

CASE REPORT

# Three-dimensional perfused blood volume in hyperacute stroke using 64-section MSCT

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## Introduction

Early diagnosis of acute ischaemic stroke and the identification of irreversibly impaired brain tissue and reversibly impaired tissue ("tissue at risk") are important due to the time limits for thrombolytic treatment. The value of cerebral computed tomography perfusion (CTP) imaging, which provides haemodynamic information of ischaemic brain tissue, has been evaluated in clinical and experimental studies.<sup>1–3</sup> It has been shown that CTP could help select suitable candidates for thrombolysis. However, dynamic CTP is essentially a two-dimensional (2D) technique that is restricted to a relatively small volume. Ischaemia lying outside the imaging sections would be excluded and the extent of infarction could be underestimated.<sup>4,5</sup> Wider detectors and alternative imaging techniques, such as the Volume Shuttle, have recently been able to enlarge the coverage to up to 80 mm, which has a larger coverage scope from the basal ganglia up to the lateral ventricle,<sup>6</sup> but is still a 2D technique and cannot cover the whole brain. Volume Shuttle is often, but not always, adequate for CTP imaging in acute ischaemic patients, but requires a higher dose and sacrifices temporal resolution.

The newly developed three-dimensional (3D) NeuroPBV (Siemens, Forchheim, Germany) can overcome the coverage extent drawback using 40 or more sections. To obtain sufficient cerebral haemodynamic information, 3D perfused blood volume (PBV) can be applied based on CT angiography (CTA) and non-enhanced CT (NECT) images covering the whole brain without delivering an

extra dose, as these images are often routinely generated. In the present study, NeuroPBV was used to semi-automatically calculate colour-coded, 3D PBV images of whole brain; the CT perfusion findings in comparison with the PBV findings in a case of acute cerebral infarction are presented.

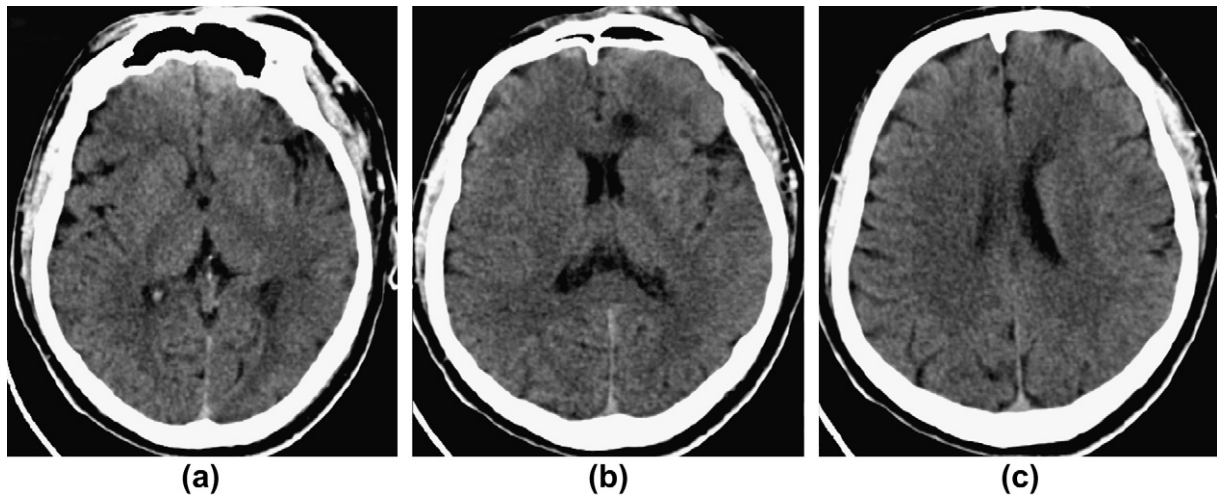
## Case report

A 47-year-old male presented to the emergency services of our hospital with complaints of loss of strength in the right side of his body and the inability to speak, which had begun 2 h earlier. Right hemiplegia was found in a neurological examination. Muscle strength was 0 out of 5 in the right arm and 1 out of 5 in the right leg based on the Medical Research Council (MRC) standards. The National Institutes of Health Stroke Scale (NIHSS) score on admission was 10. The decision was made to administer venous thrombolytic treatment (100 IU urokinase) as the patient was within the 3 h treatment window. The symptoms gradually improved after treatment; the muscle strength of the right limbs increasing to 3 out of 5.

