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The ONE Guides

4D Neurological Imaging

2010

ONE
Aquilion
dynamic volume CT

Made for Life™

TOSHIBA MEDICAL SYSTEMS CORPORATION

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Table of Contents

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.

Preface

Aquilion ONE™ is the world's first dynamic volume CT system. Volumetric scans of up to 16 cm in length permit the entire brain to be scanned in a single gantry rotation. Sequentially acquired volumetric scans provide dynamic volume imaging, allowing time-based functional studies.

For the first time in CT, dynamic volume imaging of the brain during contrast medium infusion provides true 4D CT DSA images of the intracranial circulation. The Neuro ONE protocol is designed specifically for comprehensive stroke assessment of the entire brain in one 60-second scan sequence. All dynamic volume imaging neurological applications are possible with a low contrast medium dose and exposure dose.
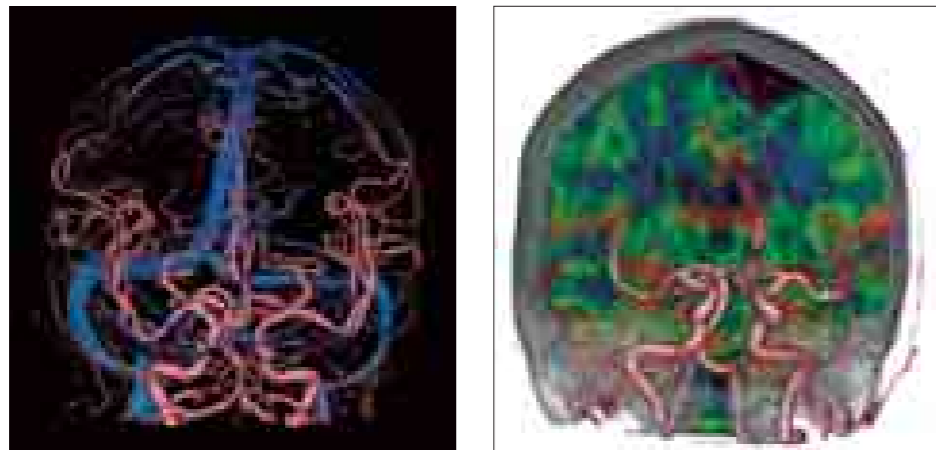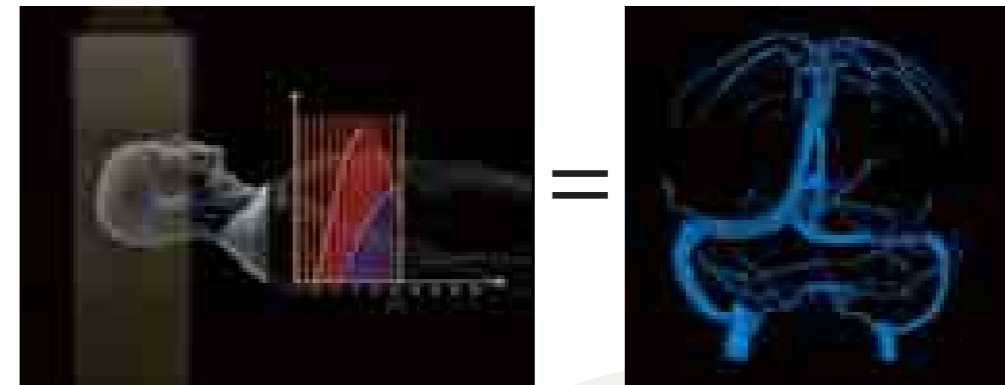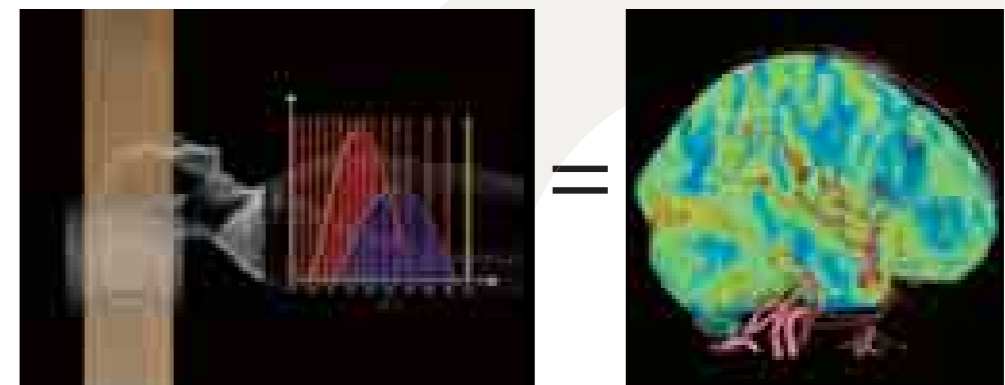

This guide provides instructions for scanning:

• Neuro ONE brain perfusion protocol: Comprehensive stroke evaluation
• 4D CT DSA protocol: The new standard in cerebrovascular imaging
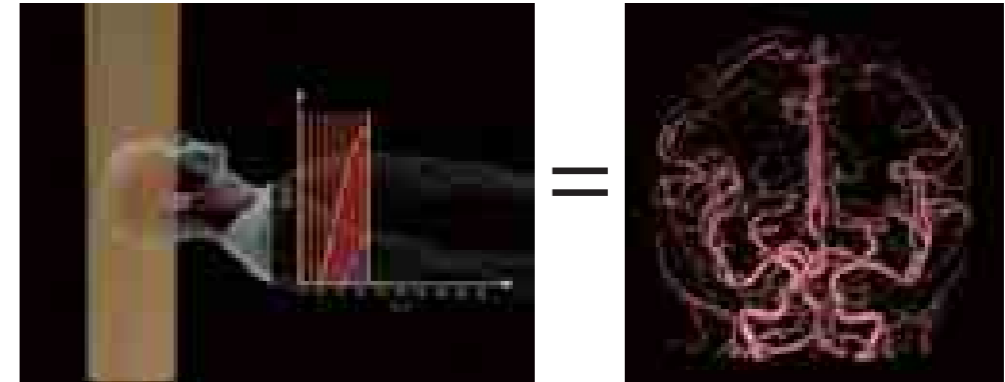
Arterial

Venous

Whole-brain perfusion & DSA

Neuro ONE Brain Perfusion

Introduction

The Neuro ONE scan protocol provides:
• CT angiography
• CT venography
• 4D CT digital subtraction angiography (DSA)
• Whole-brain perfusion

Dynamic volume imaging with the Neuro ONE protocol allows comprehensive examination of the intracranial vasculature to evaluate for stenosis and aneurysm, with the dynamic flow images permitting accurate visualization of collateral circulation. Whole-brain perfusion images are calculated to quantify the functional consequences of any vascular pathology. This complete evaluation can be completed in less than 10 minutes.

In acute stroke imaging, the time to diagnosis and treatment directly affects the degree of injury to brain tissue. Complete and rapid diagnosis of cerebral ischemia can directly influence the patient's quality of life. Aquilion ONE provides the new standard for imaging stroke patients using CT.

Clinical Examples

Acute Stroke:
In this case the perfusion maps demonstrate low cerebral blood flow, decreased blood volume, prolonged mean transit time and delayed time to peak. Close analysis of the CT angiographic images demonstrate an embolic occlusion of the temporal branch of the middle cerebral artery. An old infarct at the apex of the brain is also shown.

| CBF | CBV | MTT | TTP |
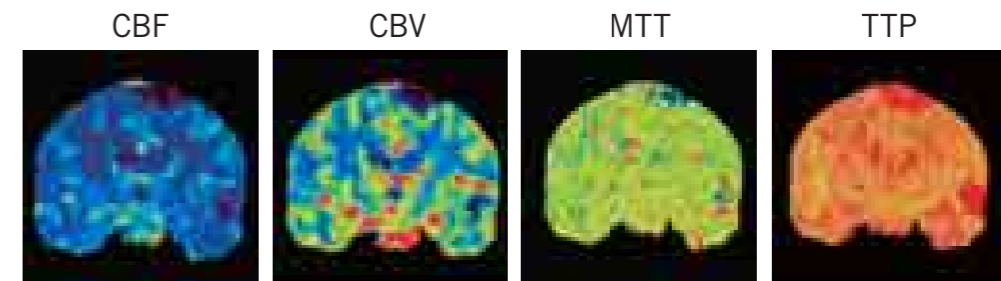
Acute Stroke:
In this case, the perfusion maps demonstrate an area of decreased perfusion in the base of the temporal lobe. The CTA demonstrates occlusion of the anterior temporal artery supplying this region. This is an excellent example of the advantages of whole-brain perfusion.

| CBF | CBV | MTT | TTP |
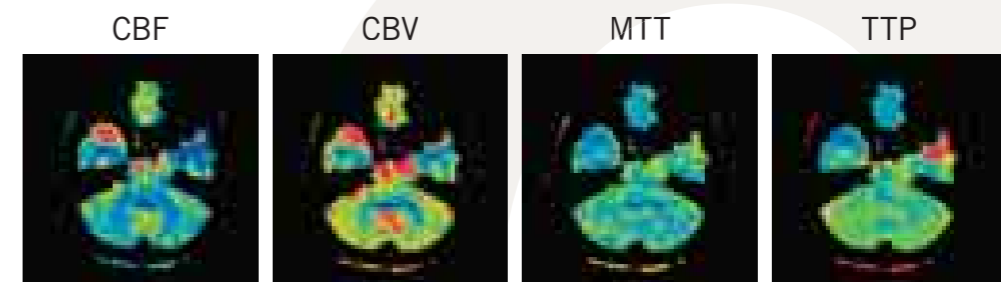
Neuro ONE Brain Perfusion

Carotid Occlusion:
In this case, an occlusion of the right carotid artery is shown. The perfusion images demonstrate no perfusion defects. Close examination of the DSA images show that the right MCA is supplied by the basilar artery via the posterior communicating artery.

