Original article

Perfusion computed tomography relative threshold values in definition of acute stroke lesions

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Abstract

Background: Perfusion computed tomography (CT) is a relatively new technique that allows fast evaluation of cerebral hemodynamics by providing perfusion maps and gives confirmation of perfusion deficits in ischemic areas. Some controversies exist regarding accuracy of quantitative detection of tissue viability: penumbra (tissue at risk) or core (necrosis).

Purpose: To define brain tissue viability grade on the basis of the perfusion CT parameters in acute stroke patients.

Material and Methods: A multimodal CT imaging protocol; unenhanced CT of the brain, CT angiography of head and neck blood vessels, followed by brain perfusion CT and 24 h follow-up brain CT was performed. Perfusion deficits were detected first visually, with subsequent manual quantitative and relative measurements in affected and contra-lateral hemisphere in 87 acute stroke patients.

Results: Visual perfusion deficit on perfusion CT images was found in 78 cases (38 women, 40 men; mean age, 30–84 years). Penumbra lesions ($n = 49$) and core lesions ($n = 42$) were detected by increased mean transit time (MTT) on perfusion CT maps in comparison to contra-lateral hemispheres. Cerebral blood volume (CBV) mean values in the penumbra group were increased in the penumbra group and decreased in the core group. Cerebral blood flow (CBF) values were decreased in penumbra and markedly decreased in core lesion.

Conclusion: Perfusion CT measurements are reliable in estimation of penumbra and core lesions in acute stroke patients, if relative threshold values are used. The most accurate parameter of hypoperfusion is increased MTT above 190%. Relative threshold values for irreversible lesion are CBF <30–40% and CBV <40% in comparison to contra-lateral hemisphere. Penumbra lesion is characterized by MTT increase and CBF decrease, while CBV shows variable values.

Keywords: Computed tomography, perfusion, stroke

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Perfusion computed tomography (CT) method is playing an increasing role in the initial evaluation of acute stroke, it allows qualitative and quantitative evaluation of cerebral hemodynamic that is shown in perfusion color maps: cerebral blood flow (CBF); cerebral blood volume (CBV); and mean transit time (MTT). The technique is based on the central volume principle (CBF = CBV/MTT), after complex deconvolution algorithms perfusion color maps are produced. This method gives visual confirmation of perfusion deficit in ischemic area: penumbra (tissue at risk) that surrounds core (necrosis). Despite controversies in accuracy of this technique, perfusion CT has been found to be useful for non-invasive diagnosis of cerebral ischemia and with more defined threshold values it may be used also as parameter in optimal treatment selection (1, 2).

The purpose of this study was to define brain tissue viability grade on the basis of the perfusion CT parameters in acute stroke patients and determine relative threshold values.

Material and Methods

As a prospective study a multimodal CT imaging protocol (unenhanced CT of the brain, CT angiography of head and neck blood vessels, followed by brain perfusion CT and 24 h follow-up brain CT) was performed in 87 patients (average age, 77 years; 54 women, 34 men) within 9 h (average, 3.5–4.5 h) after onset of acute ischemic stroke symptoms, admitted to the emergency department. Diagnostic imaging was performed using a 64-row multi-slice CT scanner during the period of January 2011 until July 2012 with standardized protocol and safe ionizing radiation exposure.

Patients with hemorrhagic stroke or ischemic areas seen on unenhanced CT and wake up strokes were not included in the study. CTA data were used to confirm stroke territory, vessel occlusion site and to evaluate extracranial blood vessel changes.

Acquired perfusion CT data (8 levels, 712 images for each person) were analyzed by semi-automated deconvolution postprocessing software. Perfusion deficits were detected first visually, using three perfusion color maps; mean transit time (MTT) in seconds, cerebral blood flow (CBF) as mL per 100 g brain tissue per min and cerebral blood volume (CBV) as mL per 100 g of brain tissue. Manual quantitative and relative measurements were performed in affected and contra-lateral hemisphere, drawing different regions of interest (ROI) and defining values for penumbra (potential reversible) and core (irreversible) lesions (Fig. 1), respectively; data were divided in two groups.

Technically impaired exams with motion artifacts ($n = 5$) and perfusion maps without visual perfusion lesion were excluded from further analysis ($n = 4$).

Results

Focal brain perfusion deficit on perfusion CT images was found in 78 cases (38 women, 40 men; mean age, 30–84 years). Penumbra lesions ($n = 49$) and core lesions ($n = 42$) corresponding to clinical symptoms were detected by increased MTT on perfusion CT map; penumbra area showed mean values 202.40% (113–345% ± 57.17) and core area showed 192.40% (41–320% ± 64.53) in comparison to contra-lateral hemisphere.

CBV mean values in the penumbra group were increased by 113.10% (45–276% ± 36.29) and in the core group decreased till 41.82 (3–107% ± 27.09). CBF values were decreased on average till 65.63% (31–137% ± 22) in penumbra lesions and markedly decreased till 25.94% (4–79% ± 17.35) in core lesions. Using the non-parametric T-test there was no significant difference in the MTT values between the two groups ($t = 0.78$; $P = 0.43$), but we detected statistically significant difference between groups in values of CBF ($t = 9.44$; $P = 0.0001$) and CBV ($t = 10.47$; $P = 0.0001$) (Table 1).

