

Neuro Volume Perfusion CT

Whole-Brain Coverage with Improved Perfusion Analysis

White Paper

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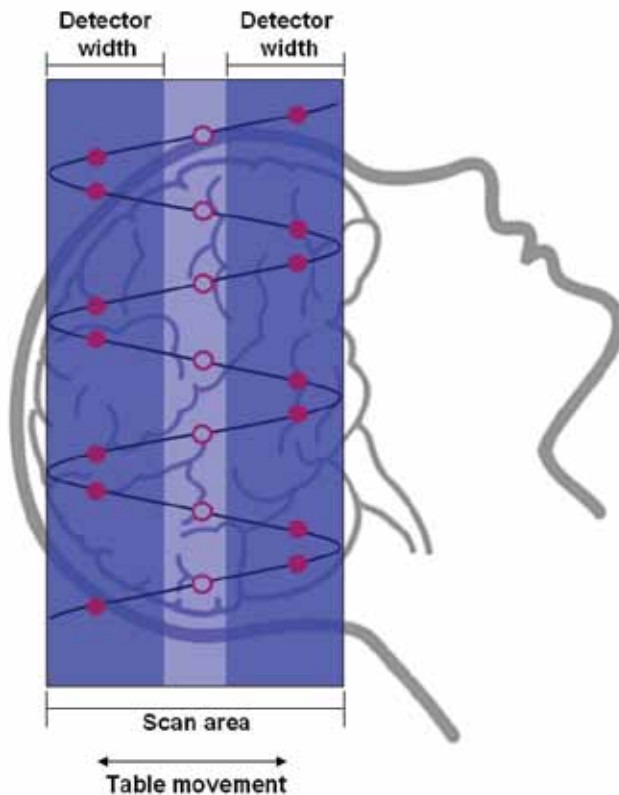
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Brain perfusion CT whose principles were established more than 30 years ago has now become a routine clinical application in many hospitals. Although brain perfusion CT is mostly used for evaluation of acute ischemic stroke, it is also applied for evaluation of brain tumors and other cerebrovascular disorders that affect blood supply to brain tissue (e.g., vasospasm after subarachnoid hemorrhage, severe head trauma, Moyamoya disease, etc.). In stroke patients, perfusion CT provides valuable clinical information by identifying the regions of irreversibly damaged tissue (infarct core) and tissue at risk (penumbra), which can be salvaged if the treatment results in a proper recanalization of the blocked vessel. A recent study by Lin et al¹ has shown that perfusion CT is significantly more sensitive and accurate compared to unenhanced CT in the detection of acute brain ischemia.

Until recently, a significant limitation of perfusion CT was insufficient coverage, which was restricted to the detector width (2–4 cm). This limitation did not allow evaluation of the entire brain volume affected and was one of the reasons why many neuro practices referred their stroke patients for diffusion and perfusion MRI rather than perfusion CT. To overcome this restriction, several vendors developed different approaches to extend the scan range to 8–16 cm. A so-called “toggling table” technique moves the table back and forth between two adjacent positions doubling the coverage (e.g., from 4 to 8 cm).

At each position, a conventional axial perfusion CT acquisition is performed allowing temporal sampling rates of 3–4 s. A different approach to increase the coverage is to use extra wide detectors. However, systems with very wide detectors (16 cm) suffer from considerably more scatter radiation (about 20%), which reduces low contrast detectability and makes them less dose efficient. 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 5 s in later phases. Unfortunately, these protocols might not work for every patient in clinical settings. In the 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. A reliable delay correction on such data (see below) is also potentially impaired. In addition, these sampling schemes have never been validated against traditional equidistant sampling.

