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4D Neurological Imaging

Comprehensive Acute Stroke Management

ONE
Aquilion
dynamic volume CT

Case Study Brochure

Millard Fillmore Gates Circle Hospital



TOSHIBA MEDICAL SYSTEMS CORPORATION

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ONE
Aquilion

4D Neurological Imaging

Comprehensive Acute Stroke Management

Introduction

Millard Fillmore Gates Circle Hospital is a 189-bed acute care medical center located in Buffalo, in western New York. The hospital runs several specialized programs and is the primary acute care stroke center in the region, servicing a wide geographical area.

Stroke is the third-leading cause of death and the leading cause of adult disability in the United States. In fact, in the USA alone, someone has a stroke every 45 seconds and someone dies from a stroke every 3 minutes. Successful recovery from a stroke or improving patient outcomes depends on how quickly blood flow can be restored to the affected brain tissue. The most effective treatment window is within just 3 hours from the onset of symptoms, but this can be extended to 6 hours depending on the patient’s clinical condition. Therefore, it is always a battle against time to correctly diagnose patients with stroke and to choose the most appropriate treatment option.

Imaging plays a critical role in the evaluation and management of stroke patients. MDCT has traditionally been in the first line of diagnostic procedures, but this exam is limited to only a small portion of the brain, often necessitating an MRI exam to obtain a definitive diagnosis.

In the summer of 2008, we installed the Aquilion ONE™ dynamic volume CT system, which has provided game-changing technology for our acute stroke care center. This CT system is able to provide fully quantitative perfusion analysis of the entire brain in a 1-minute scan. Additionally, a dynamic subtracted angiogram is obtained from the same scan data, offering the unique display of both morphological and functional information.

This scanner has certainly reduced the need for additional imaging, saving both time and money, but in particular reducing the time to diagnosis. These benefits are as we expected. What has been a surprise is the unexpected information this system delivers with whole-brain perfusion. There have been several cases in which the Aquilion ONE has correctly identified perfusion deficits in unexpected territories of the brain that would not have been seen on an MDCT scan. Equally important is the ability to confidently rule out perfusion deficits in patients with stroke-type symptoms.

Currently at our hospital, 15 to 20 acute stroke patients are imaged every day using the Aquilion ONE. This brochure presents a collection of interesting cases examined over the course of 1 week in 2009.

Dr. Michael Miller, MD

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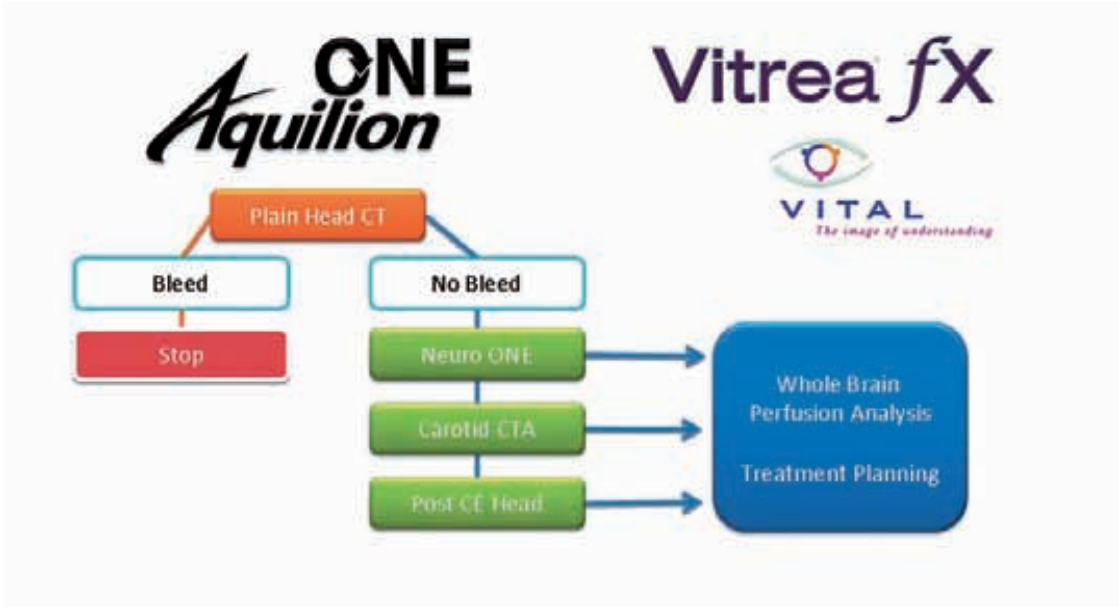
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WARNING: Any reference to x-ray exposure, intravenous contrast dosage, and other medication is intended as a reference guideline only. The guidelines in this document do not substitute for the judgment of a healthcare provider. Each scan requires medical judgment by the healthcare provider about exposing the patient to ionizing radiation. Use the As Low As Reasonably Achievable radiation dose principle to balance factors such as the patient’s condition, size and age; region to be imaged; and diagnostic task.

Acute Stroke Imaging Protocol

Patients who present to Millard Fillmore Gates Circle Hospital with symptoms of acute stroke are sent directly to the CT department for a comprehensive evaluation using the Aquilion ONE.

The following imaging algorithm is used for all acute stroke patients.



In the imaging algorithm outlined above, the perfusion analysis is often performed in cooperation with the interventional neurovascular physicians. This analysis is performed on the Vitrea™ fX workstation, which has been developed to analyze dynamic volume studies performed on the Aquilion ONE.

A stroke patient’s prognosis is strongly determined by how quickly blood flow can be restored to the ischemic brain. The time from scanning to diagnosis is critical. Accordingly, Toshiba and Vital Images joined in a collaborative effort with the physicians at Millard Fillmore Gates to develop a workflow solution that makes it possible to perform whole-brain perfusion imaging and dynamic intracranial DSA in just 4.5 minutes from the start of the scan to display of the images on the Vitrea fX workstation.



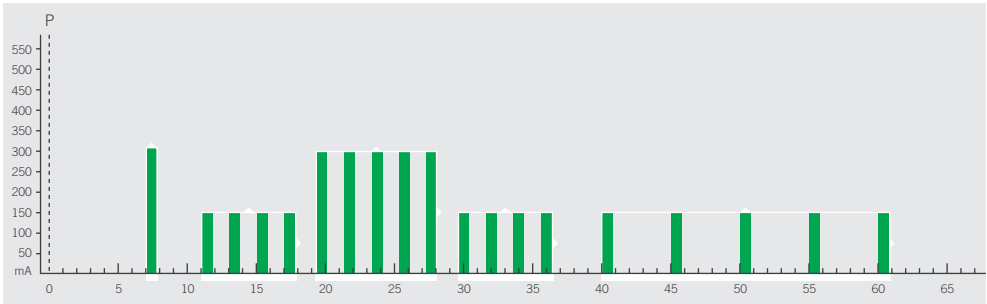
The carotid CTA and post-contrast brain scan are acquired while the physicians analyze the perfusion data. These scans are available for review in time for the next stage of treatment planning. The carotid arteries are evaluated for plaque and stenosis, and the angiographic access via catheter is determined if necessary. If the decision has been made to perform intra-arterial intervention, the patient is often already on the way to the angiographic suite during this step.

Neuro ONE Protocol (with mA Boost)

In the Neuro ONE protocol, a series of intermittent volume scans is performed over a 60-second time period. The first volume is used as the mask for dynamic subtraction, much like a mask in DSA.

A series of low-dose scans are performed, initially every 2 seconds during the arterial phase, then spaced out to every 5 seconds to capture the slower venous flow.

The mA is increased during peak arterial flow to ensure that the highest quality 3D arteriogram is available for image interpretation to permit the detection of small peripheral arterial lesions.



The entire protocol is performed at 80 kV, for an exposure dose of approximately 6 mSv, using 50 mL of intravenous contrast medium. The Neuro ONE protocol supports whole-brain perfusion and dynamic CT DSA, providing all the information clinicians need to evaluate patients with nonhemorrhagic stroke.

* This protocol is the standard default in the Aquilion ONE.

Calculating Perfusion

Introduction

Only eight years after Sir Godfrey Hounsfield performed the first head CT scan on a human patient (to examine a cranial cyst), Dr. Leon Axel proposed that dynamic CT could be used to measure tissue perfusion.

The perfusion of oxygenated blood is not directly observable. It is approximated by measuring enhancement following the introduction of a radiopaque contrast agent such as intravenous iodine.

There are several complex mathematical models that have been developed to approximate perfusion. However, the use of perfusion as a tool for diagnosis and as an aid in determining the best treatment options for each patient requires a certain level of understanding that can be applied in the clinical context.

