Whitepaper

CT Neuro Perfusion in ischemic stroke management

Whole brain dynamic imaging with automated perfusion analysis

Markus Juergens, Andrew Primak

↗ siemens-healthineers.us/ct

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Introduction

Stroke is a common disease. It affects one in four people over their lifetime, and there are estimated to be 13.7 million incidences of strokes globally each year. This is expected to increase with an ageing population. Stroke is the second leading cause of death, and third leading cause of disability in adults globally[1]. Strokes are broadly categorized as either ischemic strokes or hemorrhagic strokes. Ischemic stroke, the most common kind of stroke, occurs due to insufficient brain perfusion.

Perfusion is the process by which oxygen and nutrition are delivered to the biological tissues and carbon dioxide and cellular waste are carried away from the biological tissue, via the vascular system. More specifically the term perfusion refers to blood flow, which conventionally represents how many milliliters of blood enter 100 g of tissue in 1 minute [ml/100 g/min]. An ischemic stroke occurs when blood flow, and hence the oxygen delivery to the brain is hindered, thereby causing damage to the cerebral tissue. The goal of stroke therapy is to protect the tissue before development of irreversible injury, and time is of essence.

Imaging is essential to the management of stroke. Non-contrast head CT imaging is excellent in discriminating the presence of intracranial hemorrhage which typically precludes patients from thrombolytic treatment. If no signs of hemorrhage are detected, if indicated, additional dynamic imaging including CT angiography (CTA) and CT perfusion (CTP) studies are performed. CTA is helpful for evaluation of large vessel intracranial stenoses and occlusions, while CTP helps characterize the functional properties of brain tissue.

Based on the results of the DAWN[2] and DEFUSE(3)[3] trials in early 2018, AHA/ASA updated the Acute Ischemic Stroke Management and Treatment Guidelines[4]. Figure 1 shows the timeline for treatment and imaging as recommended in the 2018 AHA guidelines. The window for potential endovascular thrombectomy (EVT) treatment was extended beyond 6 hours and up to 24 hours from symptom onset. Studies have suggested that advanced neuroimaging-based selection for endovascular thrombectomy nearly doubles the probability of good functional outcomes[5-6], as the selection is based on stroke physiology as opposed to an approximate time window. The AHA 2018 guidelines recommend CTP or MR perfusion (MRP) for selection of eligible patients for this extended treatment by mechanical thrombectomy. CTP is readily accessible and typically requires less time to acquire compared to MRP.

The goal of stroke therapy is to protect the tissue before development of irreversible injury, and time is of essence.

Studies have suggested that advanced neuroimaging-based selection for thrombectomy nearly doubles the probability of good functional outcomes.

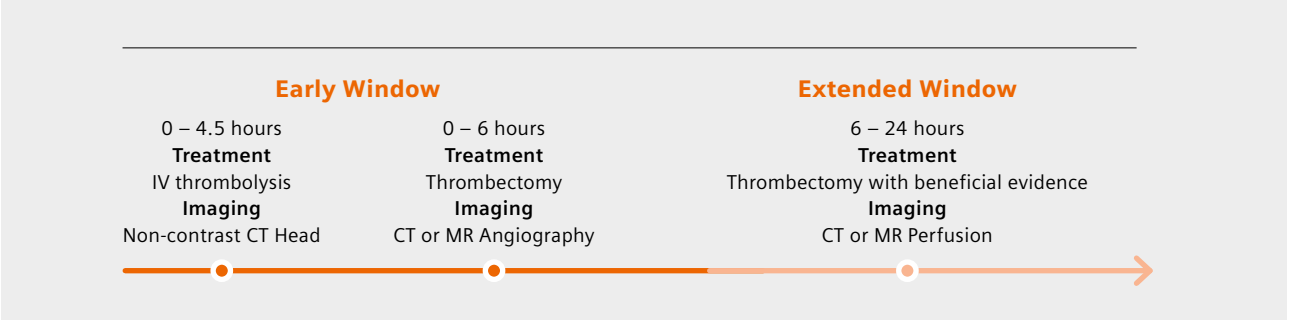

Figure 1: Treatment and imaging guidance as per the 2018 AHA guidelines for stroke management. This is a representation, please see [4] for the detailed discussion.

Infarct core (non-viable tissue) and penumbra (tissue at risk)

The infarct core defines the non-viable tissue in an acute ischemic stroke, the portion that is irreversibly damaged and cannot be salvaged by reperfusion. The penumbra is the surrounding tissue that is at risk due to being hypoperfused but can potentially be salvaged with timely reperfusion treatment. CTP can be used to identify the presence and extent of the infarct core and the penumbra to make informed decisions on revascularization treatment. Presence of a substantial penumbra is a good indicator for extending the intravascular therapeutic window[7], and CTP can be used to predict the benefit of such therapeutic treatments[8].

Studies have shown good agreement of CTP findings with the gold standard techniques like Diffusion-weighted imaging (DWI) and MRP[9,10].

CT Perfusion

In CTP imaging, a short and fast bolus of contrast media is injected intravenously, and images are continuously acquired before, during, and slightly after the first passage of contrast media through the brain. Attenuation changes over time are considered proportional to the contrast media and hence the perfusion. By fitting the measured data to physical models, different perfusion parameters are derived, and brain perfusion maps are produced during CTP analysis. Figure 2 shows schematics of the time attenuation curve with different perfusion parameters for the Maximum Slope (MS) (Figure 2a) and Deconvolution (DC) (Figure 2b) models. Figure 3 shows representative brain perfusion maps produced by CTP analysis using the DC model. Table 1 describes the various CTP parameters and how they change in the presence of an ischemic stroke.

CTP can be used to identify the presence and extent of the infarct core and the penumbra to make informed decisions on revascularization treatment.

