CT Angiography in Acute Stroke?
Do Collaterals Count?

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UCLA

President-Elect, Society of Vascular and Interventional Neurology (SVIN)
President, American Society of Neuroimaging (ASN)
Board of Directors, World Stroke Organization

Neurovascular Imaging Research Core at UCLA

January 24, 2019

Consultant to Genentech, Vesalio, Cerenovus, Stryker and Medtronic

Multimodal CT

- Noncontrast CT as standard in clinical practice of stroke triage for decades

- Triage of ICH cases and thrombolytic decisions for ischemia can be made solely with noncontrast CT

- CTA/CTP provide additional detail regarding vascular lesions and downstream/tissue effects

- Acquisition of CTA/CTP often as simple as noncontrast CT
  - Increasing availability
  - Logistic challenge of additional studies after noncontrast CT

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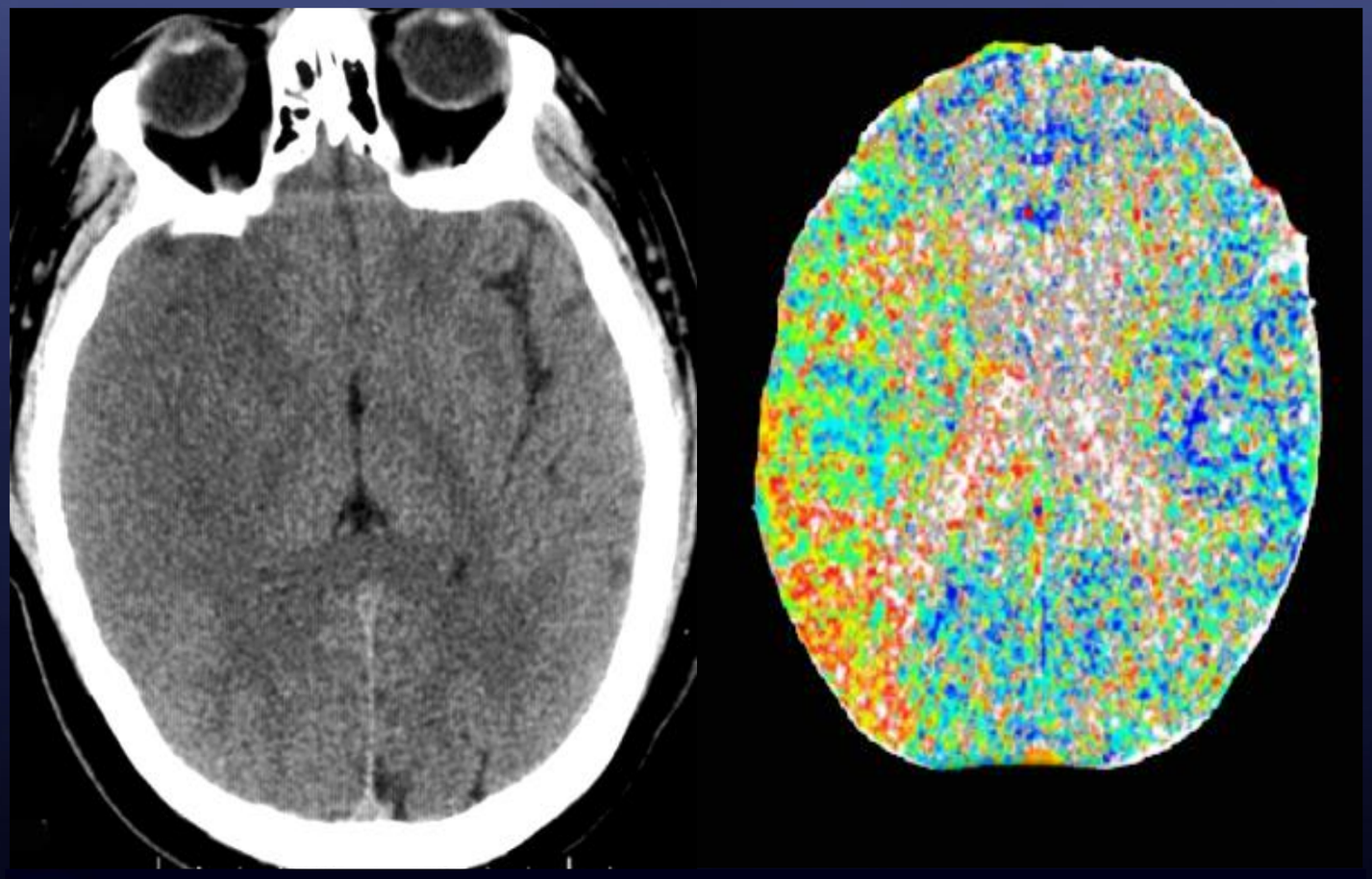
Multimodal CT



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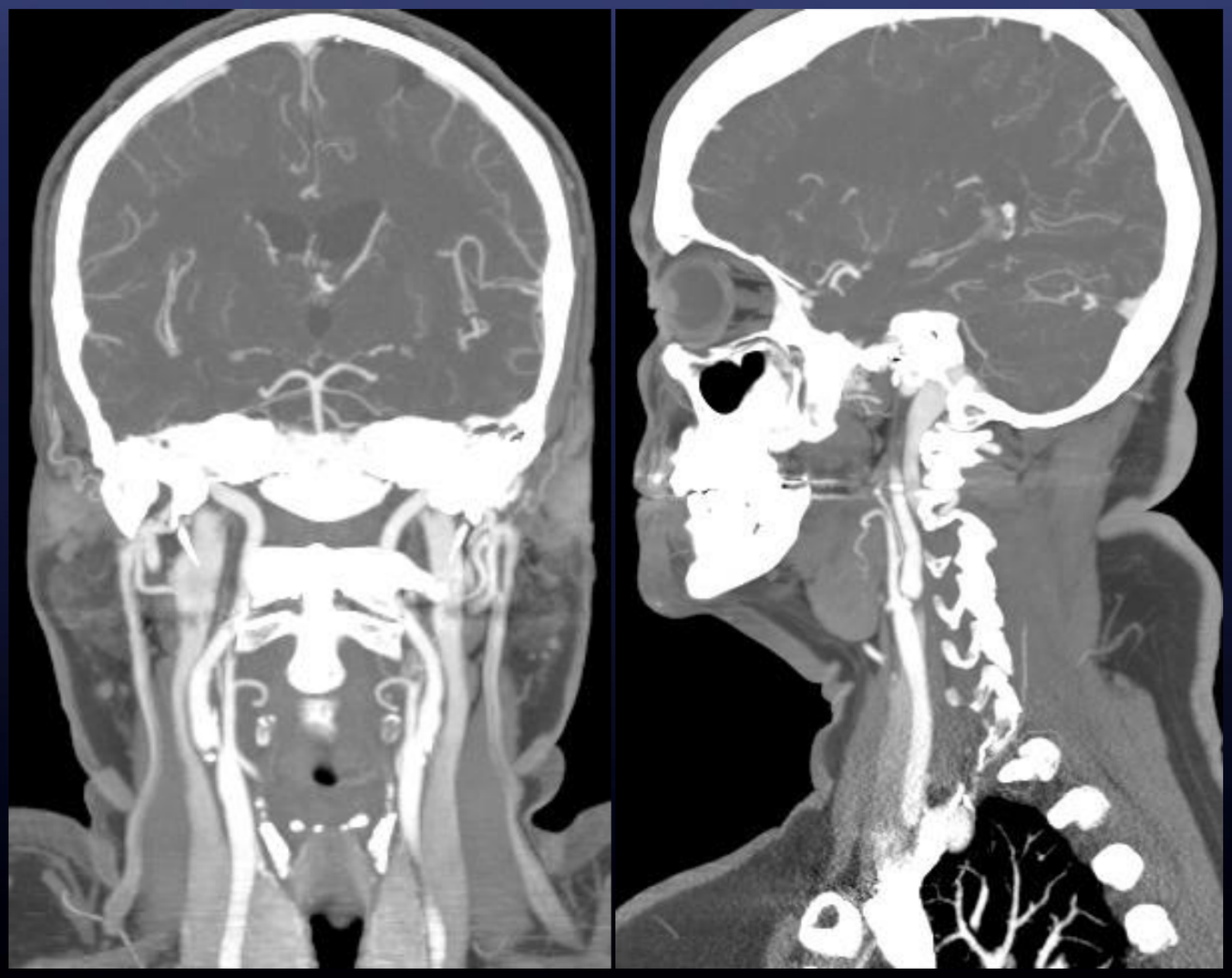
Rapid use of CTA in acute stroke