Basic Principles

Quantitative perfusion is calculated from a dynamic CT acquisition during the intravenous injection of contrast media. The perfusion software requires three input readings:

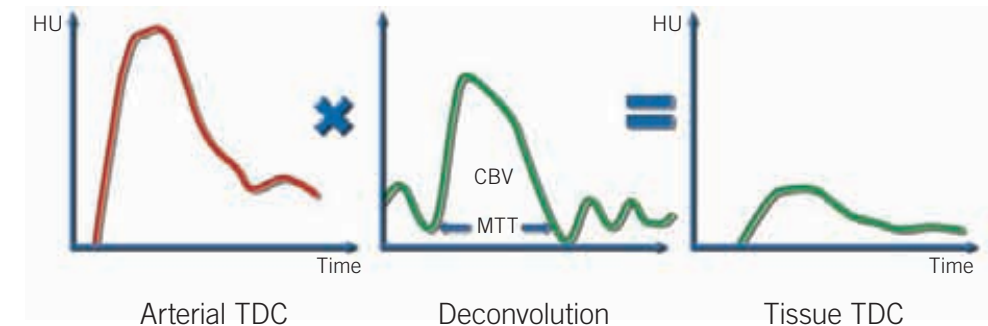
1. The arterial enhancement time-density curve (TDC)
2. The venous enhancement TDC
3. The tissue enhancement TDC

Since the target arteries in the brain can be affected by partial volume averaging, the venous TDC is used to correct the height of the arterial TDC.

Brain tissue perfusion can be calculated by looking at the difference between the arterial TDC and the tissue TDC. (Perfusion is calculated for each tissue voxel.)



Deconvolution permits quantification of the blood volume flowing through the brain tissue, as well as the transit time for the blood to flow through the tissue.



Cerebral blood flow (CBF) is defined as the cerebral blood volume (CBV) divided by the mean transit time (MTT).

Toshiba and Vital Images have co-developed the most advanced method for calculating cerebral blood perfusion, known as Singular Value Decomposition Plus (SVD+).

SVD+ Deconvolution Algorithm

SVD+ is based on the standard singular value decomposition (SVD) deconvolution algorithm.

However, SVD+ has been designed to be delay-insensitive.

Analysis using the SVD+ algorithm does not include any delay of contrast arrival (delayed flow) in the calculation of the MTT and therefore provides an accurate MTT measurement according to the definition.

Since perfusion is calculated as CBV/MTT , reporting physicians need to be aware that, unlike other less-sophisticated algorithms, delayed flow is not shown as low flow.

For whole-brain perfusion imaging, delay-insensitive deconvolution is ultimately the only correct computation. Without delay insensitivity, where a single arterial input function is used, the computed blood flow would appear to gradually decrease in cranially scanned slices due to natural blood flow dynamics.

In the case of arterial occlusion, brain tissue survives if sufficient collateral flow is present. In essence, it does not matter when the oxygenated blood arrives in the brain, as long as it arrives in the appropriate concentration. A delay in blood flow can therefore be ignored for perfusion.

Calculating Perfusion (continued)

The following quantitative maps are generated with SVD+:

- CBF (cerebral blood flow)
- CBV (cerebral blood volume)
- MTT (mean transit time)
- TTP (time to peak)
- Delay time

Cerebral blood flow (CBF)

This is defined as the blood volume flowing through the capillary blood vessels per unit time per unit brain tissue. CBF identifies areas of low blood flow.

CBF is measured in units of mL/min/100 mL of brain tissue.

Cerebral blood volume (CBV)

This is the distribution of blood per unit brain tissue. CBV permits evaluation of autoregulation (collateralization).

CBV is measured in units of mL/100 mL of brain tissue.

Mean transit time (MTT)

This is the average amount of time that blood takes to flow through the capillary vessels. An increase in MTT indicates a vasodilatory response to reduced flow.

MTT is measured in seconds.

Time to peak (TTP)

This is the relative time to peak enhancement for brain tissue voxels. TTP provides an indication of delayed flow due to stenosis or occlusion and is useful for identifying collateralization.

TTP is measured in seconds.

Delay time

This is the relative arrival time of contrast medium for tissue voxels. The information provided by the delay map is similar to that provided by TTP, although the calculation method differs. (The delay time is used to correct the MTT values.)

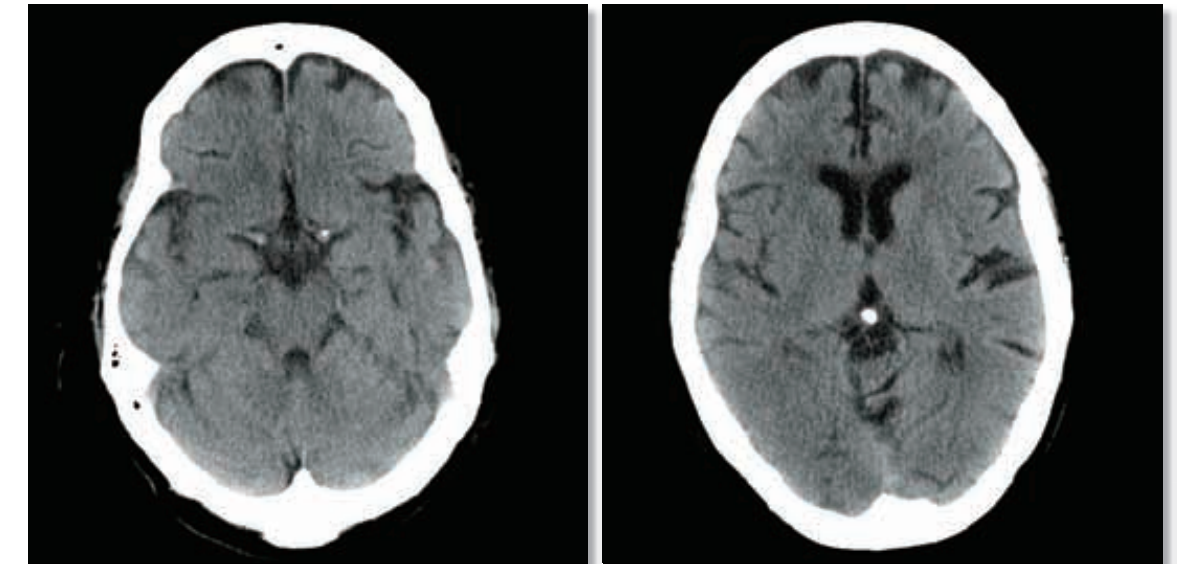
Delay time is measured in seconds.

Right ICA Occlusion

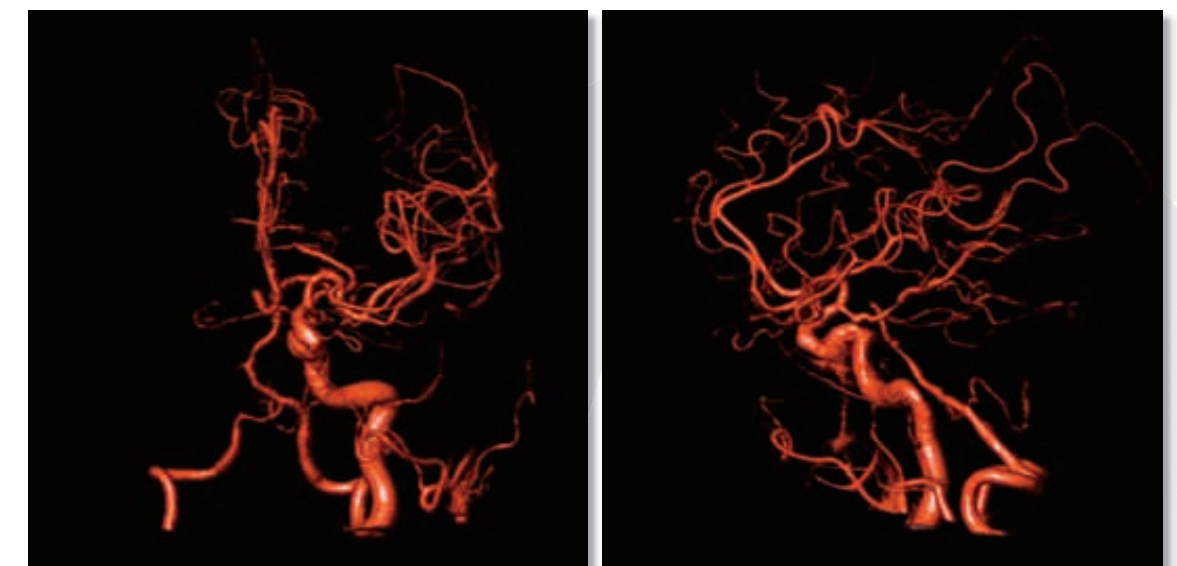
Patient History

A 90-year-old woman presented to the emergency department with atrial fibrillation and the sudden onset of marked left-sided weakness. The acute stroke imaging protocol was performed without delay.

Findings



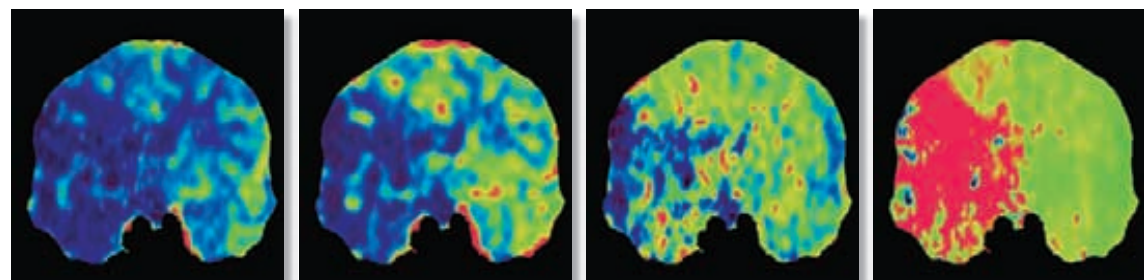
Axial images from the pre-contrast volume brain scan demonstrate increased density of the supraclinoid right ICA consistent with thrombus or embolus. The subtle loss of gray-white differentiation in the right cerebral hemisphere posteriorly is suggestive of early ischemic change.