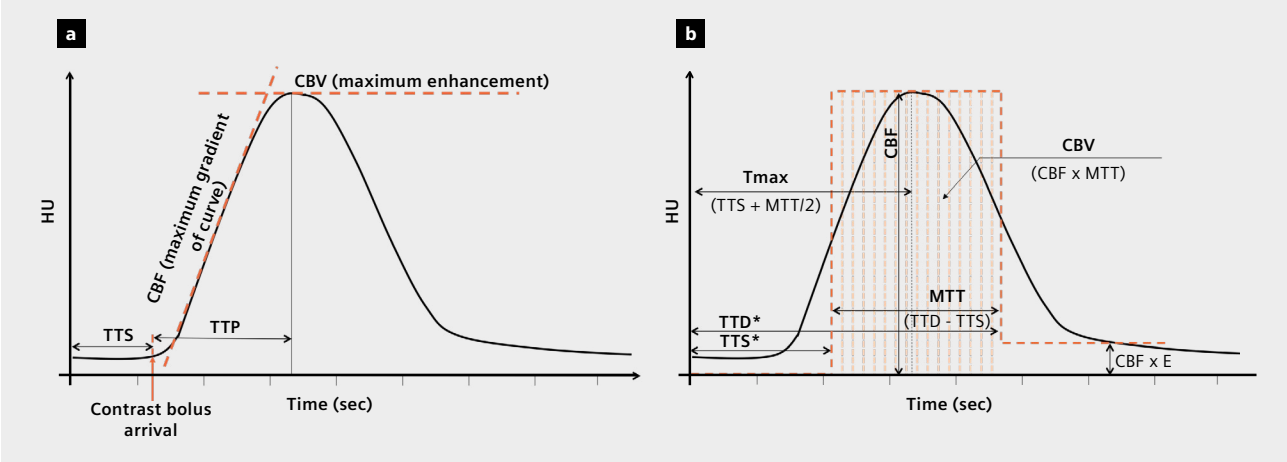

Figure 2: Time attenuation curve schematic showing different CT Perfusion parameters[18].
(a) Maximum Slope model (b) Deconvolution model.

**DC parameters are defined relative to the arterial input function (AIF), and do not depend on the baseline (unlike the MS model).*
E is a constant, assuming there is no backflow from the extravascular region to the capillaries.

Table 1: CTP Parameters

Parameter Name	Definition
Cerebral Blood Flow (CBF)	The amount of blood flowing through a given volume of brain in a specific amount of time (mL/100 mL/min). CBF identifies areas of hypoperfusion, including the infarct core and the penumbra. The infarct core has markedly decreased CBF compared to the penumbra.
Relative CBF (rCBF)	The ratio of the CBF in the affected hemisphere to that in the contralateral hemisphere.
Cerebral Blood Volume (CBV)	The volume of the blood flowing through a given volume of brain (mL/100 mL). The ischemic penumbra has a normal or increased CBV due to autoregulation.
Relative CBV (rCBV)	The ratio of the CBV in the affected hemisphere to that in the contralateral hemisphere.
Mean Transit Time (MTT)	The average amount of time it takes for blood to flow through a given volume of brain (sec). MTT increases as a vasodilatory response to reduced flow.
Time To Peak (TTP)	The time required to reach peak enhancement (sec). Increased TTP indicates delayed flow due to stenosis or occlusion.
Time To Start (TTS)	The time required for the contrast bolus to enter the given volume of brain (sec).
Time To Drain (TTD)	The time required for the contrast bolus to exit the given volume of brain (sec). This is a Siemens specific parameter.
Tmax	The time required to reach peak after deconvolution (sec). Increased Tmax indicates delay in arrival of the contrast bolus.
Temporal Maximum Intensity Projection (tMIP)	The maximum value image in every projected plane from the time-phase direction on all timepoints from a CTP acquisition. tMIP improves the detection of ischemic area as compared to non-contrast CT and helps assess the vessels, i.e., the collateral status.
Mismatch Volume	The difference in volume between the total hypoperfused region and the infarct core. This equals the ischemic penumbra, the volume of salvageable tissue.
Mismatch Ratio	The ratio of the volumes of the total hypoperfused region and the infarct core.

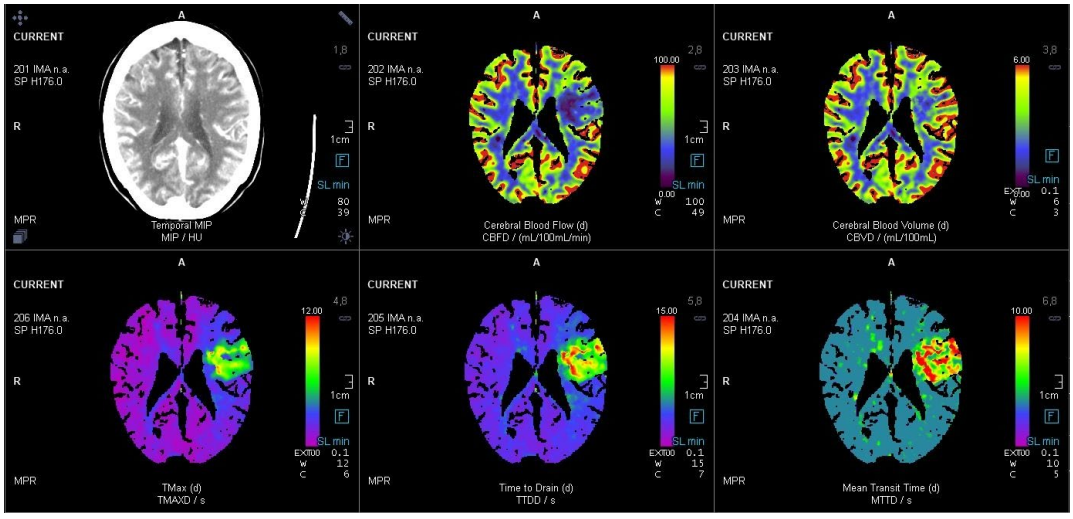

Figure 3: VPCT Neuro multi-parameter analysis with DC model showing axial views of Temporal Maximum Intensity Projection (tMIP), Cerebral Blood Flow (CBF), Cerebral Blood Volume (CBV), Tmax, Time To Drain (TTD) and Mean Transit Time (MTT). Figure shows a case with left MCA occlusion, the left hemisphere has decreased cerebral blood flow as seen in the CBF map (top center). The increased cerebral blood flow is also reflected in the increased Tmax (bottom left) as well as the TTD (bottom center) and MTT (bottom right). The CBV values (top right) on the other hand are not lowered to the same extent as the CBF values indicating a potential tissue at risk area.