Figure 1



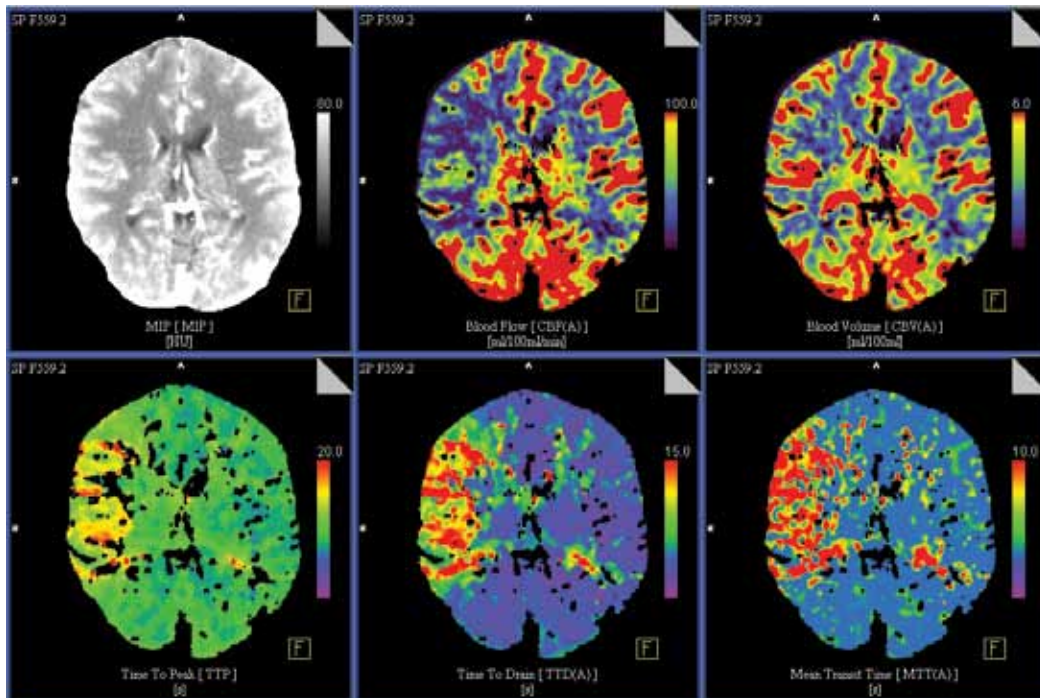
The Adaptive 4D Spiral mode allows time-resolved scanning of areas larger than the detector width by continuous periodic table motion between two end positions. The temporal sampling of the scan range is equidistant in the central part (open circles) and non-equidistant in the peripheral regions (filled circles).

The Siemens approach to extend perfusion coverage is based on a periodic spiral technique with variable pitch. In the so-called adaptive 4D spiral mode, the table continuously performs a smooth (but relatively fast) periodic motion between two end positions (Figure 1). Thus, this approach avoids both the abrupt motion associated with the “toggling table” technique and dose inefficiency of wide detectors but still has sufficient temporal sampling to analyze subtle changes of regional cerebral mean transit time (MTT). The brain volume perfusion CT (VPCT) with the Adaptive 4D Spiral mode is available on all scanners of the SOMATOM® Definition family. Sampling rates from 1 to 1.5 s with z-coverage from about 7 to 15 cm are available for image reconstruction at every z-position for the 128-slice systems (Definition AS+ and Definition Flash) allowing whole-brain coverage. However, VPCT is available not only for these high-end scanners but also for more affordable systems such as the Definition AS 20/40/64. Even a small community hospital that has one of these scanners can now extend perfusion coverage for its stroke patients up to 7 cm.

Since wider coverage is associated with a higher radiation dose and can result in direct irradiation of the eye lenses, always using the maximum available coverage (e.g., 15 cm) is not necessarily the best solution. Instead of using a “one-size-fits-all” approach, the optimal coverage should be selected based on the clinical needs of an individual patient, with the maximum coverage being applied only when justified². This approach helps avoid unnecessary radiation and, hence, better complies with the ALARA (As Low As Reasonably Achievable) principle. For example, the scan range of ~10 cm is usually sufficient for stroke imaging as it mostly covers the whole supratentorial brain and avoids direct irradiation of the eye lenses.

All VPCT protocols on all Definition scanners are set to be performed at 80 kVp, because this setting has 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 never be raised to higher values. This might lead to unacceptably high dose values.

Figure 2



VPCT Neuro multi-parameter display showing axial views of Maximum Intensity Projection (MIP), Cerebral Blood Flow (CBF), Cerebral Blood Volume (CBV), Time To Peak (TTP), Time To Drain (TTD, Siemens specific parameter) and Mean Transit Time (MTT).

Using the default settings, a typical VPCT scan of the whole supratentorial brain on the Definition AS+ (80 kVp, 200 mAs, 45 s) results in a $CTDI_{vol}$ of 220 mGy and an effective dose of about 5 mSv. This is an order of magnitude below any potential skin reaction, and the stochastic radiation risk corresponds to about 2 years of natural background radiation.

Volume coverage provided by the new Adaptive 4D Spiral perfusion mode helps achieve a 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, a proper motion correction is crucial for accurate perfusion analysis. This is especially true for deconvolution-based models, which are very sensitive to the accurate shape of the arterial input function (AIF). Siemens incorporated a deconvolution-based model³ into the new perfusion analysis software (VPCT Neuro) that can display all relevant perfusion parameters including MTT and time to drain (TTD: mean time when tracer exits the voxel, Siemens' specific parameter) in one view (Figure 2). A different model based on the maximum slope approach is also included in the software

package. Although this model lacks the MTT map, it provides diagnostic perfusion results even in the case of severe patient motion, which might occur despite the recommended stable patient head positioning.

