

Whole brain CT perfusion on a 320-slice CT scanner

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Abstract

Computed tomography perfusion (CTP) has been criticized for limited brain coverage. This may result in inadequate coverage of the lesion, inadequate arterial input function, or omission of the lesion within the target perfusion volume. The availability of 320-slice CT scanners offers whole brain coverage. This minimizes the chances of misregistration of lesions regardless of location, and makes the selection of the arterial input function easy. We present different clinical scenarios in which whole brain CTP is especially useful.

Key words: 320-slice CT scanner; whole brain CT perfusion; CT scan

Introduction

The major limitation of computed tomography perfusion (CTP) has been its limited brain coverage. This may result in inadequate coverage of the lesion, inadequate arterial input function, or omission of the lesion within the target perfusion volume. This is important especially in diffuse and multifocal diseases such as vasculitis or vasospasm, arteriovenous malformation (AVM), and chronic ischemia.

The other available options for evaluating brain perfusion are nuclear medicine studies such as positron emission tomography (PET) and single photon emission computed tomography (SPECT). However, accessibility and spatial resolution are a major limitation. In addition, the resolution of these imaging studies may be a limiting factor. MRI perfusion (MRP) is a promising technology, offering the ability to image the whole brain. The major disadvantage of MRP is that the perfusion parameters are relative rather than absolute, unlike those in CTP.

Imaging of the whole brain can be done with 320-slice CT

scanners. The other major advantage is the possibility of getting time-resolved CT angiographic information from the same data set, without additional contrast or radiation.^[1] The purpose of this article is to review the clinical situations in which whole brain CTP is useful.

Principle and Method

We retrospectively reviewed patients who underwent whole brain CTP for various clinical indications between May 2008 and March 2009 at a single institution. The study was approved by our institutional ethics committee. All studies were performed on a 320-slice CT scanner (Toshiba Medical System, Nasu, Japan).

Imaging protocol

CT perfusion was performed using 40 mL of nonionic iodinated contrast media (Omnipaque, 300 mg/mL of iodine; Amersham Heath, Princeton, NJ, USA), injected intravenously at the rate of 4 mL/s. A total of 19 volumes covering the whole brain were acquired, with each volume consisting of 320 images of 0.5 mm thickness covering a total of 16 cm of the head in the z direction. The first volume was acquired with an acquisition delay of 7 s after the injection of contrast media. The time delay allowed the acquisition of baseline images without contrast enhancement, which were used as a mask for obtaining bone subtraction for subsequent computed tomographic angiogram (CTA). The acquisition parameters for the first volume were 80 kVp and 300 mA. Next, 13 volumes of the brain were acquired starting at 11 s after the injection of contrast media at a sampling interval of one volume every 2 s. These volumes

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were acquired during the arterial and the capillary phase. Then, five volumes were acquired at a sampling interval of one volume every 5 s. The acquisition parameters for all volumes after the first volume were 80 kVp and 100 mA. The total duration of the acquisition was 60 s.

Data processing

Postprocessing was performed on a Vitrea fx, version 1.0, workstation (Vital Images Inc., MN, USA) using the delay-insensitive singular-value decomposition (SVD) plus nonparametric deconvolution method. The supraclinoid segment of the internal cerebral artery was chosen to measure the reference arterial input function to avoid any volume averaging. The posterior portion of the superior sagittal sinus was selected for the same reason, to evaluate the venous output function.

Color maps of the hemodynamic parameters such as blood flow (BF), blood volume (BV), mean transit time (MTT), and time to peak (TTP) were calculated using the SVD plus deconvolution method. The specific hemodynamic information of the diseased portion of the brain was obtained by drawing various regions of interest (ROIs) in the area and then comparing them with the ROIs of the normal brain.

In most cases, CTP was requested by the referring doctors for clinical indications. In other cases, CTP data was acquired from the time-resolved CT angiograms of the brain performed for other clinical indications.

