Original Contribution

Regional Comparison of Multiphase Computed Tomographic Angiography and Computed Tomographic Perfusion for Prediction of Tissue Fate in Ischemic Stroke

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Background and Purpose—Within different brain regions, we determine the comparative value of multiphase computed tomographic angiography (mCTA) and computed tomographic perfusion (CTP) in predicting follow-up infarction.

Methods—Patients with M1-middle cerebral artery occlusions were prospectively included in this multicenter study. Regional analysis was performed for each patient within Alberta Stroke Program Early CT Score regions M2 to M6. Regional pial vessel filling was assessed on mCTA in 3 ways: (1) Washout of contrast within pial vessels; (2) Extent of maximal pial vessel enhancement compared with contralateral hemisphere; (3) Delay in maximal pial vessel enhancement compared with contralateral hemisphere. Cerebral blood flow, cerebral blood volume, and Tmax data were extracted within these Alberta Stroke Program Early CT Score regions. Twenty-four- to 36-hour magnetic resonance imaging/CT was assessed for infarct in each Alberta Stroke Program Early CT Score region (defined as >20% infarction within that region). Mixed effects logistic regression models were used to compare mCTA and CTP parameters when predicting brain infarction. Area under the receiver operating characteristics was used to assess discriminative value of statistical models.

Results—Seventy-seven patients were included. mCTA parameter washout and CTP parameter Tmax were significantly associated with follow-up infarction in all models ($P<0.05$). The area under the receiver operating characteristic for mCTA models ranged from 92% to 94% and was not different compared with all CTP models ($P>0.05$). Mean Tmax and cerebral blood volume values were significantly different between each washout score ($P<0.01$) and each delay score category ($P<0.01$). Mean Tmax, cerebral blood flow, and cerebral blood volume values were significantly different between each extent score category ($P<0.05$).

Conclusions—Similar to CTP, multiphase CTA can be used to predict tissue fate regionally in acute ischemic stroke patients. **(*Stroke*. 2017;48:00-00. DOI: 10.1161/STROKEAHA.116.015969.)**

Key Words: infarction ■ logistic models ■ magnetic resonance imaging ■ stroke ■ tomography

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Multiphase computed tomographic angiography (mCTA) and computed tomographic perfusion (CTP) have been used for patient selection in recent clinical trials and are used in clinical routine as a result.[1–3] CTP generates quantitative functional maps of regional brain hemodynamics and perfusion, including collateral and microvascular hemodynamic efficiency,[4,5] whereas mCTA depicts whole-brain time-resolved images of pial arteries and veins beyond an occlusion, while informing on thrombus location/size and extracranial vessel patency and tortuosity.[5,6] A perceived advantage of CTP over multiphase CTA has been an inability to use the latter tool to predict fate of ischemic tissue regionally. To address this issue,

Received November 8, 2016; final revision received January 2, 2017; accepted January 31, 2017.

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Guest Editor for this article was Stephen M. Davis, MD, FRACP.

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The online-only Data Supplement is available with this article at http://stroke.ahajournals.org/lookup/suppl/doi:10.1161/STROKEAHA.116.015969/-/DC1.

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we systematically examine mCTA parameters of delay in maximal pial vessel enhancement compared with contralateral hemisphere, washout of contrast within pial vessels, and extent of maximal pial vessel enhancement compared with contralateral hemisphere in their ability to predict tissue fate regionally. We compare these parameters to well-established parameters of cerebral blood flow, blood volume, and Tmax on CTP.

Methods

Patients

Data are from the Prove-IT study, a prospective, multicenter study that acquired acute multimodal CT imaging (mCTA and CTP) at baseline among ischemic stroke patients.[5] All patients in this study have been published in previous studies by the authors.[5,7,8] Local ethics review committees approved the study. Only patients with known symptom onset time and complete middle cerebral artery-M1 segment occlusion at baseline were included for this analysis.

Imaging Protocols

At admission, all patients had a noncontrast CT scan, head/neck multiphase CTA, and CTP.[5]

Multiphase CTA

Time-resolved cerebral angiograms of the brain vasculature were generated following the injection of 80 mL of contrast agent injected at a rate of 5 mL/s followed by a saline flush of 50 mL at 6 mL/s. For the first phase, the aortic arch-to-vertex helical scan was timed to be in the peak arterial phase of normal brain by triggering the scan based on bolus tracking. This first phase acquisition was 7 seconds in length. The second phase was acquired after a delay of 4 seconds allowing for table repositioning to the skull base. Scan duration for each additional phase is 3.4 seconds. Thick-section axial maximum intensity projections at 24 mm thickness and 4 mm intervals were reconstructed.