Multimodal CT protocols, including NECT, CTP, and CTA, were performed immediately using 64-section MSCT (Somatom Sensation cardiac 64, Siemens, Erlangen, Germany). Informed consent was obtained from the relatives of the patient before the examination. NECT with spiral mode covering the base to vertex was performed using the following parameters: 120 kVp, 380 mAs, 32 × 0.6 mm collimation, 15.4 mm/rotation table feed, and 1 s rotation time. These images were reconstructed using a 5 mm section thickness and an increment of 5 mm. Early signs of ischaemic stroke were not observed on the NECT, except for an old infarction on the left frontal lobe (Fig. 1).

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**Figure 1** A 47-year-old man with right hemiplegia. No marked signs of acute infarction could be noted on the NECT images 3 h after the onset of acute symptoms.

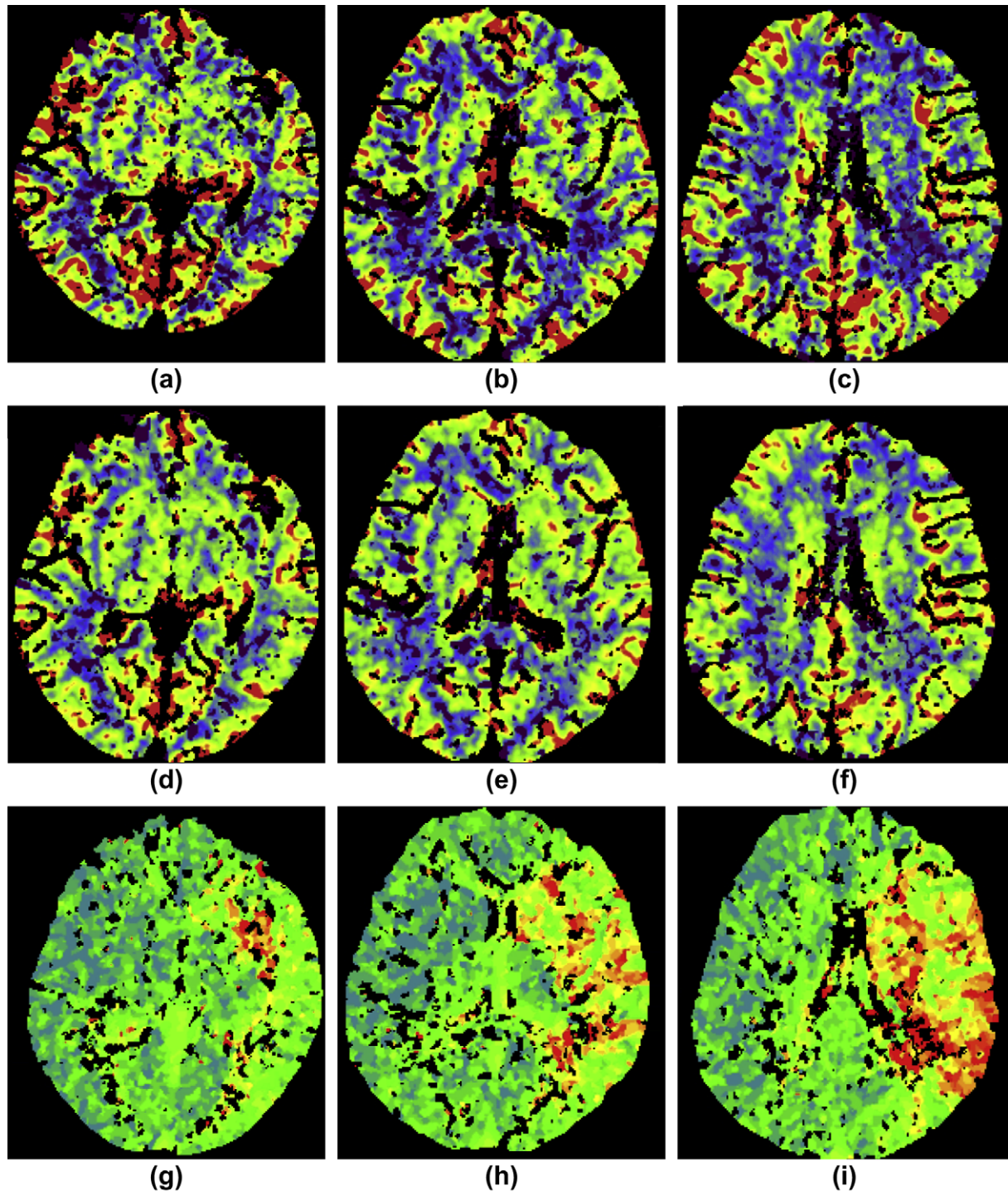
Following the NECT, CTP was performed with multi-section imaging on 80 kVp and 270 mAs. CTP was used to examine a 28.8 mm-thick section (three adjacent slices) covering the basal ganglia. To achieve a compact bolus, 40 ml non-ionic contrast material (370 mg I/ml iopromide; Ultravist, Schering, Berlin, Germany) was rapidly injected into an antecubital vein using Medrad CT power injector (Spectris, Medrad, Indianola, USA) at a flow rate of 8 ml/s. These images were post-processed and evaluated using CT perfusion software (Siemens, Forchheim, Germany). Cerebral blood flow (CBF), cerebral blood volume (CBV), and time to peak (TTP) images were obtained. CBF was slightly decreased in the left corona radiata. CBV was found to be normal. However, TTP showed a significant delay on the left hemisphere (Fig. 2).