Results

A total of 81 patients (35 males and 46 females) with a mean age of 56.5 years (range, 31–85 years) underwent whole brain CTP in our institute for various clinical indications as shown in Table 1.

Cases

Since the patients with brain tumors were studied with limited-slice CTP on another CT scanner as part of another ongoing study, most of the patients in our study had one or the other form of ischemia.

Acute stroke

In cases of acute stroke, whole brain CTP demonstrates the whole extent of the infarct. These can be either territorial infarcts [Figure 1] or multiple embolic infarcts. In cases of multiple emboli, whole brain perfusion helps in the localization of infarcts and in determining their age [Figure 2]. This is particularly helpful in cases where infarcts are located at the extreme ends of the brain, i.e., near the vertex or posterior fossa. Using conventional CTP with limited brain coverage, it is often difficult to obtain an adequate arterial input curve in these areas.

Table 1: Various clinical conditions for which whole brain CTP was performed

Indications	Number of cases
Chronic stroke	23
Acute stroke	9
Vasospasm	12
AVM	13
AVF	4
Post STA-MCA bypass	4
Vasculitis	2
DVA	2
SDH	2
Moyamoya disease	1
CVT	1
Dimox study	1
Superior ophthalmic vein thrombosis	1
Intracerebral hematoma	1
Meningioma	1
Radiation necrosis	1
Brain death	1
Air embolism	1
Myxoma vasculopathy	1

STA-MCA: Superficial temporal artery–middle cerebral artery; AVF: arteriovenous fistula

CT perfusion is helpful in evaluating patients with an impaired level of consciousness, for whom clinical examination has limited scope. Whole brain CTP is important in localizing unsuspected infarcts in this group of patients. This may be seen in patients with intracranial hemorrhage, in whom the infarcts occur secondary to mass effect or from vasospasm after aneurysmal subarachnoid hemorrhage [Figure 3]. These ischemic lesions may be reversible with timely intervention, especially in cases of vasospasm [Figure 3].

Chronic ischemia

In patients with chronic ischemia of the brain, a wide spectrum of findings such as multiple, patchy ischemic lesions or lesions quite remote from the actual site of ischemia can be seen. In crossed cerebellar diaschisis (CCD), there is metabolic depression in the cerebellum contralateral to supratentorial lesions.^[2] This entity has been described on PET and MRI perfusion studies.^[3,4] However, to the best of our knowledge, it has not been described on conventional CTP due to reasons of limited coverage. With the whole brain CTP, we have seen evidence of CCD in patients with supratentorial lesions^[5] [Figure 4].

In the case of the chronic occlusion of a major artery with chronic hemispheric ischemic symptoms, surgical revascularization is an option. The assessment of the cerebrovascular reserve is critical to determine whether patients will benefit from bypass surgery.^[6] Whole brain

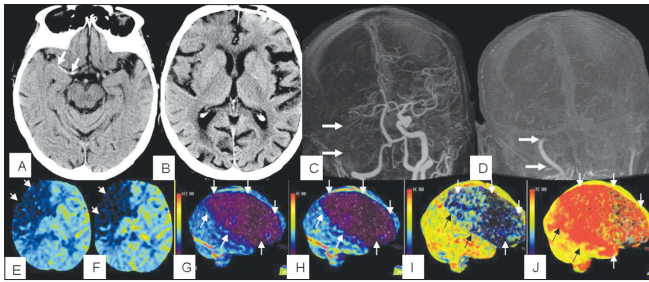


Figure 1: A 95-year-old woman presented with left hemiplegia. CT scan of the brain (A) shows a positive “dense MCA sign” (arrow) with the rest of the brain (B) showing relatively preserved gray–white matter differentiation. Time-resolved CTA (C) shows lack of flow in the right internal carotid artery (arrow) and the right middle cerebral artery (MCA) territory with delayed filling of the right distal internal carotid artery (ICA; arrow in D). Whole brain perfusion shows an almost complete right MCA territory-matched defect (arrows) on cerebral blood flow (CBF; E) and cerebral blood volume (CBV; F) maps. The whole extent of the right MCA territory infarct is better seen on the 3D reconstruction of CBF (G), CBV (H), mean transit time (I), and time to peak (J) maps