CT Perfusion

Forty-five milliliter of CT contrast agent was power injected at 4.5 mL/s followed by a saline flush of 40 mL at 6 mL/s. Sections of 8 cm thickness were acquired at 5 mm slice thickness. Scanning began after a delay of 5 seconds from contrast injection in up to 2 phases (scanning intervals): first phase every 2.8 seconds for 60 seconds (in 30 patients) and an additional second phase every 15 seconds for 90 seconds (in 47 patients). One author processed each study using commercially available delay-insensitive deconvolution software (CT Perfusion 4D, GE Healthcare, Waukesha, WI). For each study, the arterial input function was manually selected from the basilar artery or internal carotid artery using a 2 voxel×2 voxel (in-slice) region of interest. Absolute maps of cerebral blood flow (CBF; $mL \cdot min^{-1} \cdot (100\ g)^{-1}$], cerebral blood volume (CBV; $mL \cdot (100\ g)^{-1}$], and Tmax (seconds) were calculated by deconvolution of tissue time–density curves and the arterial input function using a delay-insensitive algorithm (CT Perfusion 4D, GE Healthcare).[7] Average maps were created by averaging the dynamic CTP images over the duration of the first pass (66 seconds) of contrast. In-plane patient motion was minimized using automated software (CT Perfusion 4D), and volumes were manually removed, as needed, by visual inspection of the cine series and time density curve.

Image Analysis

Regional analysis was performed for each patient within 5 Alberta Stroke Program Early CT Score (ASPECTS) regions, M2 to M6, by consensus of 2 readers who were blinded to all other clinical and imaging information. The M1 region was not included as pial vessel filling is difficult to interpret in this area of the brain, and there are also beam-hardening artifacts caused by the subjacent sphenoid bone.

Multiphase Computed Tomographic Angiography

Pial vessels were assessed in each ASPECTS region using these 3 parameters: (1) washout of contrast agent within pial vessels; (2) extent of maximal pial vessel enhancement compared with contralateral hemisphere; (3) delay in maximal pial vessel enhancement compared with contralateral hemisphere (Figure 1). All parameters were scored on a 3-point scale, where 1=poor, 2=intermediate, and 3=good (ie, higher score means better collaterals). Each parameter was scored as follows:

1. Washout of contrast agent within pial vessels. Washout was assessed by comparing pial vessel enhancement on the ipsilesional side across phases II and III and scored as follows: 1=no washout of contrast agent, that is, no difference in pial vessel enhancement between the second and third phases;

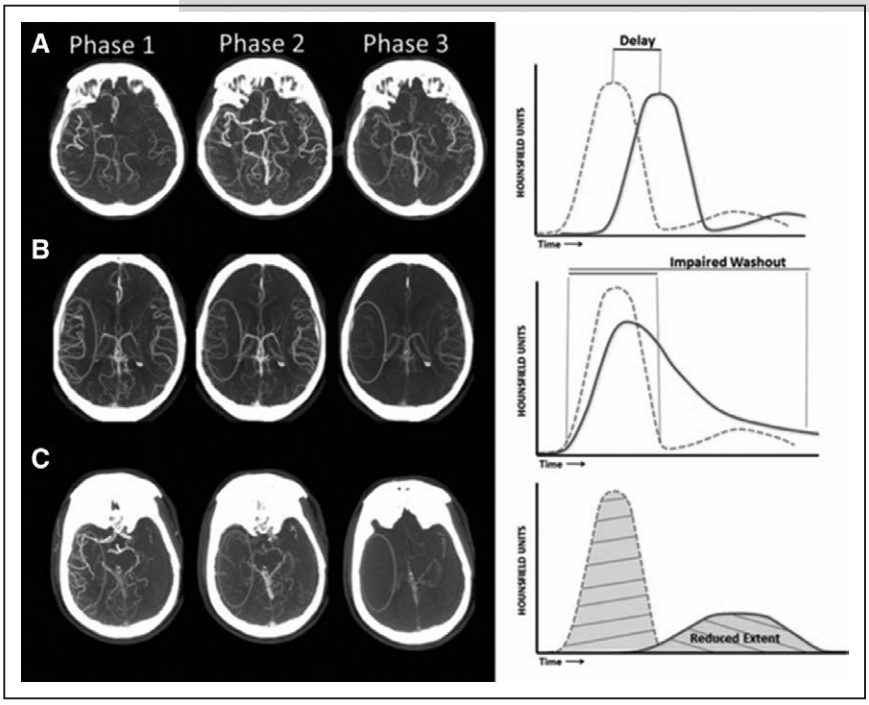

Figure 1. Admission multiphase computed tomographic angiography (mCTA) profiles for (**A**–**C**) 3 patients with L-middle cerebral artery-M1 occlusions, and corresponding hypothetical time–density curves for pial vessel enhancement. Contralateral hemisphere is outlined in blue for all patients and used as reference to ipsilateral enhancement. Delay was assessed by comparing the maximal appearance of CT contrast in the pial vessels in the ischemic region to maximal appearance within the same region within the normal hemisphere. Washout was assessed by comparing the pial vessel enhancement on the third phase mCTA compared with the second phase within each hemisphere. Extent was assessed by comparing the number of pial vessels in a particular ischemic region with the corresponding contralateral hemisphere in all phases of the mCTA acquisition.