There was highly significant correlation between CBF and CBV decrease in core lesion ($r = 0.841$; $P < 0.01$) and decreased CBF ($r = 0.461$; $P < 0.01$) with variable CBV values in penumbra locations ($r = 0.240$; $P < 0.05$).

Discussion

Perfusion deficits seen on CT maps are related to brain autoregulation mechanisms. Any perfusion pressure decrease appears as increased MTT on perfusion CT maps (3). It is a visually easy detectable parameter, but non-specific for the definition of perfusion deficit grade as shown by the results of this study. There are authors that defined MTT value above 145% as optimal for ischemic lesion detection (4), although our study shows higher threshold value.

If CT angiography does not correspond to perfusion CT findings with increased MTT, transitory circulation changes or other stroke mimicking pathologies, e.g. neoplasm, venous thrombosis, or seizure-related hypoperfusion should be considered (2, 4). Therefore not all perfusion abnormalities seen on perfusion CT maps are specifically related to cerebrovascular disease. MTT increase may also be seen in proximal causes of delayed blood supply to the brain (2), such as extracranial vessel stenosis, occlusions that may cause delay or dispersion of the bolus of contrast material. This flow pattern should be assessed on CT angiography before interpretation of perfusion CT maps.

Table 1 CT perfusion relative threshold values in core and penumbra lesions

Parameter	rCBV	rCBF	rMTT
Penumbra (mean ± SD)	**113.10** ± 5.184 $n = 49$	**65.63** ± 3.143 $n = 49$	**202.40** ± 8.167 $n = 49$
Core (mean ± SD)	**41.82** ± 4.180 $n = 42$	**25.94** ± 2.677 $n = 42$	**192.40** ± 9.957 $n = 42$
***P* value**	<0.0001	<0.0001	0.4351
Confidence interval (CI)	57.71 to 84.81	31.33 to 48.06	−15.39 to 35.40

n, number of patients; r, relative meaning of value, e.g. rMTT is relative MTT

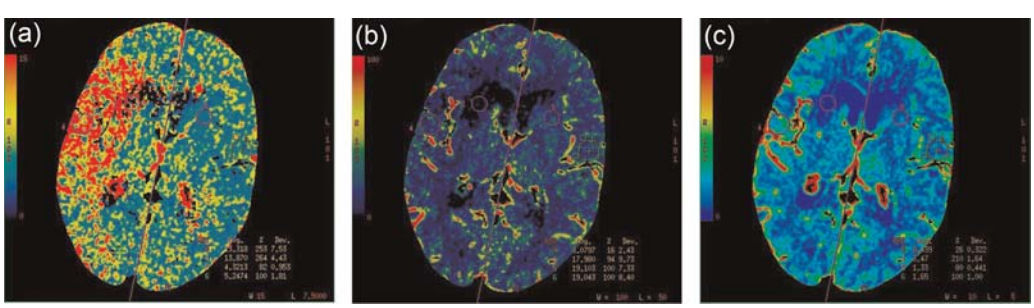

Fig. 1 A 62-year-old man, with left hemiparesis, 2 h after onset. (a) MTT map, (b) CBF map, (c) CBV map. All three perfusion CT maps show irreversible (core) lesion at the level of right basal ganglia, surrounded with penumbra lesion, detected by mismatch of CBV and CBF maps and quantitative mismatch with MTT map (relative MTT – 264%)

Although there are known absolute values for normal perfusion in gray and white matter (5), ischemic region that includes both substances, the relative values are more reliable and reproducible. Penumbra tissue maintains regional CBF by vasodilatation, to provide more oxygen to the area and results in normal or increased CBV level. Our results correlate to that CBV (cerebral blood volume) maps show the competency of autoregulation mechanisms and show different results in penumbra lesions. Core lesion is characterized by depletion of autoregulation mechanisms and CBV decrease.

Our results with rCBF in core lesions $<40\%$ correlate to other author data that ischemic tissue with CBF $>35\%$ may be salvageable, if recanalized during 5 h after onset (4).

Brain perfusion deficit grades according to our and other studies can be defined based on differences in perfusion CT maps, based on CBV and CBF map mismatch in penumbra lesion and CBV and CBF lesion congruency.

In conclusion, our study demonstrates that perfusion CT measurements are reliable in estimation of penumbra and core lesions in acute stroke patients, if relative threshold values are used. Most accurate parameter that confirms presence of hypoperfusion is increased MTT above 190%. Proposed relative threshold values for brain tissue necrosis: CBF <30–40% and CBV $<40\%$ in comparison to contra-lateral hemisphere. Penumbra lesion is characterized by increased or normal CBV or decreased not $>40\%$ of normal value, while CBF is decreased and MTT increased.

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