CBF   CBV   MTT   TTP

Anterior   Superior   Left Lateral (Cut)
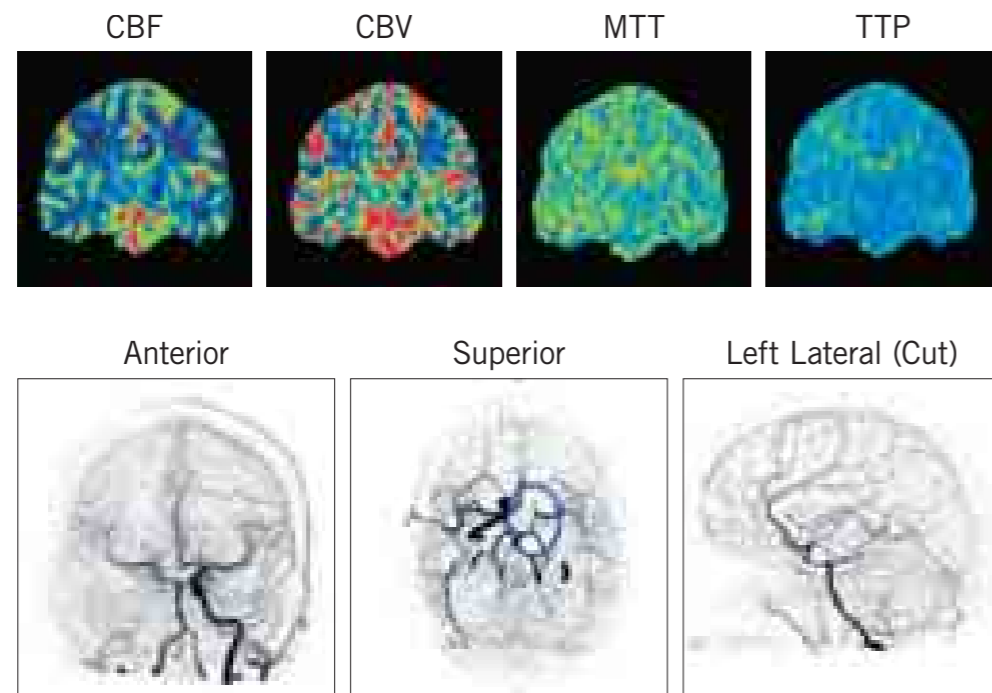
"The single biggest benefit that I've seen of this type of approach is finding areas of pathology where you didn't expect them. For example, when you do brain perfusion with a 64-detector row scanner, you have to predict where the abnormality is going to be. What I've found is that we see abnormalities in various parts of the brain that I wouldn't have suspected, so in finding disease that I didn't suspect and, in fact, that I've never seen before."

Dr W. Orrison, Nevada Imaging Centre, Las Vegas

Protocol Outline

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

A series of low-dose scans are performed, first for every two seconds during the arterial phase, and then spaced out to every 5 seconds to capture the slower venous flow. The exposure is increased during the peak arterial enhancement to provide superior 3D images of the intracranial arteries. These images are often preferred for evaluation of the fine peripheral arteries in 3D volume rendering.

Scan	kV	mA	Rotation Time	Sample Time	Acquisition Interval
1	80	310	0.75 s	7 s	-
2	80	150	0.75 s	11-15 s	2 s
3	80	300	0.75 s	17-27 s	2 s
4	80	150	0.75 s	30-37 s	2 s
5	80	150	0.75 s	40-60 s	5 s
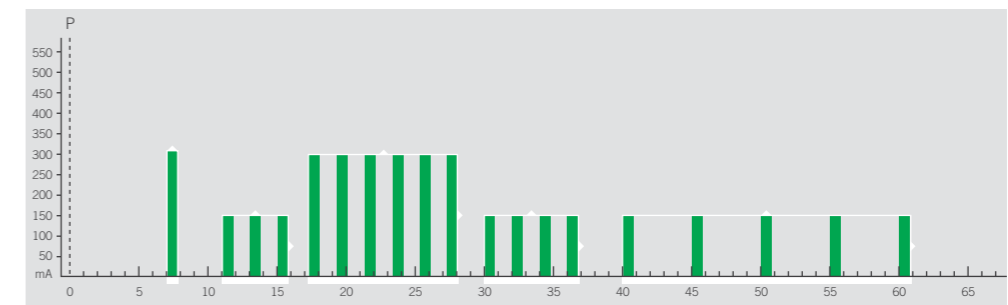
The above protocol is standard in Aquilion ONE CT systems. Toshiba Application Specialists can also help you to create and use custom protocols.
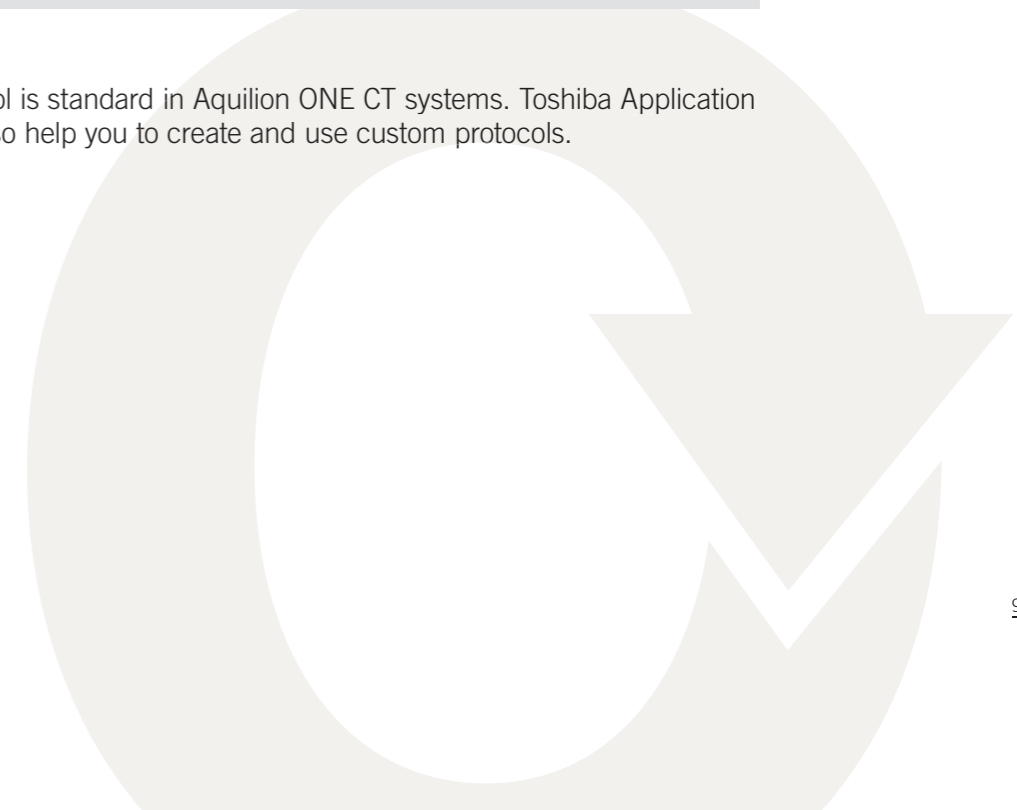
Examination Guidelines

Patient Preparation and Positioning

- Give the patient a full explanation of the procedure (if possible).
- Place an 18- or 20-gauge cannula in the right arm.
- Position the patient for a lateral scanogram.
- Position the head as symmetrically as possible.
- Position the head so the OM baseline (mid-orbit to EAM) is perpendicular to the floor (or as close as possible).
- Immobilize the patient with the head strap and pads to ensure that the patient remains still during the examination.
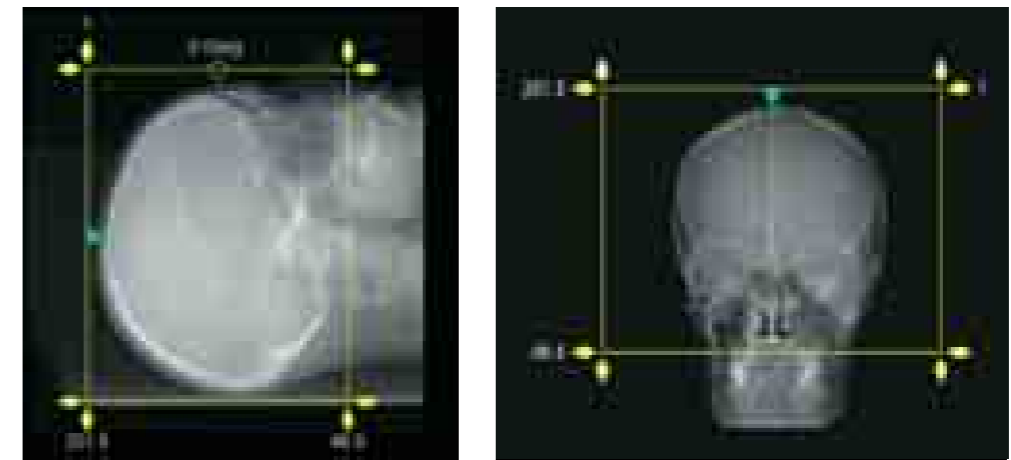

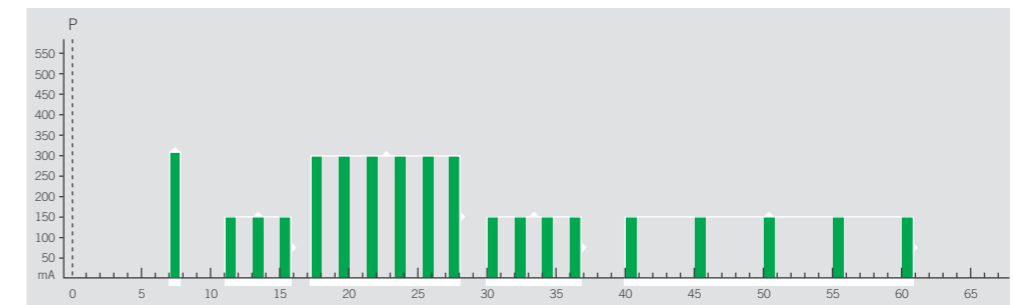### Guidelines for Neuro ONE Scanning

Select and perform the Neuro ONE brain perfusion protocol.