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2=intermediate washout, that is, decrease in pial vessel enhancement in the third phase as compared with the second phase; and 3=complete washout, that is, no luminal contrast in the pial vessel enhancement on the third phase.

2. Extent of pial vessel enhancement compared with contralateral hemisphere. Extent was assessed by comparing visually the maximal number of pial vessels in a particular ischemic region across all phases of the mCTA acquisition when compared with the corresponding contralateral hemisphere region.
   1=0% to 50% pial vessels compared with contralateral region; 2=50% to 99% pial vessels compared with the contralateral side; and 3=number of pial vessels indistinguishable from the corresponding contralateral hemisphere region.
3. Delay in maximal pial vessel enhancement across all phases compared with contralateral hemisphere. Delay was assessed by comparing the maximal appearance of CT contrast in the pial vessels in each ipsilesional ischemic region to maximal pial vessel enhancement in the corresponding contralateral hemisphere region and scored as follows: 1=2-phase delay; 2=1-phase delay; and 3=no delay.

Six regions had no contrast filling of pial vessels in all 3 phases. In these regions with 0% pial vessel enhancement, washout and delay could not be scored.

Computed Tomographic Perfusion

Within each ASPECTS region, a gray and white matter tissue mask was manually segmented using the CTP-average image based on individual Hounsfield Unit thresholds. This tissue mask was applied to the CBF, CBV, and Tmax functional maps. Regional gray and white matter perfusion values were extracted from each ASPECTS region, removing any large vessels.[9]

Recanalization/Reperfusion

The last run of the digital subtraction angiography post endovascular treatment was assessed for reperfusion in each of the ASPECTS regions (M2–M6), respectively, using a previously published template for regional assessment of angiographic images.[10] The presence of capillary blush in each ASPECTS region was considered as evidence of reperfusion. A minority of patients (11/77) with either no recanalization (no change in baseline thrombus) or complete recanalization (no thrombus in any pial artery) on repeat CT angiography

Table 1. Demographic, Clinical and Imaging Characteristics of Patients Included in the Study (N=77 Patients and n=385 ASPECTS Regions)

Variables	Central Tendency				
Age, y [mean (SD)]	70.1 (14.3)				
Sex (% female)	54				
Baseline ASPECTS [median (IQR)]	7 (6–9)				
Onset to CT time, m [mean (SD)]	227.9 (258.6)				
Recanalization (modified TICI 2b/3), %	81				
Baseline NIHSS [median (IQR)]	18 (15–23)				
24 h NIHSS [median (IQR)]	10 (4–18)				
	Imaging characteristics				
	M2	M3	M4	M5	M6
Multiphase CTA parameters, N (%)					
Washout					
1=none	26 (35)	7 (9)	0 (0)	14 (18)	5 (6)
2=intermediate	48 (61)	50 (65)	21 (27)	46 (60)	36 (47)
3=complete	3 (4)	20 (26)	56 (73)	17 (22)	36 (47)
Extent					
1=poor	11 (12)	13 (17)	7 (9)	9 (12)	5 (6)
2=intermediate	40 (52)	30 (39)	26 (34)	36 (46)	31 (40)
3=good	26 (36)	34 (44)	44 (57)	32 (42)	41 (54)
Delay					
1=2 phase	7 (9)	3 (4)	0 (0)	6 (7)	3 (4)
2=1 phase	53 (69)	39 (51)	34 (44)	39 (51)	30 (39)
3=none	17 (22)	35 (45)	43 (56)	32 (42)	44 (57)
CT perfusion parameters, mean±SD					
Tmax, s	14.7±6.2	12.6±4.9	11.3±5.7	13.7±6.3	11.7±4.9
Cerebral blood flow, $mL \cdot min^{-1} \cdot (100\ g)^{-1}$	15.2±9.6	14.8±7.1	16.9±8.6	14.6±7.7	15.8±7.2
Cerebral blood volume, $mL \cdot (100\ g)^{-1}$	3.9±1.8	3.3±1.3	3.3±1.4	3.5±1.3	3.4±1.4

ASPECTS indicates Alberta Stroke Program Early CT Score; CTA, computed tomographic angiography; and IQR, interquartile range.