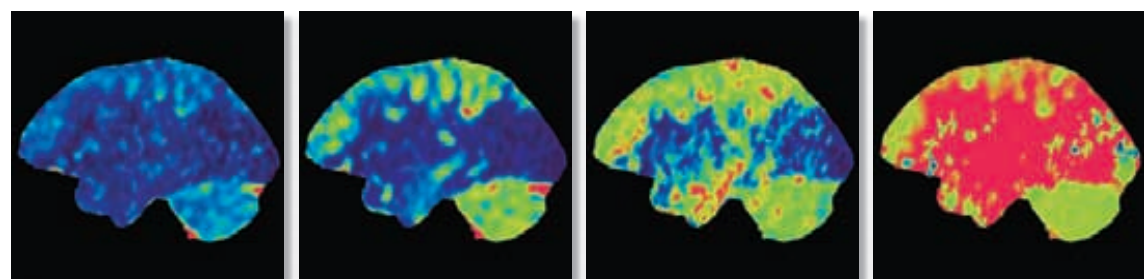
The early arterial-phase images demonstrate an absent right ICA. The P1 segments of the posterior cerebral arteries are severely hypoplastic, and there is a large left posterior communicating artery. Slow flow is seen in a large right posterior communicating artery in the CT DSA images.

Right ICA Occlusion (continued)

Coronal perfusion maps



Sagittal perfusion maps



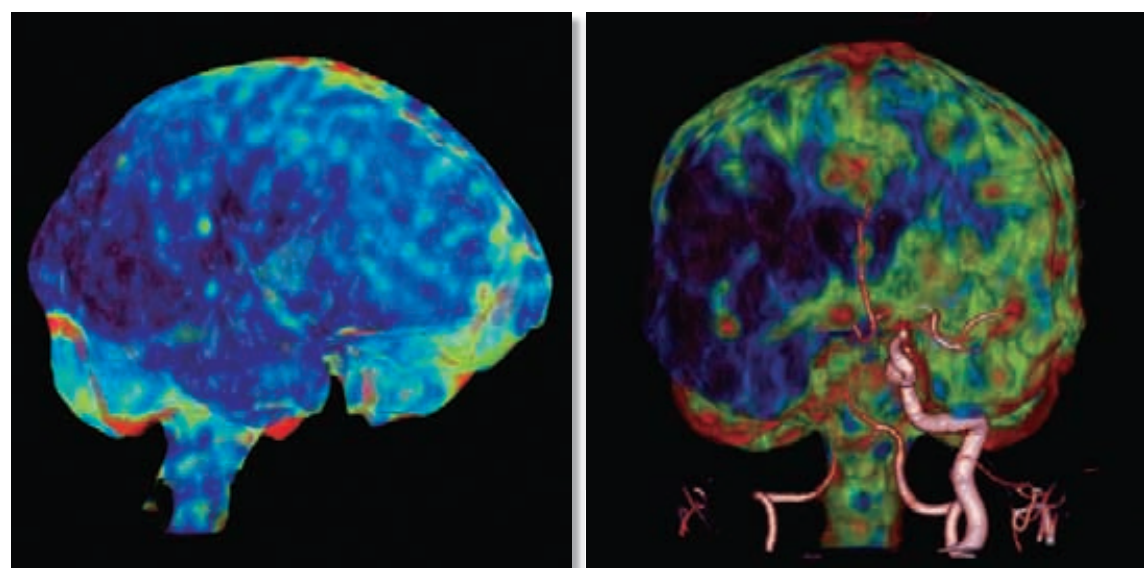
CBF

CBV

MTT

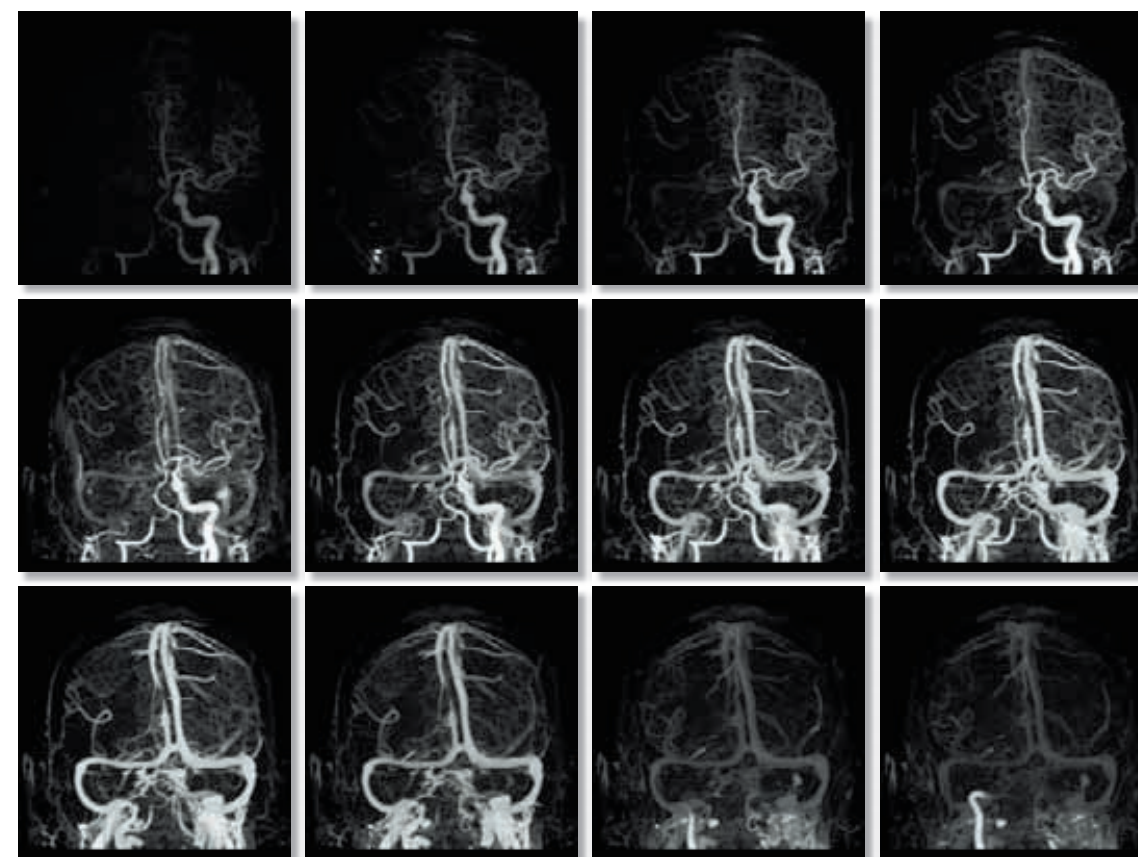
TTP

An extensive perfusion abnormality is demonstrated in the right cerebral hemisphere in the MCA and PCA territories, with sparing of the ACA territory, as shown in these coronal and sagittal images. There is a marked increase in time to peak perfusion shown on the TTP maps, as expected with distal right ICA occlusion, fetal origin of the right PCA, and near occlusion of the MCA. The cerebral blood flow is decreased, as is the cerebral blood volume, indicating large areas of cerebral infarction mostly invisible on the noncontrast CT brain scan. The decrease in MTT indicates localized microvascular changes within a large portion of this deficit.



The large perfusion deficit in the right MCA and PCA territories is shown in the 3D perfusion images. The ability to fuse the CTA and perfusion data brings together functional and morphological imaging in one intuitive image.

CT DSA



CT DSA images are automatically generated from the same scan data. Dynamic viewing demonstrates the collateral flow to the right cerebral hemisphere. Additionally, late partial flow is seen in the distally occluded right ICA.

Conclusion

The ability to review CT DSA and whole-brain perfusion images at the same time from the same scan has become an invaluable tool in the diagnostic work-up of patients with stroke. All this data is available on the workstation within just 4.5 minutes from the commencement of the scan, providing a much faster time to diagnosis compared to an MRI examination.

The resolution of the CT DSA images is outstanding, and the automated subtraction works well, even in patients who are cerebrally irritated.

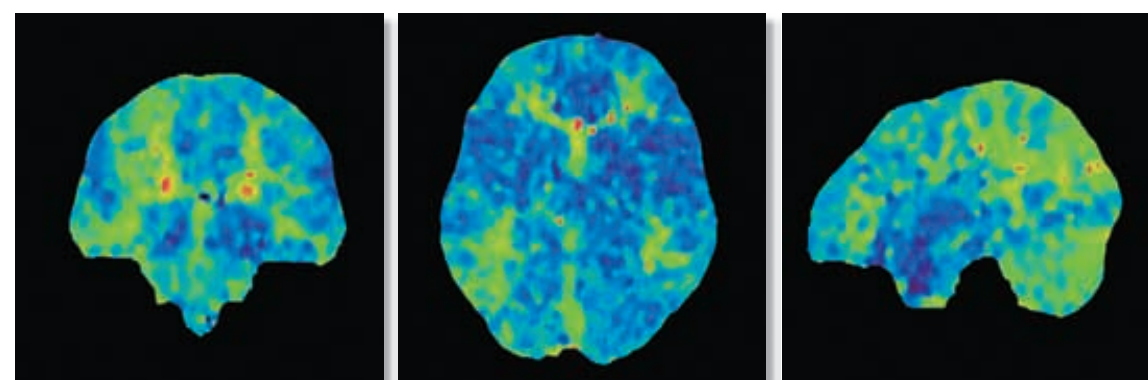
Treatment planning decisions are now being made with a much higher degree of confidence than ever before with CT.