Time is Brain

In this paper we summarize the Siemens Healthineers' approach for CTP acquisition and analysis to enable reliable and quick image interpretation and assist with accurate and timely responses to ischemic stroke.

A number of different post-processing methods for CTP analysis have been studied and based on a combination of different CTP parameters and thresholds, multiple definitions for the best predictors of infarct core and penumbra have been proposed. Review of these methods and definitions can be found in literature (eg., see[12]) and is beyond the scope of this paper. Some of these studies are based on thresholds for a single parameter, like absolute CBF. While others are based on the concept of cerebral vascular autoregulation, where autoregulation is preserved in the penumbra, but lost in the core. These studies use a combination of parameters, like CBF and CBV, or CBV and MTT, to name a few.

Differences in CTP hardware and software, along with non-standardized triaging protocols for individual institutes is a confounding factor with quantitative CTP. A consensus regarding the CTP parameter (or combination of parameters) that most accurately predicts the core and penumbra has not been reached. Significant discrepancies have been shown in volumes of infarct core and hypoperfusion when generated using software from different vendors[13]. Nevertheless, feasibility of achieving high concordance between different post-processing software packages, both in terms of core and penumbra volume as well as therapeutic decision making, has been shown[14].

In the Adaptive 4D Spiral (A4DS) and Flex 4D Spiral (F4DS) modes the table continuously performs a smooth (but relatively fast) dynamic scan with periodic motion between two end positions.

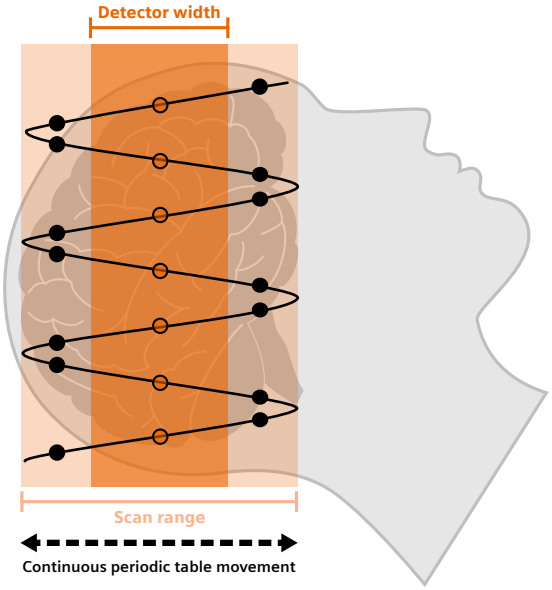

Figure 4: The A4DS mode allows dynamic time-resolved scanning of areas larger than the detector width by continuous periodic table movement between two end positions. The temporal sampling of the scan range is equidistant in the central region (empty circles) and non-equidistant in the peripheral regions (filled circles).

Acquisition

All major vendors have developed different approaches to extend the CTP scan coverage range to 8 cm and beyond to allow evaluation of the entire brain volume. The Siemens Healthineers' approach to extend perfusion coverage is based on a periodic spiral technique with variable pitch. In the Adaptive 4D Spiral (A4DS) and Flex 4D Spiral (F4DS) modes the table continuously performs a smooth (but relatively fast) dynamic scan with periodic motion between two end positions (Figure 4). This technique allows sufficient temporal sampling to analyze subtle changes of regional cerebral mean transit time (MTT). Brain volume perfusion CT (VPCT) with the A4DS mode is available on the SOMATOM Drive and Force. For sampling rates from 1 to 1.5 s, VPCT offers flexible scan range coverages. The default recommended scan range coverage, to optimally cover the brain, using the A4DS mode is 11.4 cm on SOMATOM Force; and 10 cm on SOMATOM Drive. The scan range coverage for the F4DS mode is 12.5 cm on NAEOTOM Alpha.Prime and NAEOTOM Alpha.Peak; 11.5 cm on NAEOTOM Alpha.Pro; 8.5 cm on SOMATOM Pro.Pulse; 11 cm on SOMATOM X.ceed; 10 cm on SOMATOM X.cite; and 8.5 cm on SOMATOM go.All and go.Top.

A different approach to extend the CTP scan range is the "toggling table" technique, where the table moves back and forth between two adjacent positions doubling the coverage (e.g., from 4 to 8 cm or from 8 to 16 cm). At each position a conventional axial CTP acquisition is performed allowing temporal sampling rates of 3-4 s. The jolts from the table motion affect patient comfort. If these critically ill patients are unable to remain perfectly still, the image quality is also adversely affected. An added drawback with this technique is the inability to perform 3D motion correction. Another approach to increase the CTP scan range is to use extra wide detectors. However, systems with very wide detectors (16 cm) suffer from considerably more scatter radiation which reduces low contrast detectability and makes them less dose efficient (about 20% noise increase[15]). In order to compensate for the higher dose required by the extra wide detectors their advocates have suggested a variety of heterogeneous sampling schemes that reduce the sampling rate down to 5s in later phases of the acquisition. Unfortunately, these protocols might not work for every patient in clinical settings. In case of a substantial contrast delay (e.g., patient with weak cardiac output or extracranial bypass) relevant phases of the regional time attenuation curves might be sampled insufficiently, compromising the accuracy of the calculation.

The Siemens Healthineers approach with A4DS and F4DS avoids both the abrupt motion associated with the "toggling table" technique and dose inefficiency of extra wide detectors while still achieving wider coverage.