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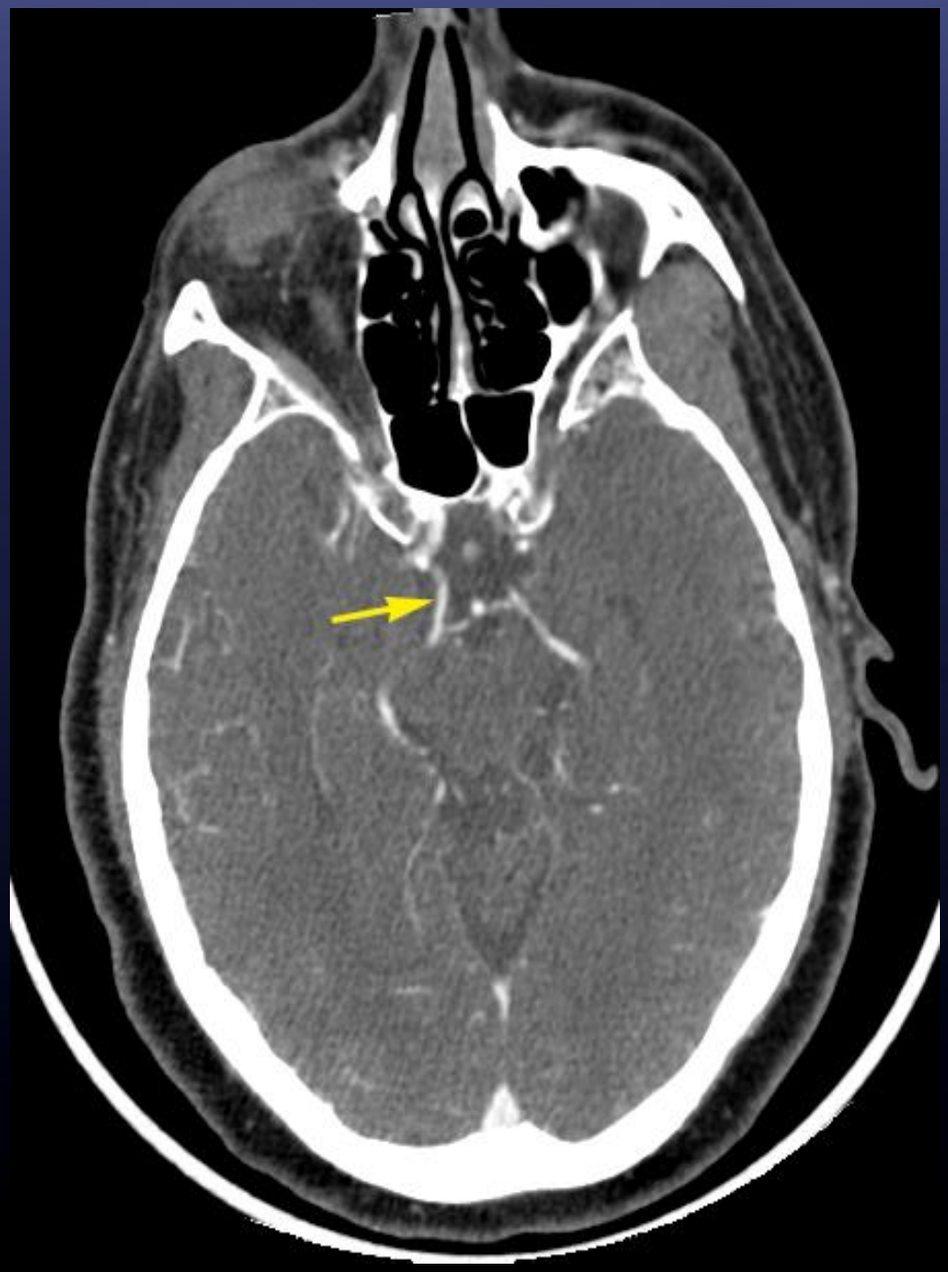
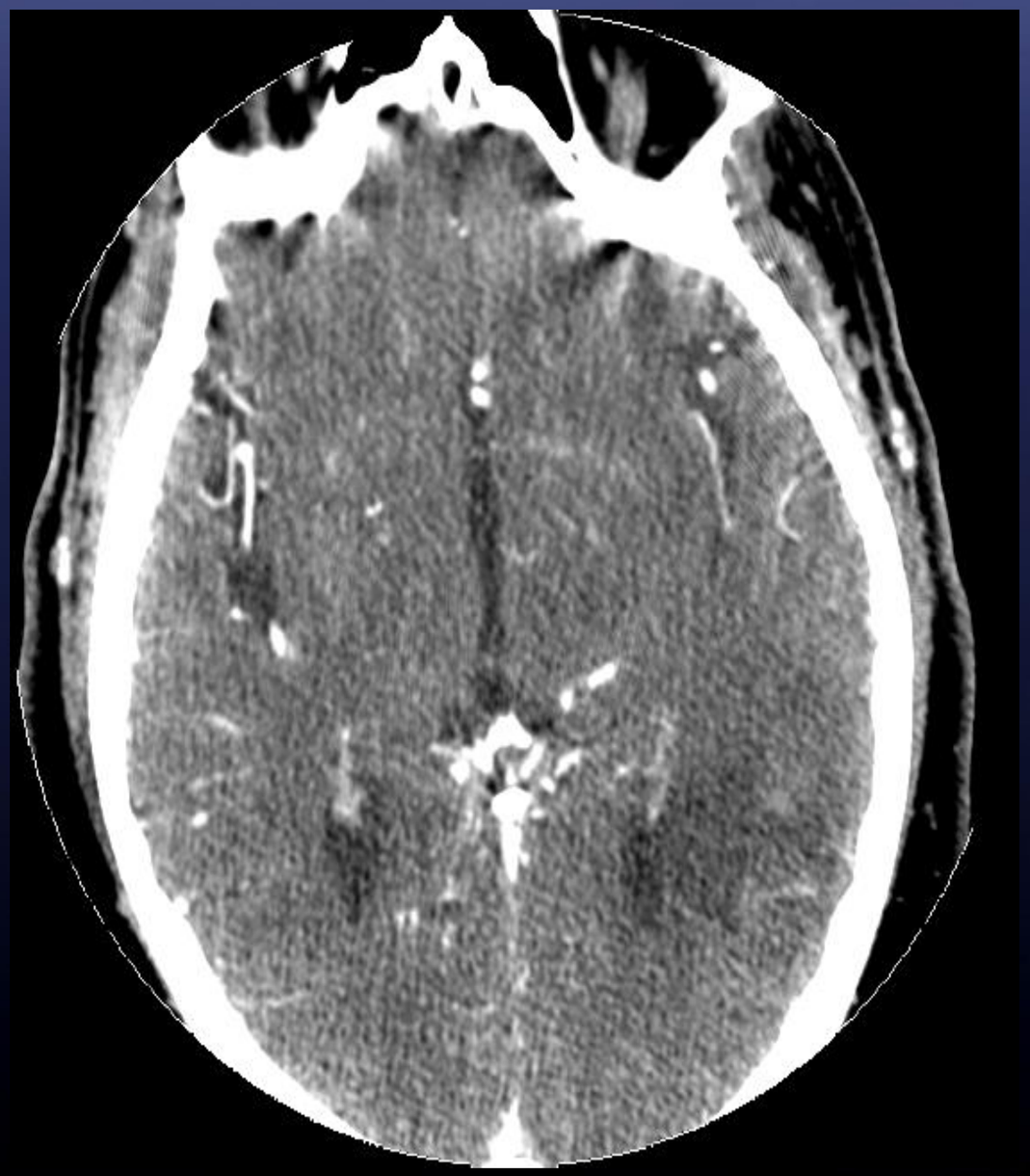
CTA of collateral circulation