Delay-Insensitive Deconvolution

Patient History

A 55-year-old woman who works as a school teacher experienced progressive blurring of her vision while driving, she went to the school nurse, who contacted her primary physician, who also noted that she had a slight left-sided facial droop and complained of facial numbness. The patient said it had happened before but went away, and she is likely to have experienced two previous transient ischemic attacks (TIAs). She was referred to MFG for a complete emergent stroke work-up.

Findings

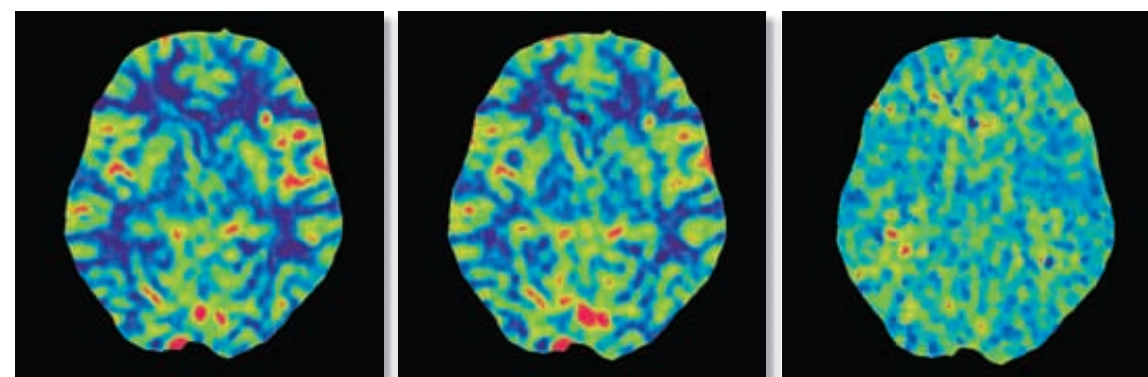


TTP - Coronal

TTP - Axial

TTP - Sagittal

In the initial review of the perfusion images, the TTP maps showed delayed enhancement in the right posterior cerebral artery territory.

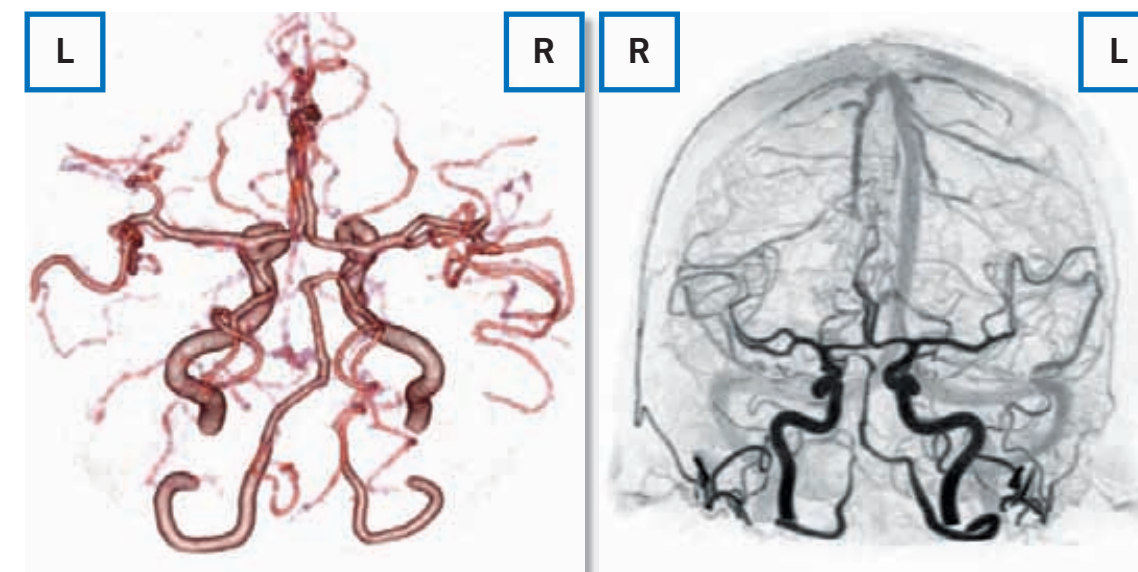


CBF - Axial

CBV - Axial

MTT - Axial

The CBF, CBV, and MTT maps showed no perfusion asymmetry, and no abnormality in the right PCA territory.



3D CTA - Superior

MIP CTA - Anterior

The CTA images show a dominant left vertebral artery, with the right vertebral artery terminating at the PICA. The basilar artery is small. The left PCA-p1 segment is hypoplastic, and the posterior communicating arteries are large. The right PCA fills more slowly from a patent P1 segment arising from the basilar artery and the posterior communicating artery.

Conclusion/Treatment

In this case, the normal variation of the vascular anatomy caused a tracer delay to the right PCA territory as shown in the TTP map images. However, the SVD+ algorithm, which is designed to be delay-insensitive, correctly shows the underlying brain tissue to be normally perfused.

In less sophisticated deconvolution algorithms, the delayed arrival of contrast would have been included in the calculation of the MTT parameters and therefore reflected in the CBF map images.

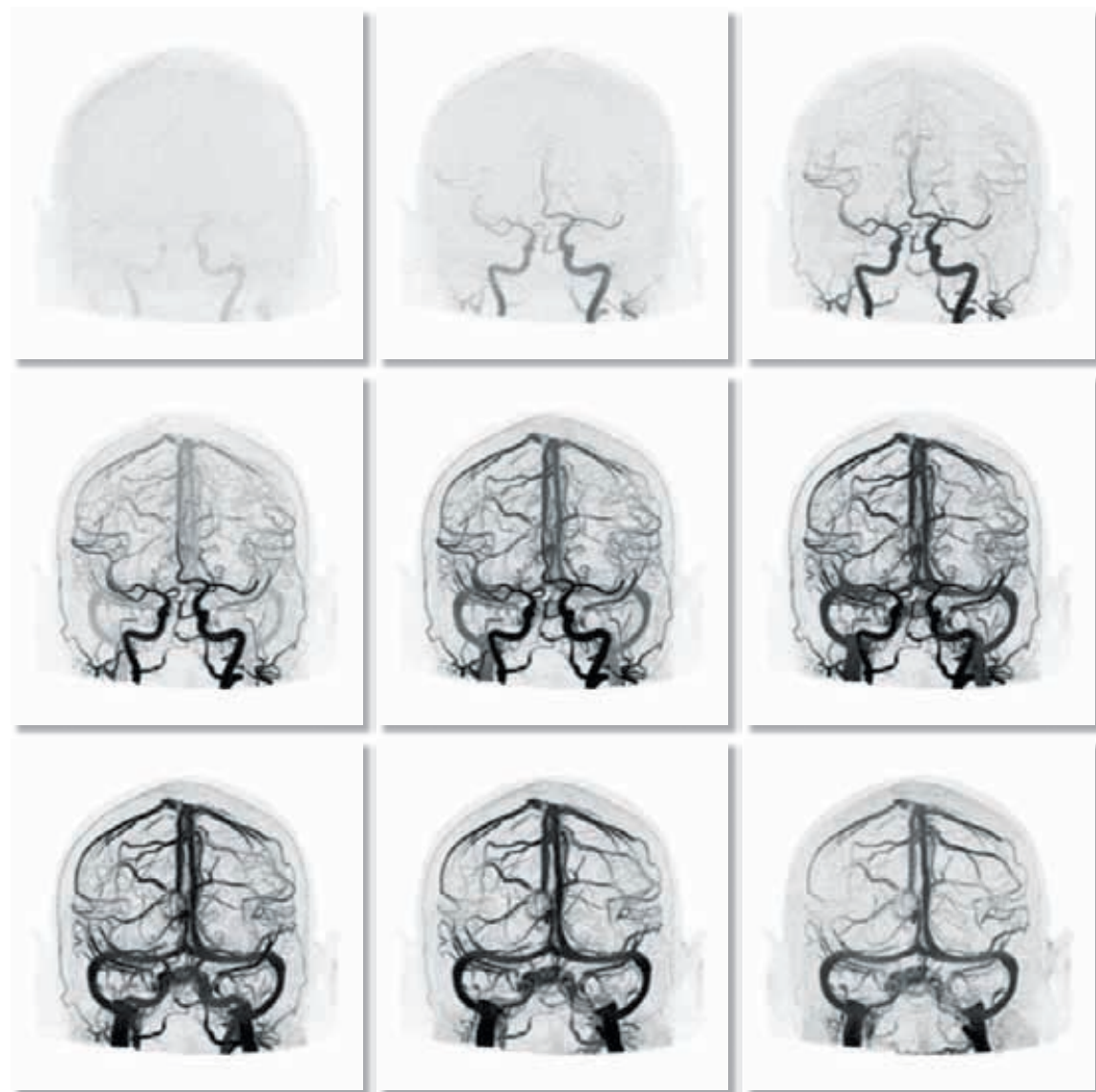
The patient's facial droop and numbness were apparently transient, and it was concluded that another TIA had occurred. She was cleared for discharge under treatment with low-dose statins and low-dose daily aspirin for the prevention of a future stroke.

