Investigations on the Flat-Detector Computed Tomography–Based CBV Map Acquisition Using a Left Ventricle Contrast Media Injection Protocol

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■ OBJECTIVES: **Cerebral blood volume (CBV) acquired with the use of flat-detector computed tomography with contrast media (CM) injected at the ascending aorta provides real-time brain functional information with minimized CM usage; however, unexpected asymmetric perfusion is observed for certain patients without cerebral circulatory disorders. This work tested the feasibility of left ventricle (LV) CM injection to achieve symmetric perfusion.**

■ METHODS: **CBV maps were acquired for 10 patients without perfusion-related cerebral abnormities. Perfusion symmetry was predicted with the use of color-coded quantitative digital subtracted angiography with CM injected at ascending aorta. Time density curves were extracted at bilateral common carotid arties with area under curves calculated. Planes were selected on CBV maps with regions of interest defined covering characteristic regions, where asymmetric perfusion most likely to appear.**

■ RESULTS: **No adverse physiological changes were detected for any patient. Non-uniform CM distributions were detected for 4 patients with relative area under curves 0.66 ± 0.03, indicating asymmetric perfusion using ascending aorta injection. With LV injection, all the patients demonstrated good perfusion symmetry with relative CBV 1.03 ± 0.07.**

■ CONCLUSION: **CBV maps acquisition with LV injection offered an approach to acquire immediate brain functional information for patients who are limited by asymmetric perfusion using ascending aorta injection and are sensitive to CM dose.**

INTRODUCTION

Cerebral perfusion is a recognized parameter of tissue viability and functionality and its measurement can be useful in the detection and characterization of various pathological changes. Cerebral perfusion imaging enables evaluation of the hemodymamic characteristics in specific regions, and it has become a valuable tool in the assessment of stroke patients. There is evidence that the perfusion parameter cerebral blood volume (CBV), describing the amount of blood per unit of brain tissue, may be the best predictor of infarct core (3, 4, 10). With rapid development in imaging technology and postprocessing techniques, a CBV map can be generated in the angiographic suites equipped with flat detector computed tomography (FDCT), such that direct brain functional analysis can be performed during neurointerventional procedures (1-3, 13, 14). Real-time monitoring of CBV variations during the interventional treatment of acute ischemic stroke patients may add further value in decision making regarding whether to continue further attempts

Key words
- Cerebral blood volume
- Color-coded quantitative digital subtraction angiography
- Flat-detector computed tomography
- Left ventricle
- Perfusion symmetry

Abbreviations and Acronyms
AUC: Area under the curve
CBV: Cerebral blood volume
CCA: Common carotid artery
CCQ-DSA: Color-coded, quantitative digital subtraction angiography
CM: Contrast medium
DSA: Digital subtraction angiography
FDCT: Flat-detector computed tomography
IA: Intra-arterial
IA-FDCT-CBV: Intra-arterial aorta CM injection FDCT CBV maps
LV-FDCT-CBV: Left ventricle CM injection FDCT CBV maps
rAUC: Relative area under the curve
rCBV: Relative cerebral blood volume
ROI: Region of interest
TDC: Time density curve

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of revascularization. In addition, this technique offers significant advantages in patient management, because the patient does not have to be transferred between different clinical units for imaging and treatment, improving clinical workflow and increasing patient safety.

The CBV map, conventionally acquired with this technique by intravenous contrast medium (CM) injection (i.e., intravenous CM injection FDCT CBV maps), has been validated in a number of clinical studies, proving good correlation between the CBV maps generated from FDCT and from multislice CT (5, 15-17). However, with this type of injection protocol, the CM will be diluted during the transit until reaching systematic arterial circulation, and thus only a portion of the injected CM contributes to the formation of CBV maps. Some recent studies have focused on exploring the value of using FDCT with intra-arterial CM injection to acquire whole-brain CBV maps (IA-FDCT-CBV). With this injection protocol, the CM is injected at the ascending aorta and then flows directly into the brain, so that the CM dose could be remarkably reduced (e.g., 350 mgI/mL, total amount 96 mL, 20% diluted vs. 80 mL, no dilution). Besides, during the interventional procedure, the catheter is already in place, and thus its operation is more convenient without the need of reconnecting power injector, potentially reducing overall operation time. This method has also been tested and confirmed against conventional CT perfusion imaging with intra-venous CM injection (7, 20). However, individual vasculature variations at aortic arch, high blood flow speed, and limited length of the ascending aorta lead to inhomogeneous CM distribution, which in turn could cause unexpected and incorrect asymmetric perfusion in 2 hemispheres, mainly in the territories of anterior and middle cerebral arteries, for certain patients even without cerebral circulatory disorders (8, 20).

