Cerebral Blood Flow Measurements Using Stable Xenon CT with Very Short Inhalation Times

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Abstract

A noninvasive, simplified method using inhalation of stable xenon (Xe<sub>s</sub>) and computed tomographic (CT) scanning to estimate regional cerebral blood flow (rCBF) and regional partition coefficient (rλ) is described. Twenty-four patients with cerebrovascular occlusive disease and six volunteer controls inhaled 30% Xe<sub>s</sub> and 70% oxygen for 180 seconds and exhaled for 144 seconds during serial CT scanning without denitrogenation. The end-tidal Xe<sub>s</sub> concentration was continuously monitored with a thermodconductivity analyzer to determine the build-up range (A value) and build-up rate constant (K value) for arteries with the curve fitting method. The time-CT number (Hounsfield unit) curve for cerebral tissue during the Xe<sub>s</sub> washin and washout phases was used to calculate rλ and rCBF using least squares curve fitting analysis. The resultant rλ and rCBF map demonstrated a reliable distribution between the gray and white matter, and infarcted areas. rCBF was high in gray matter, low in white matter, and much lower in infarcted areas than in white matter. rλ was high in white matter, low in gray matter, and much lower in infarcted areas. Xe<sub>s</sub> CT-CBF studies with very short inhalation of 180 seconds is a clinically useful method for evaluation of rCBF in patients with cerebrovascular diseases.

Key words: cerebrovascular diseases, regional cerebral blood flow, stable xenon, computed tomography, very short inhalation

Introduction

The method of three-dimensional measurement of regional cerebral blood flow (rCBF) using stable xenon (Xe<sub>s</sub>) and computed tomographic (CT) scanning provides excellent spatial resolution and allows the determination of partition coefficients, so it has many clinical applications. The measurement of end-tidal Xe<sub>s</sub> concentrations using a thermodconductivity analyzer is less invasive than direct sampling of arterial blood. However, even using 30% Xe<sub>s</sub>, some patients entered the second stage of anesthesia (excitation), stopping the examination due to violent body movements or difficulty in interpreting images due to artifacts.

The present study investigated very short Xe<sub>s</sub> inhalation times combined with a newly developed CT scanner.

Materials and Methods

Xe<sub>s</sub> CT-CBF was measured a total of 38 times in 30 subjects, consisting of 24 with occlusive cerebrovascular disease in the acute (six cases) and chronic (18 cases) stages and six healthy volunteers. There were seven of perforator thrombosis, eight of internal carotid artery stenosis or occlusion, seven of middle cerebral artery (MCA) stenosis or occlusion, one of posterior cerebral artery (PCA) occlusion, and one of MCA occlusion and severe PCA stenosis. Their ages ranged from 46 to 84 years (mean 61.2 years) in cerebrovascular disease patients and from 22 to 46 years (mean 29.6 years) in normal controls.

Two arbitrary slices including the region of interest in the head were defined. The subjects inhaled air followed by a mixture of 30% Xe<sub>s</sub> and 70% oxygen for 180 seconds. Then, after the subsequent 144
seconds desaturation process, serial CT scanning for 3 seconds was performed every 18 seconds for a total of 10 serial scans at each slice. The arterial blood Xe concentration was measured using a thermoconductivity analyzer, and the end-tidal Xe concentration was continuously recorded. The A and K values in arterial blood were calculated from the time-CT number data using the previously reported equations. The Xe was supplied by an Xetron III model AZ-723 (Anzai Sogyo, Tokyo) and a newly developed CT scanner, Quantex RX (Yokogawa Medical System, Tokyo).

**Results**

The Xe CT-CBF measurement method produced partition coefficient (λ) and CBF (f) maps with reliable distribution profiles. On the λ map the concentration was high in the white matter, low in the gray matter, and still lower in old infarcted areas, and intermediate between the white and gray matter.

![Fig. 1](image1.png)

*Fig. 1* Changes of the CT number during 30% Xe inhalation (180 seconds) and washout (144 seconds) processes in controls (n = 6). Hounsfield units (HU) in frontal white matter (●), posterior limb of the internal capsule (■), head of caudate nucleus (○), and frontal gray matter (□). Values are means ± SD.

![Fig. 2](image2.png)

*Fig. 2* Precontrast CT scans (left), partition coefficient (λ) maps (center), and CBF (f) maps (right) in a 35-year-old male volunteer (Case 1).

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in the thalamus. On the f map, the flow was high in the gray matter, low in the white matter, and still lower in infarcted areas. Changes in the CT number during the 30% Xe 180 seconds washin and 144 seconds washout periods in the gray and white matter were studied in six volunteers (Fig. 1). Both increase and decrease were more rapid in the gray matter than in the white matter. The increase in the white matter exceeded twice the standard deviation (1.7 HU × 2) for the Quantex RX.