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Circle of Willis done 2 to 4 hours from baseline imaging were also included in this analysis.

Final Tissue Fate

Twenty-four- to 36-hour magnetic resonance diffusion weighted imaging (preferably) or noncontrast CT was assessed to assess extent of infarct in each of the 5 ASPECT regions (M2–M6). Greater than 20% infarction within an ASPECTS region as assessed by 2 experts by consensus was classified as an infarct positive region.

Statistical Analysis

We used a mixed effect logistic regression analysis to study the impact of mCTA and CTP parameters on follow-up infarction while adjusting for patients' clinical and demographic characteristics, and considering the patients and their brain regions (nested within each patient) as random effects variables. The regression models were independently developed for mCTA and CTP modalities separately. The mCTA models were as follows: All imaging parameters adjusted for recanalization/reperfusion and demographic/clinical variables (age, sex, and baseline National Institutes of Health Stroke Scale [NIHSS]; model-1A), adjusted for demographic/clinical variables only (model-2A), adjusted for reperfusion only (model-3A), and only mCTA imaging parameters (model-4A). CTP models were as follows: All imaging parameters adjusted for recanalization/reperfusion and demographic/clinical variables (age, sex, and baseline NIHSS; model-1B), adjusted for demographic/clinical variables only (model-2B), adjusted for recanalization/reperfusion only (model-3B), and only CTP imaging parameters (model-4B). The six regions with 0% pial vessel enhancement did not have any scores for washout and delay and were therefore excluded by default from regression analyses. The effect of each variable was estimated using odds ratios and 95% confidence intervals. Receiver operator characteristic curves were plotted and area under the receiver operator characteristic curve along with 95% confidence intervals were reported for each model. Differences in the area under the receiver operating characteristics of the predictive models for mCTA and CTP parameters were compared using Delong's method.[11] The relationship between mCTA parameters with CTP parameters was assessed using analysis of variance. Reliability between 2 raters in assessing mCTA parameters washout, extent, and delay at the regional level was assessed using unweighted Fleiss's κ. Statistical significance was assessed at α=0.05. All analyses were performed using R (version 3.2.1).

Results

The demographic, clinical, and imaging characteristics of participants are summarized in Table 1. Of the 77 study participants, 42 (54%) were female. The mean age was 70.1 (SD ±14.3) years, with 72% of the patients being 65 years or older. Median NIHSS score was 18 (interquartile range 15–23). Mean onset to CT time was 227.9 (SD ±258.6) minutes. Median baseline ASPECTS was 7 (interquartile range 6–9). Follow-up infarction was assessed using magnetic resonance imaging in 45 of 77 (58.4%) patients, whereas the rest were assessed on CT. All 6 regions with 0% pial vessel enhancement developed follow-up infarction.

Tables 2 and 3 describe the results for the mixed effect logistic regression analysis for the mCTA and CTP models, respectively. Washout parameter on mCTA was significantly associated with follow-up infarction in all mCTA models (P<0.05). The Tmax parameter was significantly associated

Table 2. Odds Ratio (95% CI) for Demographic, Clinical, and mCTA Parameters Associated With Follow-Up Brain Infarction*

Predictors	Model-1A	Model-2A	Model-3A	Model-4A
	Odds Ratio (95% CI)			
Recanalization/reperfusion	0.69 (0.26–1.84)	…	0.55 (0.21–1.47)	…
Demographics/clinical characteristics				
Age	1.90† (0.99–3.64)	1.87† (1.10–3.19)	…	…
Sex	0.89 (0.26–2.98)	0.56 (0.20–1.60)	…	…
NIHSS (baseline)	1.81 (0.94–3.48)	2.07† (1.19–3.62)	…	…
Onset to imaging time	0.74 (0.33–1.61)	1.14 (0.62–2.09)	…	…
Multiphase CTA parameters				
Extent=1 (reference)	1	1	1	1
Extent=2	0.58 (0.10–3.30)	0.79 (0.17–3.71)	0.53 (0.09–3.07)	0.86 (0.18–4.08)
Extent=3	0.28 (0.05–1.73)	0.47 (0.09–2.32)	0.25 (0.04–1.55)	0.47 (0.09–2,36)
Washout=1 (reference)	1	1	1	1
Washout=2	0.26† (0.08–0.81)	0.29† (0.10–0.84)	0.21† (0.07–0.65)	0.23† (0.08–0.68)
Washout=3	0.06† (0.01–0.25)	0.08† (0.02–0.30)	0.05† (0.01–0.20)	0.06† (0.01–0.24)
Delay=1 (reference)	1	1	1	1
Delay=2	0.22 (0.01–5.48)	0.17 (0.01–2.98)	0.24 (0.01–6.94)	0.15 (0.01–3.19)
Delay=3	0.68 (0.02–18.83)	0.48 (0.02–9.59)	0.71 (0.02–22.94)	0.41 (0.02–9.40)
AUC, % (95% CI)	93 (90–96)	92 (90–95)	94 (91–96)	93 (91–96)

AUC indicates area under the receiver operator characteristic curve; CI, confidence interval; CTA, computed tomographic angiography; mCTA, multiphase CTA; and NIHSS, National Institutes of Health Stroke Scale.

