Chapter XL
Imaging the Human Brain with Functional CT Imaging

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ABSTRACT

Recent advances in multi-detector computed tomography (CT) have revitalized its role in the clinical routine. In the field of cerebral perfusion, CT provides a rapid, low-cost functional imaging, which by the utilization of a suitable tracer kinetic analysis can provide valuable information in many clinical applications, like acute stroke, cerebrovascular reserve capacity, vasospasm after subarachnoidal hemorrhage, cerebral trauma, tumor imaging, and brain death diagnosis. The limitations of the existing commercially available post processing software are discussed and a new distributed-parameter tracer kinetic model for generating more accurate perfusion parametric maps is introduced.

INTRODUCTION

Recent advances in multidetector computed tomography (CT) have resulted in subsecond volumetric patient scanning, revitalizing the role of CT in the clinical routine. Such quantum technological laps combined with the availability and turnaround efficiency of CT have had a notable impact on the imaging paradigms of the critically ill such as stroke and trauma patients and those under intensive care. CT perfusion is a brilliant example of a protocol that has undergone significant improvements bearing considerable impact on patient care in the acute setting.

In the field of cerebral perfusion, CT overcomes other imaging modalities (e.g., magnetic resonance imaging [MRI], xenon computed tomography, positron-emission tomography [PET], and single-photon-emission computed

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tomography [SPECT]) through the rapid, low-cost generation of meaningful images and available user-friendly postprocessing software that interprets the data in a clinically relevant manner. The theory behind perfusion CT is a tracer kinetic analysis of the rapidly intravenously injected contrast material.

The purpose of this chapter is to revisit the assessment of perfusion CT imaging in many clinical applications, to suggest new clinical fields (e.g., brain-death diagnosis) for possible future applications of perfusion CT, and to emphasize the pitfalls of the method, suggesting a new distributed-parameter (DP) kinetic model for generating more accurate perfusion parametric maps.

IMAGING TECHNIQUES, INDICATORS, AND TRACER KINETICS MODELS

The measurement of cerebral perfusion relies on a triad including an imaging technique, an indicator, and a model. In the case of CT imaging, the sequential acquisition of cerebral sections (one or more sections per second) is performed during the rapid (6 mL/sec in our clinical protocol) intravenous administration of an iodinated contrast agent (50 mL of a 400 mg/dL non-ionic iodinated contrast material in our protocol).

The iodinated contrast agent is restrained in the cerebral vascular bed, at least at first pass and in healthy cerebral tissue. Tracer kinetic-analysis methods for estimating microcirculatory parameters can generally be grouped under two classes (Larson, Markham, & Raichle, 1987; Lee, 2002): (a) model-independent approaches that include numerical deconvolution-based methods and (b) model-dependent or parametric-fitting approaches. In the model-dependent approach, the tracer kinetics models used for parametric fitting of the dynamic imaging data are usually linear compartmental models that can be further classified as conventional compartmental (CC) or DP models.

Three main models have been used for model-independent approaches including the maximum-slope model, the equilibring-indicator model, and the central-volume principle. The maximum-slope model requires very short injection times, which are not always tolerable by the patients, and tends to underestimate the cerebral blood flow (BF). Moreover, there is no general consensus regarding the reference arterial input function, which is necessary for the calculation of the perfusion parameters. On the other hand, the equilibring-indicator model and the central-volume model require a mathematical operation called deconvolution (Axel, 1981; Ostergaard et al., 1996). Deconvolution can be realized in two ways. The first method to solve the deconvolution problem is a parametric method in which supplemental hypotheses regarding the anatomical structure or the behaviour of the indicator are taken into account. The second method, called nonparametric, can be performed with single-value deconvolution and involves less source hypotheses. Deconvolution-based CT perfusion offers a fast and robust analysis of neurovascular disorders and has been an important strategy to assess stroke and to characterize intracranial tumors.

On the other side, comprehensive studies have indicated that linear compartmental models could allow a more complete analysis of the kinetic parameters. Also, as illustrated in various works, DP models possess more realism than CC models (Koh, Cheong, Hou, & Soh, 2003). The reason for this is that the tracer concentration gradients within compartments are taken into account in DP models, while in CC models, tracer concentration gradients are assumed to be zero at all times and thus the

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