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ER, OR, Angio suite, ICU

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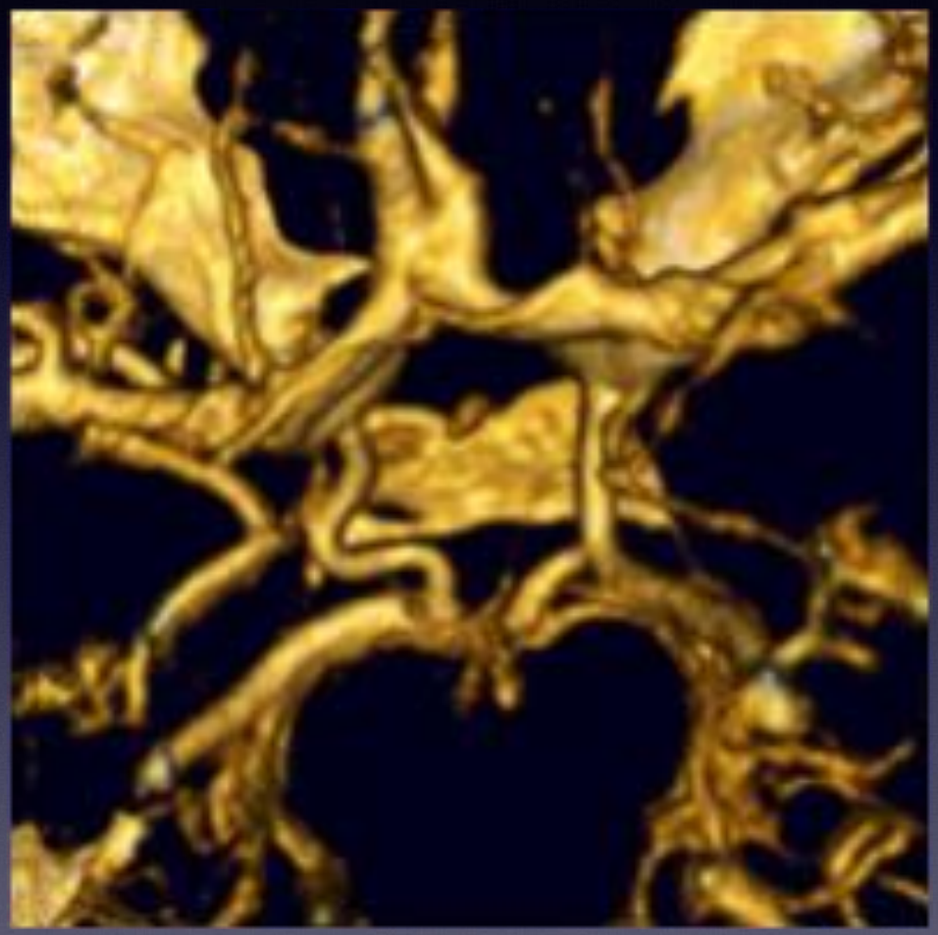
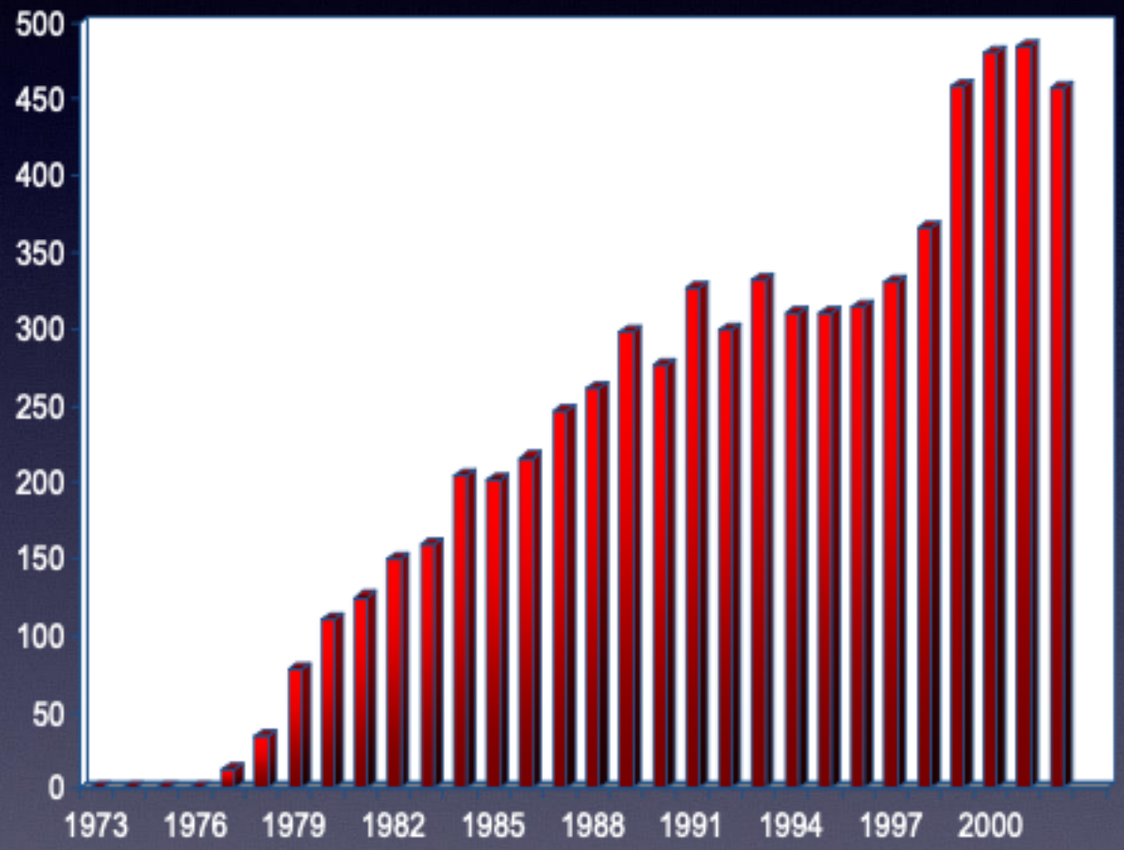
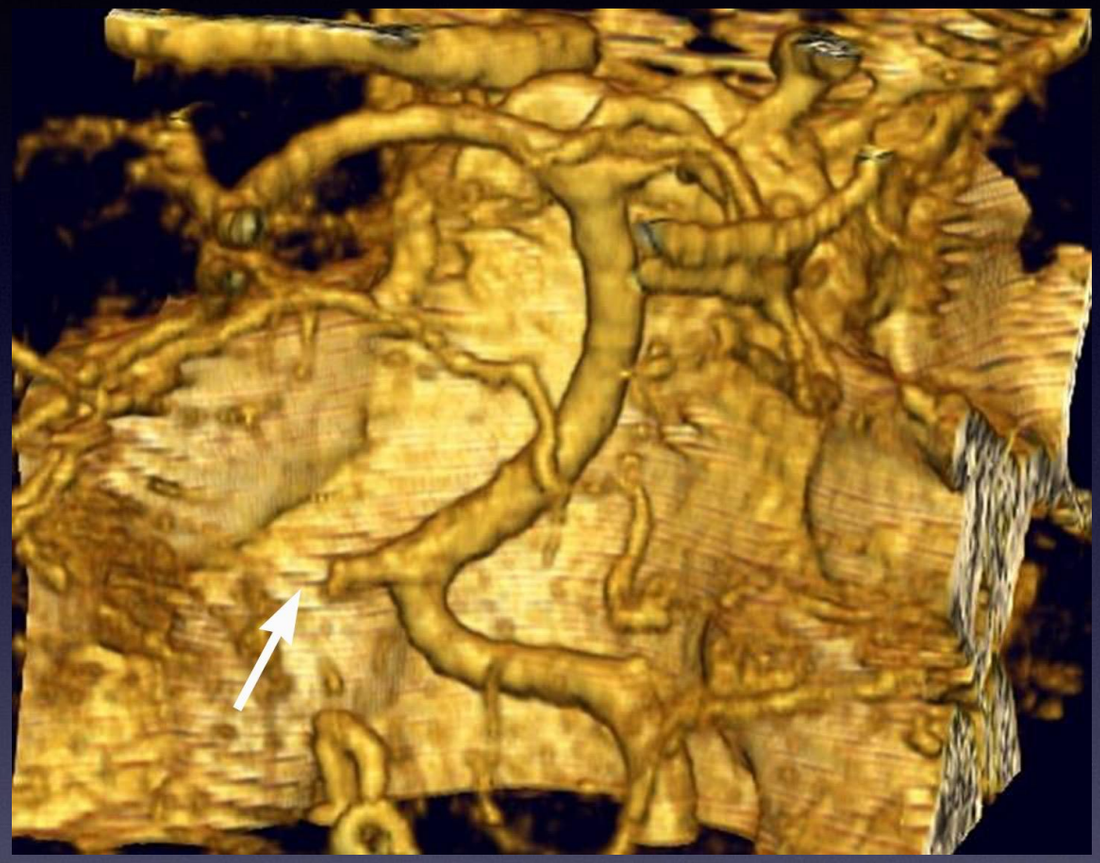
1997 - CTA evolution from CT



