Innovations in CT imaging of acute stroke: Adding value, reducing dose, improving consistency

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Stroke remains a leading cause of mortality and permanent disability worldwide.[1] Brain imaging plays a crucial role in early diagnosis and yields essential information regarding tissue integrity, a factor that is determinant in identifying patients likely to benefit from thrombolytic therapy. Readily available in most settings, computed tomography (CT) maintains a dominant role in the evaluation of patients with acute stroke. In this paper, we discuss several innovations in perfusion and CT angiography of acute stroke, which have an impact on quality, consistency, and radiation dose.

CT stroke imaging algorithm

A comprehensive stroke imaging protocol commonly includes a noncontrast CT (NCCT), CT perfusion (CTP), and CT angiography (CTA) as part of the pretherapeutic diagnostic work-up. The first diagnostic test for the emergency evaluation of acute stroke, a NCCT is acquired to detect hemorrhage and the presence of infarction. Signs of acute infarction include obscuration of normal brain structures, such as the insular ribbon[2] and lentiform nucleus,[3] hyperdense artery,[4] or in less acute cases, parenchymal hypodensity and mass effect (Figure 1). First level decisions about the appropriateness of thrombolytic therapy in patients with acute stroke are largely based on the findings from CT, as the presence of significant infarction raises the risk of hemorrhage, thus the reader must be sensitive to these often subtle changes that identify acute infarction.

When indicated because of the potential for thrombolysis, a CTP study is performed. Today's CT scanners are capable of whole brain coverage (120-145 mm) via adaptive shuttling techniques or with an extended coverage detector (160 mm). CTP exams are conventionally performed at 80 kVp at a fixed rate of 1 to 4 sec-per-pass over a period of approximately 40 sec.[5-7] Scanning begins 7 to 8 sec after the injection of a contrast bolus of 40 mL of high concentration (370-400) nonionic-iodinated contrast media administered at a rate of 4 to 5 ml/sec, followed by a saline flush of 40 mL at 3 ml/sec.

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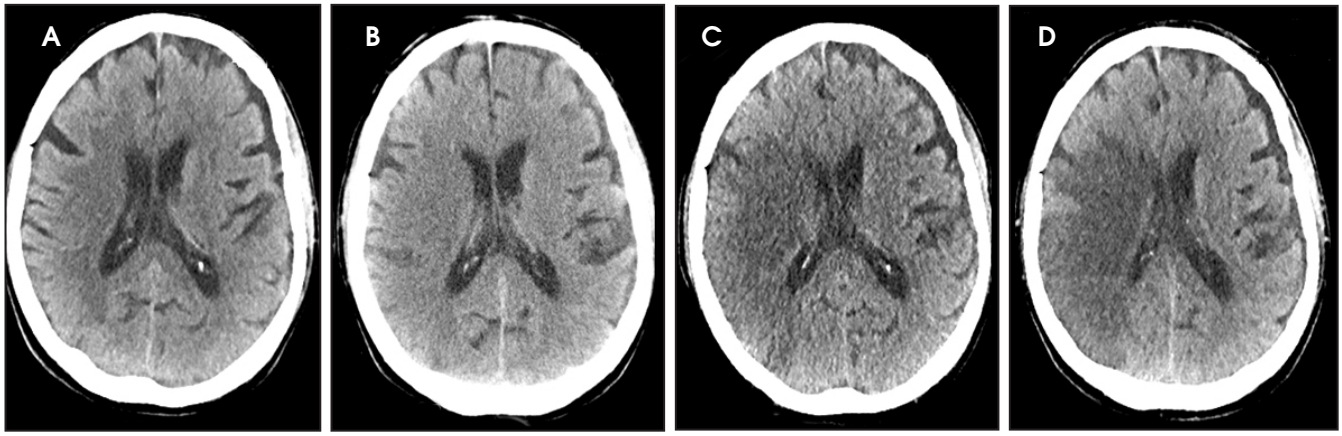

FIGURE 1. *Evolving right MCA infarction. (A) Initial NCCT scan with a routine SAFIRE low-dose CT protocol. (B) Follow-up CT performed at standard dose 8 hours later. Note the subtle obscuration of the gray-white matter interface and poor definition of the caudate. Follow-up (C) ultra-low dose SAFIRE exams 28 hours and (D) 40 hours after the initial exam (A).*