*Six regions with 0% pial enhancement were excluded from analysis.

†Significant variable with P<0.05 significance level.

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Table 3. Odds Ratio (95% CI) for Demographic, Clinical, and CTP Parameters Associated With Follow-Up Brain Infarction

Predictors	Model-1B	Model-2B	Model-3B	Model-4B
	Odds Ratio (95% CI)			
Reperfusion	0.81 (0.32–2.07)	…	0.47 (0.20–1.14)	…
Demographics/clinical characteristics				
Age	1.64 (0.92–2.96)	1.62* (1.03–2.55)	…	…
Sex	0.53 (0.16–1.74)	0.60 (0.24–1.51)	…	…
NIHSS (baseline)	1.33 (0.74–2.42)	1.63* (0.74–2.41)	…	…
Onset to CT time	0.86 (0.48–1.53)	1.10 (1.01–2.63)	…	…
CTP parameters				
Tmax	3.85* (1.75–8.44)	3.40* (1.71–6.76)	3.72* (1.72–8.06)	3.51* (1.78–6.97)
CBF	2.01 (0.90–4.50)	2.24* (1.12–4.50)	1.78 (0.80–3.98)	2.08* (1.03–4.17)
CBV	0.69 (0.37–1.30)	0.74 (0.42–1.28)	0.80 (0.43–1.52)	0.81 (0.46–1.42)
AUC, % (95% CI)	91 (87–94)	90 (87–93)	92 (88–95)	91 (88–94)

AUC indicates area under the receiver operator characteristic curve; CBF, cerebral blood flow; CBV, cerebral blood volume; CI, confidence interval; CT, computed tomographic; CTP, CT perfusion; and NIHSS, National Institutes of Health Stroke Scale.
*Significant variable with $P<0.05$ significance level.

with follow-up infarction in all CTP models ($P<0.05$). The area under the receiver operating characteristics for mCTA models ranged between 92% and 94%, whereas all CTP models had an area under the receiver operating characteristics between 90% and 92%. The addition of recanalization/reperfusion and clinical parameters did not significantly affect the discriminative value of the models. There was no statistically significant difference between mCTA and CTP models (all P values >0.05).

The relationship between mCTA parameters and CTP parameters are shown using box plots (Figure 2). The mean Tmax and CBV values were significantly different between each washout score ($P<0.01$) and each delay score ($P<0.01$), respectively. The mean Tmax, CBF, and CBV values were significantly different between each extent score ($P<0.05$). Washout grade 1 on mCTA corresponds to a Tmax value of around 15 seconds, whereas grade 3 corresponds to a Tmax value of 10 seconds. A 2-phase delay on mCTA corresponds to a Tmax of around 14 seconds, whereas no delay corresponds to a Tmax of around 10 seconds. Comparative mCTA and CTP parameter values across all parameters are shown in Figure 2 and in Table I in the online-only Data Supplement. Interrater reliability for the mCTA parameters was highest for washout (κ 0.89; $P<0.01$) followed by delay (κ 0.75; $P<0.01$) and extent (κ 0.60; $P<0.01$).

Discussion

In this analysis, we show that imaging parameters on multiphase CTA are predictive of follow-up infarction regionally in patients with acute ischemic stroke. We also find that mCTA and CTP modalities have similar accuracy in predicting follow-up infarction when using the ASPECTS template and that the mCTA imaging parameters of washout, extent, and delay have comparable values of Tmax, CBF, and CBV on CTP.

The multiphase CTA imaging modality is used to assess pial vessel filling and collateral status in patients with acute ischemic stroke and was successfully used as an imaging selection tool in the ESCAPE trial.[1] Because anterior cerebral artery to middle cerebral artery collaterals are likely different from posterior cerebral artery (posterior cerebral artery–middle cerebral artery) collaterals, the technique has been adapted in the past to assess collateral status and consequent tissue fate in these 2 vascular territories differently.[12] Nonetheless, the ability of multiphase CTA to predict tissue fate in smaller ischemic regions of the brain was as yet unexplored. We recently showed that hang up of contrast within pial vessels on mCTA was more reliable than single phase CTA in detecting distal intracranial occlusions.[6] In the current article, we sought to analyze in detail all available spatial and temporal information in a multiphase CT angiogram using imaging parameters like degree of washout, extent of filling, and delay in filling of contrast within pial arteries over time. Conceptually, these mCTA imaging parameters are very similar to the CTP parameters of transit time delay, blood volume, and blood flow (Figure 1).