Here we describe representative cases.

Case 1 (Fig. 2): The Xe CT-CBF at rest was measured in a 35-year-old male volunteer without neurological abnormalities or unusual CT findings. Xe concentration was high in the white matter and low in the gray matter on the λ maps, but the reverse was seen on the f maps.

Case 2: A 79-year-old female was admitted to our hospital immediately after the development of left hemiparesis, right conjugate deviation of the eyes, and disturbed consciousness (somnolence). She had chronic atrial fibrillation. On admission, CT scans showed a slight low-density area in the right cerebral hemisphere, and sequential Xe CT-CBF measurements disclosed a large low-CBF region extending from the right MCA to the right PCA territories (Fig. 3), which was considered to be the right MCA and PCA occlusions. Angiography demonstrated complete occlusion of the right MCA together with severe stenosis of PCA (Fig. 4).

Case 3: A 71-year-old female with a history of atrial fibrillation developed motor aphasia but it gradually improved. One week later, left hemiparesis and somnolence occurred, and she was admitted 6 hours after the onset. CT scans showed a high-density area in the left frontal lobe and a low-density area in the right frontal lobe. Xe CT-CBF study demonstrated high CBF in the left frontal and right parietal lobes, and low CBF in the right frontal lobe (Fig. 5). Cerebral angiography disclosed occlusion of a right MCA branch.

Embolization of the right MCA had occurred 1 week earlier but had spontaneously recanalized. Subsequently, the right MCA trunk or its bifurcation was apparently embolized, with distal migration of the emboli at the time of hospitalization.

Discussion

The CT enhancement by Xe inhalation is now applied to CBF measurement. Xe CT-CBF measurements provide excellent spatial resolution compared with other tomographic methods for rCBF measurement, and the tissue-blood partition coefficient can

Fig. 3 Case 2. left: Precontrast CT scans demonstrating a slight low-density area in the right cerebral hemisphere. right: The f maps showing a large low-flow region.

Fig. 4 Case 2. Right common carotid angiograms, anteroposterior (upper) and lateral (lower) views, demonstrating right MCA occlusion and severe stenosis of ipsilateral PCA.
Fig. 5 Case 3. left: Precontrast CT scans showing a high-density area in the left frontal lobe and a low-density area in the right frontal lobe. right: The f maps demonstrating high CBF in the left frontal and right parietal lobes and low CBF in the right frontal lobe.

also be measured. However, there are some disadvantages, such as the high price of Xe, the large x-ray dosage needed, and excitation and/or depression of respiration due to the anesthetic action of Xe.

To overcome these disadvantages, we previously developed a Xe CT-CBF method using a low Xe concentration and short inhalation time (30%, 4 minutes). With stepwise Xe inhalation, the arterial blood Xe concentration increases monoeXponentially, while the brain tissue Xe concentration follows a biexponential increase given by substituting the arterial function in the Kety-Schmidt equation and integrating. Thus, by stepwise Xe inhalation, the arterial blood and brain tissue Xe concentrations can be expressed by a monoeXponential increase/decrease and a biexponential increase/decrease. The K values for the arterial blood and brain tissue must remain constant throughout the saturation and desaturation periods. The following methods can provide a continuous series of Xe concentration determinations in arterial blood: 1) Direct sampling of arterial blood. 2) The shuttle method of direct scanning of the common carotid artery simultaneously with cranial scanning, by which values are obtained in situ. Measurement of the end-tidal Xe concentration with a thermoconducXivity analyzer. We use the third method at present.

We attempted to use 4-minute inhalation in clinical applications of CT-CBF measurements, but in certain patients we failed to obtain satisfactory images due to body movement during the excitation phase of anesthesia (stage II). We also wished to establish a method for hemodynamic evaluation in outpatients with cerebrovascular diseases.

This study evaluated the use of 3-minute inhalation for determining CT-CBF. The maximum rise in CT values for the cortex and white matter exceeded twice the standard deviation of the Quantex scanner, and both λ and f maps agreed with the previous results. In Case 2, the mean CBF in the right MCA and PCA was calculated to be less than 15 ml/100 gm/min. Subsequent CT scans disclosed low-density regions coinciding with the low-CBF areas. In Case 3, differences in rCBF in the recanalized and the occluded regions were clearly seen.

This is a convenient method to determine the prognosis and indications for surgery in patients with ischemic cerebrovascular conditions. We now plan to study a larger series of patients.

References


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