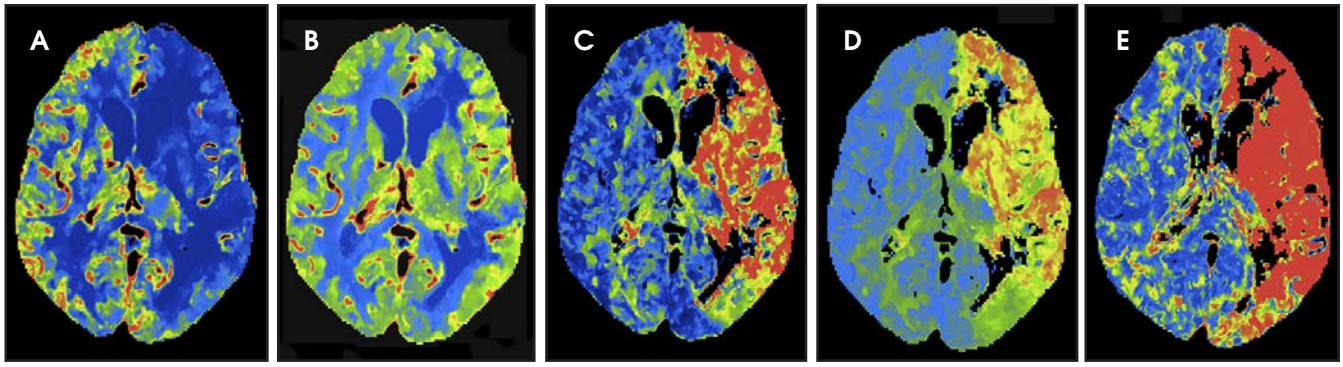

FIGURE 2. *70 kVp CTP left MCA ischemia. (A) Cerebral blood flow (CBF), (B) cerebral blood volume (CBV), (C) time-to-peak (TTP), (D) mean transmit time (MTT), and (E) Tmax. Note the reduced CBF and prolonged transit times associated with preserved CBV consistent with ischemia.*

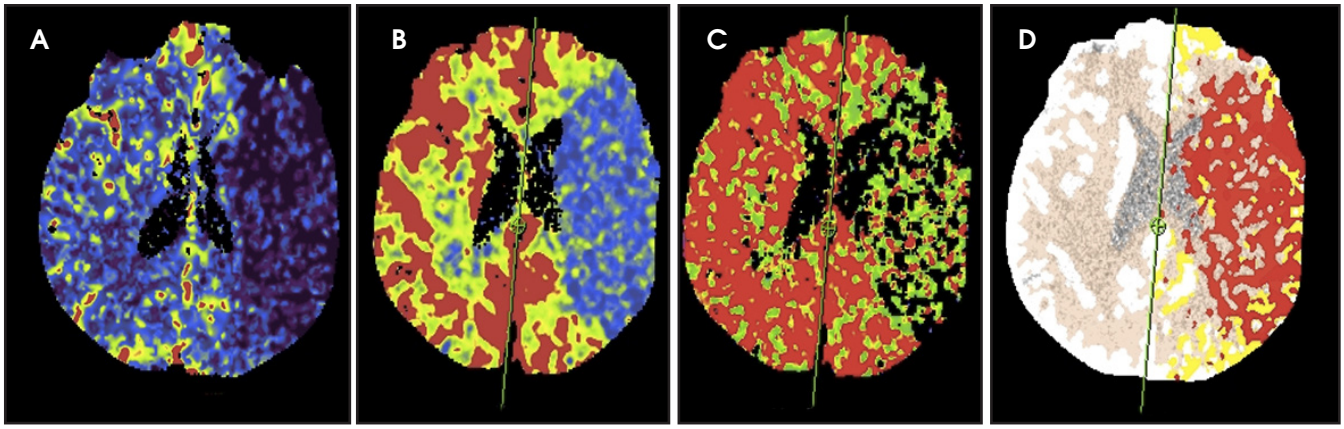

FIGURE 3. *70 kVp CTP left MCA infarct. (A) CBF, (B) CBV, (C) MTT, and (D) tissue characterization. Note the reduced CBF and CBV with prolonged transit times over a slightly larger territory.*

Managing radiation dose

Reducing tube voltage

At present, the widely practiced standard for CTP is 80 kVp at 200 mAs or less.[5,8] Reducing tube voltage has a disproportionate effect on dose (difference roughly squared). Wintermark et al demonstrated that moving CTP to 80 kVp from 120 kVp reduced radiation dose and made contrast enhancement more effective.[5] Recent investigations have shown that reducing kilovoltage to 70 kVp offers additional advantages.[9] Since 70 kVp more closely approximates the iodine k-edge (33.2 KeV),[10] the effective attenuation of contrast increases further. The net result is superior CTP image quality at lower net dose per whole-brain pass. Examples are shown in Figures 2 and 3.