CTA with spiral mode covering the vertebral body C5 to vertex was performed using the following parameters: 120 kVp, 100 mAs,  $32 \times 0.6$  mm collimation, 23 mm/rotation table feed, and 0.5 s rotation time. The start time of the scan was determined by the peak enhancement in the superior sagittal sinus, as indicated by the CTP examination. Reconstructed minimum intensity projection (MIP) images showed a distal occlusion of the left middle cerebral artery (Fig. 3). 3D PBV was processed based on 1 mm reconstructions of NECT and CTA data with NeuroPBV software. The software automatically registers NECT and CTA images; segments cerebral tissue, bones, vessels, and cerebral spinal fluid; coregisters the head position; and performs 3D corrections to the datasets if head movement occurred. The cerebral parenchyma is enhanced by subtracting the NECT data from the CTA data. A distinct

colour scale is added to the absolute parenchymal enhancement on a voxel-by-voxel basis. Colour maps were displayed in three orthogonal views (transverse, sagittal, and coronal). The integrated capability for 3D reformation allowed an easy assessment of the three-dimensional extent of the ischaemic lesions. 3D PBV showed a perfusion defect in the right corona radiata and semioval central. The central region of the perfusion defect was more remarkable than periphery areas (Fig. 4). After 1 week, a follow-up NECT of the patient showed the extent of infarction correlating with the findings on the 3D PBV. The brain tissue with progressing infarction was limited to the central region of the perfusion defect (Fig. 5).

## Discussion

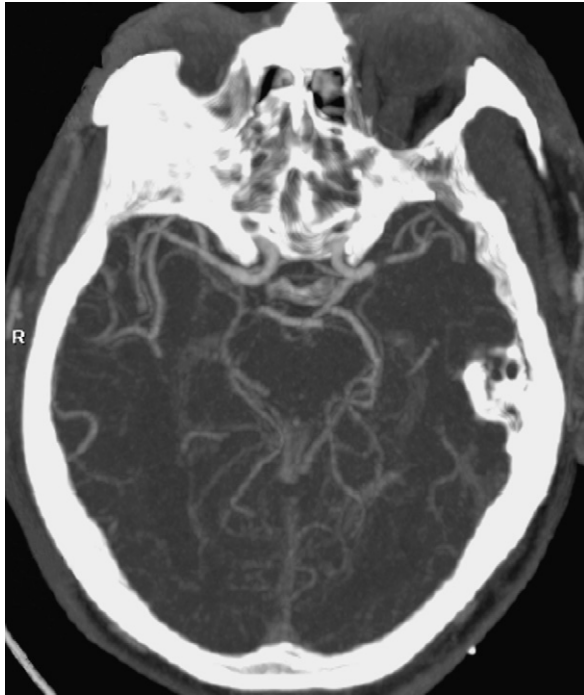
Worldwide, stroke is the second leading cause of death and the main cause of permanent disability.<sup>7</sup> Thrombolysis therapy could save reversibly damaged brain tissue (penumbra). Penumbra is defined as an area of reduced perfusion with loss of function and neurons that are still viable. Timely reperfusion of these tissues may prevent cell death and help re-establish normal function. Therefore, imaging methods could help indicate patients who would benefit from therapy at an earlier stage. The availability of optimized protocols using 64-section MSCT, has further increased the role of CT in making therapy decisions in patients with acute stroke. By combining NECT, CTP, and CTA, "multimodal" CT protocols enable a comprehensive diagnosis of emergency stroke patients in less than 15 min.<sup>8,9</sup>