Since wider coverage is associated with a higher radiation dose and can result in direct irradiation of the eye lenses, the optimal coverage should be selected based on clinical needs of an individual patient, with the maximum coverage being applied only when justified[16]. This approach helps avoid unnecessary radiation and, hence, better complies with the ALARA (As Low As Reasonably Achievable) principle. A VPCT scan range of ~10 cm is usually considered adequate for stroke imaging as it allows an acceptable prediction of tissue outcomes[17] and covers the whole supratentorial brain while avoiding direct irradiation of the eye lenses.

Neuro VPCT protocols on Siemens scanners are set to be performed either at 70 or 80 kVp, as these settings have the lowest radiation dose for a specific iodine contrast to noise ratio (CNR). Since iodine CNR is the most relevant parameter for a perfusion scan, the kVp should not be raised to higher values. This might lead to unacceptable high dose values.

Using the default protocol settings, a typical VPCT scan of the whole supratentorial brain with a 12.5 cm coverage on the NAEOTOM Alpha.Prime scanner (70 kVp, 167 mAs, 46.5 s) results in a CTDIvol of 184 mGy. This is well below any potential skin reaction, and the stochastic radiation risk corresponds to about 2 years of natural background radiation.

Recommendation for injection protocol:
Injection flow rate of 5–6 ml/s or higher.
Pre-heat the contrast medium to decrease viscosity and enable high flow rates.
18 g needle (green), or larger, into right antecubital vein.
Injection duration lower than 8 seconds.
A contrast medium volume not too small, to ensure detectable enhancement changes.
Saline flush at the same flow rate.
Short delay between injection and scan (~ 4 seconds), unless using test bolus to determine delay.

Postprocessing

For the most accurate analysis of VPCT data acquired in the A4DS and F4DS modes, Siemens Healthineers recommends using the *syngo*.CT Neuro Perfusion software that has several important features. Volume coverage provided by these spiral acquisition modes helps achieve better motion correction in 3D which can be insufficient with the conventional 2D approach. Since it is quite common for stroke patients to move during the acquisition, proper motion correction is crucial for accurate perfusion analysis. This is especially true for DC models which are very sensitive to the accurate shape of the arterial input function (AIF). Reconstructions at 5mm thickness and 3mm increment or at 1.5mm thickness and 1mm increment are recommended. Thicker slices and larger increments may limit the effectiveness of the 3D motion correction, i.e., it might be impossible to correct patient motion properly with too thick slices. The 50% overlap of the reconstructed images is deliberate to improve detection of small objects, e.g., the collaterals.

Being confident that motion can be properly accounted for, Siemens Healthineers *syngo*.CT Neuro Perfusion uses a DC model[18] as default. Within *syngo*.via, all relevant perfusion parameters can be displayed in one view (Figure 3). The MS model is also included in the software package. This model is less sensitive to a delayed bolus or a shortened scan time. For both models, the perfusion parameters to be displayed can be selected according to user preference in *syngo*.CT Neuro Perfusion (Figure 5).

The sensitivity of CTP algorithms to delayed contrast arrival is also very important for perfusion analysis. A vendor cross comparison study conducted by Kudo et al.[19] showed that perfusion maps derived from delay-sensitive algorithms overestimate the final infarct size. This study also showed the delay insensitivity of the MS model, which has been commercially available on Siemens products since 1998. This fact was also favorably reviewed in a corresponding editorial by Konstas and Lev[20]. The DC model used by *syngo*.CT Neuro Perfusion is delay-insensitive by its design because it includes the local bolus arrival time as one of the fitting parameters. A study by Abels et al.[18] demonstrated that, when the same source data and preprocessing steps were used, both models yielded comparable qualitative and quantitative results which would have led to the same therapy decision.

The availability of two models for perfusion analysis adds more flexibility to *syngo*.CT Neuro Perfusion and results in a robust performance for patients, even in suboptimal conditions.