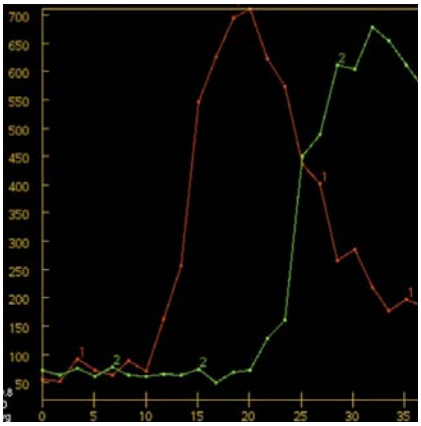

FIGURE 4. *Example of suboptimal contrast circulation capture using standard fixed sampling every 1.7 sec for 39 sec (after an 8 sec delay). Due to physiologic variation there is prolonged sampling before contrast arrival and the scanning window closed before venous return to baseline.*

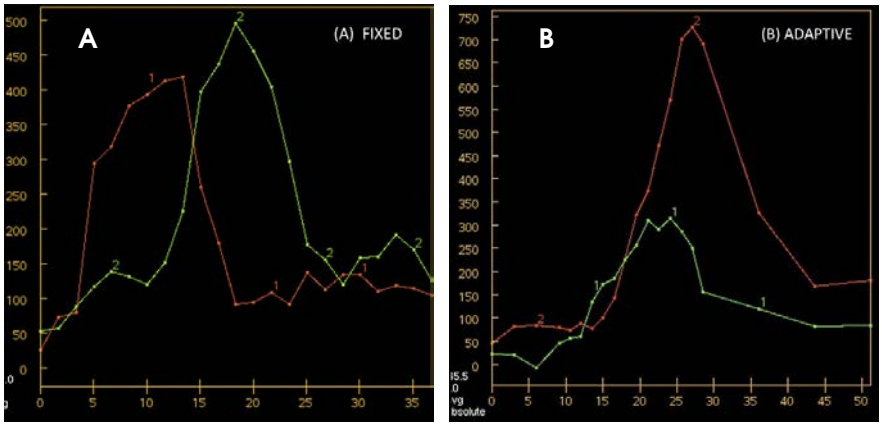

FIGURE 5. *Time attenuation curves for two different temporal sampling schemes: fixed (1.7 sec) (A) and variable (3/1.5/7.5) sec per pass (B).*

Adaptive variable and extended sampling

Overall scan time can be reduced in the interest of dose management. Shorter scan times increase the risk that, due to physiologic factors, such as variability in cardiac output, some exams may not continue through venous return to baseline, challenging calculation of deconvolution-based parametric maps (Figure 4).[11,12] A recent retrospective study by McLellan et al showed that almost 50% of their studies performed with a 'classic' 40 sec protocol do not image the full contrast cycle.[9] Longer sampling periods can provide greater consistency of contrast capture from arterial arrival through venous return over a broad range of cardiac outputs but require an increase in dose.[9]

Wider CTP sampling intervals have also been employed to minimize radiation dose. While sampling rates from 1 to 4 sec have been proposed, the optimal sampling rate remains controversial[6,7,12,13-16] As opposed to traditional fixed sampling approaches, which scan at a uniform rate over the entire CTP acquisition, variable sampling intervals allow strategic flexibility. As certain segments of the contrast passage are likely less critical to sample rapidly, such as the pre-enhancement baseline and the downward slope toward the return to and