Left MCA Occlusion

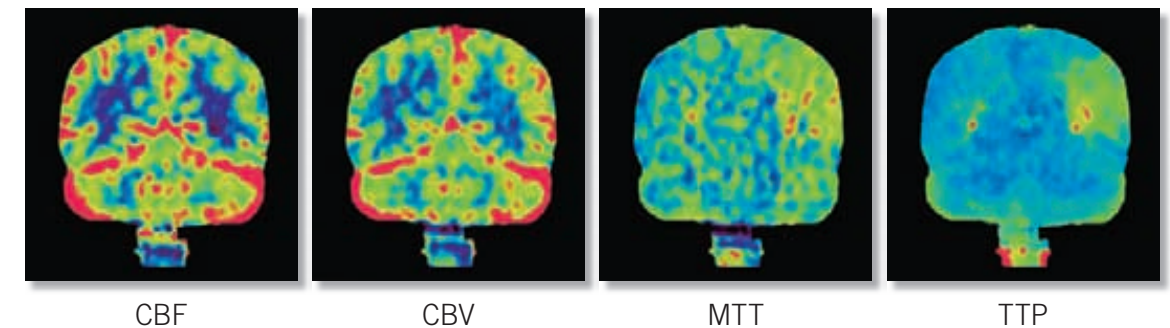
Patient History

A 76-year-old woman was having dinner when she noticed difficulty finding words and with her speech. She called her internist, who advised her to take 325 mg of aspirin and go to the emergency room. By the time she reached the emergency room, her symptoms had resolved. She was admitted for further evaluation and management. The acute stroke imaging protocol on the Aquilion ONE CT system was requested as a matter of priority.

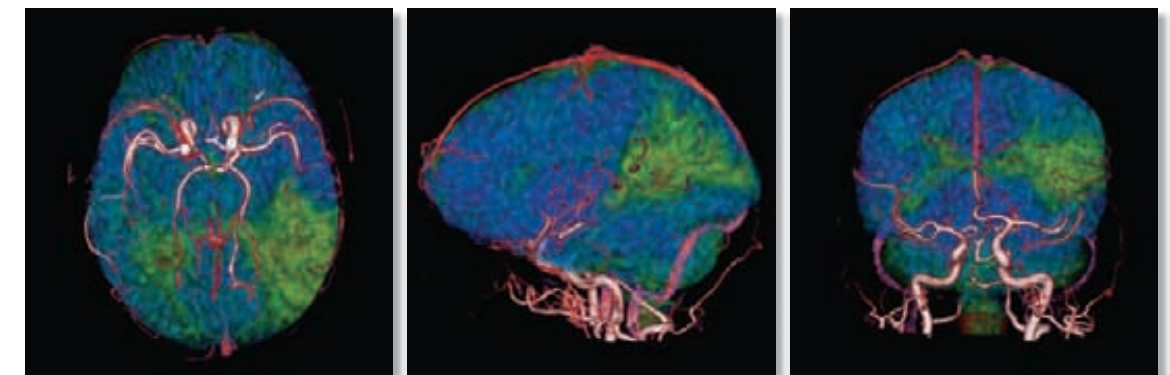
Findings



The CT DSA images clearly demonstrate near-complete occlusion in the inferior division of the left MCA at the M2 level, with collateral flow and reconstitution of some MCA branches distally. These images were generated automatically with perfect bone subtraction.



Abnormal perfusion is demonstrated in the left posterior temporal and parietal regions, characterized by increases in TTP and MTT, with a decrease in CBF. The CBV within this lesion is increased, indicating good autoregulation.



The fused 3D TTP maps are excellent for showing the anatomical relationships of the occluded MCA branch and the resultant perfusion deficit.

Conclusion/Treatment

Based on the clinical presentation of the patient in combination with the findings of the acute stroke imaging protocol, the neurovascular team recommended no intervention. The patient was treated with IV Coumadin and heparin and oral Lipitor. The embolus resolved with medical therapy.

In-Stent Thrombosis

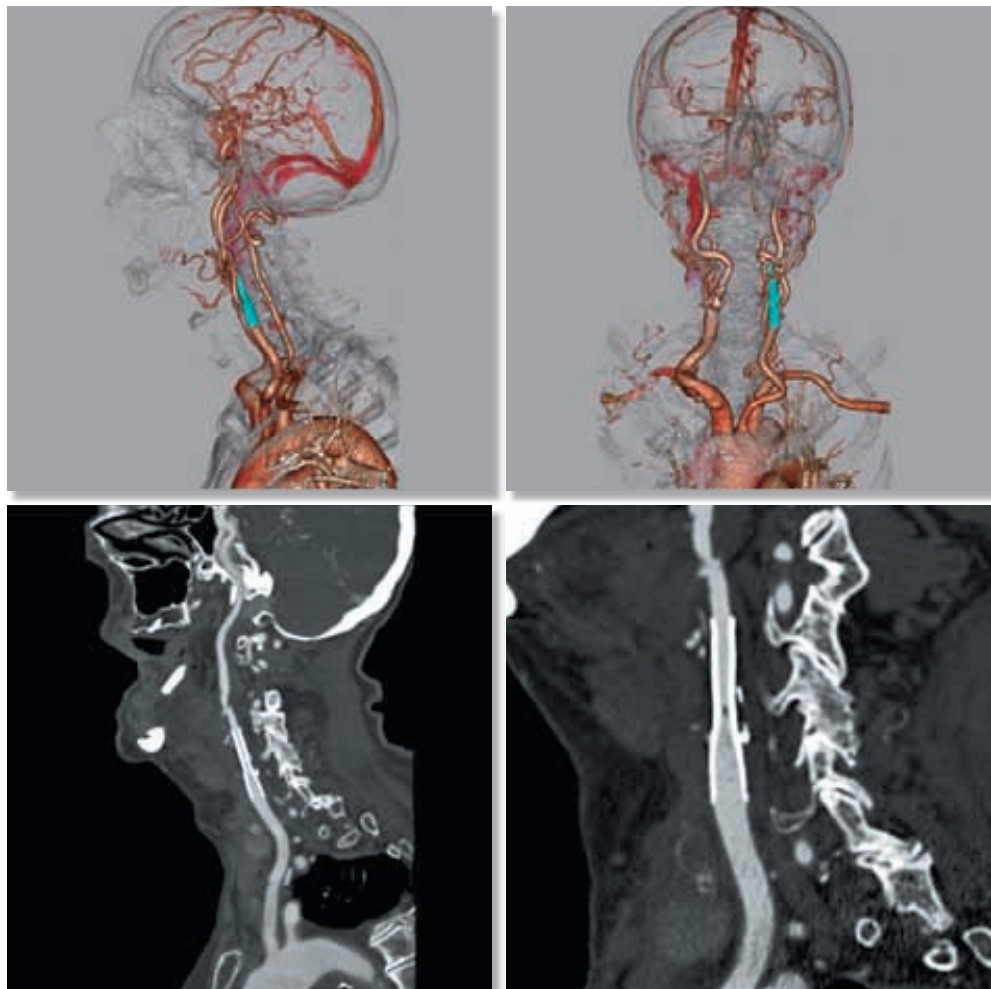
Patient History

A 91-year-old woman presented to the emergency room after several hours of slurred speech, left-sided facial droop, right-sided upper extremity pronator drift, and altered mental status.

The CT stroke protocol confirmed an acute right distal middle cerebral artery stenosis and a significant left internal carotid artery stenosis, which was treated by percutaneous placement of a stent as an emergency procedure in the interventional angiography suite.

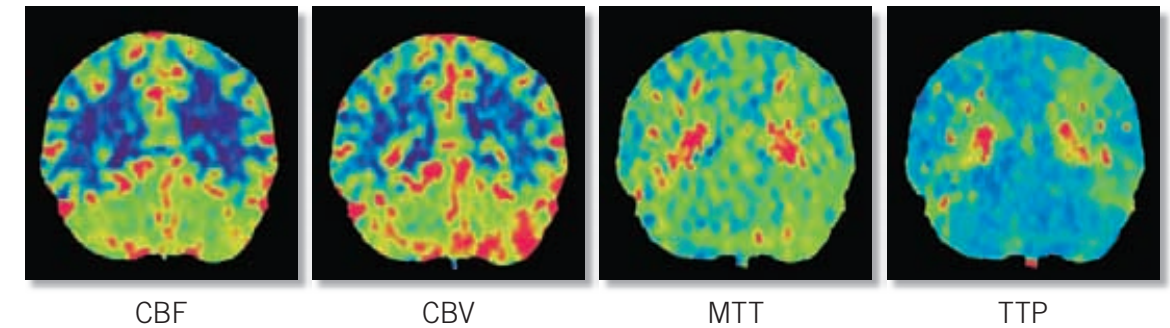
The patient was admitted to telemetry for further evaluation post stent placement, but soon after the procedure, she developed slurred speech and was immediately taken for a follow-up CT scan.