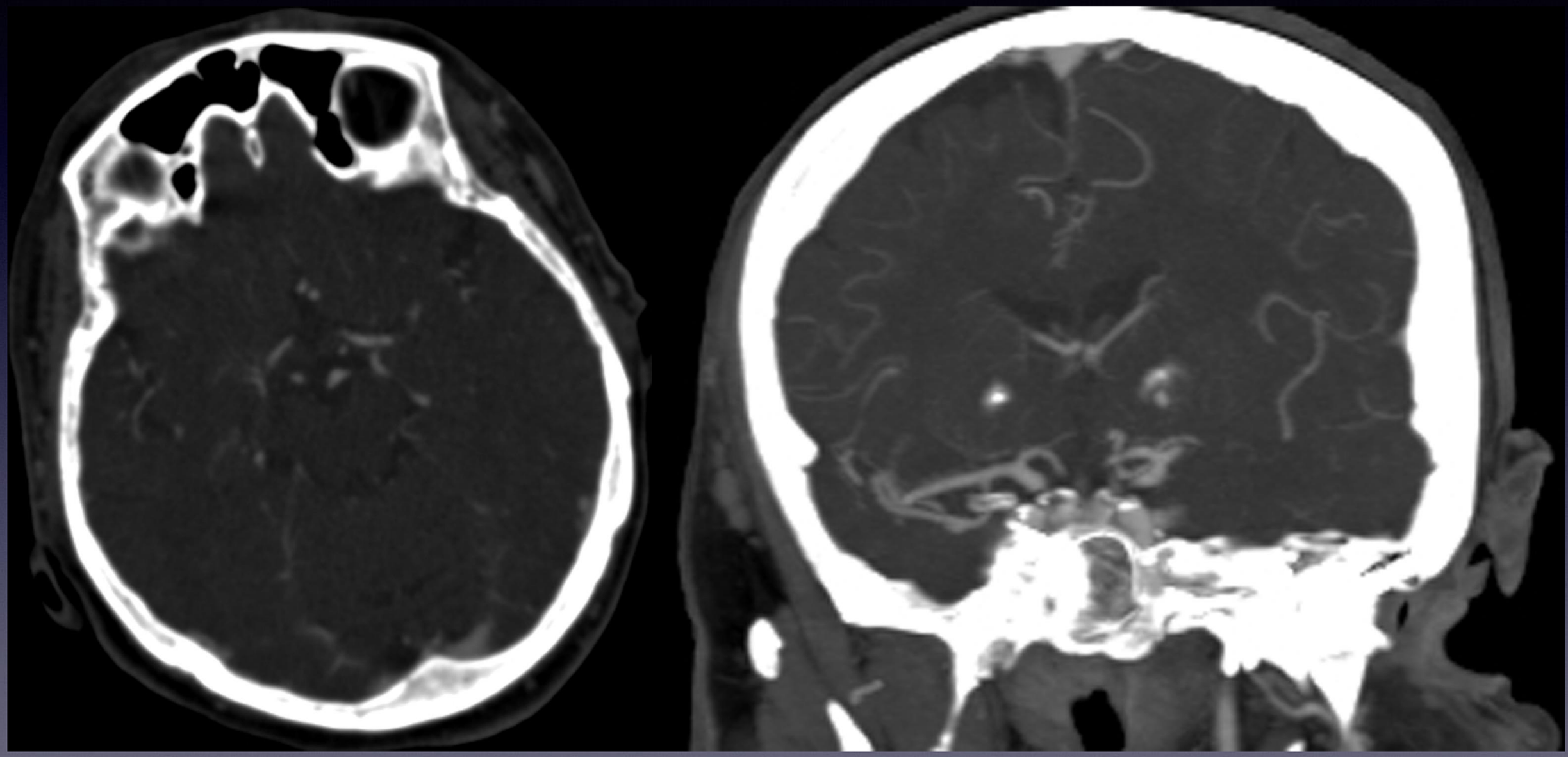


CTA occlusions and collaterals

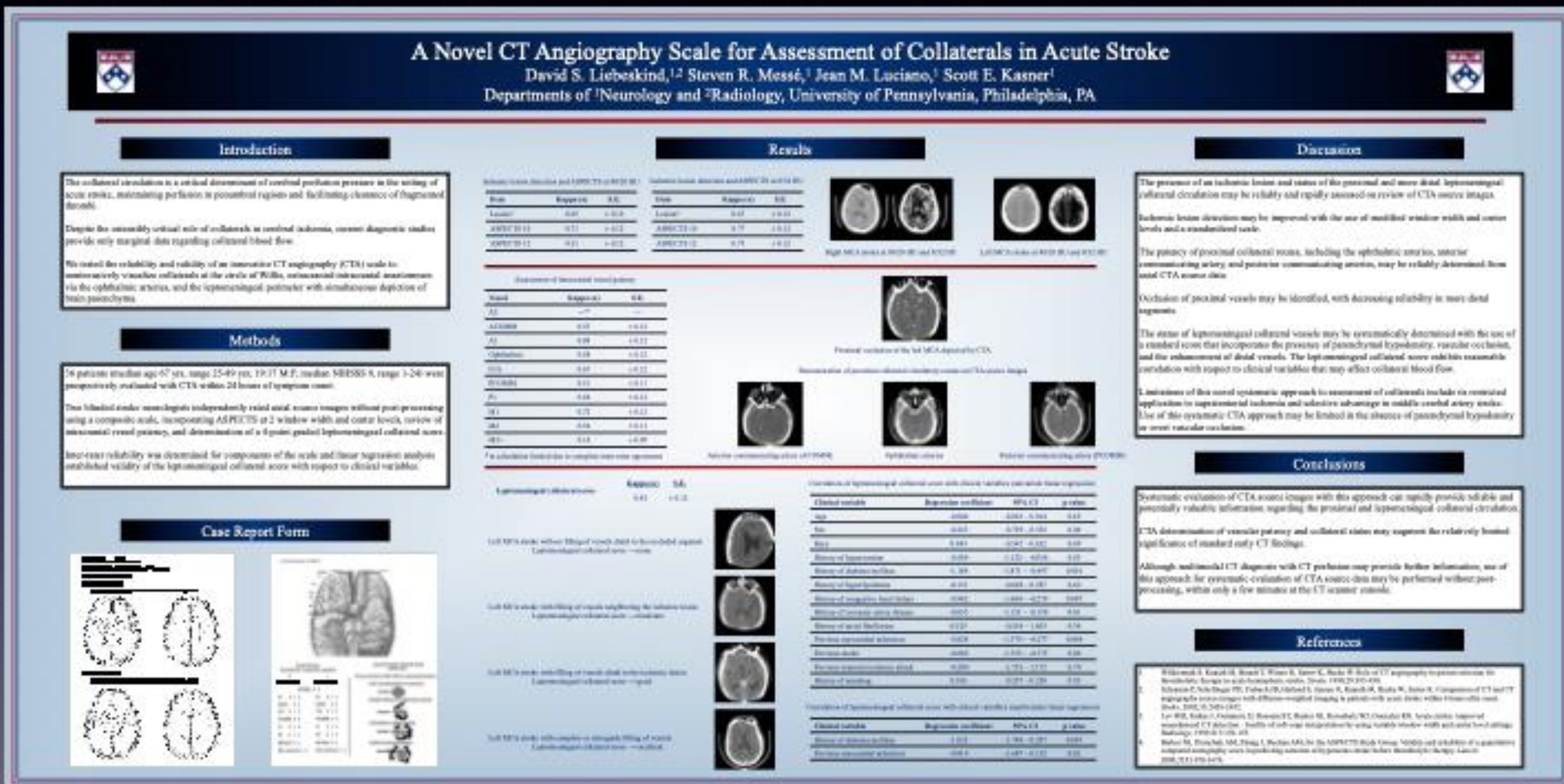


CT angiography in acute stroke

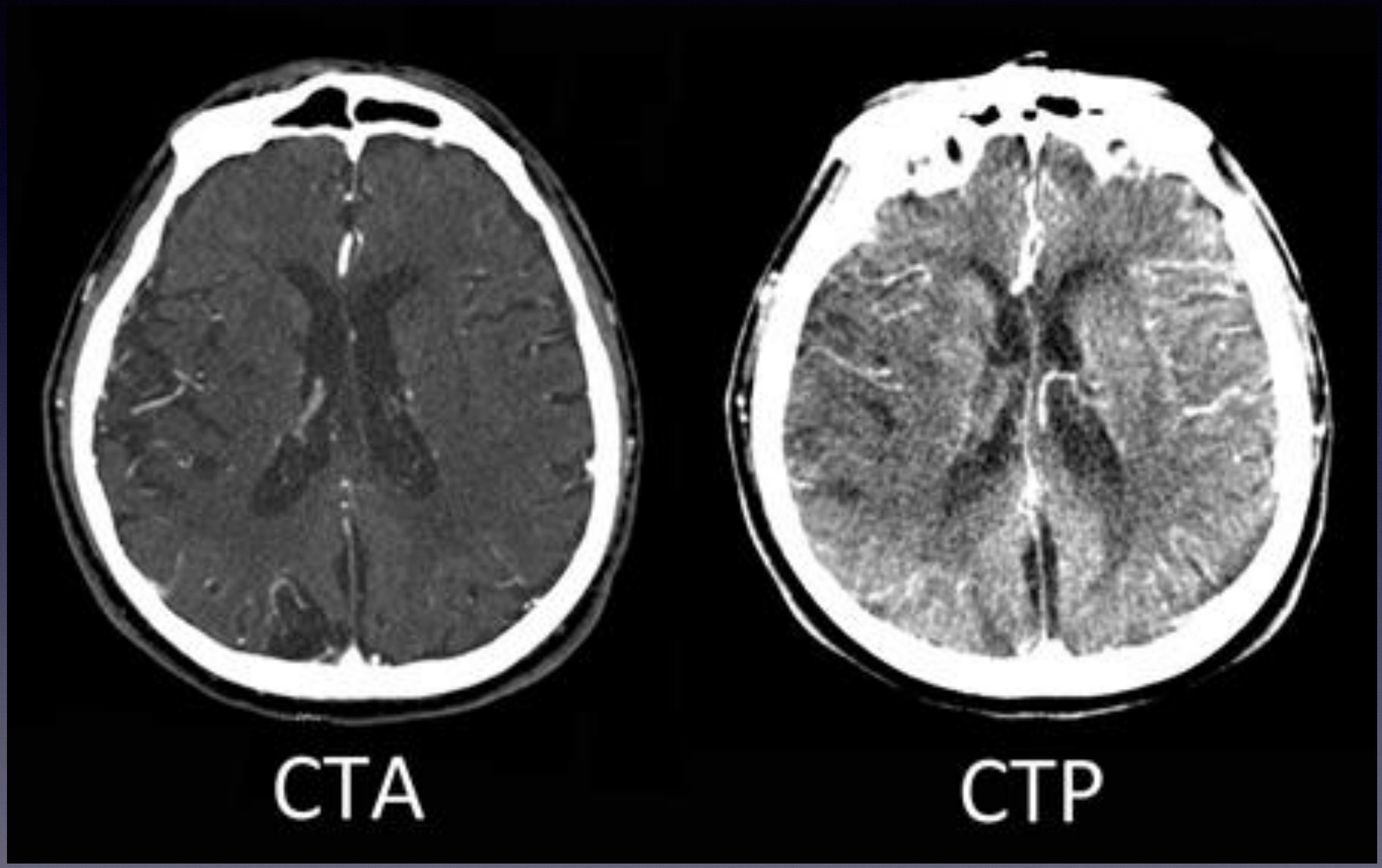
Pitfalls and opportunities



CTA collateral scale circa 2002



CTP complements CTA



CTA of collaterals

Table 3: CT-based collateral scoring methods

Modality	Description	Grading	Author (No.)	Acute (<24 hr from Symptom Onset)/ Non-Acute	Reliability Assessed?	Prognostic Significance of Good Collateral Flow Grade in Acute Stroke
Axial CTA-SI	Extent of perilesional vessel filling	None, moderate, good, excellent	Liebeskind[64] (36)	Acute	Yes, ICC = 0.81	NS
CTA-SI	Comparison of Sylvian collaterals with contralateral hemisphere	Absent, less, equal to, greater than contralateral hemisphere, exuberant	Rosenthal et al[65] (44) Maas et al[66] (135) Lima et al[67] (196)	Acute	No	Beneficial[65-67]
CTA-SI and MPR	Extent of perilesional enhancement	Good, poor	Schramm et al[68] (20) Tan et al[69] (113)	Acute	Yes, κ = 0.494	Beneficial[68,69]
CTA-SI and reconstructions	MCA filling in Sylvian fissure	Good, moderate, absent	Wildermuth et al[70] (40)	Acute	Yes	Beneficial[70,71]
			Knauth et al[71] (21)		88% agreement between 2 raters[71]	
CTA MIP	Extent of filling in territory of occluded vessel	0–3	Tan et al[69] (113)	Acute	Yes	Beneficial[69,72,73]
			Tan et al[72] (85)		κ = 0.669[69], ICC 0.87[72]	
			Soares et al[73] (22)			
CTA, MIP, CTP	Retrograde filling of MCA	Good, moderate, poor	Miteff et al[5] (92)	Acute	Yes	Beneficial
					κ = 0.93	
(TCTP)	Extent of perfusion deficit on TCTP	Severe, moderate	Lee et al[34]	Acute	No	NS

Note:—NS indicates not stated; ICC, intraclass correlation coefficient; CTA-SI, CT angiography source images; MPR, multiplanar reconstruction; MIP, maximum intensity projection; TPCT, triphasic CTP.