**Figure 2** CBF (first row) was slightly decreased in the left corona radiata. CBV (second row) maps showed no significant abnormality. Time to peak (third row) maps showed a delay in the left hemisphere.

NECT examination is used for excluding bleeding and indicates early signs of ischaemic stroke. Sometimes the early signs of ischaemia can be observed using NECT. These signs include hyperdensity in the middle cerebral artery, hypoattenuation in the lentiform nucleus, oedema in the insular cortex (insular ribbon sign), disappearance

of grey–white matter delineation, and obliteration of the sulci due to oedema. However, these appearances are not usually observed within 2–3 h from symptom onset. The NECT images of the case reported in the present study were not found to be abnormal within 3 h after symptom onset. Therefore, there is a requirement for more reliable



**Figure 3** CTA images indicated a distal MCA occlusion on the left middle cerebral artery.

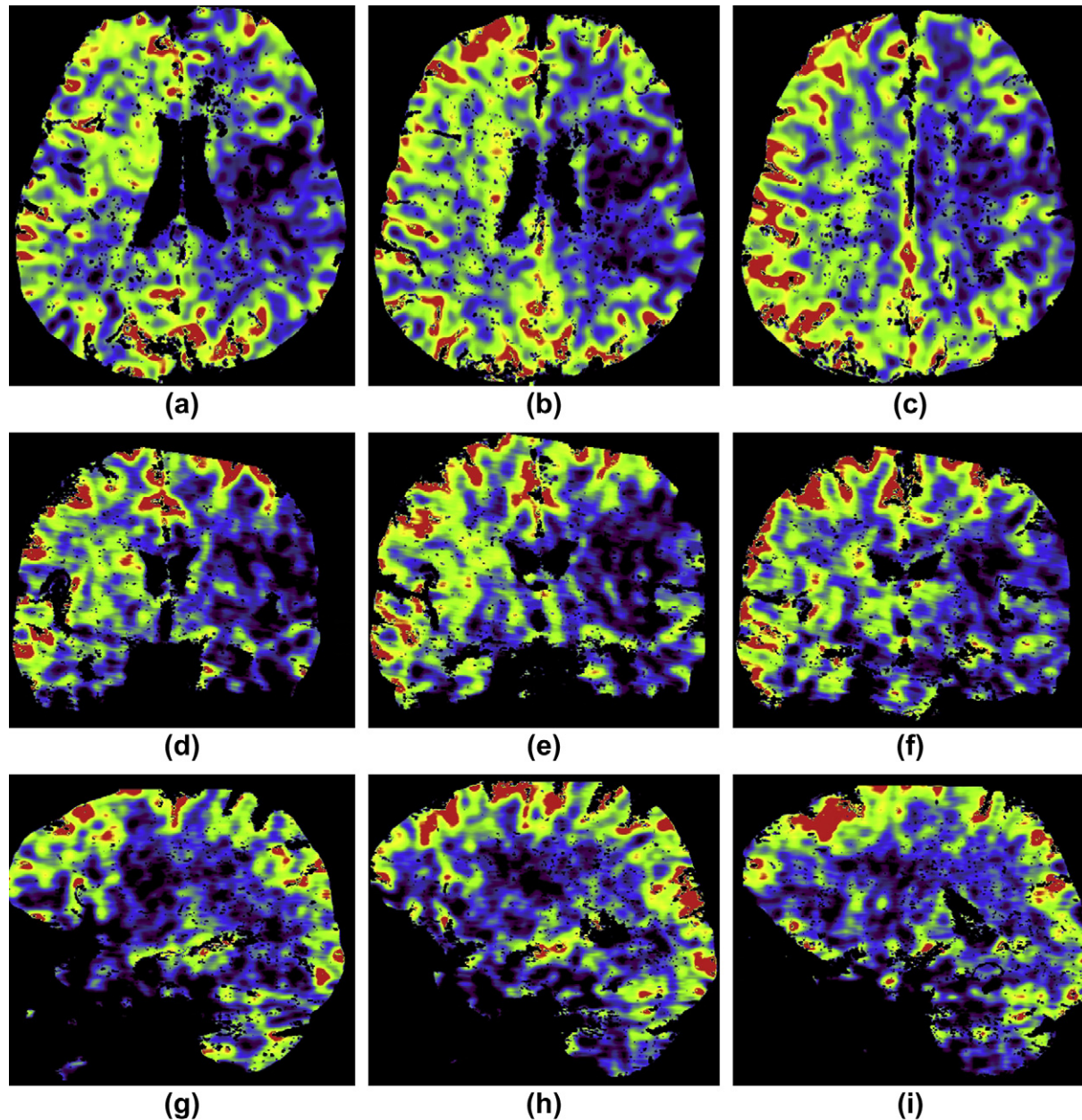
and robust diagnostic imaging techniques to elucidate ischaemic perfusion deficits at much earlier stages. In 1981, Berninger et al.<sup>10</sup> first reported the visualization of cerebral ischaemia from dynamic CT images using functional image formation. CTP was applied to measure tissue perfusion on the basis of the indicator-dilution method, using the bolus tracking principle, which enables the determination of several parameters of tissue perfusion, including CBF, CBV, and TTP maps.