Findings



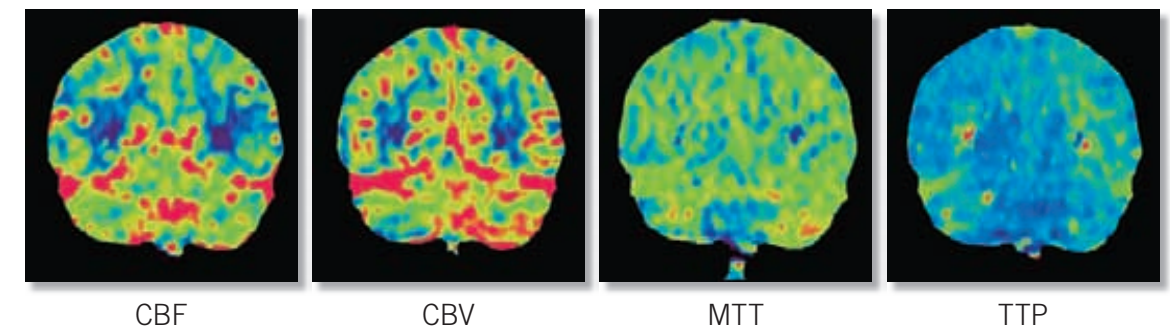
The stent is shown from the distal left common carotid artery extending into the internal carotid artery. A small low-density intraluminal thrombus is seen in the curved reformatted images. This clot could only be appreciated in curved images through the lumen centerline. The patient was returned to the angiography suite for removal of the thrombus by a clot retrieval device procedure.

Post Stenting



Decreased perfusion is seen in the left parietal lobe. The CBV map shows an increased cortical blood volume, indicating that collateral circulatory systems are in effect.

Post Clot Removal



The follow-up study performed after removal of the in-stent thrombus shows immediate improvement of blood flow to the left hemisphere.

Conclusion/Treatment

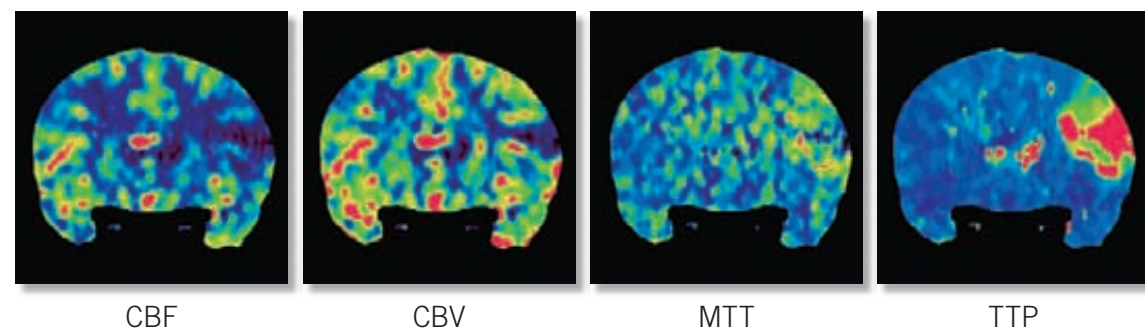
The clot was successfully removed from the stent, and IV heparin was administered to prevent recurrence. The patient continued to improve during her hospital stay. She was discharged to subacute rehabilitation 5 days later and was able to walk with assistance.

Left M4 Segment Embolus

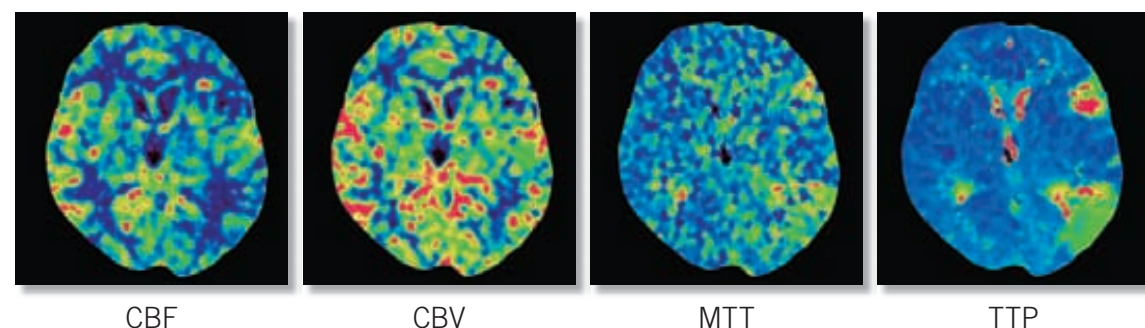
Patient History

An 87-year-old man with a prior history of a left cerebellar perfusion deficit image and treatment 1 month previously presented with the acute onset of a right-sided facial droop and expressive aphasia, with a very limited vocabulary but the ability to follow commands. He was sent to CT for whole-brain perfusion imaging.

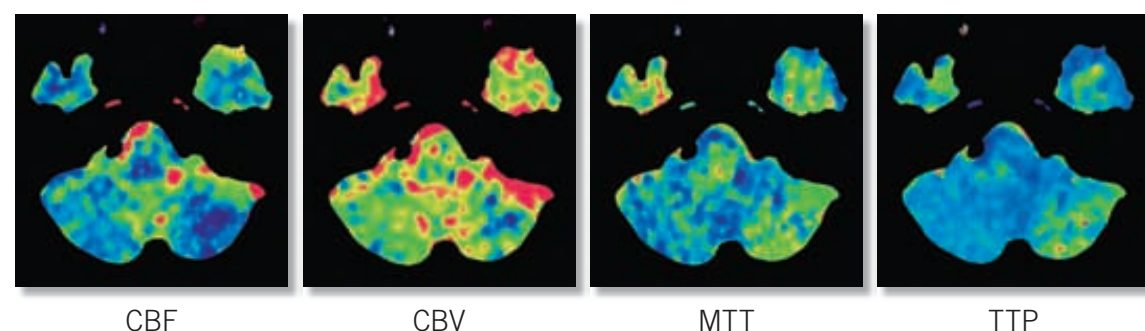
Findings



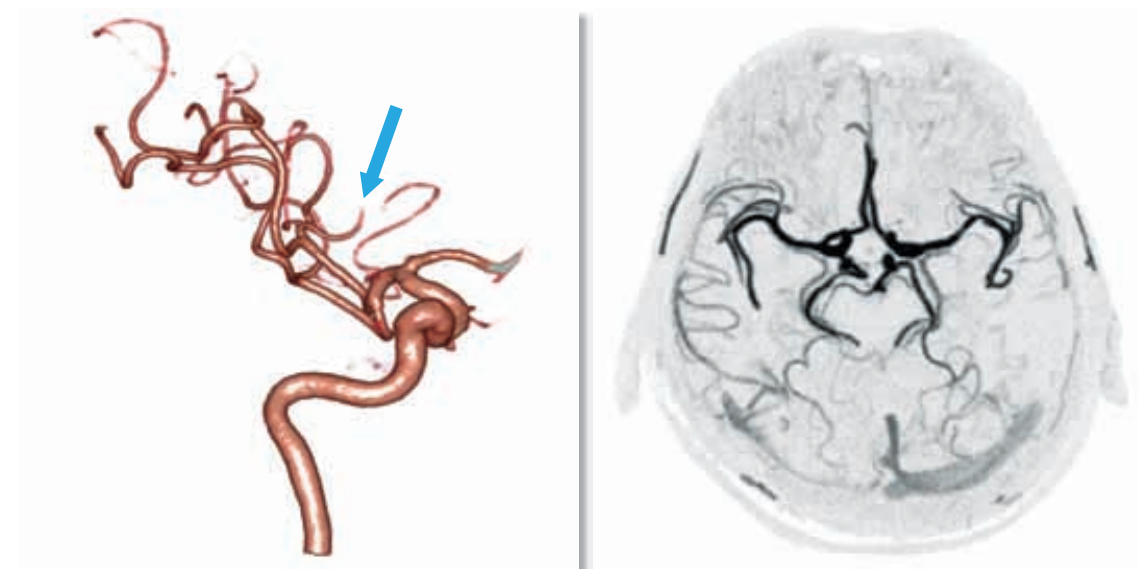
Perfusion asymmetry is demonstrated in the left frontal lobe in these coronal perfusion images. The TTP map clearly shows the delay in tracer enhancement in this region of brain tissue. The reduced blood volume centrally in this region suggests a small cerebral infarction core with a larger ischemic penumbra.



A second perfusion deficit is demonstrated in the left posterior temporo-occipital region in these axial images, with an increase in time to peak perfusion, an increase in mean transit time, a decrease in cerebral blood flow, and a mild increase in cerebral blood volume. These findings are consistent with ischemia, and possibly with early infarction.



This study also shows a persistent perfusion abnormality in the inferior left cerebellar hemisphere, corresponding to the patient's recent infarction.