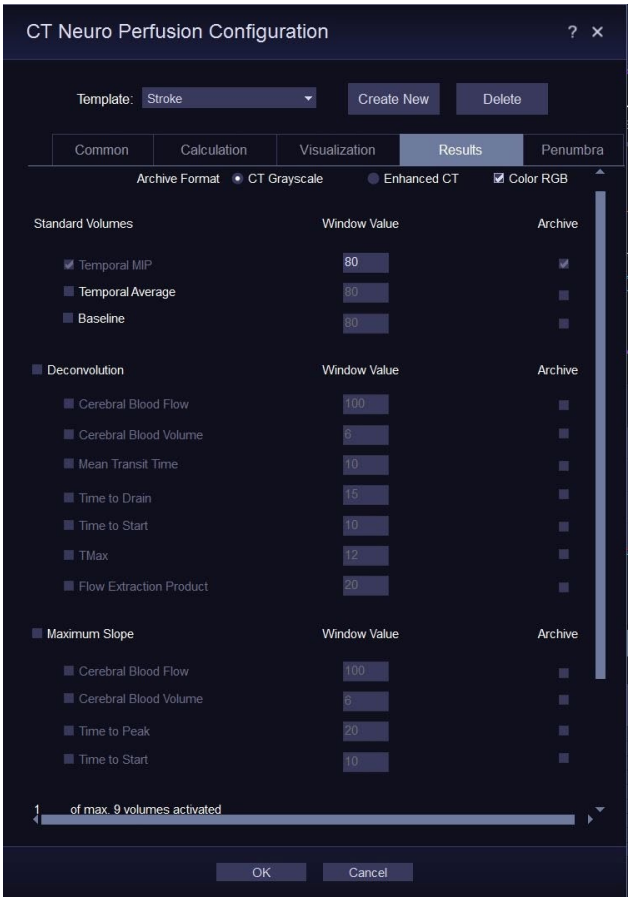

Figure 5: CT Perfusion parameter selection on *syngo*.CT Neuro Perfusion

Another important feature of *syngo*.CT Neuro Perfusion is the Siemens Healthineers' exclusive 4D noise reduction algorithm which utilizes a spatiotemporal multi-band filtering approach. In this approach, images from every time frame in the dynamic series are decomposed into multiple (spatial) frequency bands. The lowest frequency band predominately includes information about the smooth image content (i.e., image contrast), while the higher frequency bands predominantly contain information about the edge details and noise. After averaging different bands with different weighting functions in the temporal domain (i.e., a very narrow function for the lowest frequency and broader functions for the higher frequencies), all bands are recombined to produce the final image. This final image contains the unchanged information about iodine enhancement (i.e., the time attenuation curves are not modified) but has reduced noise since the temporal averaging of the higher (spatial) frequency bands is equivalent to collecting more x-ray photons. The 4D noise reduction can be used either to improve the quality of the perfusion maps (i.e., fewer areas where the model fails due to insufficient signal-to-noise ratio as shown in Figure 6) or reduce the radiation dose while maintaining the same image quality. Keeping dose at a low level is a major concern for brain perfusion since a dynamic acquisition at multiple time points can result in radiation dose levels higher than routine diagnostic CT exams.

The periodic table movement during the dynamic scan acquisition results in an equidistant temporal sampling in the central slice of the VPCT scan range and non-equidistant temporal sampling in the peripheral slices (Figure 4). Since conventional brain perfusion uses equidistant sampling (between 1 – 4 s), it has been questioned if the dynamic spiral acquisition approach can allow an accurate calculation of the quantitative perfusion parameters. However, the non-uniformity of the A4DS and F4DS modes with the dynamic spiral acquisition sampling scheme is explicitly taken into account in the dedicated algorithms used by the *syngo*. CT Neuro Perfusion software. The accurate shape of the arterial input function (AIF) can be obtained from the central slice which has the equidistant sampling of 1.5 s, even in case of a substantial contrast delay. The perfusion parameters can be reliably estimated for the time-attenuation curves of brain tissue with the shape-based DC model and the AIF, even with the non-equidistant temporal sampling in the peripheral slices. The accuracy of the dynamic spiral volume perfusion technique has been validated in the study by Haberland et al.[21]. The results of this work have shown that the performance of this technique is equivalent to the performance of standard dynamic modes with equidistant sampling.

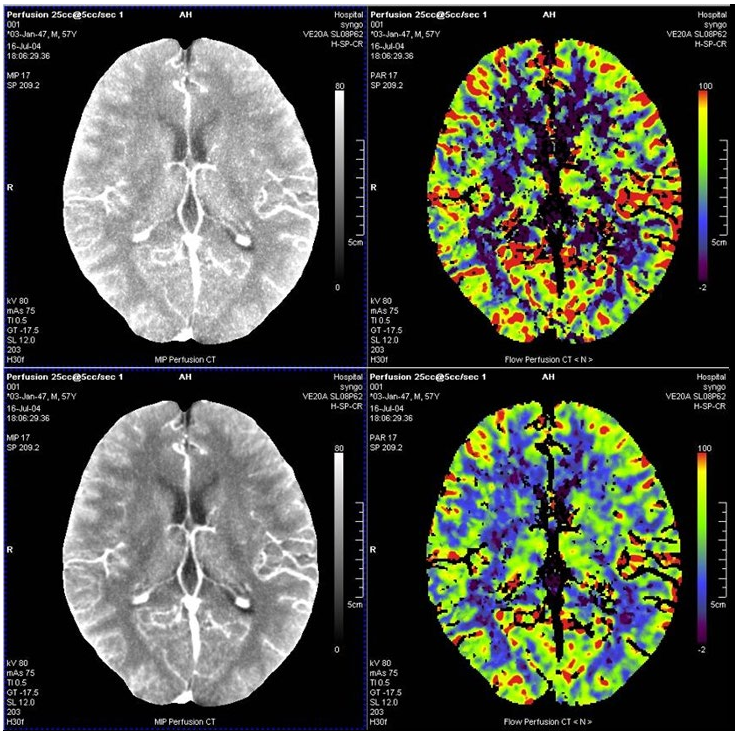

Figure 6: An example of how the 4D noise reduction algorithm improves the quality of the MIP (left column) and CBF (right column) images. The CBF image with the 4D noise reduction (bottom row) has fewer areas where the model fails due to insufficient signal-to-noise ratio, compared to the image without 4D noise reduction (top row).

With whole-brain coverage, the full extent of the disease can be evaluated and perfusion parameters can be visualized in 3D with axial, coronal and sagittal views. Moreover, using the appropriate configurable threshold values for different perfusion parameters (e.g., CBV and CBF), both the infarct core and penumbra regions can be identified and color coded to facilitate the analysis of the core/penumbra mismatch (Figure 7). Compared to the qualitative assessment frequently used, this approach is more objective for the determination of core/penumbra mismatch. It should be noted, however, that the actual thresholds for the core and penumbra must be defined by the user according to their respective institution guidelines. Studies have shown that there is a large overlap of perfusion values in the infarcted and surviving areas.

Perfusion analysis by *syngo*.CT Neuro Perfusion (VB10 or higher on CT scanners, or VB20 or higher on *syngo*.via) can be performed in a fully automated fashion using the Auto Stroke feature.

The optimal threshold maximally predicts the final infarct with the least amount of over or under estimation. Some suggestions for model dependent thresholds can be found in Abels et al.[18] If desired, the core and penumbra thresholds can be configured to match the settings employed in the DAWN and DEFUSE 3 trials[2,3].

Auto Stroke, in combination with Siemens Healthineers Recon&GO or Rapid Results technology can auto-archive the automatically generated results (e.g., perfusion maps, core and penumbra volumes, etc.) to PACS without user interaction.