Some clinical and experimental studies have showed that PCT can predict cerebral infarction with a high sensitivity and specificity. However, as mentioned by most authors, a major limitation of the PCT technique is that only single or dual sections with the chosen section width could be measured. Although major ischaemic events will be visualized within this area, ischaemia lying outside the area, such as cerebellar infarcts, would not be detected. Similarly, the extent of infarction may be underestimated. Even with the advent of 64-section MSCT machines, only a relatively small volume (28.8 mm) is covered. Because sufficient information about the perfusion of the entire brain is not available, it is likely that haemodynamic alterations distant from the measurement area will be missed. The treatment strategy of acute stroke would not differ when vascular occlusion and threatened tissue are evident without

haemorrhage, even though a portion of the brain is not included in the CTP area. However, whole-brain methods are desirable, particularly for those patients whose lesions have not been found on CTP. 3D PBV has the potential to demonstrate small areas of ischaemia and provide high detection rates in acute ischaemic stroke patients. 3D PBV is a fast and potentially cost-effective method for assessing whole-brain haemodynamics.<sup>11</sup>

Several studies have shown that axial CTA images could be used in acute stroke to extract perfused blood volume information, and predict infarct volume and clinical outcome.<sup>11–13</sup> Schramm et al.<sup>14</sup> have shown a close correlation of the ischaemic volume on CTA-source imaging with initial volume on diffusion-weighted imaging (DWI). Most routine applications of this concept are based on a careful visual examination of CTA source images. CTA shows the type and location of vascular occlusion. In this study, we used the software of NeuroPBV based on the work of Hamberg et al.<sup>11</sup> It performs semiautomatic calculations on PBV images and displays them with distinct 3D colour-coded images on a standard workstation. 3D PBV is based on the CTA and the NECT images that cover the whole brain. The technique requires no additional examinations or contrast medium injections and can be performed in a short period of time. Total processing time is about 3–5 min. Therefore, timely, optimized stroke protocols can easily be performed. 3D PBV has the potential to provide volumetric calculation of the threatened tissue and avoid omitting lesions. 3D PBV is produced by subtracting NECT data from the CTA data. The subtraction technique could offer an effective, rapid, and semiautomatic (operator-independent) procedure with improved distinction between bones and vessels.<sup>15</sup> The advantage of CTA is that the type and location of the vascular occlusion can be verified, and thus, it is necessary part of the assessment of ischaemic stroke patients.