Our results show that the imaging parameter washout on mCTA correlates with follow-up infarction in acute ischemic stroke patients. Washout is a measure of the local perfusion pressure (inversely proportional to mean transit time) at the region. Prolonged washout would signify an ischemic region to which collateral supply is also poor, that is, severe ischemia. Interestingly, the CTP measure that best correlated with follow-up infarction in our analysis was also a measure that is the summation of T_0 (difference in contrast appearance time in the artery and region) and mean transit time (a surrogate marker of local perfusion pressure), that is, Tmax.[7] The mCTA parameters delay and extent were not independently associated with follow-infarction in our analysis in all models when adjusting for washout. Of note however, all 6 regions with 0% pial vessel enhancement (poor extent) went on to develop infarction on follow-up. Similarly, although CTP parameters CBF (significant in models 2B and 4B alone) and CBV were not independently associated with follow-up infarction in all models

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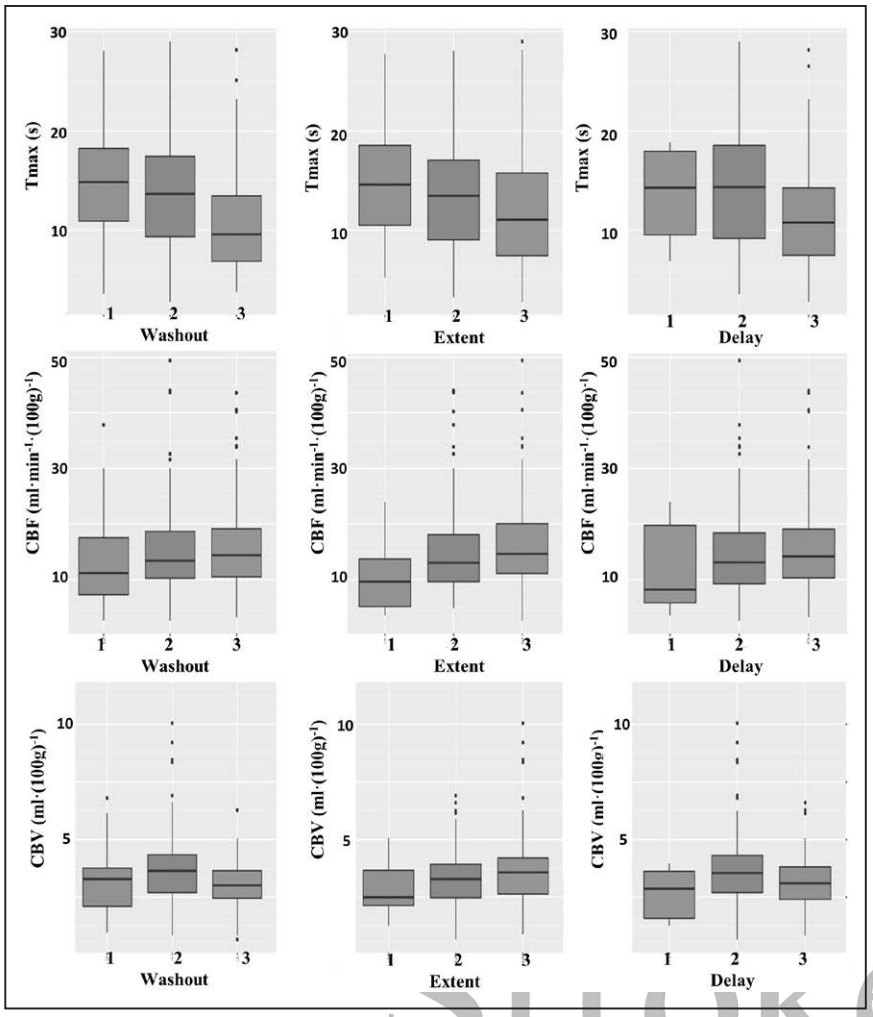

Figure 2. Box plots for the relationship between individual multiphase computed tomographic angiography parameters: washout, extent, and delay respectively, and individual computed tomographic perfusion parameters: Tmax (s), cerebral blood flow (CBF; mL·min⁻1·(100 g)⁻¹), and cerebral blood volume (CBV; mL·(100 g)⁻¹).

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when adjusting for Tmax, this may be because of colinearity with Tmax and our approach of estimating mean values of CTP parameters within ASPECTS regions rather than at a voxel level.