CTA - clot burden score (CBS)

Fig. 1 Ten-point clot burden score (CBS): one or two points each (as indicated) are subtracted for absent contrast opacification on computed tomography angiography (CTA) in the infraclinoid internal carotid artery (ICA) (1), supraclinoid ICA (2), proximal M1 segment (2), distal M1 segment (2), M2 branches (one each) and A1 segment (1). The CBS applies only to the symptomatic hemisphere.

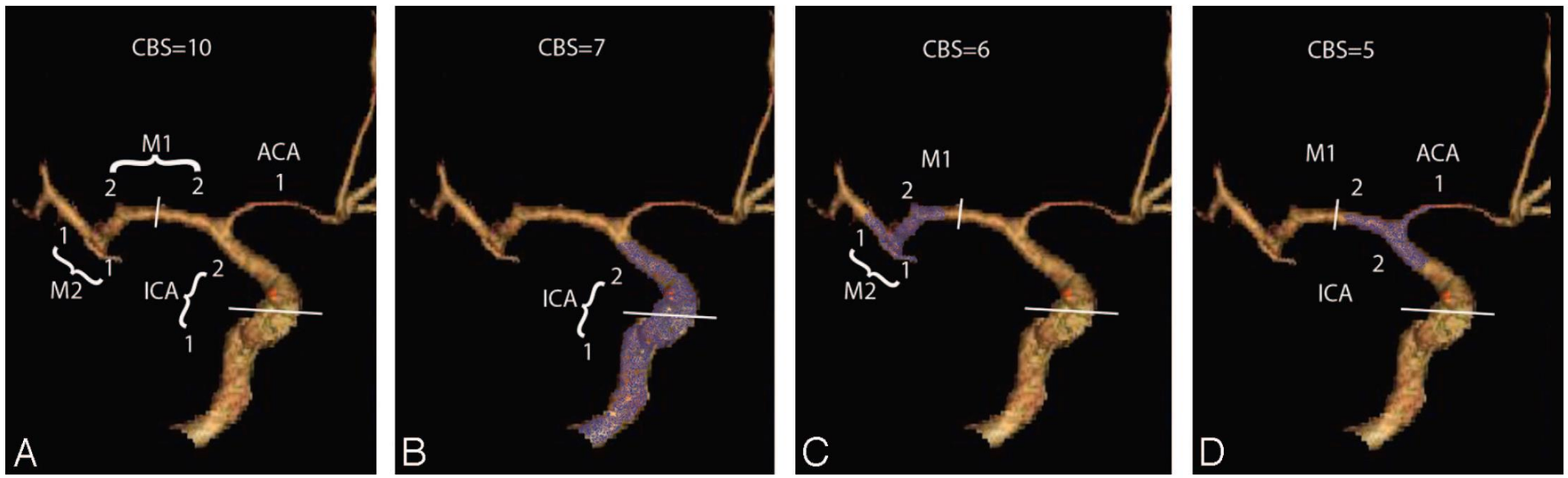
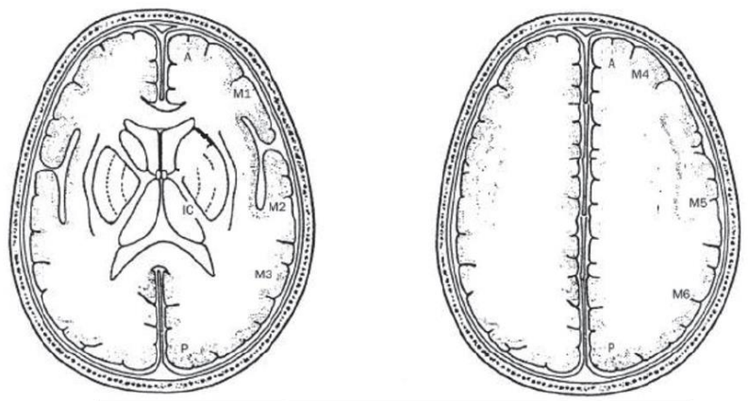


Fig 1. Illustration of CBS. *A*, A 10-point score is normal, implying absence of thrombus. Two points (as indicated) are subtracted for thrombus found on CTA in the supraclinoid ICA and each of the proximal and distal halves of the MCA trunk. One point is subtracted for thrombus found in the infraclinoid ICA and A1 segment and for each affected M2 branch. *B*, Occlusion of infra- and supraclinoid ICAs with a CBS of 7. *C*, Distal M1 and 2 M2 branch occlusions produce a CBS of 6. *D*, Occlusion of the terminal ICA, proximal M1, and A1, with a resultant CBS of 5.

Regional leptomeningeal collateral score (rLMC)



Regions	Score 0 occlusion (0 – artery not seen, 1- less prominent, 2- equal or more prominent when compared to a matching region in the opposite hemisphere)
M1	
Sylvian Sulcus	
M2	
M3	
M4	
M5	
M6	
ACA	
Basal Ganglia	
rLMC score	_____/20