1. Acquire lateral and AP scanograms of the patient's head.
2. Position the dynamic volume sequence to cover the entire brain.

Scan Plan Example

Time Sequence Display

3. Set the power injector protocol and connect to the patient.
   - The following injection protocol is recommended with a contrast medium iodine concentration of at least 350 mgI/mL.

Single-Phase Contrast Medium with Saline Flush	
Phase 1 (Contrast medium)	50 mL @ 4-6 mL/s
Phase 2 (Saline)	50 mL @ 4-6 mL/s

4. Start the injector and scan together.
   - This will ensure correct timing of the scan sequence.

Nineteen volumes will be automatically reconstructed from this protocol.

Examination Guidelines

Guidelines for Carotid CTA Scanning (Site Option)

Following the Neuro ONE scan, a CTA of the carotid arteries can be performed to provide a complete diagnostic picture of the blood supply to the brain. The necessity of this scan will depend on your site's stroke workup protocol.

Select and perform the carotid CTA protocol.
- Scanograms to include the entire neck can be programmed into the Neuro ONE protocol, so reacquisition is unnecessary.

1. Position the carotid CTA scan to include the range from above the base of the skull to the aortic arch (top-down technique).

2. Position the ᔆᵁᴿᴱStart™ test slice below the base of the skull. Visual triggering will be used at the time the contrast medium reaches the internal carotid arteries.
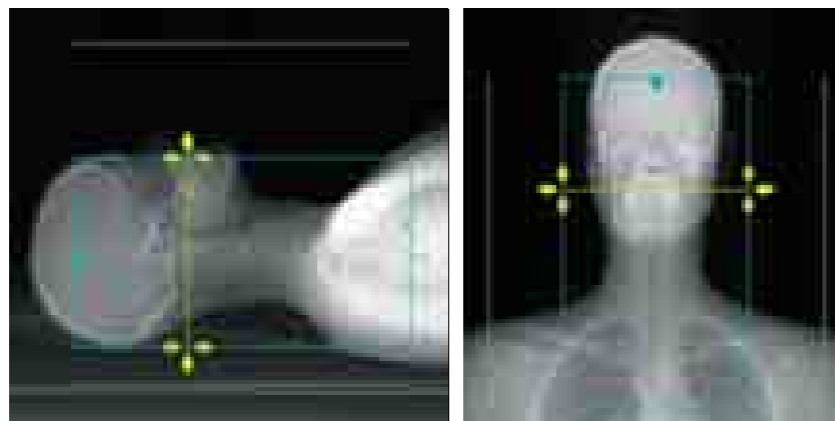
A second injection of contrast medium is necessary for this scan.

3. Set the power injector protocol and connect to the patient.
- The following injection protocol is recommended with a contrast medium iodine concentration of at least 350 mgI/mL.
- Use higher injection rates for large patients.
- The contrast medium amount should be tailored to the scan time and injection rate used. This will ensure good washout of contrast medium arriving via the subclavian vein.

Single-Phase Contrast Medium with Saline Flush	
Phase 1 (Contrast medium)	XX mL @ 4-5 mL/s
Phase 2 (Saline)	50 mL @ 4-5 mL/s

XX = (Scan time + 10) x injection rate

4. Acquire the ᔆᵁᴿᴱStart image.
- The scan is triggered manually as soon as contrast medium is seen.
- Select Manual triggering.

5. Start the scan and injection together.

6. During ᔆᵁᴿᴱStart, click the "Next Scan" button as soon as contrast medium is seen.
- Helical scanning will commence after the breathing instruction.

A Helical Volume will be reconstructed and automatically transferred to the Vitrea fX workstation for further evaluation of the carotid circulation.

NOTE: As part of your site's stroke workup protocol, a diagnostic post-contrast brain scan may also be necessary. This is best performed after the carotid scan.
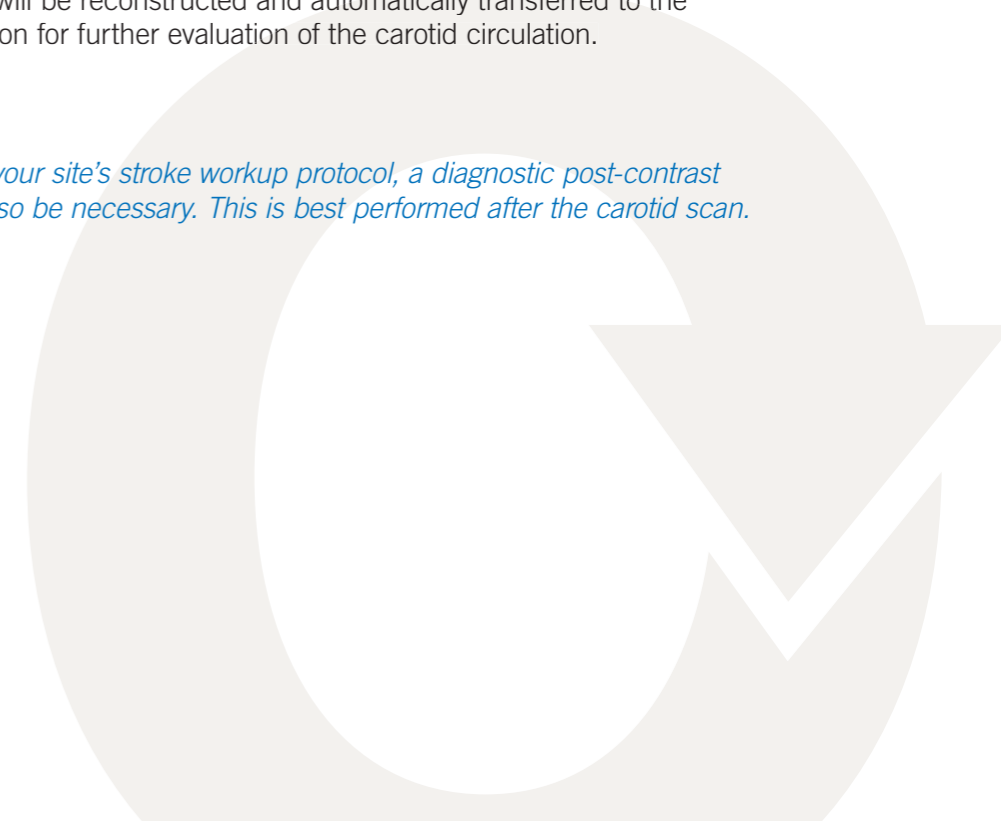
Neuro ONE Post Processing: Toshiba Console

Following completion of the scan, the reconstructed volumes can be loaded into the 4D Perfusion program for comprehensive analysis at the scanner. This software will provide volumetric multiplanar perfusion maps and subtracted 4D DSA images.

1. Select the 4D brain Perfusion analysis software in the clinical applications screen.
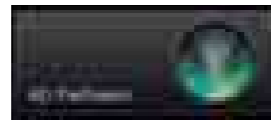

2. Load the 19 volumes reconstructed from the Neuro ONE protocol.

3. Review the volumes in 4D. Select the earliest filling artery for the arterial input function.
   - Click the Artery button and place the ROI on the artery.
   - Click Analyze to begin processing.
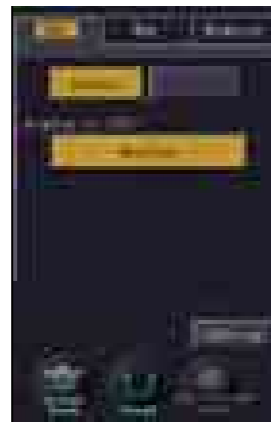
4. The software will ask you to confirm automatic selection of the SSS (Superior Sagittal Sinus) ROI before proceeding to review the perfusion maps.