The regional assessment approach is conceptually all that may be required for acute decision making. It may not be necessary to know exact volumes for clinical decision making, more so because of the inherent measurement uncertainty. Although on average, poor clinical outcome is observed with predicted ischemic core volumes of 70 mL or greater, regional assessment of pial vessel filling may be equally useful.[13–15] Our analysis suggests that regions with no pial vessel enhancement are likely to be infarcted on follow-up imaging. Our analysis also shows that mCTA parameters like washout and delay correlate with CTP parameters like Tmax and CBF (Figure 2). Significantly impaired washout or a 2-phase delay in pial vessel filling in ASPECTS regions is likely suggestive of a Tmax >14 to 16 seconds within that same ASPECTS region, whereas quick washout of contrast or no delay in filling of pial vessels when compared with the contralateral side may suggest a regional Tmax of around 8 to 10 seconds (Figure 3). Assessment of mCTA pial vessel filling could therefore provide surrogate regional measures of ischemia status and at risk brain tissue over the time it takes for reperfusion to be achieved.

The mCTA imaging modality has limitations. The presence of poor cardiac output or flow limiting proximal stenosis can cause delay and dispersion in pial vessel contrast filling, potentially confounding measurements that are based on comparison to contralesional normal side. Delay-insensitive deconvolution algorithms in use with CTP potentially correct for some of these problems. The spatial resolution of the mCTA imaging modality is still limited when compared with CT perfusion, especially when trying to predict tissue fate where bone artifact occurs such as the posterior circulation and M1 ASPECTS region, isolated white or deep gray matter ischemia and smaller brain regions than the size of an average ASPECTS region. We limited our sample to middle cerebral artery-M1 occlusions to account for the effect of early recanalization/reperfusion on our analysis. Future study would include assessing the ability of the mCTA imaging parameters individually and together in predicting regional tissue fate in all patients with acute ischemic stroke (including those with more distal occlusions).

Conclusions

In summary, our analysis shows that the mCTA imaging modality compares well with CTP in ability to predict ischemic tissue fate in ASPECTS regions in patients with major disabling ischemic strokes.

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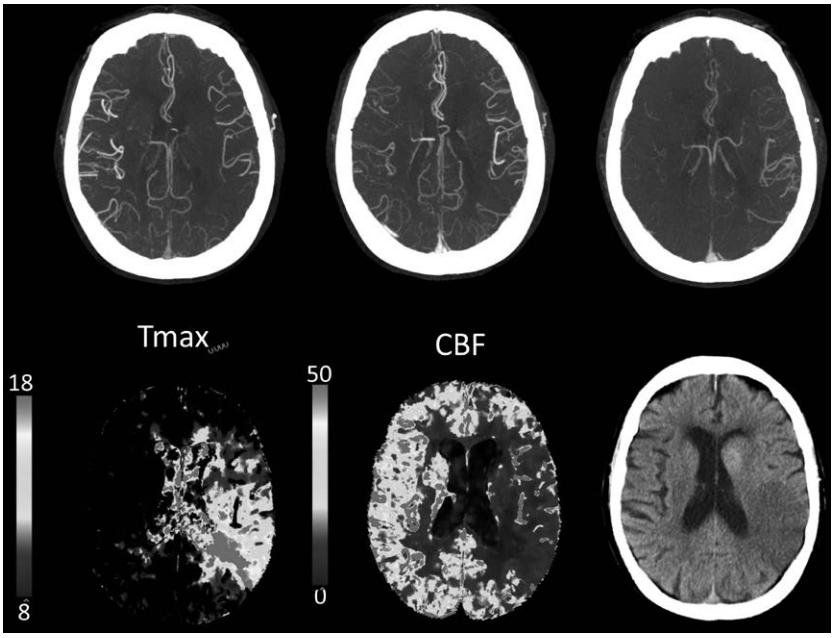

Figure 3. Multiphase computed tomographic angiography (mCTA; 3 phases) maximum intensity projection images and computed tomographic perfusion (CTP) functional maps performed at 2 h 57 min post symptom onset for a patient with baseline NIHSS of 13 and left middle cerebral artery M1 segment occlusion. The multiphase CTA scoring within M4–M6 is congruent with the CTP Tmax profile: the M4 region shows no delay and good washout of contrast filling within pial vessels on mCTA with Tmax≈8–10 s; the M5 region shows 1-phase delay and poor washout on mCTA with Tmax of ≈16 s; the M6 region shows 2-phase delay and reduced extent with Tmax of ≈20 s. Recanalization occurred 96 min post CTP. Follow-up noncontrast CT shows that M5 and M6 regions went on to infarction. Tmax=seconds, cerebral blood flow (CBF)=mL·min^{-1}·(100 g)$^{-1}$.