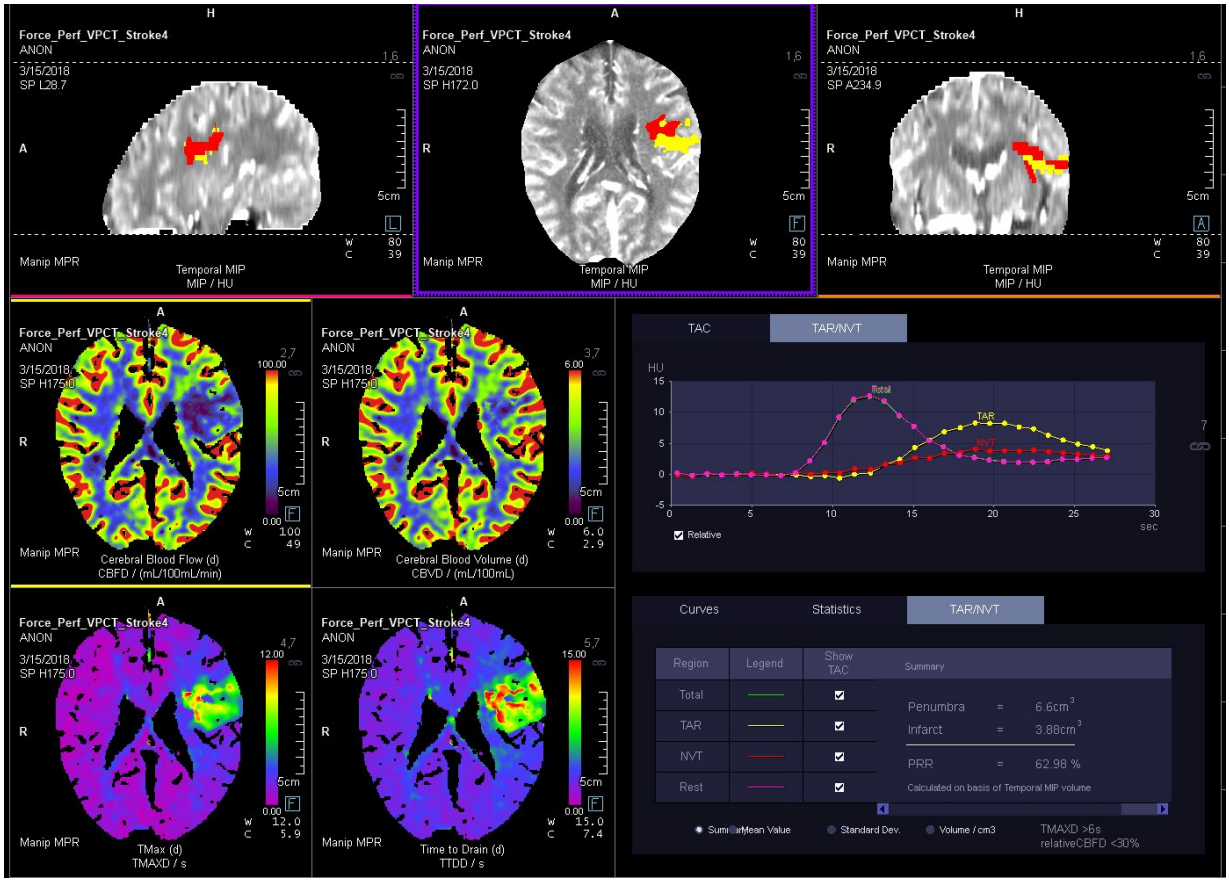

Figure 7: With the user defined perfusion parameters and threshold values, a 3D evaluation of brain tissue for the mismatch between the infarct core (red) and the penumbra (yellow) can be performed demonstrating the full extent of ischemic damage. Figure shows the results for the case presented in Figure 3.

Perfusion analysis with *syngo*.CT Neuro Perfusion (VB10 or higher on CT scanners, or VB20 or higher on *syngo*.via) can be performed in a fully automated fashion using the Auto Stroke feature. Auto stroke performs the Motion Correction, Segmentation, and Vessel Definition steps automatically with no user interactions. The results can then be reviewed by scrolling through the data before confirming the analysis (Figure 8). Auto Stroke, in combination with Siemens Healthineers Recon&GO or Rapid Results technology can auto-archive the automatically generated results (e.g., perfusion maps, core and penumbra volumes, etc.) to PACS without user interaction. Customized parameter settings and penumbra analysis parameters must be predefined based on the user preferences within *syngo*.CT Neuro Perfusion software configuration. Auto Stroke and Recon&GO or Rapid Results have made post-processing neuro perfusion data a seamless and user-friendly workflow 24 hours a day. It is important to note though, in cases with suboptimal or poor-quality perfusion data acquisition (e.g., severe patient motion, inadequate contrast enhancement, etc.), fully automated processing may fail and produce inaccurate perfusion maps. Therefore, Auto Stroke results should be checked for quality assurance and the data re-processed if necessary, using the manual workflow option. (Please refer to *syngo*.CT Neuro Perfusion manual).

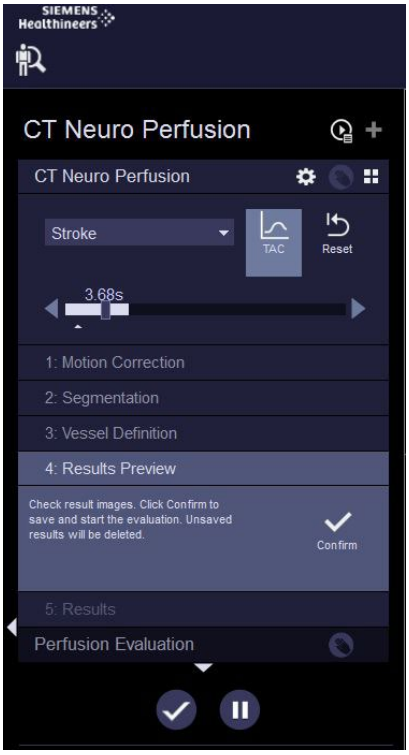

Figure 8: Auto Stroke performs the Motion Correction, Segmentation, and Vessel Definition steps automatically with no user interactions. Before confirming, the results can be reviewed by scrolling through the dataset.

