Comparison of Aortic Arch and Intravenous Contrast Injection Techniques for C-arm Cone Beam CT:

Implications for Cerebral Perfusion Imaging in the Angiography Suite

Jesse M. Klostranec, MD, PhD, Tina Ehtiati, PhD, Swati Rao, BSc, Martin G. Radvany, MD

Rationale and Objectives: The ability to perform cerebral perfusion imaging (CPI) in the angiography suite has provided a new tool for diagnosis and treatment of neurovascular patients but requires comparable contrast perfusion to each cerebral hemisphere. In the angiography suite, contrast injection may be performed via an intra-arterial or intravenous (IV) route. The purpose of this study was to investigate whether a difference exists between contrast injection in the aortic arch (AA) and a peripheral vein (IV), particularly in the setting of stroke.

Materials and Methods: Using three canines, both AA and IV injection protocols compatible with CPI were performed prospectively at three time points after creation of a stroke. The common carotid arteries in the resulting image data sets were segmented and the means and distributions of corresponding pixel intensities analyzed with Student's *t*-test. Using similar techniques, the internal carotid arteries of three patients (one female, two males, ages 69, 29, and 20) undergoing AA contrast injection with cone beam computed tomography (CBCT) cerebral imaging were analyzed and compared retrospectively with those of three random patients (one female, two males, ages 19, 57, and 35) undergoing standard head CT scans using IV contrast administration. All acquisitions followed institutionally approved protocols and informed consent.

Results: No statistical significance ($P < .05$) was found when mean values for the right and left carotid artery pixel intensities were compared in the canine model or the clinical studies in which patients underwent imaging after AA or IV contrast administration.

Conclusions: No statistically significant difference exists between right and left carotid artery filling density using either AA or IV contrast injection methods, making both suitable for CPI in the angiography suite.

Key Words: Cerebral perfusion imaging; cone beam CT; contrast injection; stroke imaging.

Conventional digital subtraction angiography (DSA) highlights abnormalities in vascular anatomy that may be pathologic, whereas advances in technology and medical knowledge have led to the development of imaging techniques that yield clinically useful physiologic information (1–3). Examples of the latter include positron emission tomography, functional magnetic resonance imaging (fMRI), and perfusion computed tomography (CT). In cerebral perfusion imaging (CPI), measurements of cerebral blood volume (CBV), mean transit time (MTT), and cerebral blood flow (CBF) make up parameters used to describe the physiologic tissue perfusion of the brain. Such information is very helpful in assessing patients suffering acute stroke, vasospasm, and intracranial tumors (2). In fact, perfusion CT and perfusion MRI techniques are being considered as tools to extend the window for thrombolysis in acute stroke (4).

There exist several endovascular treatment options for acute stroke in the angiography suite, including intra-arterial (IA) thrombolysis and mechanical embolectomy (5–7). With these treatment methods available in the angiography suite and the strong inverse correlation between time to treatment and good outcomes, clearly it would be advantageous to have the multimodal imaging capabilities for stroke work up in the same room where therapy can take place. With the advent of Food and Drug Administration–approved C-arm-mounted flat-panel detectors in angiography suites (Artis zee biplane, Siemens Healthcare, Germany), the ability to acquire three-dimensional cone beam computed tomography (CBCT) images in addition to traditional angiographic images from standard C-arm systems inside the angiography suite is now being incorporated into routine angiography protocols (8–10). These systems are capable of producing CBV maps in

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From the Department of Medical Imaging, University of Toronto, Toronto, ON, Canada (J.M.K.); Siemens Corporation, Corporate Technology, Princeton, NJ (T.E., S.R.); Division of Interventional Neuroradiology, The Johns Hopkins University School of Medicine, 1800 Orleans Street, Bloomberg Building Room 7218, Baltimore, MD 21287 (M.G.R.). Received February 8, 2012; accepted October 16, 2012. **Address correspondence to:** M.G.R. e-mail: mradvan2@jhmi.edu

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ischemic stroke models comparable to conventional perfusion CT and, with some alterations to image acquisition protocols, are even able to provide comparable temporal MTT and CBF information (11–13).