Conclusion/Treatment

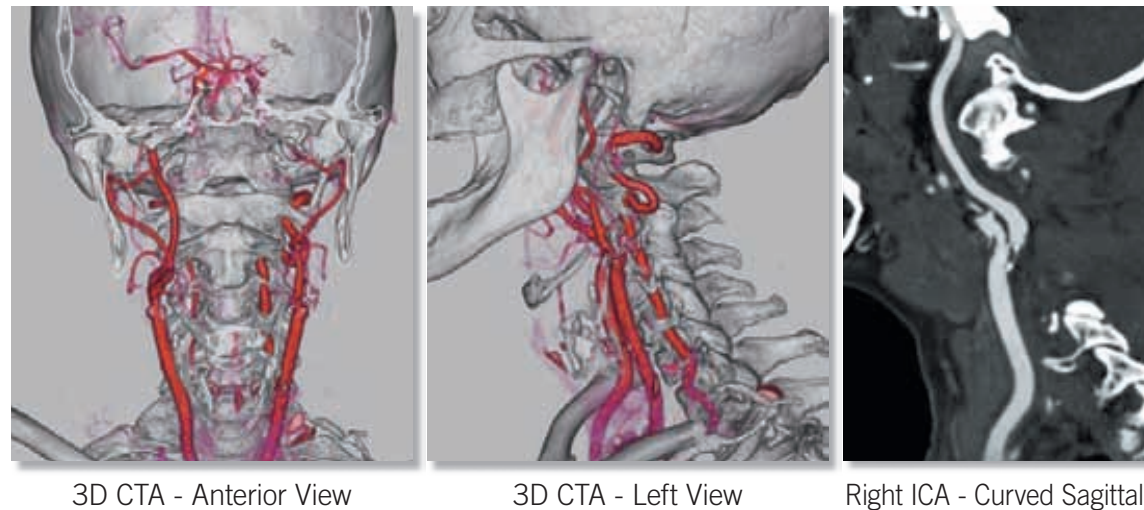
The patient was diagnosed with a new-onset CVA with bilateral changes, probably secondary to embolic phenomena. He was admitted to the medical ward and treated by the stroke team with aspirin monotherapy. He eventually stabilized and was discharged 10 days later. He is now being seen as an outpatient at the stroke clinic every 3 weeks and is undergoing rehabilitation.

Bilateral Carotid Artery Disease

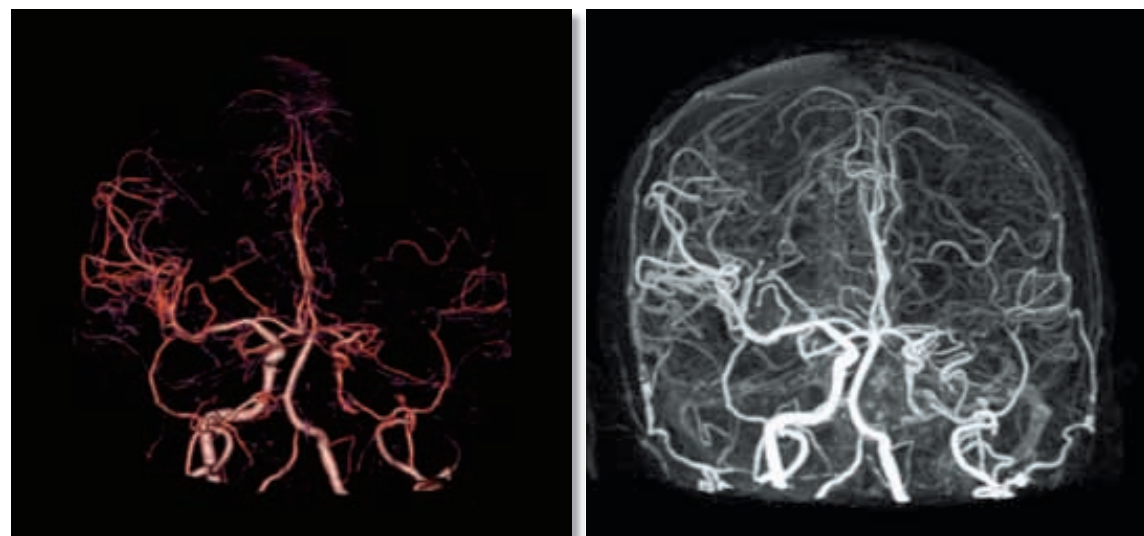
Patient History

A 72-year-old woman with a long history of smoking and hypertension was found in a collapsed unresponsive state and rushed to Millard Fillmore Gates Circle Hospital. The CT stroke protocol was performed without delay.

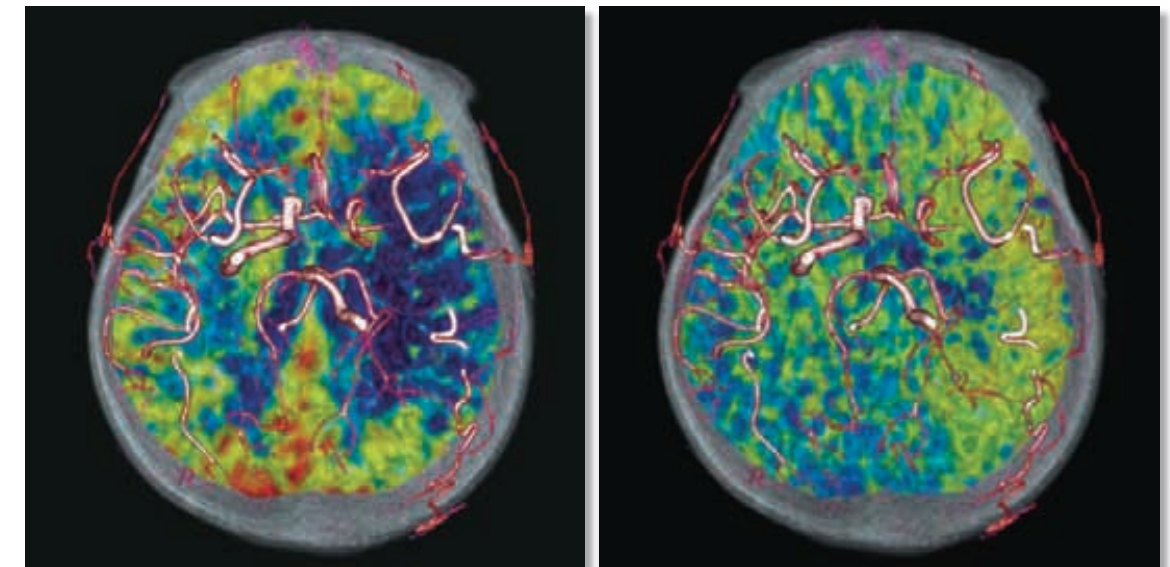
Findings



The left internal carotid artery is occluded at its origin as shown in the 3D CTA images. A very high-grade stenosis at the origin of the right internal carotid artery is shown in the curved planar image.

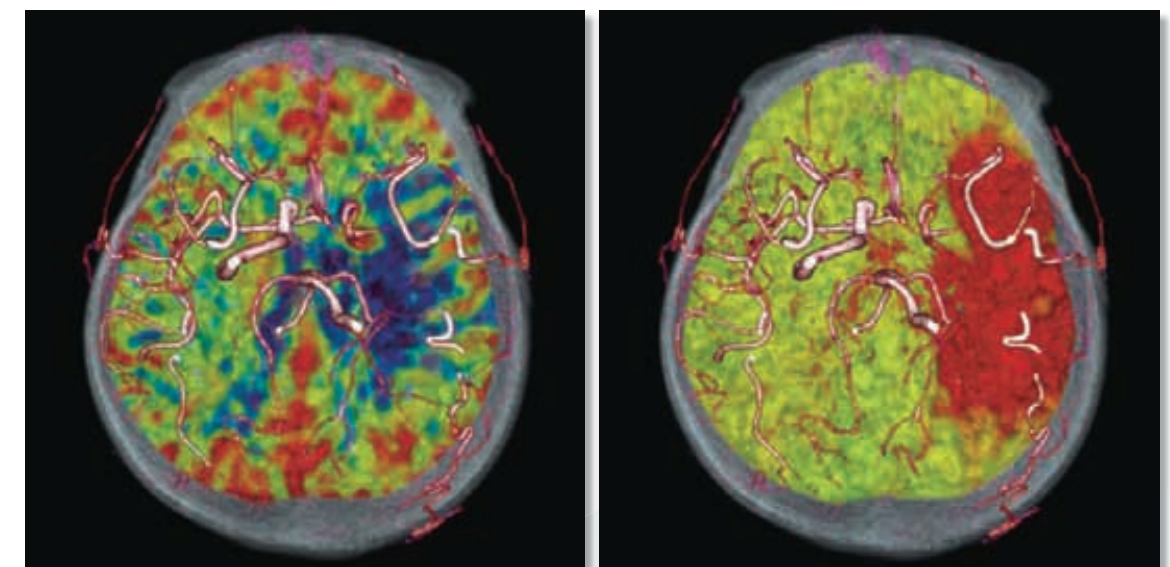


The CTA images acquired using the Neuro ONE protocol demonstrate partial filling of the left MCA/ICA via the anterior communicating artery.



CTA- CBF Fusion

CTA - MTT Fusion



CTA- CBV Fusion

CTA - TTP Fusion

The perfusion data is demonstrated volumetrically in 3D with fusion of the arterial-phase images. The large left-sided perfusion deficit is readily appreciated. The decrease in blood volume and low blood flow suggest that this lesion contains a large infarcted core with an ischemic penumbra in the cerebral cortex.