Acknowledgments

Dr Menon and A. Trivedi conceived the idea of the multiphase computed tomographic angiography parameters and the study design; Drs d'Esterre and Pordeli and M. Najm and M. Boesen contributed to data collection, processing, and analysis; Drs Menon and d'Esterre wrote the first draft; all authors contributed to study design, analysis plan, drafting, and revision of manuscript.

Sources of Funding

This study is funded through an operating grant from the Canadian Institute of Health Research (CIHR). Dr Menon also holds the Heart and Stroke/University of Calgary Professorship in Stroke Imaging and a CIHR New Investigator Award. Dr Lee receives funding from CIHR and Heart and Stroke Foundation of Canada.

Disclosures

Drs Menon, Hill, Goyal, Demchuk, and Lee have a patent pending on systems of triage in acute stroke. Drs d'Esterre, Hill, Goyal, Demchuk, Lee, and Menon hold stock in QuikFlo Health Inc. Dr Goyal has a patent on systems of stroke diagnosis using multiphase computed tomographic angiography and a licensing agreement with GE healthcare for the same. Drs Hill and Goyal have a research grant with Covidien to conduct clinical trials. Dr Lee licenses CT Perfusion software to GE Healthcare. The other authors report no conflicts.

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Regional Comparison of Multiphase Computed Tomographic Angiography and Computed Tomographic Perfusion for Prediction of Tissue Fate in Ischemic Stroke

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Stroke. published online March 14, 2017;
Stroke is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0039-2499. Online ISSN: 1524-4628

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SUPPLEMENTAL MATERIAL

Supplemental Table I. The relationship between individual multi-phase CTA parameters: Washout, Extent, and Delay respectively, and individual CT perfusion parameters: Tmax (s), CBF ($ml \cdot min^{-1} \cdot (100g)^{-1}$) and CBV ($ml \cdot (100g)^{-1}$).

	Washout = 1	**Washout = 2**	**Washout = 3**
Tmax	Mean= 14.55511 Std= 5.488056 Median= 14.8555 IQR= 7.344	Mean= 13.80929 Std= 5.9275 Median= 13.65 IQR= 8.091625	Mean= 10.65667 Std= 4.868693 Median= 9.4544 IQR= 6.579275
CBV	Mean= 3.211273 Std= 1.328878 Median= 3.283525 IQR= 1.662863	Mean= 3.780927 Std= 1.705632 Median= 3.6526 IQR= 1.64375	Mean= 2.993526 Std= 1.030032 Median= 3.0035 IQR= 1.19745
CBF	Mean= 12.903280 Std= 7.804781 Median= 11.161350 IQR= 10.289650	Mean= 15.019148 Std= 7.537569 Median= 13.397600 IQR= 8.419700	Mean= 16.417319 Std= 8.573300 Median= 14.558025 IQR= 8.703400

	Extent = 1	**Extent = 2**	**Extent = 3**
Tmax	Mean= 15.604075 Std= 6.793808 Median= 14.597725 IQR= 8.065075	Mean= 13.190076 Std= 5.683898 Median= 13.447450 IQR= 8.043400	Mean= 12.053282 Std= 5.440430 Median= 11.052575 IQR= 8.342812
CBV	Mean= 2.881314 Std= 1.066064 Median= 2.498925 IQR= 1.522938	Mean= 3.312502 Std= 1.209276 Median= 3.294350 IQR= 1.461400	Mean= 3.634395 Std= 1.753410 Median= 3.573925 IQR= 1.555188

CBF	Mean= 11.006532 Std= 6.857300 Median= 9.644100 IQR= 8.508900	Mean= 14.680405 Std= 7.626666 Median= 13.050000 IQR= 8.510100	Mean= 16.372761 Std= 8.273691 Median= 14.621700 IQR= 8.900100

	Delay = 1	**Delay = 2**	**Delay = 3**
Tmax	Mean= 13.560333 Std= 5.198227 Median= 14.268775 IQR= 8.390612	Mean= 14.154174 Std= 6.235494 Median= 14.116600 IQR= 9.492475	Mean= 11.481586 Std= 4.871097 Median= 10.766550 IQR= 6.777900
CBV	Mean= 2.666475 Std= 1.204763 Median= 2.875000 IQR= 2.044537	Mean= 3.742651 Std= 1.728529 Median= 3.557925 IQR= 1.627050	Mean= 3.144198 Std= 1.148614 Median= 3.100000 IQR= 1.411475
CBF	Mean= 12.090317 Std= 9.056744 Median= 8.195950 IQR= 13.953375	Mean= 14.674766 Std= 7.839999 Median= 13.169700 IQR= 9.071213	Mean= 15.841417 Std= 8.096871 Median= 14.150000 IQR= 8.734450