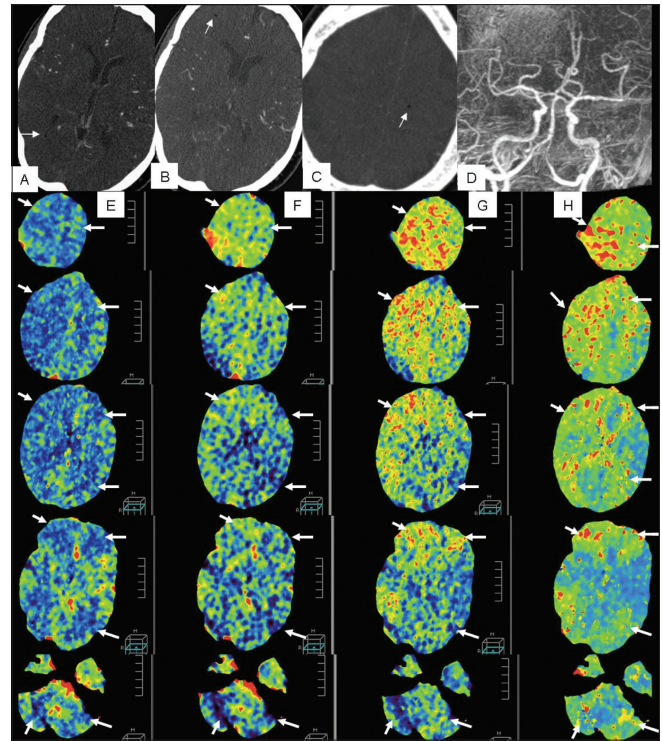


Figure 2: A 65-year-old woman collapsed immediately after bronchoscopy. CT scan of the brain (A–C) shows multiple foci of air (arrows) throughout the brain, suggestive of air embolism. CTA (D) shows no obvious abnormality. Multiple axial images of whole brain CT perfusion show the overall decrease in cerebral blood flow (arrows in E), multiple foci of decreased cerebral blood volume (arrows in F), increased mean transit time (arrows in G), and increased time to peak (arrows in H) throughout the brain

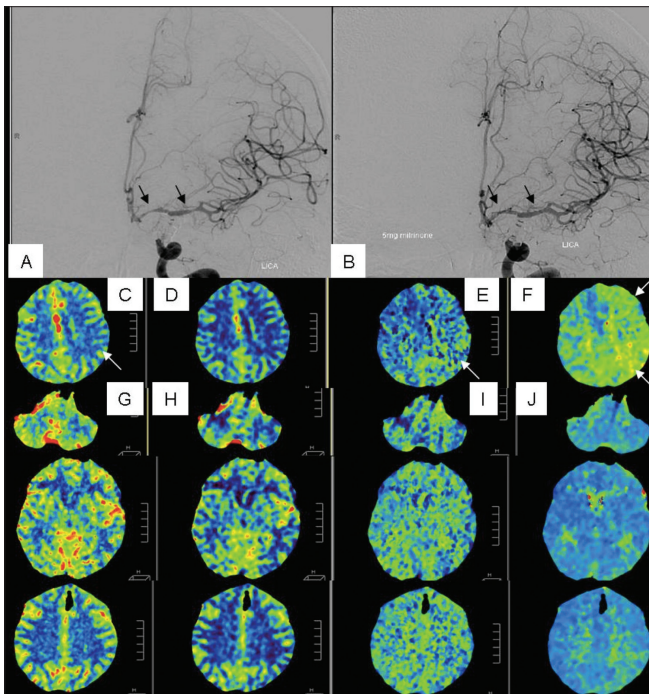


Figure 3: A 51-year-old woman with a ruptured left posterior communicating artery aneurysm developed a decreased level of consciousness and right hemiplegia, postclipping. Digital subtraction angiography (A) shows vasospasm (arrows), which improved (arrows in B), after treatment with intra-arterial milrinone. Whole brain CT perfusion shows a large area of decreased CBF (arrow in C), normal CBV (D), and increased MTT (arrow in E) and TTP (arrow in F) in the left hemisphere. Post-treatment CTP (G–J) was normal with no residual clinical deficits