The perfusion maps can be reviewed in multiple planes.
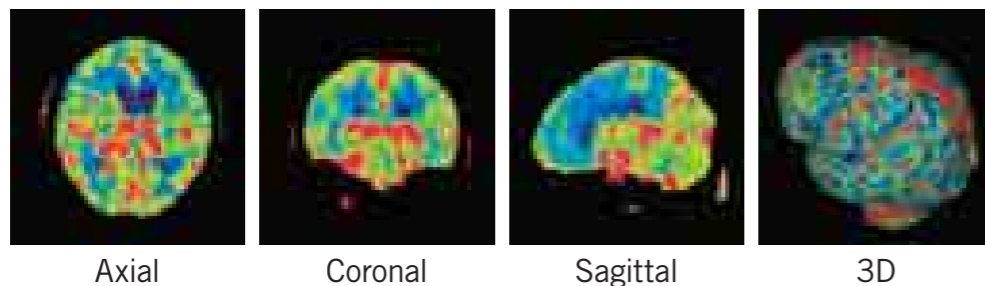
Axial   Coronal   Sagittal   3D

5. Right-click in any slice position guide to change between axial, sagittal, coronal and 3D image planes.
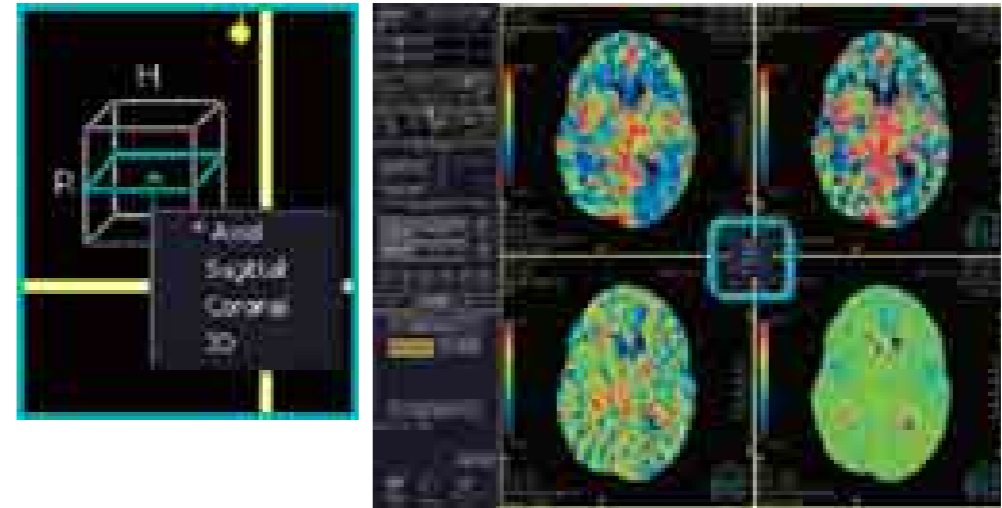
6. A selection of map images in various planes can be automatically generated and transferred. Simply click the "Auto Export" button.

   - The slice thickness, map selections and transfer destinations are made in the Settings menu. Toshiba Application Specialists can assist in setting up these options.
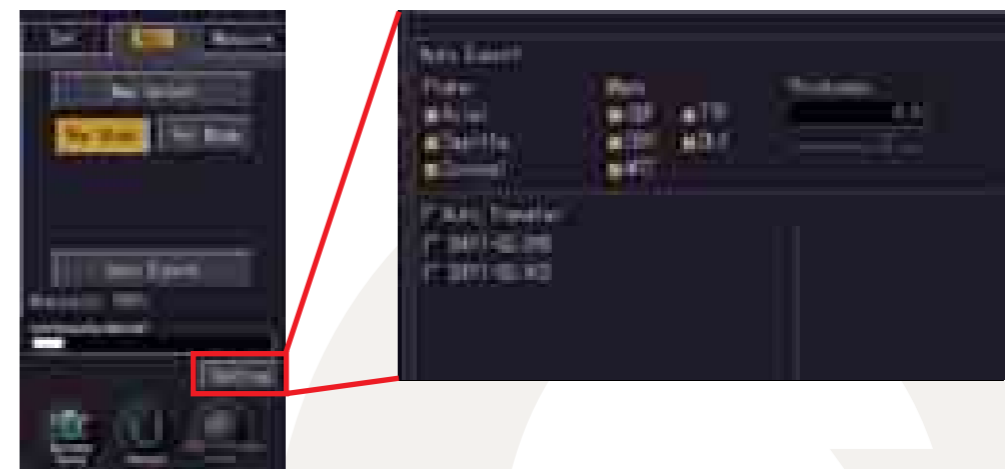
NOTE: Quantitative ROI measurements can be performed in the "Measure" tab.

7. The 4D DSA images are best viewed in the 3D software.
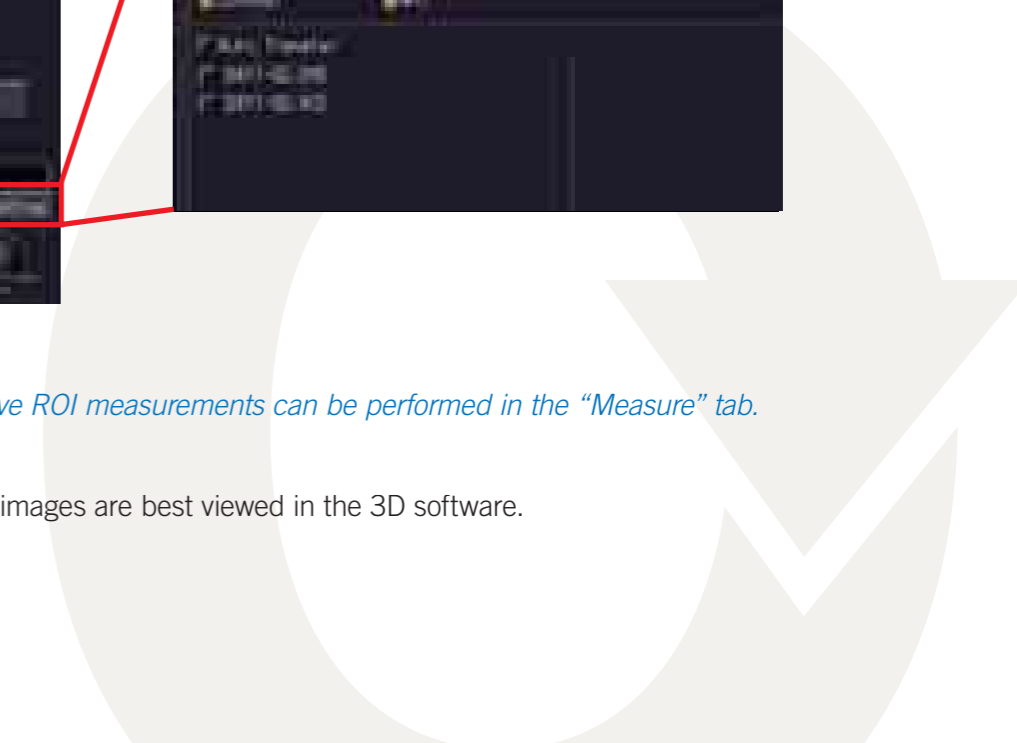
Neuro ONE Post Processing: Vitrea fX

Following completion of the scan, the reconstructed volumes are automatically sent to the Vitrea fX for comprehensive analysis on the workstation. This software automatically generates volumetric multiplanar perfusion maps and subtracted 4D DSA images.