Recommendation for injection protocol:
Patient Motion Check the shape of the AIF. Patient motion can be inferred from jumps in the AIF or the reference vessel venous output function (VOF). Patient motion is also indicated by unusually thick bones in the tMIP as well as blurry vessels. Violet areas close to the skull in the vessel masks are also indicative of patient motion.
Insufficient cardiac output Check the position of the AIF. Insufficient cardiac output is reflected in a delayed AIF peak.
Delayed contrast bolus Check the AIF and specifically the extent of the downslope of the curve that has been obtained. If the downslope is not captured, the MS model would be a better alternative to the default DC model
Injection duration lower than 8 seconds.
A contrast medium volume not too small, to ensure detectable enhancement changes.
Saline flush at the same flow rate.
Short delay between injection and scan (~ 4 seconds), unless using test bolus to determine delay.
Measures to salvage a CTP scan in case of failed automatic evaluation:
Choose a different registration base image or delete a time point if it does not align with the other volumes. Note that volumes close to the bolus peak are critical, and if these are deleted, results might be unreliable (due to an incorrect approximation of the AIF shape).
Place the VOF manually if the auto detection fails.
Place the AIF manually if the auto detection fails.

Conclusion

In recent years we have seen a significant evolution in the management and treatment for ischemic stroke (Figure 9). Advanced neuroimaging techniques like CTP are invaluable tools in evaluating the extent of the stroke and making informed decisions regarding treatment. Siemens Healthineers' dynamic spiral acquisition techniques (A4DS and F4DS) with 4D noise reduction algorithm allow whole brain perfusion imaging with near isotropic resolution. Robust motion correction and the availability of two different delay insensitive models for perfusion analysis offer diagnostic results even in suboptimal conditions. The *syngo*.CT Neuro perfusion Auto Stroke and Recon&GO or Rapid Results technology enable a streamlined workflow for processing and auto archiving the perfusion results to PACS seamlessly.

Time is brain – Optimal stroke care relies on quick imaging, diagnosis and treatment with interactions across the healthcare continuum. The Siemens Healthineers' CT imaging solutions allow for a timely and accurate response to ischemic stroke and have the potential to help reduce the door to needle time, save brain tissue and improve stroke outcomes.

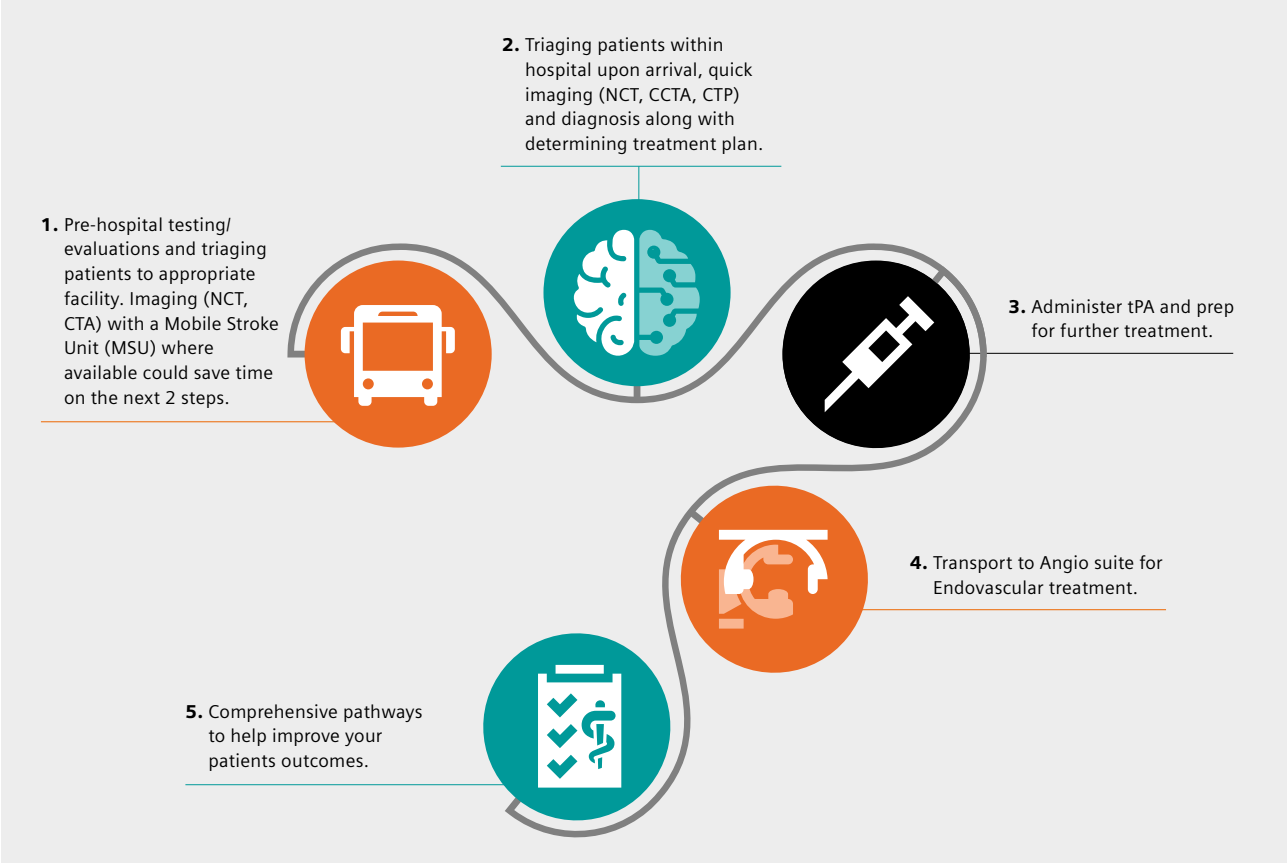

Figure 9: Example Stroke Pathway for management and treatment of ischemic stroke.