CTP can provide information regarding global cerebral hemodynamics, which are of critical importance in this clinical scenario [Figure 5].

After the external-to-internal carotid artery bypass surgery

for chronic ischemia, the hemodynamics of the brain change immediately after surgery and evolve further over time as the brain adapts to its new blood supply. We have found that in the immediate postoperative period, there is an increase in the cerebral blood flow (CBF), cerebral blood volume (CBV), and MTT compared to the decreased CBF and increased CBV and MTT in the setting of chronic ischemia [Figure 6]. The increase in the CBF may be explained by the increase in the blood flow through the bypass. However, as the bypass channel matures over time, both CBF and CBV normalize. The MTT continues to increase, possibly reflecting the low perfusion pressure through the alternate bypass channel.

Arteriovenous malformation

Although focal, AVMs can affect the global hemodynamics of the brain. This is dependent on the size and presence of high-flow channels.^[7] We have observed similar findings on whole brain CTP.^[8] The CBF and CBV are markedly elevated within the AVM nidus, reflecting high vascularity [Figure 7]. However, the perinidal areas demonstrated low CBF and CBV, suggestive of perinidal ischemia. In two of our patients with supratentorial AVMs, we found low CBF and CBV in the contralateral cerebellar hemisphere,

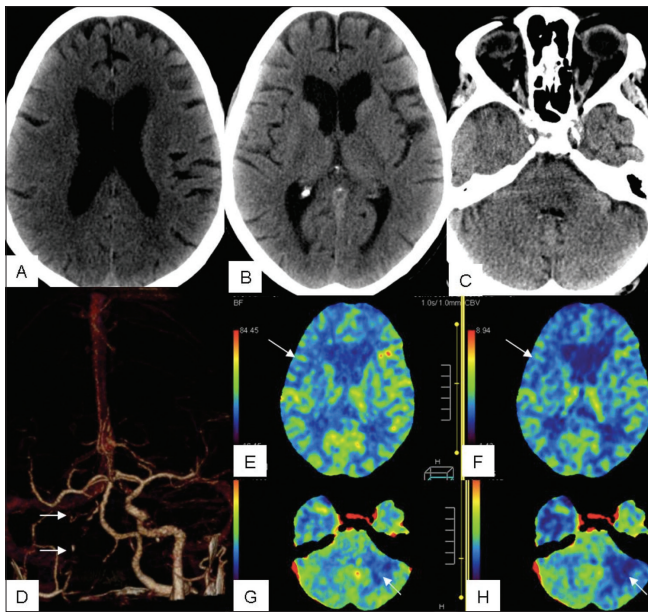


Figure 4: An 83-year-old woman with clinical evidence of right hemispheric ischemia shows no obvious infarct or chronic ischemic changes in the right cerebral hemisphere and in the cerebellum on plain CT scan of the head (A–C). Chronic right internal carotid artery occlusion (arrows) is seen on a CT angiogram image (D). Whole brain CT perfusion (E–H) shows matched decrease in CBF (arrows in E) and CBV (arrows in F) in the right middle cerebral artery distribution. There is also decreased CBF (arrows in G) and CBV (arrows in H) in the contralateral cerebellar hemisphere (arrows), suggestive of crossed cerebellar diaschisis