1. Load the datasets into the 4D brain perfusion protocol. Artery and vein selection is automatic.

2. Once the perfusion maps have been generated, multiple layouts are available for easy review.
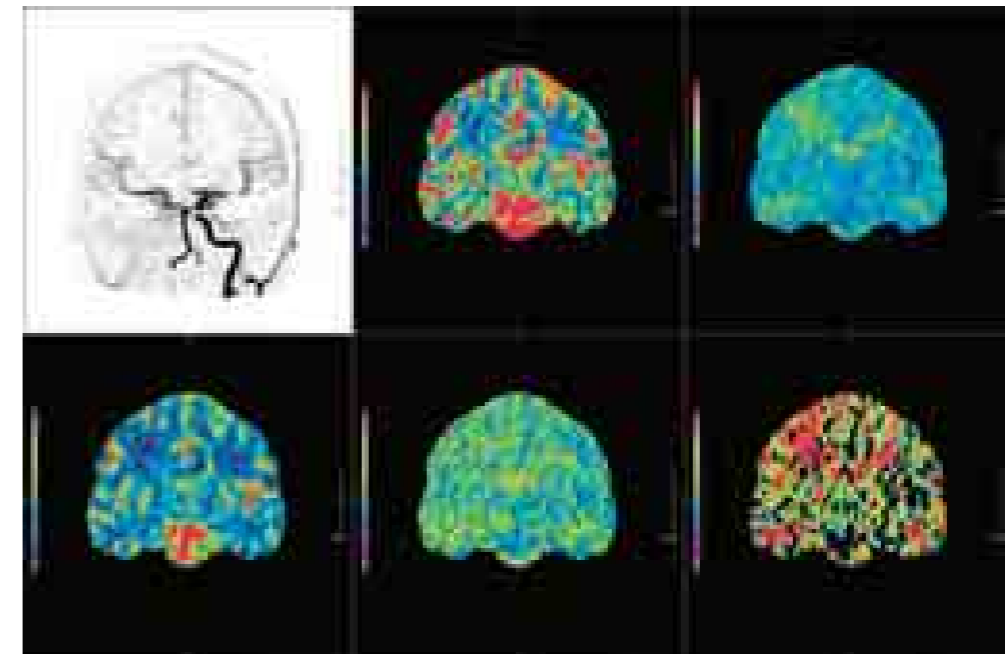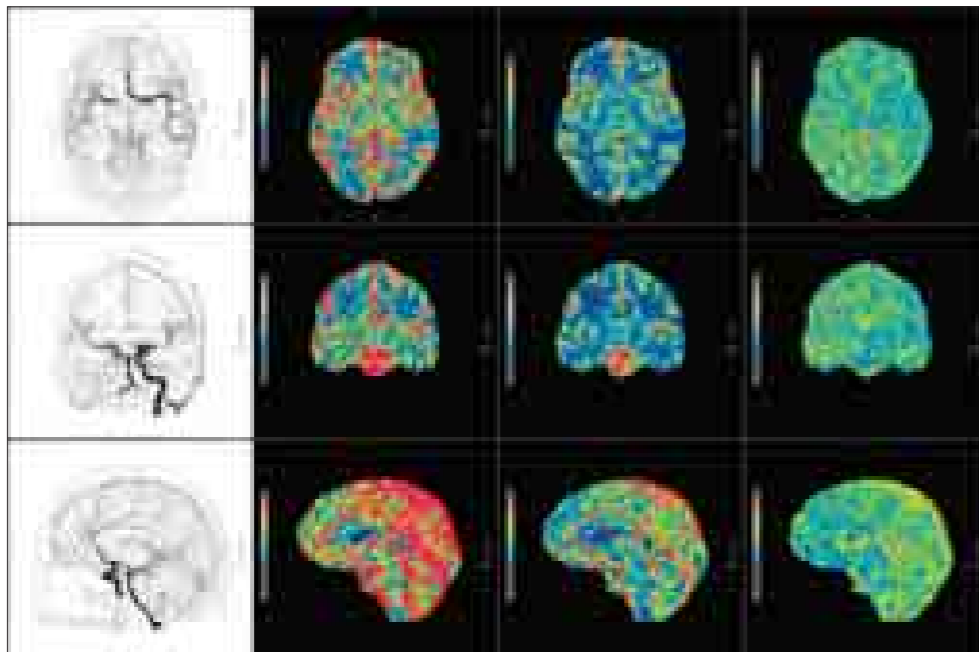
3. Quantitative ROI measurements can be performed. Click on the desired template.
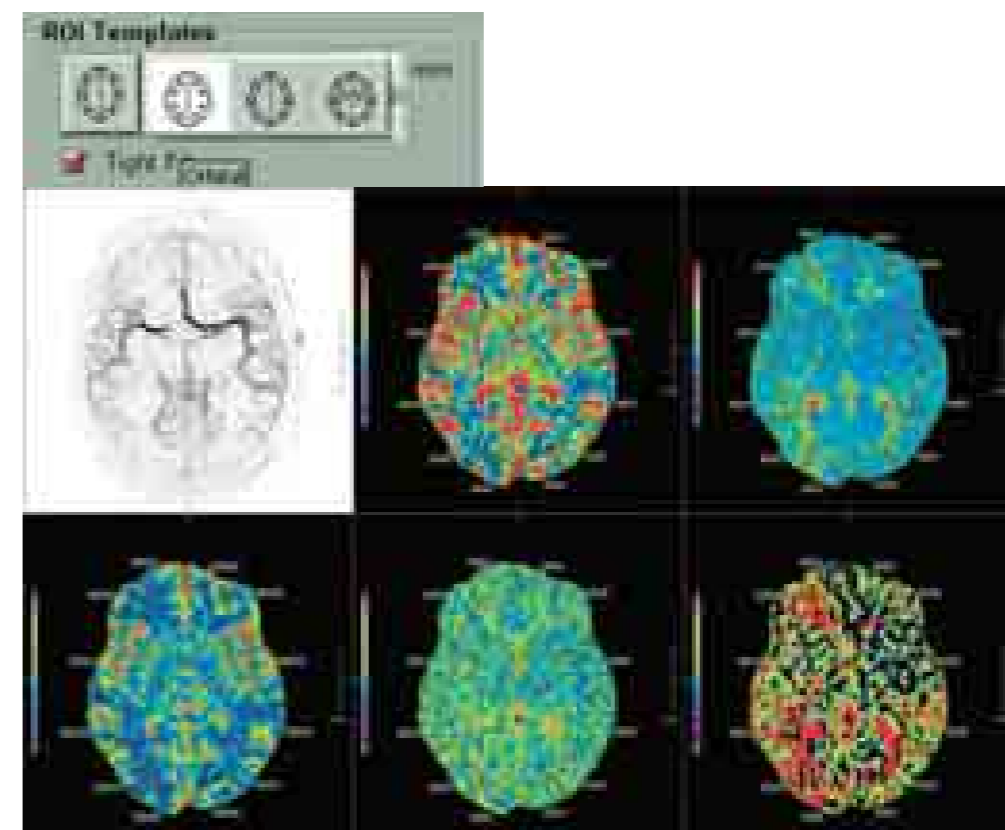
4D CT Digital Subtraction Angiography (DSA)

Introduction

This protocol provides dynamic subtracted images of the entire cerebrovascular circulation. Due to the low-exposure dose acquisition techniques made possible by dynamic volume imaging, this protocol is set to replace the standard Brain CTA scan performed routinely on multislice scanners today.

The "gold standard" in cerebrovascular system imaging is catheter angiography, which employs DSA to provide comprehensive review of the vascular circulation. 4D CT DSA provides the same dynamic information, wi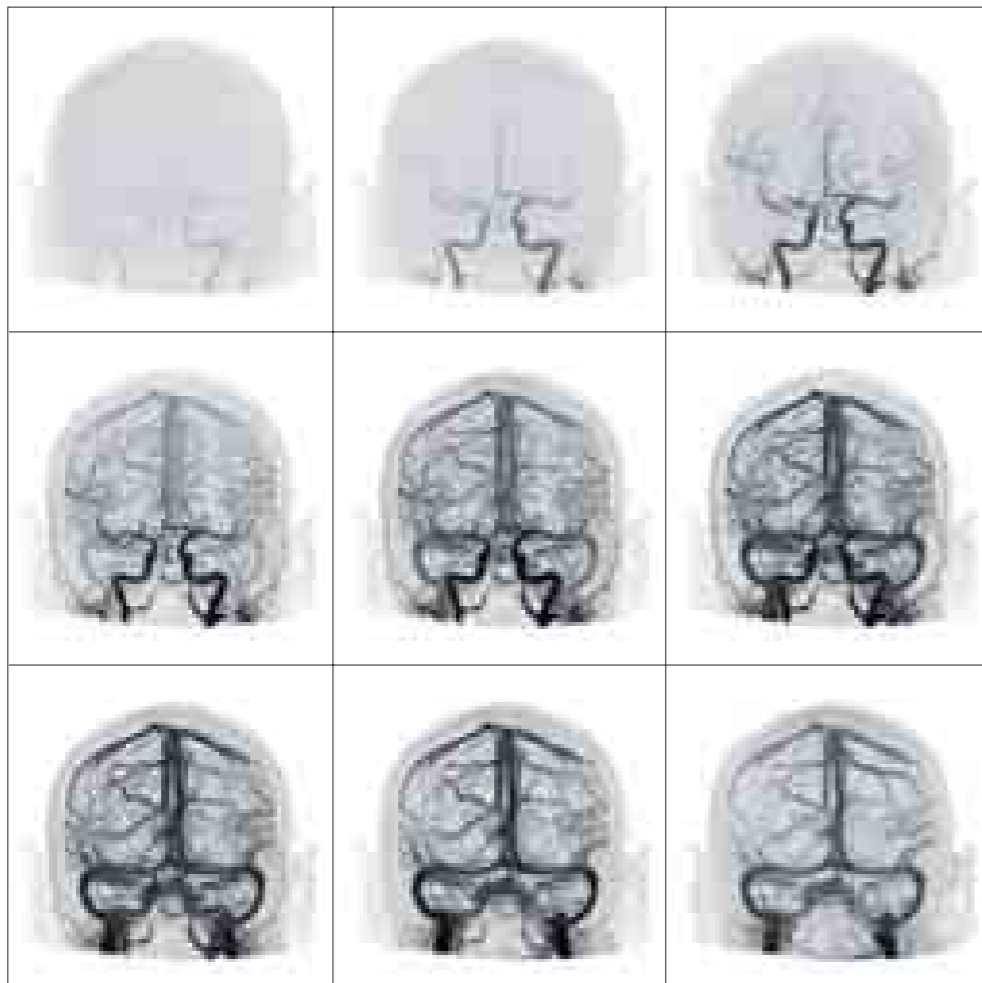th the additional benefit of producing subtracted volumetric data which can be rotated in any plane while reviewing the dynamic flow.

A test bolus scan is suggested to tailor the acquisition time for each patient to further minimize exposure dose.

4D CT DSA images

Moving Beyond Static Imaging

While fast multidetector systems armed with robust bolus tracking software produce excellent static images of the intracranial circulation, a pure arterial phase cannot be guaranteed for each patient's variable flow. Below is an example of the benefit of dynamic imaging where completely pure arterial and venous images can be generated, without overlying vessels that may obscure pathology. Additionally flow dynamics and aneurysm wall pulsation can be appreciated in 4D viewing.
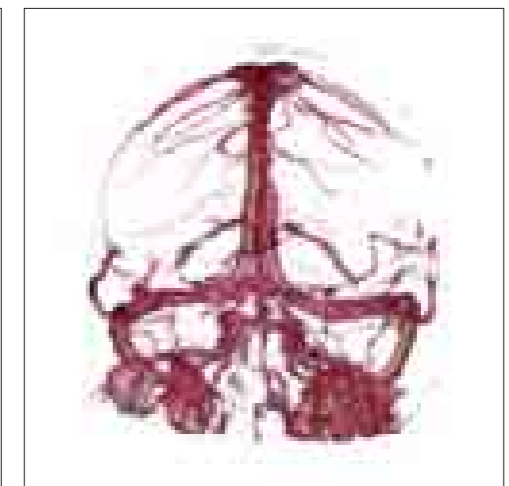
Pure Arterial   Pure Venous

4D CT Digital Subtraction Angiography (DSA)

Clinical Examples

Aneurysm:
SURESubtraction™ software automatically subtracts the bone from every volume, providing outstanding images of the carotid arteries through the base of the skull. The two left internal carotid artery aneurysms would be very difficult to visualize without artifact-free subtraction.