An essential feature required for this type of cerebral perfusion imaging is that both hemispheres of the brain receive comparable amounts of contrast. Such a requirement exists because the related contrast filling density in both hemispheres is compared to assess the degree of tissue perfusion during the clinical decision-making process (2). Therefore, ideal circumstances dictate that any differences in tissue perfusion measurements correlate solely with actual differences in tissue perfusion and not because of inherent characteristics of contrast material administration. Traditionally, intravenous (IV) routes are used to inject iodinated contrast into the blood stream for perfusion CT imaging, with the antecubital fossa being the most common site for injection (14). But with endovascular procedures in the angiography suite providing IA access, another suitable route for contrast administration may now present. Here we use image segmentation and evaluate pixel intensity values to study the relative contrast filling densities of the carotid arteries using both aortic arch (AA) and IV injection protocols in a canine acute stroke model. We then compare the contrast densities in the carotid arteries of patients undergoing AA contrast injection in conjunction with CBCT imaging of the cerebral vessels and patients undergoing standard IV contrast-enhanced CT studies of the cerebral vessels. In doing so, this study aims to determine whether the AA approach is equivalent to IV in delivering comparable amounts of contrast bilaterally to the carotid arteries, thus evaluating it as a suitable alternative for CPI in the angiography suite.

MATERIALS AND METHODS

Canine Model

All experiments involving canines followed an institutionally approved protocol. Three canines were anesthetized with Telazol (10 mg/kg intramuscularly or 2 mg/kg IV) and underwent endotracheal intubation. General anesthesia was provided via inhaled isoflurane during the arterial access procedures and then with a propofol drip (0.4–0.6 mg/kg/min IV) throughout the remainder of the study. Continuous monitoring of important physiologic parameters such as heart rate, oxygen saturation, and end-tidal carbon dioxide was performed. Endovascular access was achieved through puncture and 5F sheath placement in one of the common femoral arteries. A 5F catheter (DAV, Cook, Bloomington, IN) was then advanced under fluoroscopic guidance into the origin of the internal carotid artery (ICA), followed by coaxially advancing a 1.7F microcatheter (Echelon-10, EV-3, Irvine, CA) from the level of the distal ICA to the middle cerebral artery (MCA). Occlusive stroke of the MCA territory was achieved by injection of a 2:1 mixture of ethiodized oil: *n*-butyl cyanoacrylate embolic glue (Codman & Shurtleff, Inc., Raynham, MA) through the microcatheter.

Canine CBCT Image Acquisition

Contrast-enhanced CBCT imaging (*syngo* Inspace 3D, Siemens Healthcare, Germany) was accomplished using both AA and IV injection protocols (Fig 1). First, AA contrast injection was performed by advancing a 5F pigtail catheter (Cook Medical, Bloomington, IN) in the ascending aorta, just distal to the aortic valve, and injecting contrast via a power injector. Following a dedicated DSA protocol (Fig 1a), mask and fill run projection data acquisitions of the canines were obtained. A 12.5-second delay was used between the start of contrast injection and the beginning of the fill run data acquisition. When coupled with the 8-second fill run acquisition time, it resulted in a total injection time of 20 seconds. A 30% dilution of iohexol-300 contrast (GE Healthcare, Milwaukee, WI) in normal saline (NS) was injected at a rate of 4 mL/second during this period, for a total of 80 mL injected volume (26.4 mL of contrast material). This injection protocol was optimized during a previous set of experiments such that contrast was visualized in the superior sagittal sinus (SSS) before the fill run, providing a steady state in the parenchyma suitable for CPI measurements. The assumption was made that by continuing the contrast injection until the end of the fill run, a steady state was maintained in the carotid arteries bilaterally.

Following a delay of 5 minutes to ensure contrast concentration in the SSS had dropped back to baseline, another dedicated DSA protocol was performed for IV administration of contrast. A dual-phase contrast injection technique was used for IV studies. The antecubital fossa was cannulated and the IV injection of contrast began 5 seconds before the start of the mask run projection data acquisition (Fig 1b). Iohexol-300 contrast was injected at a rate of 2 mL/second for a total of 20 mL contrast. This was followed by injection of NS at 2 mL/second for a total of 20 mL NS. Total injection time for IV data acquisitions was 20 seconds. This resulted in an 18-second delay between the start of injection and the start of the fill run acquisition, longer than in the AA case because of the longer distance the contrast had to travel to reach the SSS. A saline flush was used at the end of each acquisition to improve the late profile of the injected bolus and decrease the volume of contrast injected (14).

These imaging protocols were repeated at three time points for each of the canines, 1, 2, and 3 hours following their induced embolic stroke, allowing for prospective analysis. Projection datasets were reconstructed using a dedicated workstation (*syngo* X Workplace VB13), yielding mask and fill run image sequences of 391 slices with a 512×512 matrix and isotropic voxels of 0.469 mm^3.

Human CBCT Image Acquisition

All imaging performed on human patients adhered to institutionally approved protocols, which included patient informed consent. The human CBCT imaging protocols were the same as those described previously (15). Briefly,