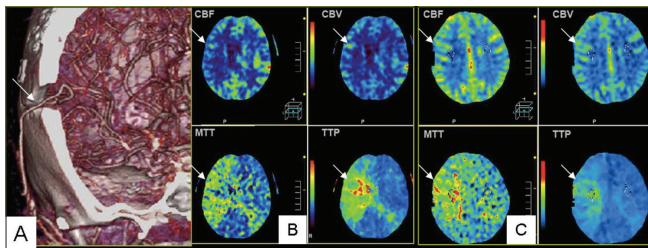


Figure 6: Patient with a right ICA occlusion underwent right superficial temporal artery–middle cerebral artery (STA-MCA) bypass surgery for right hemispheric ischemic symptoms. Time-resolved CTA (A) done after the surgery shows the patent bypass channel (A). Whole brain CTP (B and C) done before (B) and after (C) the surgery shows a marked increase in CBF (arrow) and CBV (arrow) and a relative decrease in MTT (arrow) and TTP (arrow) in the right middle cerebral artery distribution. However, the MTT and TTP continued to be elevated (arrows in C)

consistent with crossed cerebellar diaschisis [Figure 7]. Similar findings have also been described in the nuclear medicine literature.^[7]

Brain tumors

Most brain tumors can be assessed with limited-slice CTP as localization of the lesion is usually not an issue. The major limitation is the selection of the arterial input function in tumors located at the extreme ends of the brain, i.e., either

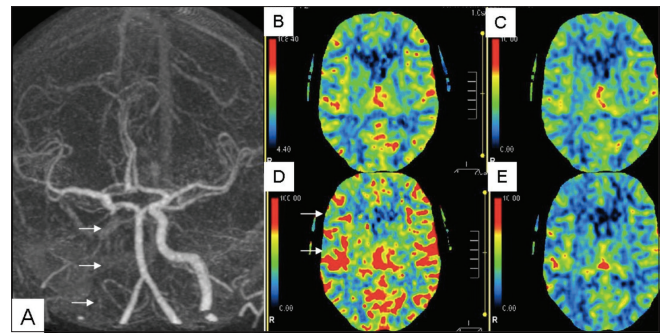


Figure 5: A 59-year-old man with a history of chronic right hemispheric ischemia. Time-resolved CTA (A) shows right internal carotid artery occlusion (arrows). Before external carotid artery (ECA)–internal carotid artery (ICA) bypass surgery, the acetazolamide test done with whole brain CT (B–E) perfusion shows an increase in CBF (arrows in D) and no change in CBV before (B and C) and after (D and E) injection of acetazolamide. This is much more pronounced in the right cerebral hemisphere (arrows in D), suggestive of a good cerebral vascular reserve. His symptoms improved following bypass surgery

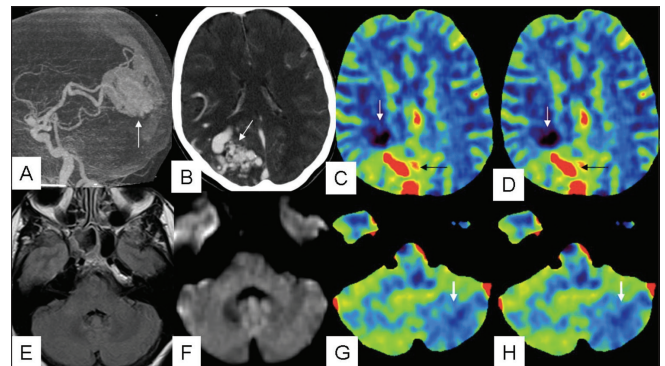


Figure 7: A 50-year-old woman presented with recently worsening headache. Time-resolved (A) and axial (B) CT angiograms show a high-flow right occipital AVM (arrows). Whole brain CT perfusion (C and D) shows high CBF (black arrows in C) and CBV (black arrows in D) in the nidus and low CBF (white arrows in C) and CBV (white arrows in D) in the perinidal area, suggestive of perinidal ischemia. There is no evidence of cerebellar ischemia on the FLAIR (E) and diffusion (F) images. CBF (arrows in G) and CBV (arrows in H) are low in the contralateral cerebellar hemisphere, suggesting crossed cerebellar diaschisis

near the vertex or in the posterior fossa [Figure 8]. The limited coverage of a large tumor on limited-slice CTP may also be inadequate in depicting tumor heterogeneity, which is an important characteristic for the grading of brain tumors on imaging.