The sensitivity of CT perfusion algorithms to delayed contrast arrival has recently become a major point of discussion in the Perfusion CT community. A vendor cross comparison study conducted by Kudo et al. showed⁴ that perfusion maps derived from delay-sensitive algorithms overestimate the final infarct size. This study also showed the delay insensitivity of the maximum slope model, which has been commercially available in the Siemens products since 1998. This fact was favorably reviewed in a corresponding editorial by Konstas and Lev⁵. The deconvolution model used by VPCT Neuro is delay insensitive by its design because it includes the local bolus arrival time as one of the fitting parameters. A recent study by Abels et al³ 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. In the end, the availability of two models for perfusion analysis

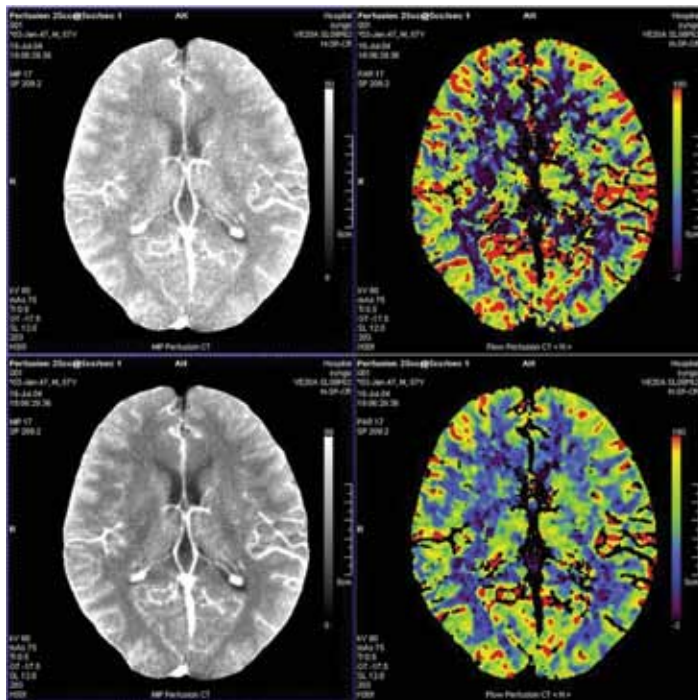
adds more flexibility to the VPCT Neuro and results in a robust performance for most patients, even in suboptimal conditions.

Another important feature of the VPCT Neuro is the Siemens 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 mostly 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 3) or reduce the dose 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.

The periodic table movement results in an equidistant temporal sampling in the central slice of the scan range and non-equidistant temporal sampling in the peripheral slices (Figure 1). Since conventional brain perfusion uses equidistant sampling with a high rate of typically 1 s, it has been questioned if the Adaptive 4D Spiral approach can allow an accurate calculation of the quantitative perfusion parameters. However, the non-uniformity of the Adaptive 4D Spiral sampling scheme is explicitly taken into account in the dedicated algorithms used by the VPCT Neuro software. The accurate shape of the AIF can be obtained from the central slice, which has the equidistant sampling of 1.5 s, even in the case of a substantial contrast delay. On the other hand, time-attenuation curves of brain tissue do not have a sharp peak like the AIF and, hence, their shape in the peripheral slices can be correctly determined even with

Figure 3



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.

non-equidistant sampling. The accuracy of the Adaptive 4D Spiral volume perfusion technique has been recently validated in the study by Haberland et al⁶. The results of this work have shown that the performance of the Adaptive 4D Spiral mode is equivalent to the performance of standard dynamic modes with equidistant sampling.