AVM:
The arterial vessels feeding this AVM are well demonstrated in this series of DSA images.

Fistula:
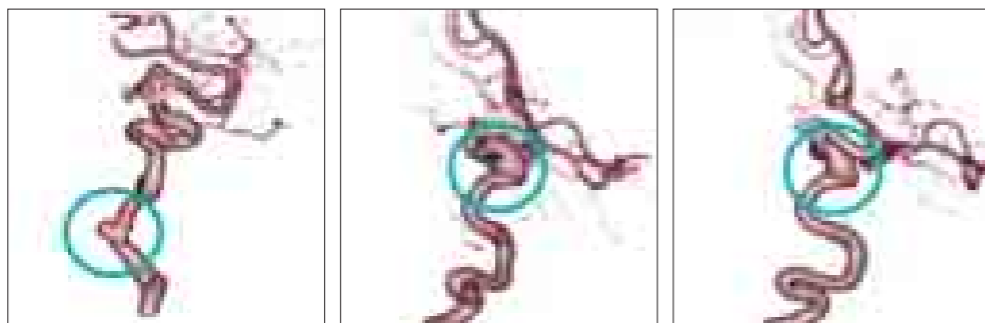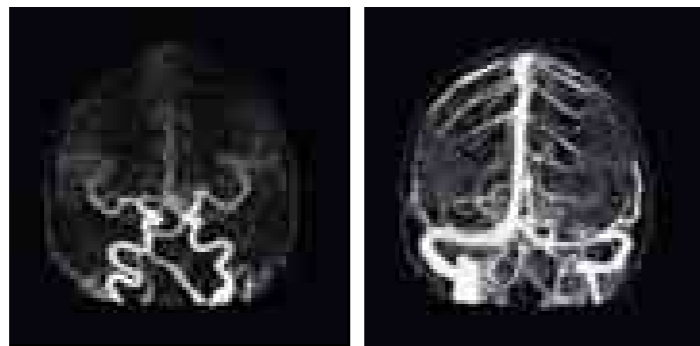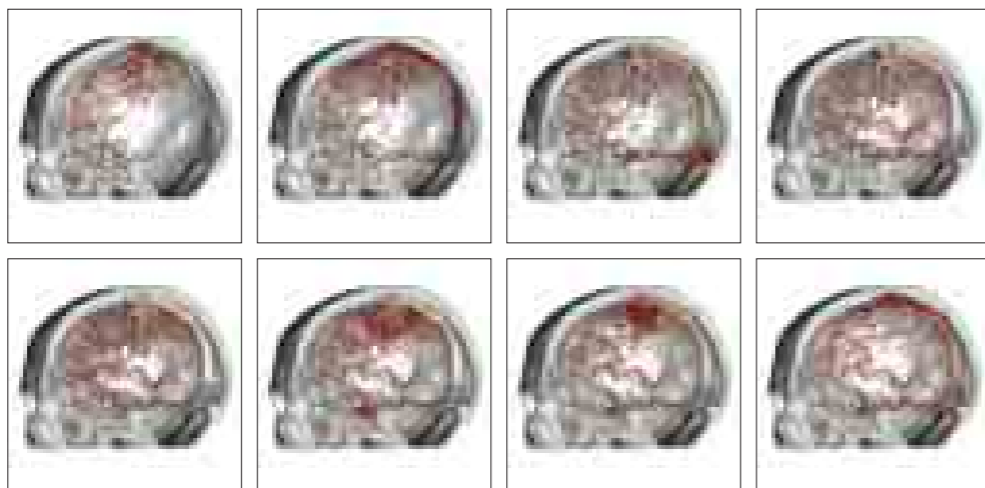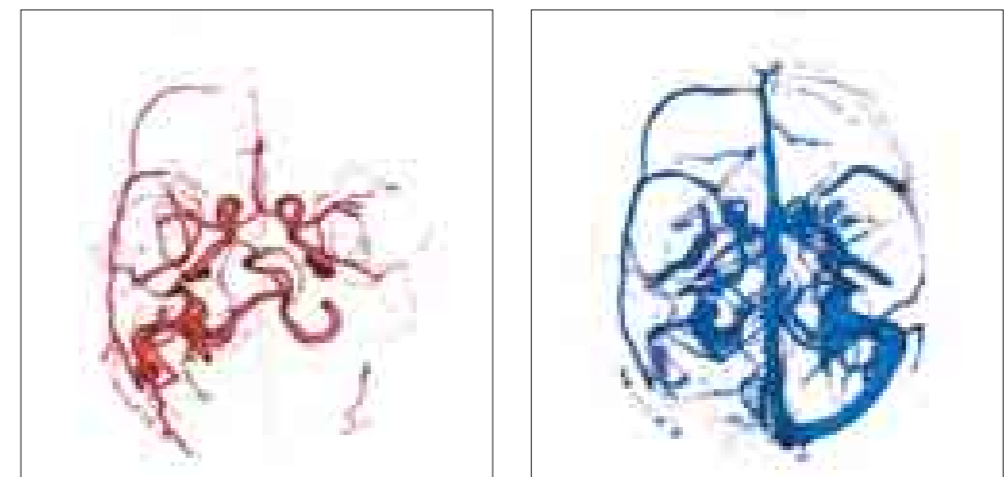An aberrant vessel can be seen in the left posterior fossa. This vessel is supplied by small arteries arising from the occipital artery. The dynamic visualization of the flow of contrast medium greatly assists the physician in planning an interventional treatment approach for this patient.
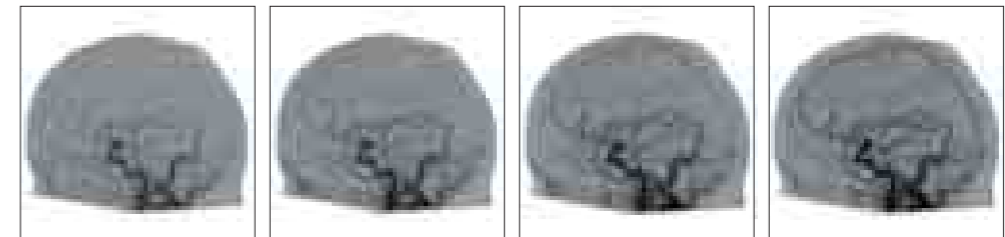
The early venous filling on the left side can be appreciated in these true arterial and true venous phase images.

"For routine neuro imaging, like for head CT, we get the same high quality, high resolution images that we had on our 64-detector row scanner, but now we have new volume techniques. We now do neuro perfusion studies that we were unable to do before. We do neuro perfusion studies of the entire brain. Also, now we are doing new and better CT angiography of the brain. With SURESubtraction and volume imaging, we can get dynamic pictures of the circle of Willis. And new for us is we are now doing CT venograms as part of the neuro perfusion study. We can actually look at the veins of the brain that we never looked at before."

Dr J Dardinger, St Elizabeth Hospital, Kentucky

Examination Guidelines

Patient Preparation and Positioning

- Give the patient a full explanation of the procedure (if possible).
- An 18- or 20-gauge cannula should be placed in the right arm.
- Position the patient for a lateral scanogram.
- Position the head as symmetrically as possible.
- Position the head so the OM baseline (mid orbit to EAM) is perpendicular to the floor (or as close as possible).
- Immobilize the patient with the head strap and pads to ensure that the patient remains still during the examination.
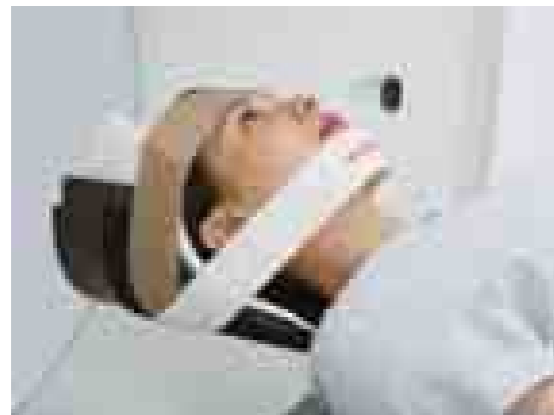
Guidelines for 4D DSA Scanning

A. Test Bolus
- Select and perform the test bolus protocol.

  1. Acquire lateral and AP scanograms of the patient's head.

  2. Position the Test Bolus slice just below the base of the skull.
     - Starting at 5 seconds and ending at 40 seconds, the test bolus protocol performs a series of low-dose scans at scan intervals of 2 seconds.
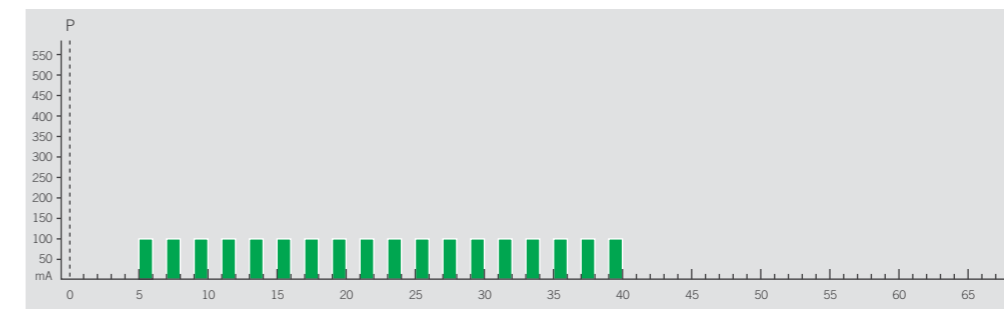
  3. Start the test bolus scan and the contrast medium injection together.
     - The following injection protocol is recommended with a contrast medium iodine concentration of at least 350 mgI/mL
     - Use the same injection rate for the 4D DSA scan.