Intracerebral hematoma

Intracerebral lobar hematomas are known to demonstrate perilesional ischemia.^[9] The presence of the positive “spot sign” has been described to be an indicator of the future growth of the hematoma.^[10] In one of our patients with lobar hematoma who demonstrated an evolving “spot sign,” there was decreased CBF and CBV in the perilesional brain parenchyma [Figure 9]. The increase in the size of the

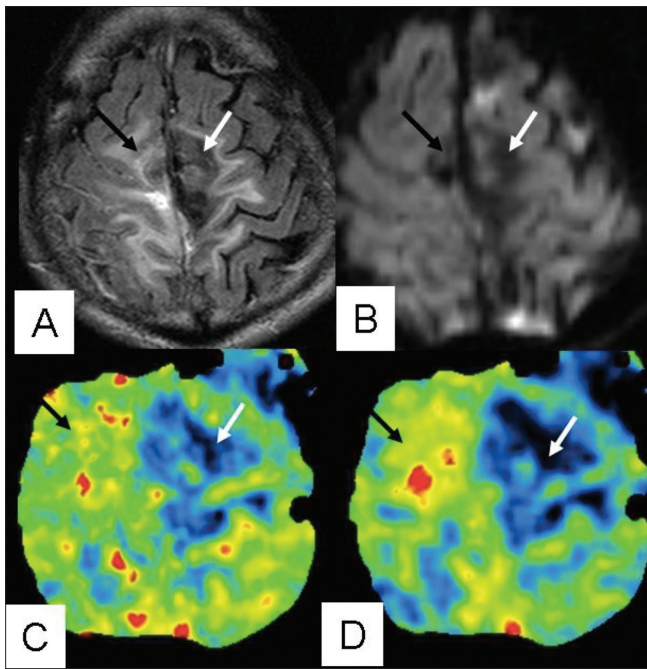


Figure 8: A 49-year-old man with a parasagittal meningioma underwent surgical resection and radiation therapy. Axial FLAIR (A) and diffusion-weighted (B) images show similar changes (arrows) in both frontoparietal regions. Whole brain CT perfusion (C and D) done to differentiate tumor recurrence from radiation necrosis shows very high CBF (black arrows in C) and CBV (black arrows in D) in the right frontoparietal lesion, most likely suggestive of tumor recurrence, compared to the left frontoparietal lesion, which shows low CBF (white arrows in C) and CBV (white arrows in D), suggestive of either postoperative changes or radiation necrosis

hematoma on the follow-up CT scan appeared to be in the area of perilesional ischemia. Whether this perilesional area of decreased perfusion is at risk of hematoma growth needs to be studied with a larger number of patients.

Discussion

Cerebral perfusion provides information about blood flow at the tissue (capillary) level.^[11,12] In the setting of cerebral ischemic disease, CTP can be used to assess the reversibility of an ischemic lesion. In the setting of acute ischemic stroke, CBV lesions represent the core of the infarct tissue whereas the CBF, MTT, and TTP lesions represent the area of ischemia. In a setting of a mismatch between the CBF, MTT or TTP lesions, and CBV lesions, the difference represents the area of the penumbra, which is ischemic but potentially salvageable tissue. This area of penumbra is the target for treatment in the setting of acute ischemic stroke. If the lesions on CBF, MTT or TTP maps, and CBV maps match, it implies that the whole area is already infarcted and there is no role of thrombolysis in the treatment of acute ischemic stroke. Many of the diseases of the cerebral vasculature have global effects rather than focal effects. So it is important to have an imaging modality that can assess the cerebral vasculature globally.