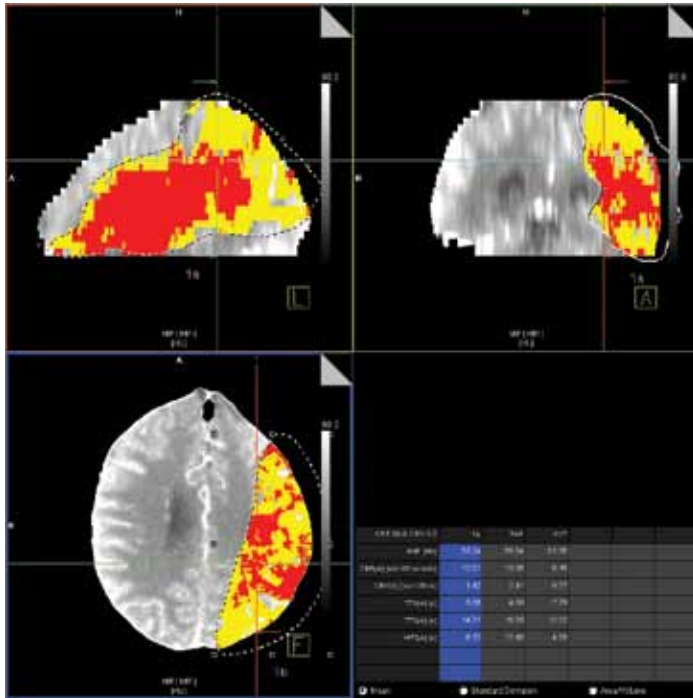
With whole-brain coverage, the full extent of a disease can be evaluated and each perfusion parameter can be visualized in 3D with axial, coronal, and sagittal views. Moreover, by using the appropriate threshold values for cerebral blood volume (CBV) and cerebral blood flow (CBF), both the infarct core and penumbra regions can be identified and color coded to facilitate the analysis of the core/penumbra mismatch. In particular, the volume of interest tool allows a 3D evaluation of ischemic tissue demonstrating the entire brain region affected by stroke (Figure 4). Compared to the typical eyeball assessment frequently used, this approach is more objective for the determination of mismatch between the CBF and CBV maps. It should be noted, however, that the actual thresholds for CBF and CBV must be defined by the user and depend on the level of risk the user wishes to define. All studies have shown that there is a large overlap of perfusion

values in the infarcted and surviving areas. Using lower threshold values might underestimate the risk, while using higher values might overestimate it. Suggestions for model-dependent thresholds can be found in Abels et al³.

Clinical Example

In the recent clinical study by Morhard et al⁷, 72 patients with suspected stroke were scanned using the Adaptive 4D Spiral volume perfusion technique with 9.6 cm coverage (Definition AS+). From the acquired volume data, a sub-volume data set with 2-cm coverage at the level of the basal ganglia was reconstructed to simulate conventional perfusion CT data. The performance of the VPCT mode was compared to the performance of the simulated standard perfusion CT mode. Out of a total of 138 brain segments with pathologic perfusion findings, only 41 lesions (30%) were detected at the level of the basal ganglia. Overall, the extended scan coverage of the VPCT mode resulted in a different final diagnosis in 25 (35%) of 72 patients. These changes in diagnosis occurred when only the infarcted areas were visible at the level of the basal ganglia, while the additional areas of penumbra

Figure 4



Using the volume of interest tool and the appropriate CBV and CBF 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.

were observed at different levels. A different (less accurate) final diagnosis based on the simulated conventional Perfusion CT data could potentially impact the therapeutic decision and result in a less effective or more dangerous treatment.

Important Points

- The Adaptive 4D Spiral dynamic perfusion mode allows whole-brain coverage and helps avoid both the abrupt motion associated with the “toggling table” technique and dose inefficiency of wide detectors.
- Volume coverage improves motion correction and allows more accurate perfusion analysis especially with deconvolution-based models.
- The VPCT Neuro software includes two different delay-insensitive models for perfusion analysis (deconvolution and maximum slope) producing reliable results for most patients, even in suboptimal conditions (e.g., severe motion).
- The dedicated algorithms implemented in the VPCT package help assure that non-equidistant temporal sampling at peripheral slices does NOT affect the overall performance of the Adaptive 4D Spiral perfusion mode.
- The 4D Noise Reduction algorithm integrated into the VPCT Neuro can be used either to help improve the quality or resolution of the perfusion maps (e.g., 5-mm slices as standard) or aid in the reduction of radiation dose associated with the perfusion exam.
- The skin dose and the dose per cm coverage of the 10-cm acute stroke mode is half of the corresponding values of standard dynamic modes.
- The extended scan coverage of the Adaptive 4D Spiral modes can result in a different (more accurate compared to conventional Perfusion CT) final diagnosis leading to an improved treatment.

Conclusion

The Adaptive 4D Spiral technique combined with the VPCT Neuro software extends the scan coverage beyond the detector width and allows perfusion imaging of the whole brain overcoming a major limitation of perfusion CT. This novel approach delivers improved results even in suboptimal conditions due to improved motion correction and the availability of two different delay-insensitive models for perfusion analysis. The Siemens exclusive 4D Noise Reduction algorithm allows almost isotropic spatial resolution of 3D perfusion images. All these improvements make CT perfusion a better and more attractive diagnostic tool for neuro practices and stroke centers.

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