Single Phase Contrast Medium with Saline Flush	
Phase 1 (Contrast medium)	20 mL @ 4-6 mL/s
Phase 2 (Saline)	50 mL @ 4-6 mL/s
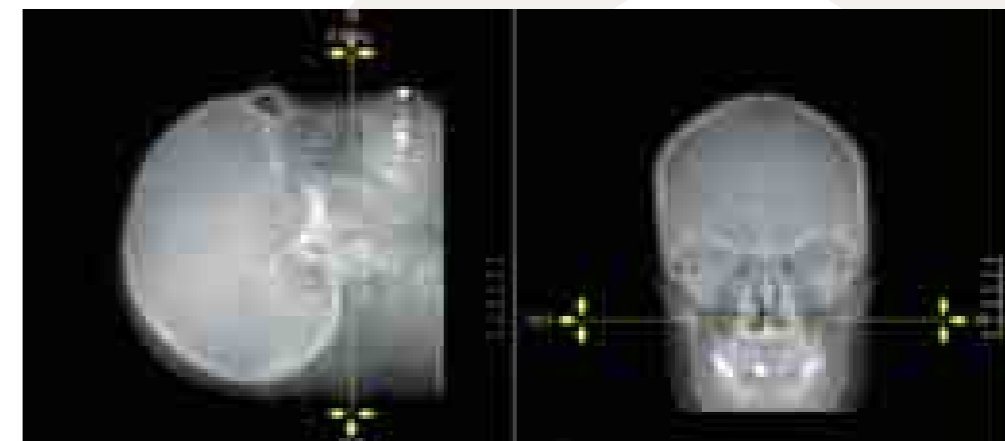
Examination Guidelines

4. Review the test bolus images and determine the contrast medium arrival time and venous washout time.
   - This can be easily determined by the delay time shown on each image.

Arrival Time　　　　　　　Washout Time

B. CT DSA Scan Protocol
- Select the 4D CT DSA protocol.

1. Position the volume to cover the entire brain.

Note: The scan range can be reduced if clinically indicated.

2. Adjust the length of the continuous dynamic scan element as determined from the test bolus timing. This can be adjusted easily from the time sequence display screen.

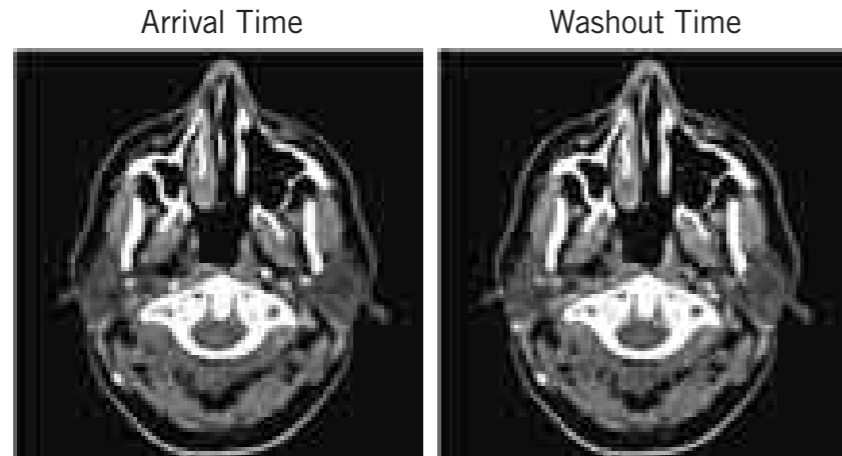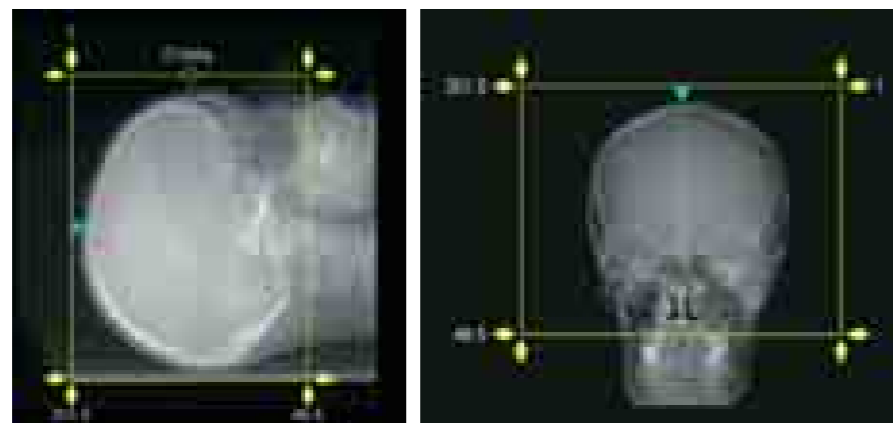   - The contrast medium arrival time determines the start of the continuous scan.

   - The venous washout time determines the end of the continuous scan.

   - The first scan is a noncontrast scan which is used as the mask for dynamic subtraction.

Scan	kV	mA	Rotation Time	Sample Time
1	80	310	0.75 s	7 s
2	80	150	0.75 s	17-30 s
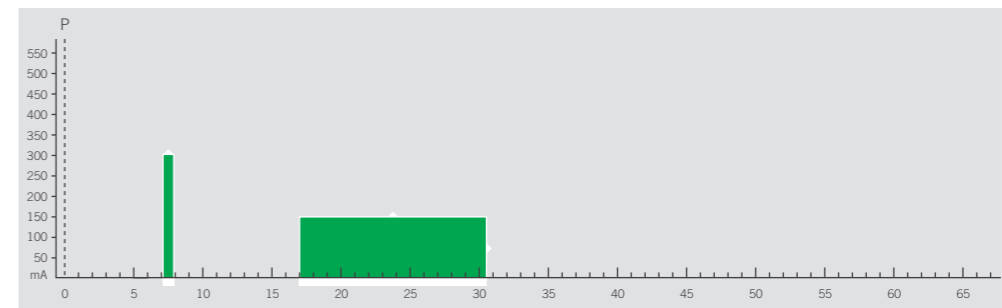
3. Set the power injector protocol and connect to the patient.
   - The following injection protocol with a contrast medium iodine concentration of at least 350 mgI/mL.

   - The following injection protocol is recommended:

	Amount
Phase 1 (Contrast medium)	50 mL @ 4-6 mL/s
Phase 2 (Saline)	50 mL @ 4-6 mL/s

Faster injection rates will provide a higher contrast-to-noise ratio and allow superior pure arterial phase and venous phase viewing.

4. Start the injector and scan together.
   - This will ensure correct timing of the scan sequence.
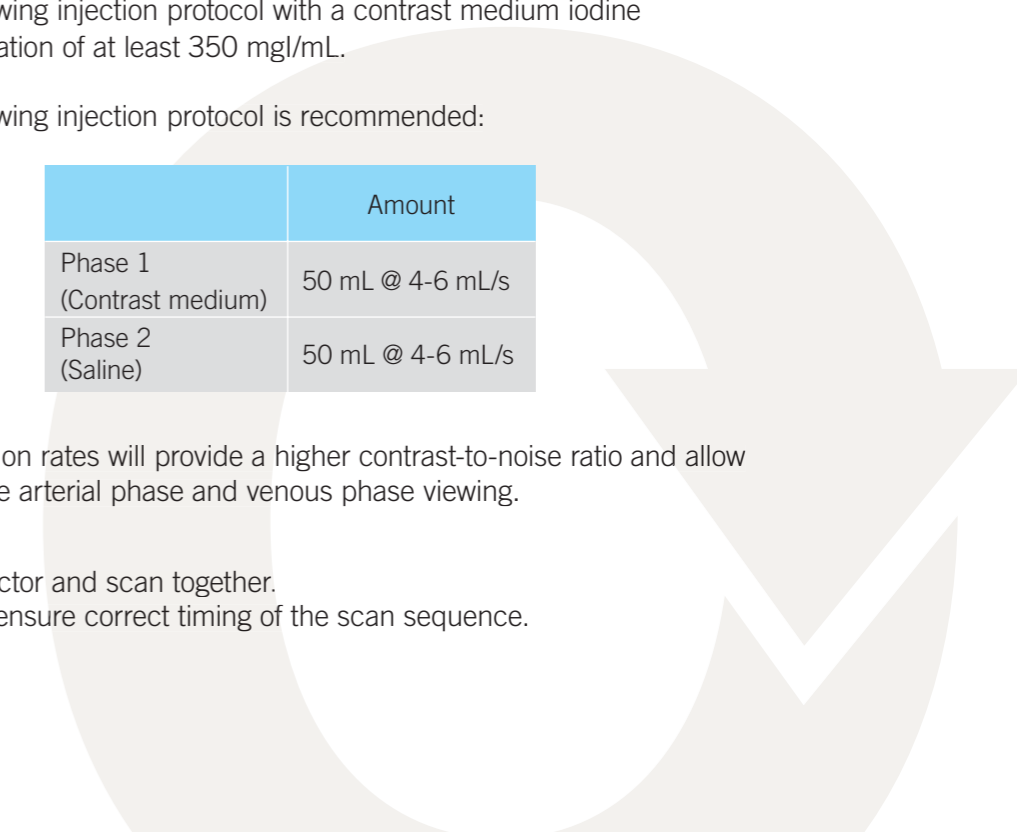
Examination Guidelines

Temporal Resolution and 4D DSA

There are two types of temporal resolution in this scan.