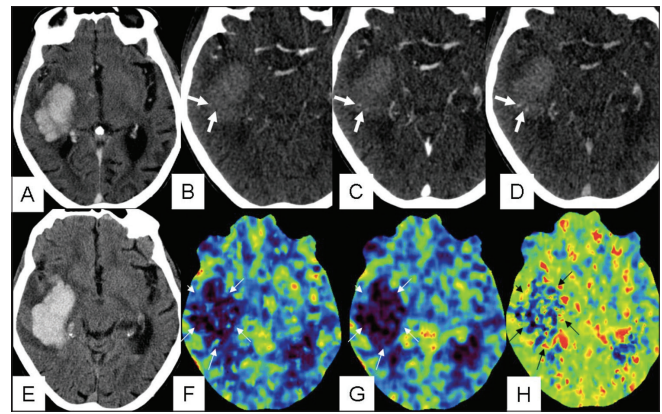


Figure 9: An 86-year-old woman presented with a large right temporal lobar hematoma, which is seen on the axial CT scan (arrows in A). On the raw data of time-resolved CT angiography (B–D), an increasing “spot sign” is seen (arrows) over the multiple volumes acquired during the late venous phase. This sign may be predictive of an increase in the hematoma volume over time, seen on the subsequent CT of the head (E) done 6 h later. The whole brain CTP (F–H) obtained from the CTA data shows evidence of perilesional ischemia with low CBF (arrows in F), low CBV (arrows in G), and high MTT (arrows in H)

Nuclear studies, including PET and SPECT and MRI perfusion, are ideal choices for these clinical situations. The disadvantage of nuclear studies is variable local experiences and availability. A major disadvantage of MRP is lack of proper validation, which however has improved with recent advances in MRP. In certain cases, MRP may not be possible due to various contraindications for MRI.

CTP is relatively new but has been better validated compared to MRP and is a more widely available modality.^[11,12] The major limitation of CTP has been its limited brain coverage. Recent studies have demonstrated the value of improved coverage, which results in the demonstration of more lesions.^[13]

Complete brain coverage is useful in cases of lesions located at the margins of the brain, for example, the vertex and posterior fossa. The selection of an appropriate arterial input function has been an issue, which can be resolved with the use of whole brain CTP.

Another advantage of the whole brain CTP is the simultaneous acquisition of the time-resolved CTA information.^[1] This reduces the radiation dose, contrast volume, and the time for acquisition compared to standard CTA and CTP protocols. This is valuable in the setting of suspected cerebral vasospasm after subarachnoid hemorrhage (SAH), where the vessel diameter and whole brain perfusion need to be assessed simultaneously.

A higher radiation dose has been one of the major concerns in whole brain CTP.^[14] However, this has to be seen in the light of the fact that both CTA and CTP information

can be obtained from the same whole brain CTP study. Moreover, the first volume of whole brain CTP, although not as good as a standard CT scan of the head, can be used as a plain head CT scan study. The poor quality can be compensated by the accompanying CTP information, which is very useful, especially in the case of ischemia. However, using different protocols for whole brain CTP, further reduction of the radiation dose is possible in these clinical situations.^[15] The average dose for whole brain CTP on a 320-slice scanner is 4.002 mSv. With a modified algorithm, it can be further reduced up to 2.1 mSv.^[15]

Shading or streak artifacts also known as Feldkamp artifacts may be observed at the edge of the scan region but usually do not affect image interpretation.^[16] There is a potential pitfall related to the delay between the appearance of the contrast in the lowermost slice as compared to the topmost slice of acquisition. This can potentially cause errors in the calculation of CBV. However, this is usually compensated by the use of delay-insensitive SVD plus nonparametric deconvolution methods.

Conclusion

We have highlighted the advantages and new implications of whole brain CTP compared to the limited-slice CT perfusion. Other avenues to harness the potential of whole brain CTP will open up with further experiences in this field. Using different protocols, the radiation dose can also be reduced for whole brain CTP.

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