Approaches have been made to apply color-coded, quantitative digital subtraction angiography (CCQ-DSA, *syngo* iFlow, Siemens Healthcare, Erlangen, Germany) generated from a conventional DSA sequence to extract quantitative flow information and to predict perfusion symmetry on patient specific basis. This was based on the fact that only the global arterial input function was used for generation of CBV maps, and thus, the difference of the supplying or input arteries (left and right) will lead to differences of the CBV values between the left and right hemisphere. This approach has been proven to successfully avoid patients undergoing CBV acquisitions who might be subject to IA injection–induced asymmetric perfusion (21, 22). However, it remains a technical challenge to generate reliable CBV maps for these patients in whom a direct evaluation on the CBV variations during the interventions is desired. It is sometimes valuable and even essential to have accurate intra-procedural CBV measurement, which enables peritherapeutic monitoring of hemodynamics and allows a timely management when endovascular treatments are encountered (11).

In this work, CCQ-DSA from routine aortic arch DSA was used for perfusion symmetry prediction supposing that CBV would be acquired with IA injection. Inspired by the cardiac left ventricle (LV) angiography technique, we adopted a new injection protocol by injecting CM into the LV of the heart to generate the FDCT-based CBV map (LV-FDCT-CBV). It was our hypothesis that because of the contraction of the ventricle, the mixing between blood and CM could be improved, leading to homogeneous CM distribution before reaching the ostia of arteries at the aortic arch, which finally would result in improved perfusion symmetry.

MATERIALS AND METHODS

Patient Selection

From September 2013 to May 2014, a total number of 10 patients (7 men, 3 women; mean age was 48.9 ± 13.3 years) without perfusion-related cerebral abnormities confirmed by diagnostic DSA were enrolled into this study. Clinical information of each patient is summarized in **Table 1**. Patients were considered to be eligible for LV-FDCT-CBV acquisitions only when the following criteria were met: no cardiac diseases such as aortic stenosis, heart failure, and cardiac arrhythmia, and no renal impairment. This study had been approved by the hospital ethics committee. All patients signed written informed consent.

CCQ-DSA Image

Intravenous sedation and local anesthesia were given to all the patients. The right femoral artery was entered using Seldinger technique, and a 4-French introducer sheath was placed. Through the indwelling femoral arterial sheath, a 4-French pigtail catheter was advanced along a 0.35-mm guidewire to reach the ascending aorta. The wire was left in the catheter slightly back from the tip and the pigtail catheter was placed forming a loop. Conventional routine DSA sequence at the aortic arch was then acquired using a rotational FDCT system (Artis zeego; Siemens Healthcare). For it, 30 mL of CM (350 mgI/mL, Iohexol 350, Beijing BEILU Pharmaceutical Co., Ltd., Beijing, China) was injected by a power injector (600 psi, Avidia; Imaxeon, Rydalmere, Australia) through the pigtail catheter at the injecting rate of 15 mL/s (**Figure 1A**). This DSA sequence was then converted to a CCQ-DSA image by

Table 1. Patient Data and Diagnostic Information

Patient No.	Age	Sex	Symptoms	DSA Diagnosis
1	59	F	Symptomless	Right posterior communicating artery aneurysm
2	31	M	Vertigo	No
3	59	M	Vertigo	Right subclavian artery stenosis
4	63	M	Vertigo	Left vertebral artery tortuosity
5	51	F	Subarachnoid hemorrhage	No
6	55	M	Vertigo	No
7	52	M	Subarachnoid hemorrhage	Right parietal lobe arteriovenous malformation
8	21	M	Epilepsy	No
9	53	M	Blurred vision	Left ophthalmic artery narrowing
10	45	F	Symptomless	Bilateral middle cerebral artery aneurysm

DSA, digital subtraction angiography.