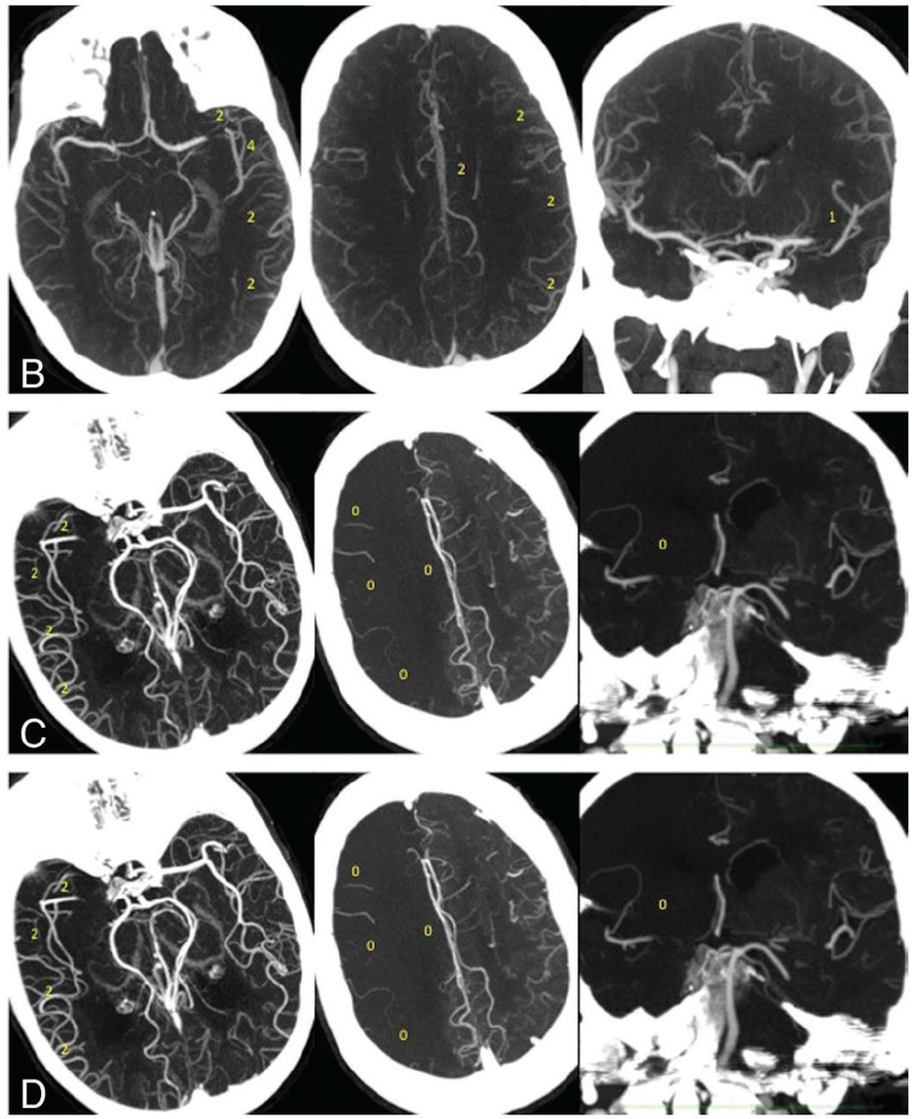


Fig 1. *A*, rLMC score is based on scoring pial and lenticulostriate arteries (0, no; 1, less; 2, equal or more prominent compared with matching region in opposite hemisphere) in 6 ASPECTS regions (M1–6) plus anterior cerebral artery region and basal ganglia. Pial arteries in the Sylvian sulcus are scored 0, 2, or 4. *B*, Left M1 MCA occlusion with prominent retrograde opacification of the pial arteries to the distal end of thrombus. rLMC score is 19. *C*, Right carotid "T occlusion" with patent ipsilateral A2 ACA segment and poor visualization of pial arteries in the right frontal and parietal regions. Note backfilling of pial arteries in the Sylvian sulcus with prominent well-visualized arteries in the temporal regions. Assessment of collateral status based on comparison of arteries in Sylvian sulcus alone suggests good PCA to MCA collaterals in the temporal regions and does not account for the poor PCA to ACA and ACA to MCA collaterals in the frontoparietal regions. rLMC score is 8. *D*, Left M1 MCA occlusion with poor leptomeningeal collateral status. All regions have less prominent or absent arteries. rLMC score is 7.

Multiphase CTA since 2008

ORIGINAL RESEARCH

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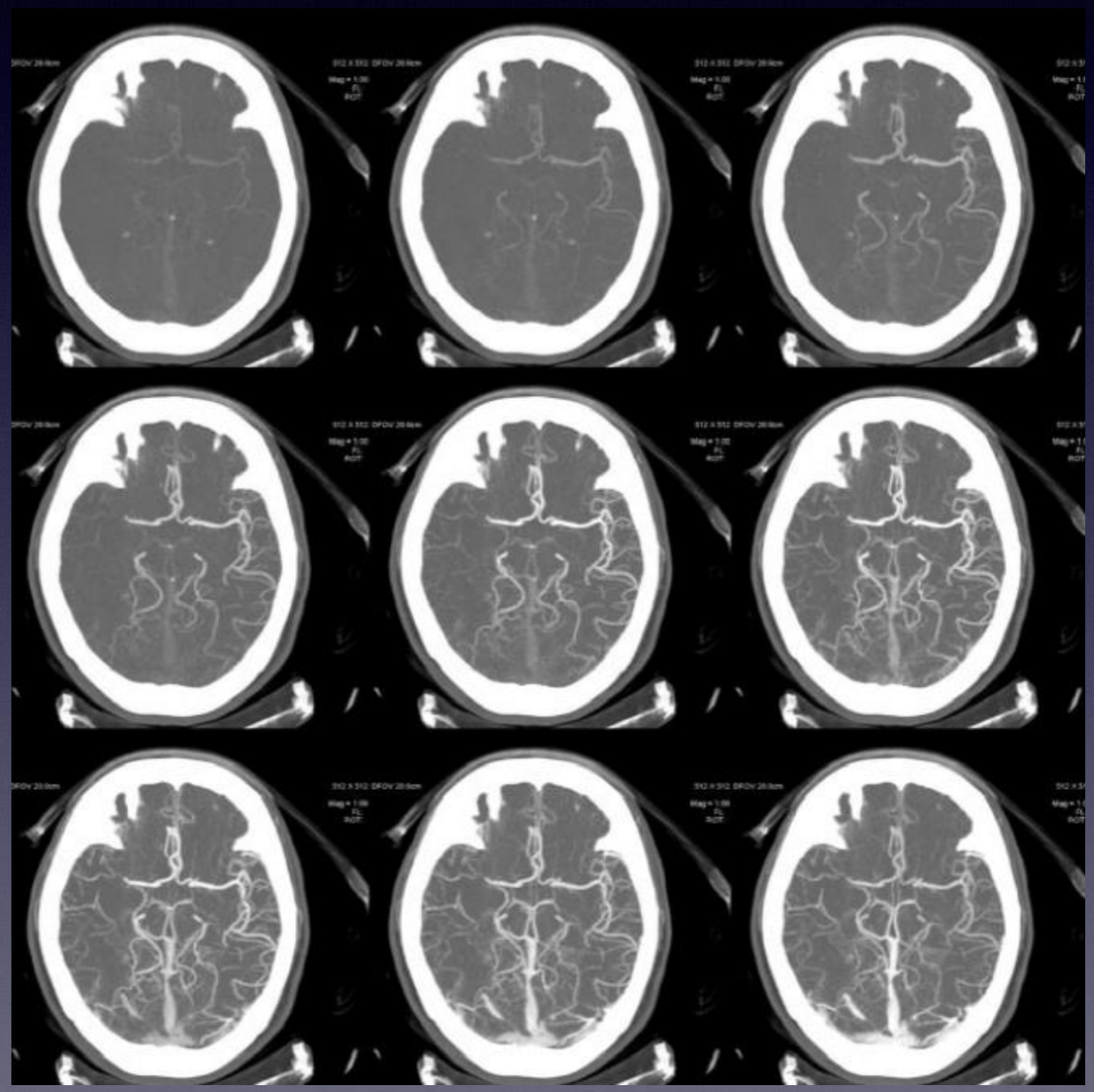
Multiphase CT Angiography versus Single-Phase CT Angiography: Comparison of Image Quality and Radiation Dose

BACKGROUND AND PURPOSE: Conventional CT angiography (CTA) is acquired during only a short interval in the arterial phase, which limits its ability to evaluate the cerebral circulation. Our aim was to compare the image quality and radiation dose of conventional single-phase CTA (SP-CTA) with a multiphase CTA (MP-CTA) algorithm reconstructed from a perfusion CT (PCT) dataset.

MATERIALS AND METHODS: Fifty consecutive patients undergoing head CTA and PCT in 1 examination were enrolled. The PCT dataset was obtained with 40.0-mm-detector coverage, 5.0-mm axial thickness, 80 kilovolt peak (kVp), 180 mA, and 30 mL of contrast medium. MP-CTA was reconstructed from the same PCT dataset with an axial thickness of 0.625 mm by using a new axial reconstruction algorithm. A conventional SP-CTA dataset was obtained with 0.625-mm axial thickness, 120 kVp, 350 mA, and 60 mL of contrast medium. We compared image quality, vascular enhancement, and radiation dose.

RESULTS: SP-CTA and MP-CTA of 50 patients (male/female ratio, 31/19; mean age, 59.25 years) were analyzed. MP-CTA was significantly better than SP-CTA in vascular enhancement ($P = .002$), in the absence of venous contamination ($P = .006$), and was significantly higher in image noise ($P < .001$). MP-CTA used less contrast medium than SP-CTA and could demonstrate hemodynamic information. The effective dose of MP-CTA was 5.73 mSv, which was equal to that in conventional PCT, and it was 3.57 mSv in SP-CTA.

CONCLUSION: It is feasible that MP-CTA may provide both CTA and PCT results. Compared with SP-CTA, MP-CTA provides comparable image quality, better vascular enhancement, hemodynamic information, and more noise with less detail visibility with a lower tube voltage. The radiation dose of MP-CTA is higher than that of SP-CTA, but the dose can be reduced by altering the sampling interval.