Conclusion/Treatment

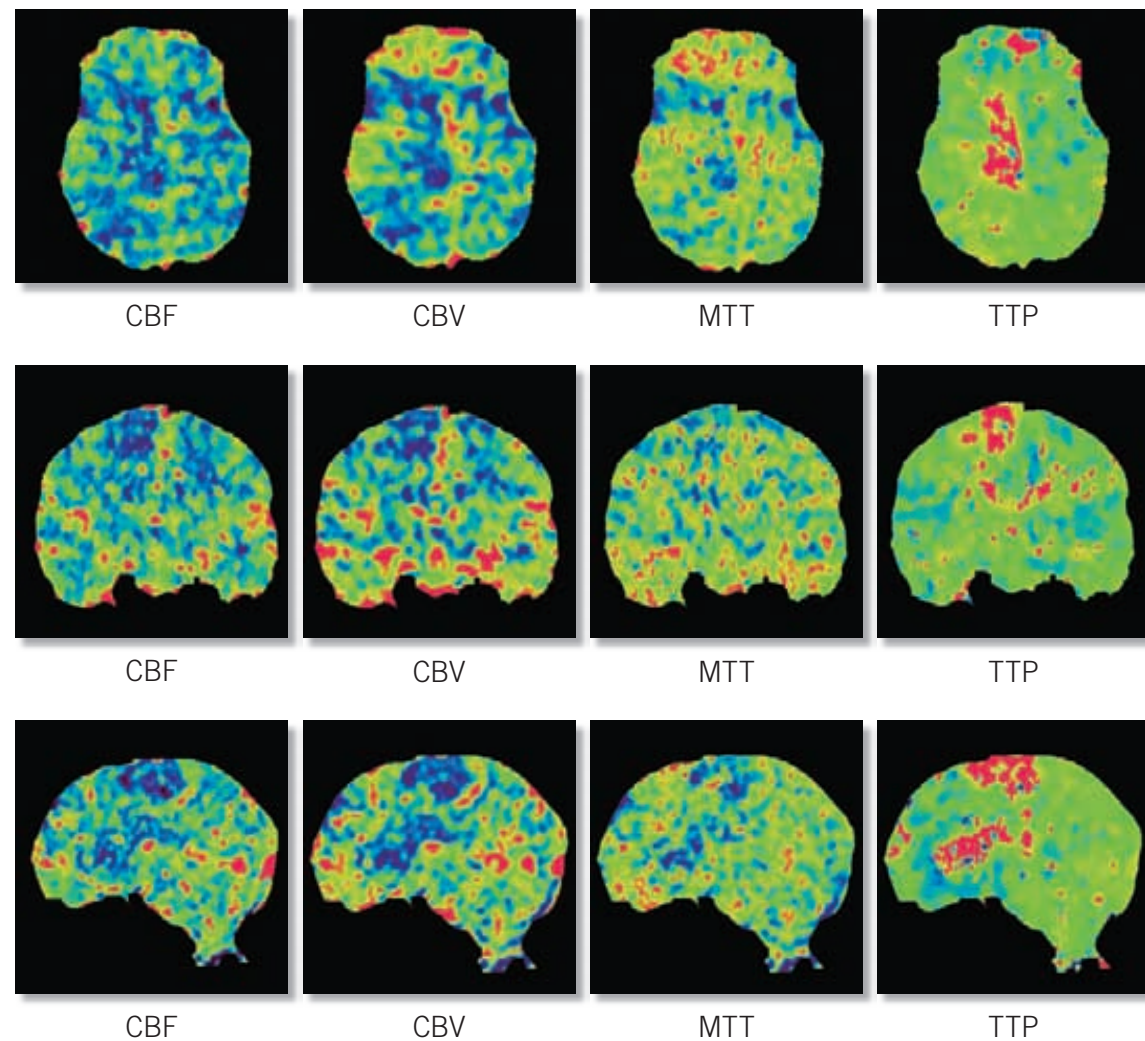
Images acquired using the CT stroke protocol show hypoperfusion in the left MCA distribution. There is complete occlusion of the left carotid artery and 80% occlusion of the right internal carotid artery, which was subsequently treated with an endovascular stent. The patient received tPA and underwent PEG tube placement for dysphagia. She was transferred to the medical ward for rehabilitation and requires moderate assistance with a hemi walker.

Frontal Lobe Deficit

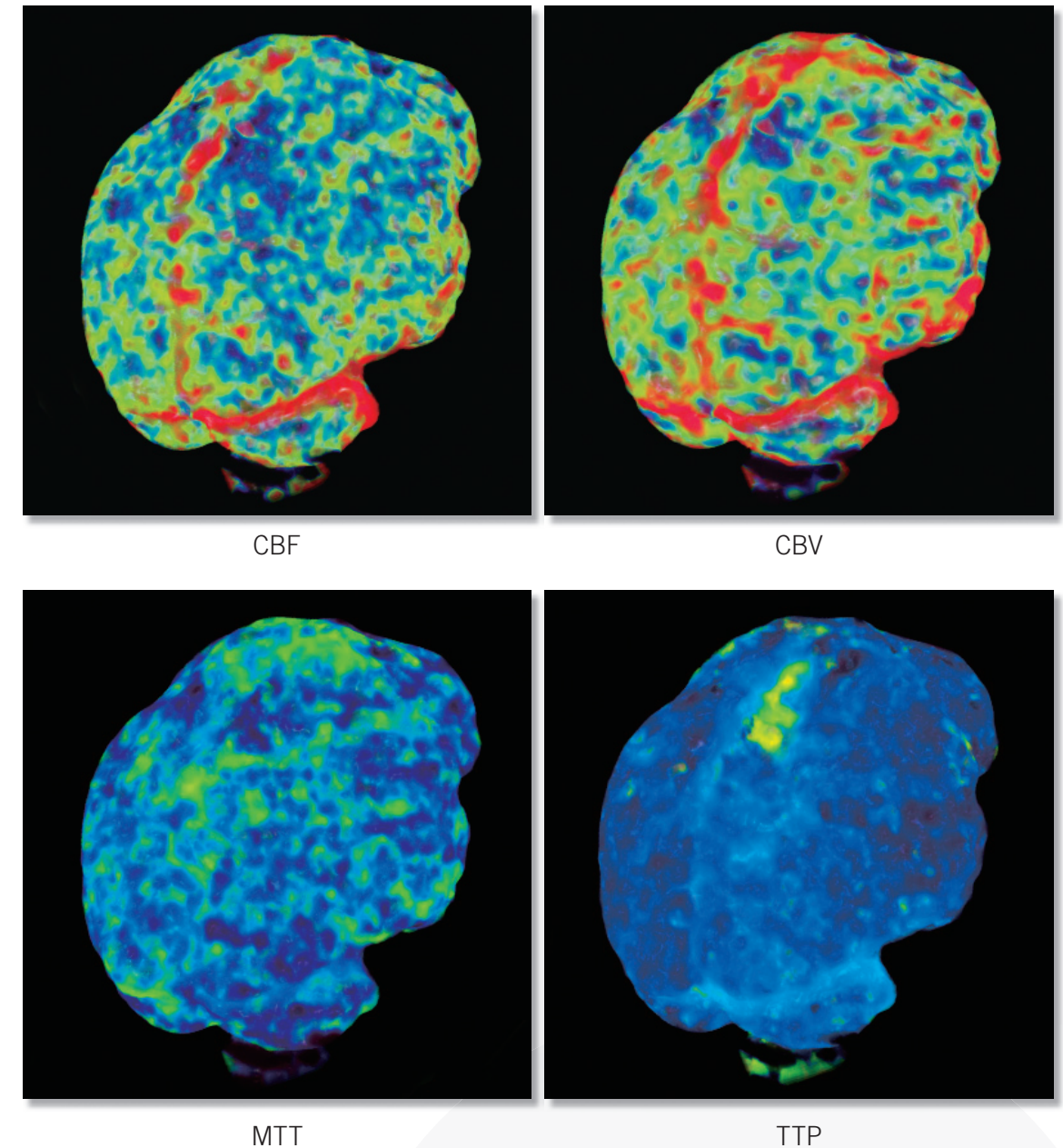
Patient History

A 76-year-old man presented to the emergency room with the acute onset of weakness in the left lower extremity, garbled speech, facial droop, and right upper arm drift, although he remained alert. Acute stroke protocol imaging by CT was requested immediately.

Findings



A focal perfusion abnormality is seen in the parasagittal right frontal lobe in the ACA territory. CTP analysis shows an increased TTP and a decreased CBF, indicating ischemia. A matching low-CBV defect is consistent with infarction without a significant ischemic penumbra. A matching infarct was confirmed on DWI MRI performed 2.5 hours later.



The lesion in the superior parasagittal right frontal lobe is well demonstrated in surface-rendered 3D perfusion images.

Conclusion/Treatment

This 76-year-old man was a good candidate for IV tPA therapy based on his NIH score of 8 and his presentation in less than 3 hours. tPA was administered without any bleeding complications. A follow-up scan and limited MRI 24 hours later confirmed a frontal lobe infarct corresponding to the CT perfusion deficit. With an improved NIH score of 5, he was discharged with medication and sent for rehabilitation therapy for residual, but improved, left leg weakness.