In the present case, CTP was performed on the basal ganglia, including the feeding areas of anterior, middle, and posterior cerebral arteries. Only the single CBF section showed a slight decrease in the left corona radiata. CBV maps showed no significant abnormality. TTP maps showed remarkable delay in the left hemisphere. However, 3D PBV on the whole brain showed the perfusion defect in the left corona radiata and semioval central. Because of its coverage limitation, the perfusion defect was underestimated using CTP when compared with 3D PBV, which showed extensively reduced regional perfusion. The perfusion defect of the central region was



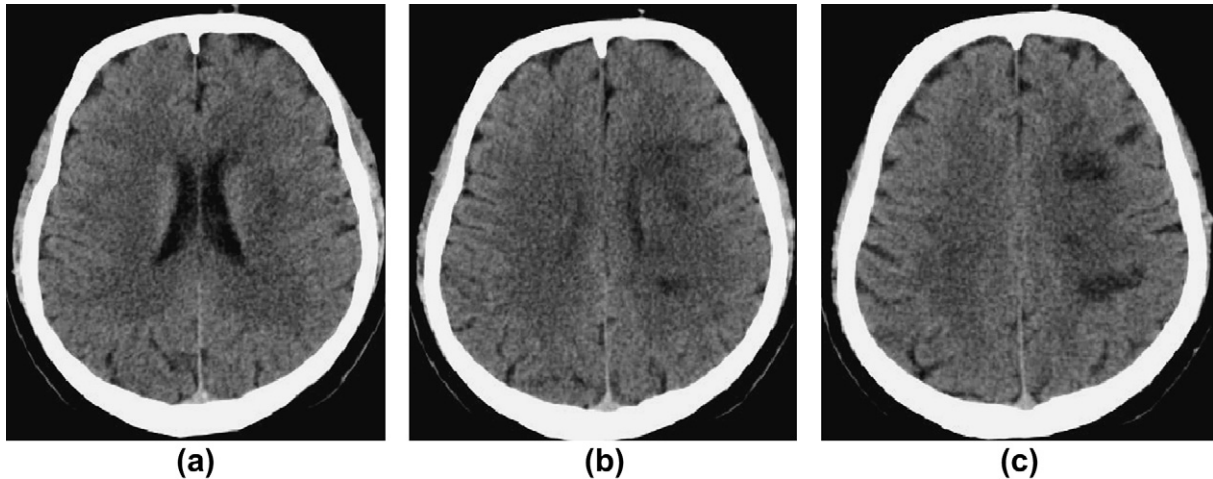
**Figure 4** 3D PBV showed the extent of the perfusion defect in the left corona radiata and semioval central in three-dimensions (first row, transverse images; middle row, sagittal images; third row, coronal images). The central region of the perfusion defect is more remarkable than the periphery areas.

more remarkable than the defects in peripheral regions. After 1 week, a follow-up NECT on this patient showed the extent of the infarction corresponding well with 3D PBV. The brain tissue with progressing infarct was limited to the central region of the perfusion defect.

Several limitations of PBV have to be addressed. So far NeuroPBV software only can provide qualitative information. It is not able to differentiate precisely between infarction core and penumbra in acute ischaemic patients. However, CTP can reliably identify the tissue at risk. Therefore, PBV

cannot replace CTP, but it can be integrated in a multimodal stroke CT protocol to enable an optimized positioning of the PCT sections. The combination of methods might increase the detection rates of ischaemia and allow better therapy strategies in the future. In addition, the definition of the final extent of the infarction using PBV is still uncertain. Further clinical studies are required to investigate the value of 3D PBV with large patient groups.

In conclusion, 3D PBV has the potential to assess the full extent of an ischaemic stroke at an early



**Figure 5** After 1 week, a follow-up NECT showed the extent of infarction correlating with 3D PBV. The brain tissue with progressing infarction was located in the central region of the perfusion defect.

stage, whereas PCT is limited to a relatively small volume. As this report indicates, the 3D PBV technique requires no additional examination or contrast medium injection, and can be performed in a short period of time. It can provide volume perfusion information that avoids omitting parts of the ischaemic lesion.

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