Appendix

SOMATOM go.All	↗ siemens-healthineers.us/somatom-go-all
Acquisition	
Scan mode	Flex 4D Spiral
Scan length	8.5 cm
Scan time	46.19 s
Tube voltage	70 kV
Effective mAs	133 mAs
Rotation time	0.33 s
Pitch	1.0
Slice collimation	32 x 0.7
Reconstruction	
Slice thickness/increment	5 mm/3.4 mm
Reconstruction kernel	Hr36
Dose	
$CTDI_{vol}$	161 mGy
DLP	1768 mGy*cm

SOMATOM go.Top	↗ siemens-healthineers.us/somatom-go-top
Acquisition	
Scan mode	Flex 4D Spiral
Scan length	8.5 cm
Scan time	46.32 s
Tube voltage	70 kV
Effective mAs	132 mAs
Rotation time	0.33 s
Pitch	0.5
Slice collimation	64 x 0.6
Reconstruction	
Slice thickness/increment	5 mm/3 mm
Reconstruction kernel	Hr36
Dose	
$CTDI_{vol}$	125 mGy
DLP	1448 mGy*cm

Appendix (continued)

SOMATOM X.cite	↗ siemens-healthineers.us/somatom-xcite
Acquisition	
Scan mode	Flex 4D spiral
Scan length	10 cm
Scan time	46.94 s
Tube voltage	70 kV
Effective mAs	149 mAs
Rotation time	0.3 s
Pitch	0.5
Slice collimation	64 x 0.6
Reconstruction	
Slice thickness/increment	5 mm/3 mm
Reconstruction kernel	Hr36
Dose	
$CTDI_{vol}$	156 mGy
DLP	1746 mGy*cm

SOMATOM X.ceed	↗ siemens-healthineers.us/somatom-xceed
Acquisition	
Scan mode	Flex 4D spiral
Scan length	11 cm
Scan time	46.62 s
Tube voltage	70 kV
Effective mAs	149 mAs
Rotation time	0.25 s
Pitch	0.5
Slice collimation	64 x 0.6
Reconstruction	
Slice thickness/increment	5 mm/3 mm
Reconstruction kernel	Hr36
Dose	
$CTDI_{vol}$	168 mGy
DLP	2086 mGy.cm

Appendix (continued)

SOMATOM Pro.Pulse	↗ siemens-healthineers.us/somatom-propulse
Acquisition	
Scan mode	Flex 4D Spiral
Scan length	8.5 cm
Scan time	46.32 s
Tube voltage	70 kV
Effective mAs	119 mAs
Rotation time	0.33 s
Pitch	0.5
Slice collimation	64 X 0.6
Reconstruction	
Slice thickness/increment	5 mm / 3 mm
Reconstruction kernel	Hr36
Dose	
$CTDI_{vol}$	123 mGy
DLP	1432 mGy*cm

SOMATOM Drive	↗ siemens-healthineers.us/somatom-drive
Acquisition	
Scan mode	Adaptive 4D Spiral
Scan length	10 cm
Scan time	46.35 s
Tube voltage	70 kV
Effective mAs	200 mAs
Rotation time	0.285 s
Pitch	0.5
Slice collimation	32 x 1.2
Reconstruction	
Slice thickness/increment	5 mm/3 mm or 1.5 mm/1 mm
Reconstruction kernel	Hr35
Dose	
$CTDI_{vol}$	139 mGy
DLP	1636.05 mGy*cm

Appendix (continued)

SOMATOM Force	↗ siemens-healthineers.us/somatom-force
Acquisition	
Scan mode	Adaptive 4D Spiral
Scan length	11.5 cm
Scan time	45.45 s
Tube voltage	70 kV
Effective mAs	200 mAs
Rotation time	0.25 s
Pitch	0.5
Slice collimation	48 x 1.2
Reconstruction	
Slice thickness/increment	5 mm/3 mm or 1.5 mm/1 mm
Reconstruction kernel	Hr36
Dose	
$CTDI_{vol}$	147.7 mGy
DLP	2183.19 mGy*cm

NAEOTOM Alpha/NAEOTOM Alpha.Peak	↗ siemens-healthineers.us/naeotom-alpha-peak
Acquisition	
Scan mode	Flex 4D Spiral
Scan length	12.5 cm
Scan time	46.49 s
Tube voltage	70 kV
Effective mAs	167 mAs
Rotation time	0.25 s
Pitch	0.5
Slice collimation	144 X 0.4
Reconstruction	
Slice thickness/increment	5 mm / 3 mm
Reconstruction kernel	Hr36
Dose	
$CTDI_{vol}$	184 mGy
DLP	2631 mGy*cm

Appendix (continued)

NAEOTOM Alpha.Pro	↗ siemens-healthineers.us/naeotom-alpha-pro
Acquisition	
Scan mode	Flex 4D Spiral
Scan length	11.5 cm
Scan time	46.62
Tube voltage	70 kV
Effective mAs	167 mAs
Rotation time	0.25 s
Pitch	0.5
Slice collimation	96 x 0.4
Reconstruction	
Slice thickness/increment	5 mm/3 mm
Reconstruction kernel	Hr36
Dose	
$CTDI_{vol}$	177 mGy
DLP	2078 mGy*cm

NAEOTOM Alpha.Prime	↗ siemens-healthineers.com/naeotom-alpha-prime
Acquisition	
Scan mode	Flex 4D Spiral
Scan length	12.5 cm
Scan time	46.49 s
Tube voltage	70 kV
Effective mAs	167 mAs
Rotation time	0.25 s
Pitch	0.5
Slice collimation	144 X 0.4
Reconstruction	
Slice thickness/increment	5 mm / 3 mm
Reconstruction kernel	Hr36
Dose	
$CTDI_{vol}$	184 mGy
DLP	2631 mGy*cm

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Siemens Healthineers Headquarters
Siemens Healthineers AG
Siemensstr. 3
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siemens-healthineers.com

USA
Siemens Medical Solutions USA, Inc.
Healthcare
40 Liberty Boulevard
Malvern, PA 19355-9998, USA
siemens-healthineers.us

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