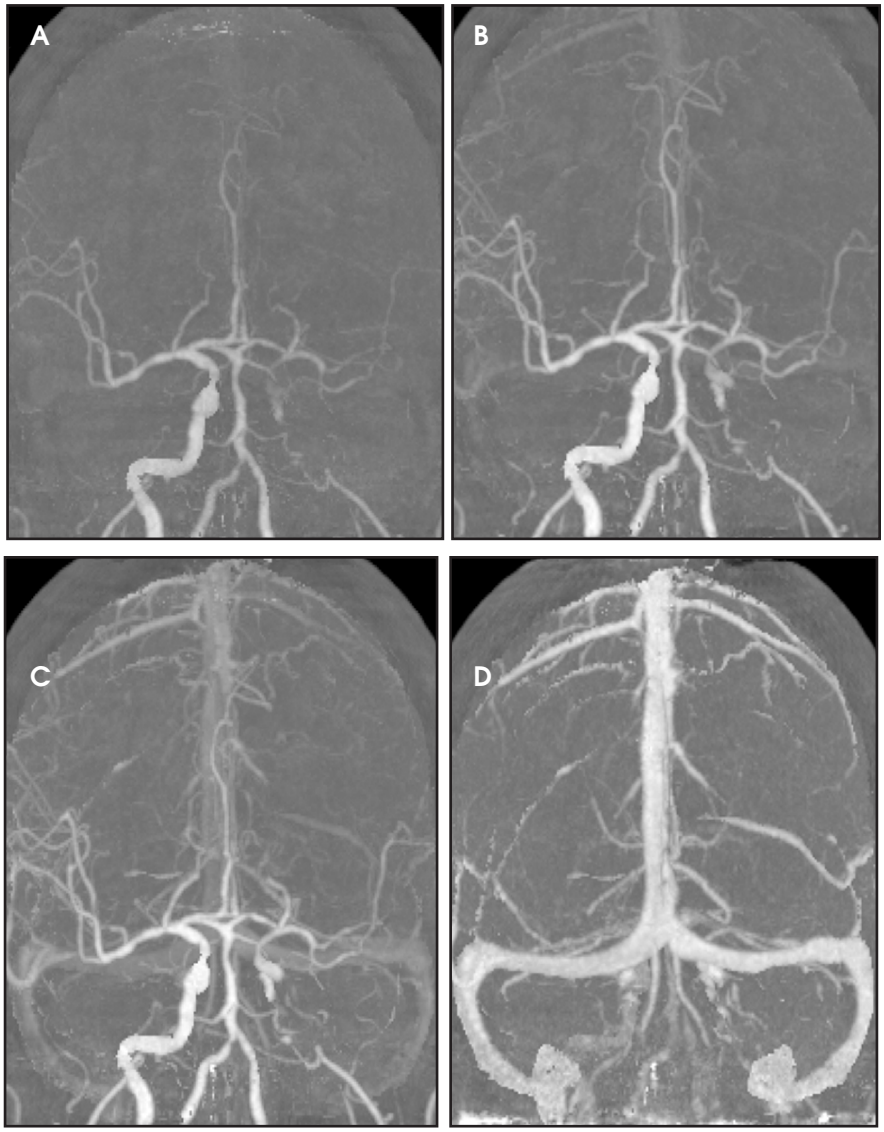

FIGURE 6. *(A - D) Time resolved 4D CTA study (selected frames) extracted from whole brain CTP. Note the left ICA occlusion with progressive cross filling of the left anterior and middle cerebral artery territories and progressive retrograde filling of the left carotid siphon.*

