTP processing and interpretation by the same groups was 5.2 ± 1.7 minutes, 4.5 ± 1.5 minutes, and 4.1 ± 1.1 minutes, respectively. There was a statistically significant difference in means between radiology residents and consultants in the CTA and CTP processing and interpretation times ($P = .02$ and $P = .01$, respectively), thus suggesting that training improves the speed of interpretation of images.⁸⁰ It is our opinion that with adequate training, CTA images can be interpreted by a trained physician with sufficient expertise and speed and appropriate clinical decisions are made.

What Advantages Does CTA Have Over MR Angiography in the Assessment of Patients With Acute Stroke or TIAs?

Although CTA involves radiation exposure and the risk of contrast nephropathy, it has several advantages over MR angiography for neurovascular imaging. Speed is of essence in the management of patients with acute stroke. Computed tomography angiography takes less time than MR angiography and provides high-resolution anatomic nonflow-dependent images when compared to MR. The speed of scanning and the nature and environment of the gantry result in significantly better patient comfort. It can easily be done in patients who have contraindications for MR like pacemakers or in situ metals, intravenous pumps, ventilators, or monitoring equipment. Severe agitation common in patients with severe stroke also prevents successful MR imaging.⁸¹ Computed tomography angiography is less prone to motion artifacts than MR. It is also more readily available than MR.^{82,83} In our opinion, based on these facts, CTA should be the first choice for comprehensive noninvasive neurovascular imaging in an acute stroke scenario. Magnetic resonance angiography may be considered in a non-emergent set up when clinical decision making can wait for the investigation to be done or when sequential imaging is necessary.

What Does the Future Hold for the Use of CTA in Acute Strokes or TIAs?

The new 320-detector row CT has a detector width of 16 cm in the z-axis. With this capability, whole-brain imaging can be done during the peak arterial phase of contrast administration with 1 gantry rotation in 1 second.^{25,84} An arch to vertex cerebral circulation image can be obtained in less than 5 seconds. Whole brain perfusion imaging can be obtained along with a base of skull to vertex time resolved CTA using the same scanning sequence³⁴ (Figure 9). Dual source spectral imaging allows for better neurovascular imaging by removing bone and calcium artifacts, thus providing high-resolution vascular imaging at the skull base and neck.^{49,50}

Figure 9. A 320-detector row CT scanner with time-resolved dynamic computed tomography angiography (CTA) and perfusion CT images acquired at the same time in a patient with a left M1 MCA occlusion and a small region of decreased CBV (arrow, figure on upper right) suggesting infarct core and low CBF, and prolonged TTP in the MCA territory (figures in lower panel) suggesting the presence of potentially salvageable brain. CBV, cerebral blood volume; CBF, cerebral blood flow; TTP, time to peak.

A Heuristic Model for Use of CTA in Patients Presenting With Acute Stroke or TIA Based on Our Experience

- We recommend the use of arch to vertex CTA in any patient who presents with symptoms of acute ischemic stroke and is a potential candidate for intravenous or
- In patients presenting with minor stroke or TIA, we recommend arch to vertex CTA unless there are any specific contraindication like known renal disease, contrast allergy

intra-arterial thrombolytic treatment. The decision to use this imaging modality in a patient who presents within 3 hours of stroke symptom onset and is a candidate for IV tPA is best left to the treating physician's discretion.

and so on. In centers with capability for doing MR-based studies, the choice of imaging modality may be best left to the treating physician with the caveat that parenchymal and neurovascular imaging in minor stroke or TIA has to be obtained as soon as possible.

- Decision to use this imaging modality when the suspicion of small vessel disease as causative etiology is high is best left to the treating physician.
- In patients with clinical suspicion of arterial dissections, vasculopathies, or any other vascular pathology thought to be responsible for the patient's symptoms, we recommend a CTA for diagnosis. In centers with capability for doing MR-based studies, the choice of imaging modality may be best left to the radiologist.^{85, 86}
- Computed tomography angiography in patients presenting with acute ICH is indicated when there is a clinical suspicion of a secondary cause. In patients with primary ICH, CTA circle of Willis to vertex will predict the risk of hematoma expansion and provide prognostic information but requires further evaluation within the context of randomized trials of hemostasis.

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