Image temporal resolution
• How well patient motion is frozen
• Determined by the gantry rotation speed and reconstruction method (full vs. half)

Physiological temporal resolution
• How often physiological motion is sampled
• Determined by the reconstruction time interval for a continuous dynamic volume scan

Exposure Dose

The exposure dose for a 4D CT DSA protocol depends specifically on the parameters for the continuous dynamic volume scan. The total scan time, as well as the rotation time, directly affects the total exposure dose. If the rotation time is halved, the mA must be doubled to maintain an appropriate signal-to-noise ratio. Although this will provide images with superior image temporal resolution, it will also result in a higher exposure dose.
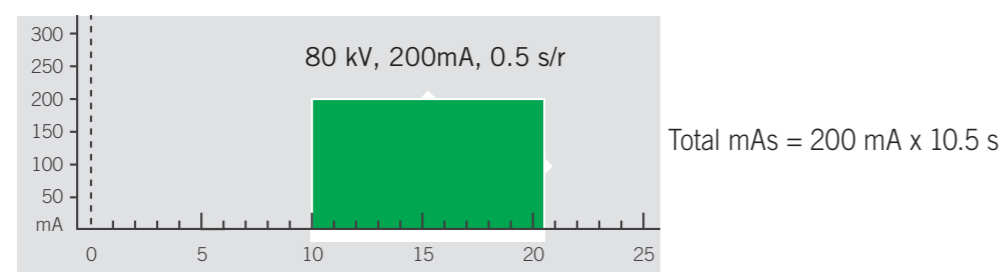
80 kV, 100mA, 1 s/r

Total mAs = 100 mA x 11 s

80 kV, 200mA, 0.5 s/r

Total mAs = 200 mA x 10.5 s
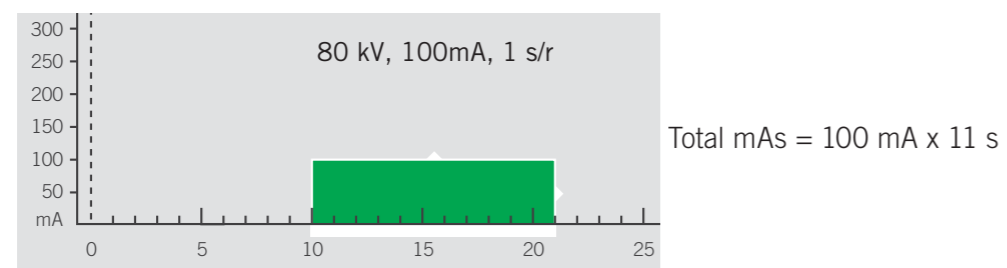
Decreasing the rotation time requires an increase in mA to maintain image quality. However, the exposure dose will be increased.

Modifying the total exposure time based on the test bolus scan for each patient's clinical presentation is the most effective way to reduce exposure dose.

4D DSA Post Processing: Toshiba Console

Following completion of the scan, the reconstructed volumes can be loaded into the 4D DSA program for automated dynamic volume subtraction.

1. Select the 4D DSA processing software in the clinical applications screen.

2. Load the 4D DSA series.

3. Check the subtraction function.
   -Click start to begin the automated subtraction.

4. The 4D DSA images are best viewed in the 3D software.

## 4D DSA Post Processing: Vitrea fX

Following completion of the scan, the reconstructed volumes are automatically sent to the Vitrea fX for comprehensive analysis on the workstation. This software automatically generates subtracted 4D DSA images.

1. Load the datasets into the 4D DSA protocol.

2. The fully automatic subtraction will be complete within 90 seconds and will then be immediately ready for review.
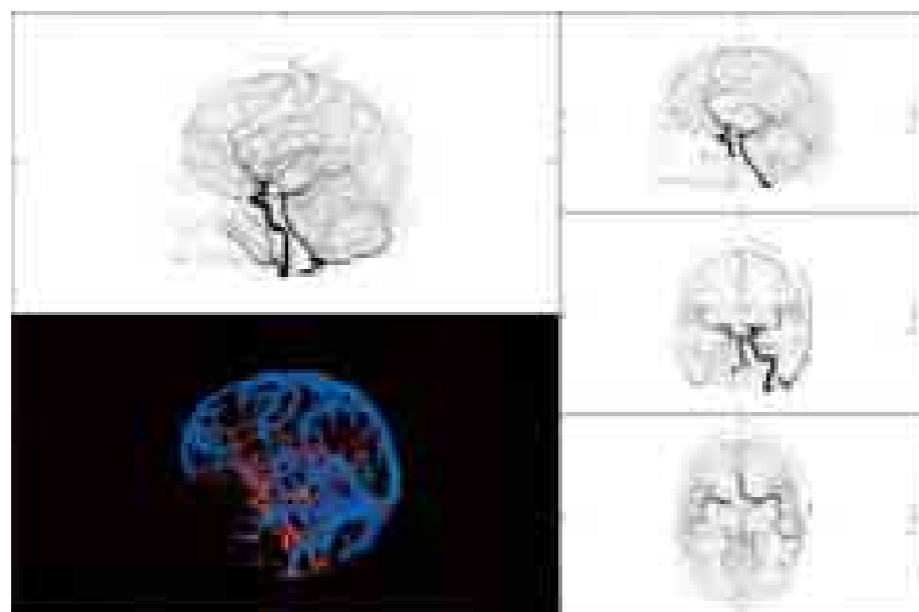
3. The color of the CTA/CTV fusion image can be changed using the region management tools.

Calculating Perfusion

Introduction

Only eight years after Sir Geoffrey 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 measurements of enhancement following the introduction of a radio-opaque contrast agent such as intravenous iodine.

There are several mathematical models that have been developed to approximate perfusion. Understanding these perfusion calculation methods is the job of engineers, mathematicians, and such likeminded people (Einstein?).

However, to use perfusion as a tool for diagnosis and to assist in determining the best treatment options for your patient's, requires a level of understanding that can be put into a 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. Arterial Enhancement Time Density Curve (TDC).
2. Venous Enhancement Time Density Curve (TDC).
3. Tissue Enhancement Time Density Curve (TDC).

As 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's. (Perfusion is calculated for each tissue voxel).

Arterial TDC   Tissue TDC

SVD+ Deconvolution Algorithm

Deconvolution provides quantification of the amount of blood volume transmitted to the brain tissue, and also determines how long the blood takes to transit through the tissue.

Arterial TDC   Deconvolution   Tissue TDC
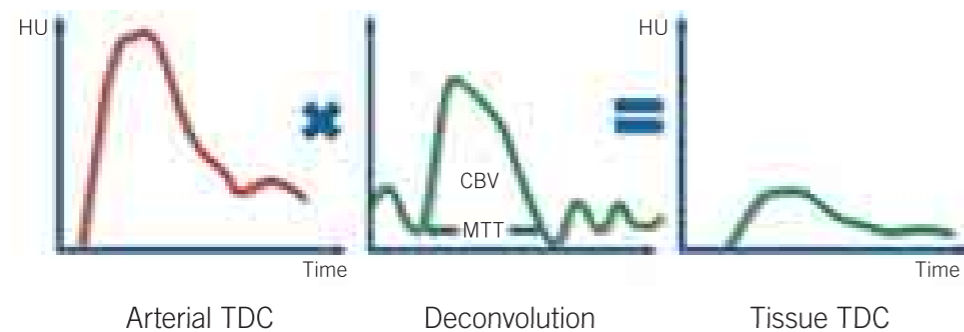
Cerebral blood flow (CBF) is defined by the blood volume (CBV) divided by the mean transit time (MTT).

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

SVD+ Deconvolution Algorithm

SVD+ is based on the standard SVD (singular value decomposition) 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 mean transit time (MTT), and therefore provides an accurate MTT measurement according to the definition.

As perfusion is calculated from CBV/MTT, reporting physicians need to be aware that unlike other less sophisticated algorithms, delayed flow will not be 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 on 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.

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)

Defined as the blood volume running 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)

The distribution of blood per unit brain tissue. It provides evaluation of autoregulation (collateralization).

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

Mean transit time (MTT)

The average amount of time that blood takes to transit through the capillary vessels. Measured from time from peak arterial enhancement to peak tissue enhancement minus the delay time.
An increase in MTT indicates vasodilatory response to reduced flow. A decrease in MTT indicates poor or absent flow within the brain tissue.

MTT is measured in seconds.

Time to peak (TTP)

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

TTP is measured in seconds.

Delay time

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

Delay time is measured in seconds.