Perfusion computed tomography for ischemic stroke

Perfusion computed tomography in ischemic stroke has become an important adjunct, along with CT angiography (CTA), to conventional unenhanced CT brain imaging.

It enables differentiation of salvageable ischemic brain tissue (the penumbra) from irrevocably damaged infarcted brain (the infarct core). This is useful when assessing a patient for treatment (thrombolysis or clot retrieval).

Although MRI is more sensitive to the early parenchymal changes of infarction its clinical application has been limited by difficulties in accessing MRI in a timely fashion in many institutions; this is especially important in this clinical setting as rapid imaging and treatment are crucial to successful intervention.

Radiographic Features

The key to interpreting CT perfusion in the setting of acute ischemic stroke is understanding and identifying the infarct core and the ischemic penumbra, as a patient with a small core and a large penumbra is most likely to benefit from reperfusion therapies.

The three parameters typically used in determining these two areas are:

mean transit time (MTT) or time to peak (TTP) of the deconvolved tissue residue function (Tmax) [1].

Cerebral blood flow (CBF)

The measurement of maximum cerebral blood flow of collateral vessels within the Sylvian fissure is a feasible quantitative collateral assessment at perfusion CT. Maximum cerebral blood flow of collateral vessels was associated with clinical outcome in patients with acute ischemic stroke. [2].

Cerebral blood volume (CBV)

Normal perfusion parameters are:

gray matter

MTT: 4 s CBF: 60 ml/100 g/min CBV: 4 ml/100 g

white matter MTT: 4.8 s CBF: 25 ml/100 g/min CBV: 2 ml/100 g

The infarct core is the part of the ischemic brain which has already infarcted or is destined to infarct regardless of therapy. It is defined as an area with prolonged MTT or Tmax, markedly decreased CBF and markedly reduced CBV [3] [4] [5]. Note, that if one uses CBF alone to visually assess core size, it is

easy to overestimate infarct core, as the penumbra often has reduced CBF also. So, even though some automated processes used CBF to define core, CBV is a safer parameter if 'eye-balling' the scan.

The ischemic penumbra, which in most cases surrounds the infarct core, also has prolonged MTT or Tmax but in contrast has only moderately reduced CBF and, importantly, near normal or even increased CBV (due to autoregulatory vasodilatation) [6) 7) 8)]

Whole-brain CT Perfusion (CTP) on Day 3 after aneurysmal subarachnoid hemorrhage (aSAH) allows early and reliable identification of patients at risk for delayed ischemic neurological deficits (DIND) and tissue at risk for delayed cerebral infarction (DCI). Additional CTP investigations, guided by Transcranial Doppler sonography (TCD)-measured blood flow velocity (BFV) increase or persisting coma, do not contribute to information gain [9)].

The method by which perfusion to an organ measured by CT is still a relatively new concept, although the original framework and principles were concretely laid out as early as 1980 by Leon Axel at University of California San Francisco.

It is most commonly carried out for neuroimaging using dynamic sequential scanning of a pre-selected region of the brain during the injection of a bolus of iodinated contrast material as it travels through the vasculature. Various mathematical models can then be used to process the raw temporal data to ascertain quantitative information such as rate of cerebral blood flow (CBF) following an ischemic stroke or aneurysmal subarachnoid hemorrhage. Practical CT perfusion as performed on modern CT scanners was first described by Ken Miles, Mike Hayball and Adrian Dixon from Cambridge UK and subsequently developed by many individuals including Matthias Koenig and Ernst Klotz in Germany, and later by Max Wintermark in Switzerland and Ting-Yim Lee in Ontario, Canada.

Tracer delay-sensitive perfusion algorithms in CT perfusion (CTP) result in an overestimation of the extent of ischemia in thromboembolic stroke. In diagnosing delayed cerebral ischemia (DCI) after aneurysmal subarachnoid hemorrhage (aSAH), delayed arrival of contrast due to vasospasm may also overestimate the extent of ischemia.

The increase in perfusion that was observed might partially be responsible for improved clinical outcome following decompressive craniectomy for major stroke. The predictive value of perfusion CT on outcome needs to be evaluated in larger trials [10)].

Decompressive craniectomy (DC) improves cerebral hemodynamics in patients with malignant middle cerebral artery infarction, and the level of improvement is related to outcome. However, some patients did not seem to experience any additional hemodynamic benefit, suggesting that perfusion CT may play a role as a prognostic tool in patients undergoing DC after ischemic stroke [11)].

[1) 5) 8)]
Campbell BC, Christensen S, Levi CR et-al. Comparison of computed tomography perfusion and magnetic resonance imaging perfusion-diffusion mismatch in ischemic stroke. Stroke. 2012;43 (10): 2648-53. doi:10.1161/STROKEAHA.112.660548

[2)]
Shi F, Gong X, Liu C, Zeng Q, Zhang M, Chen Z, Yan S, Lou M. Acute Stroke: Prognostic Value of Quantitative Collateral Assessment at Perfusion CT. Radiology. 2019 Jan 8:181510. doi:

10.1148/radiol.2019181510. [Epub ahead of print] PubMed PMID: 30620255.

3) 6) Srinivasan A, Goyal M, Al Azri F et-al. State-of-the-art imaging of acute stroke. Radiographics. 2006;26 Suppl 1 (suppl 1): S75-95. Radiographics (full text) - doi:10.1148/rg.26si065501

4) 7) de Lucas EM, Sánchez E, Gutiérrez A et-al. CT protocol for acute stroke: tips and tricks for general radiologists. Radiographics. 2008;28 (6): 1673-87. Radiographics (full text) - doi:10.1148/rg.286085502

9) Malinova V, Dolatowski K, Schramm P, Moerer O, Rohde V, Mielke D. Early whole-brain CT perfusion for detection of patients at risk for delayed cerebral ischemia after subarachnoid hemorrhage. J Neurosurg. 2015 Dec 18:1-9. [Epub ahead of print] PubMed PMID: 26684786.

10) Slotty PJ, Kamp MA, Beez T, Beenen H, Steiger HJ, Turowski B, Hänggi D. The influence of decompressive craniectomy for major stroke on early cerebral perfusion. J Neurosurg. 2015 Jan 30:1-6. [Epub ahead of print] PubMed PMID: 25635482.

11) Amorim RL, de Andrade AF, Gattás GS, Paiva WS, Menezes M, Teixeira MJ, Bor-Seng-Shu E. Improved Hemodynamic Parameters in Middle Cerebral Artery Infarction After Decompressive Craniectomy. Stroke. 2014 Apr 15. [Epub ahead of print] PubMed PMID: 24736238.