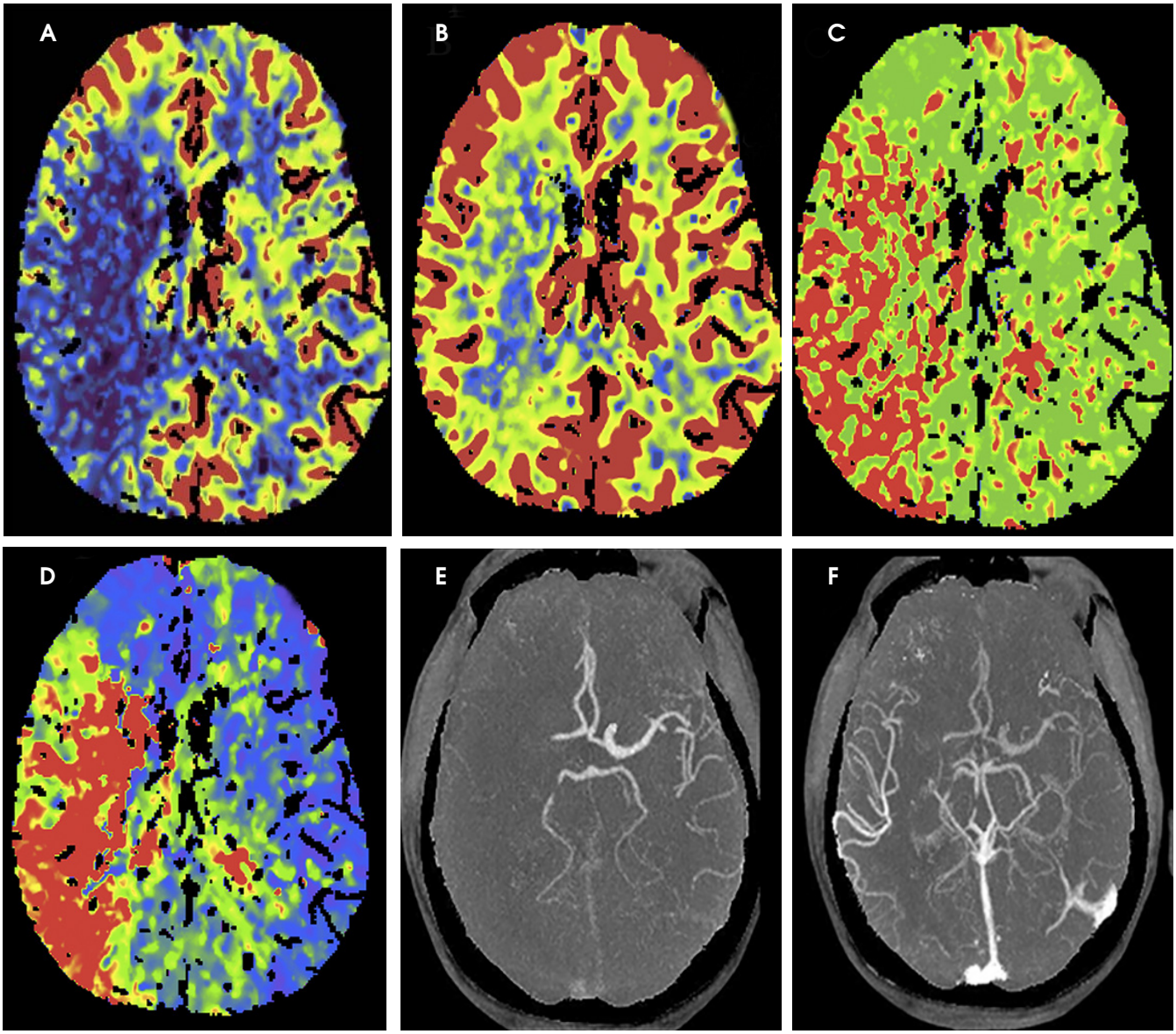

FIGURE 7. *70 kVp CTP study of the same patient shown in Figure 1. (A) CBF, (B) CBV, (C) MTT and (D) Tmax. Note the reduced CBF and CBV and prolonged transit times indicating infarction in the right MCA territory. Early (E) and late (F) phase of 4D CTA extracted from whole brain CTP illustrates occlusion of right M1 with delayed filling and drainage of the distal MCA vasculature.*

through baseline, making fewer passes during these segments is acceptable. The 'omitted' samples can be eliminated for dose reduction or traded for higher temporal resolution during the key periods of arterial tissue passage. Skipped scans can be also be traded for some at wide intervals at the end of the scanning period, affording greater protection against premature termination (Figure 5). Variable CTP sampling has been reported by investigators working with wide 320-channel detector systems with favorable results.[13] Results with a conventional scanner and 4-dimensional (4D) adaptive spiral scanning (Siemens AS+ 128) were recently presented. Employing a 70-kVp protocol with variable sampling intervals, there was improved image quality at reduced dose with greater consistency of full contrast passage capture.[9]

Advances in stroke imaging technique

Time resolved 4D CTA

CT angiography (CTA) can depict the presence and site of stenosis and occlusion and assess collateral flow—influential factors in management decision making. Typically acquired after or before CTP at the cost of additional radiation and iodinated contrast dose, today's whole brain evaluation techniques allow extraction of time resolved (TR) 4D CTA data directly from the CTP study. This not only makes the additional contrast and radiation dose associated with a dedicated CTA unnecessary but provides valuable dynamic vascular information, which can be useful in depicting collateral dynamics and in differentiating stenosis from occlusion (Figures 6 and 7).

Conclusion

Stroke is a leading cause of mortality and permanent disability worldwide.[1] Readily available in most settings, CT remains the dominant modality in the evaluation of patients with acute stroke. CTP and CTA yield essential information regarding tissue integrity, which can be determinant in identifying patients likely to benefit from thrombolytic therapy. With appropriate translation of recent technical advances, such as 70 kVp, variable sampling, and extracted TR CTA, the CT workup can be faster, more reliable, and less x-ray dose intensive.

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