Virtual CTP from CTA

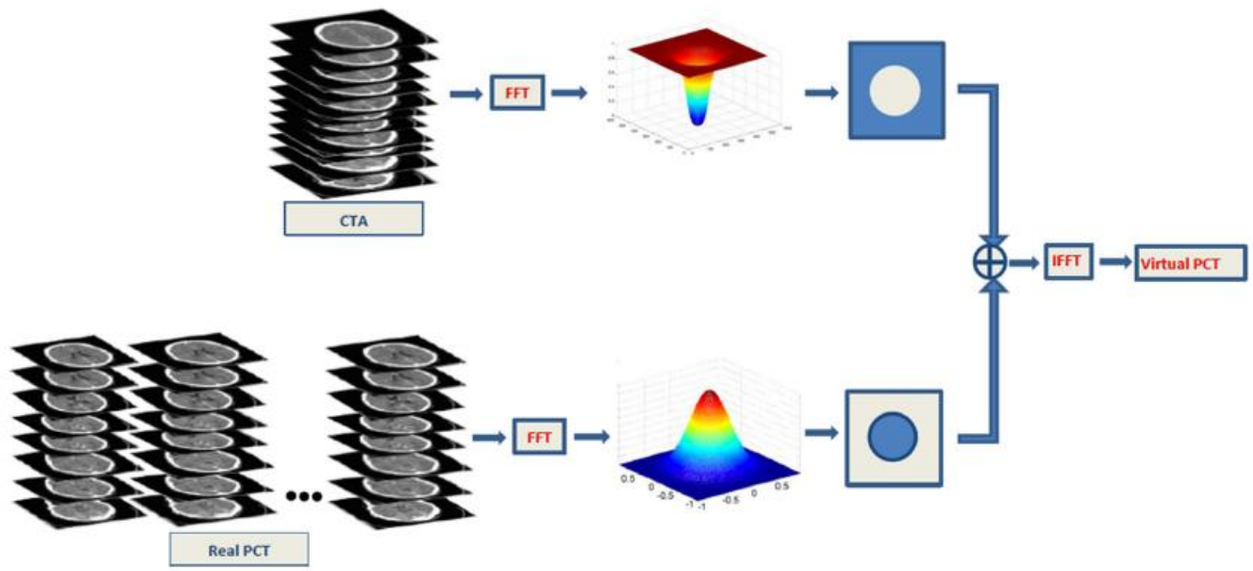


Fig. 1 Virtual PCT schematics. Fast Fourier transform (*FFT*) values of both the PCT and CTA datasets are calculated. High spatial frequencies of the CTA FFT are extracted by applying a high-pass filter, and low spatial frequencies of the PCT FFT are extracted by applying a low-pass filter. A virtual PCT dataset is reconstructed by applying inverse FFT to the combination of the low- and high-pass filter outputs

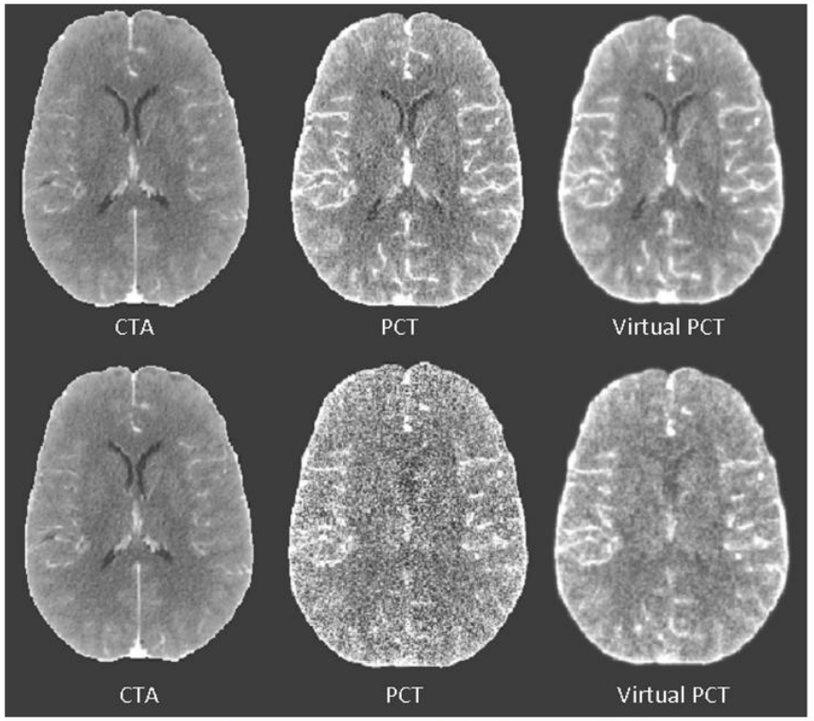


Fig. 4 Regular-dose and simulated low-dose PCT on same patient. *Top row* regular-dose dataset acquired at 100 mAs: *top left* CTA acquired at standard protocol (120 kVp, 200 mAs); *top middle* real PCT acquired at 100 mAs; *top right* virtual PCT reconstructed from real PCT acquired at 100 mAs. *Bottom row* simulated low-dose 10 mAs-equivalent dataset: *bottom left* CTA acquired at standard protocol (120 kVp, 200 mAs); *bottom middle* simulated 10 mAs-equivalent PCT; *bottom right* virtual PCT reconstructed from simulated 10 mAs-equivalent PCT

Dual-phase CTA

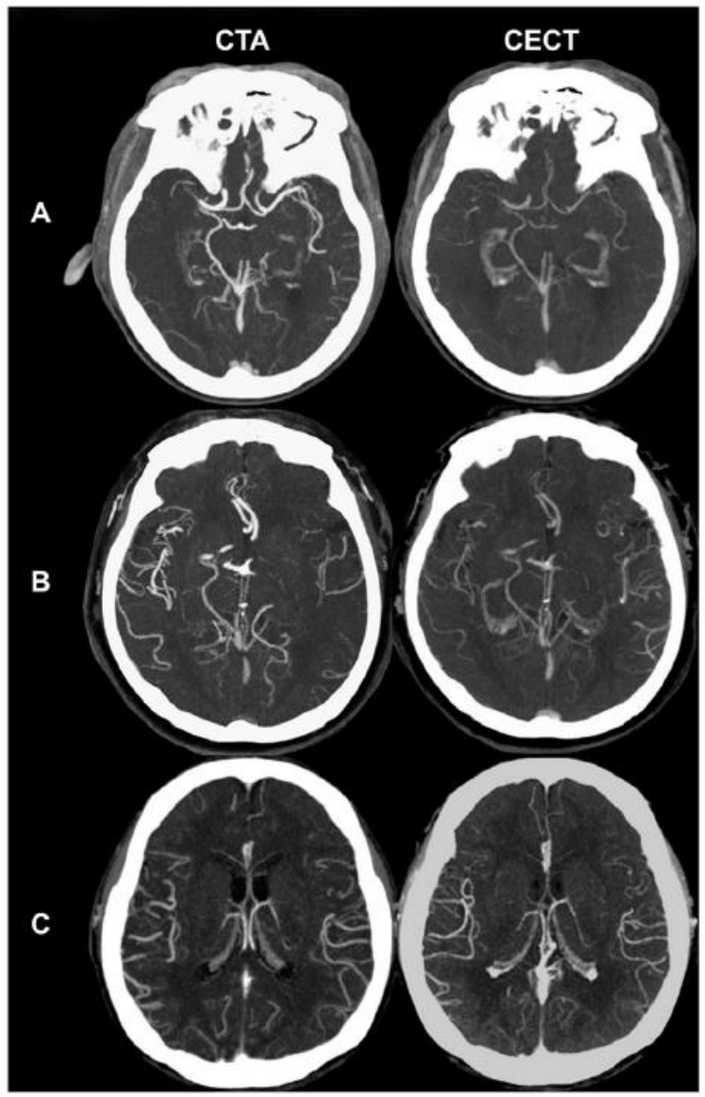
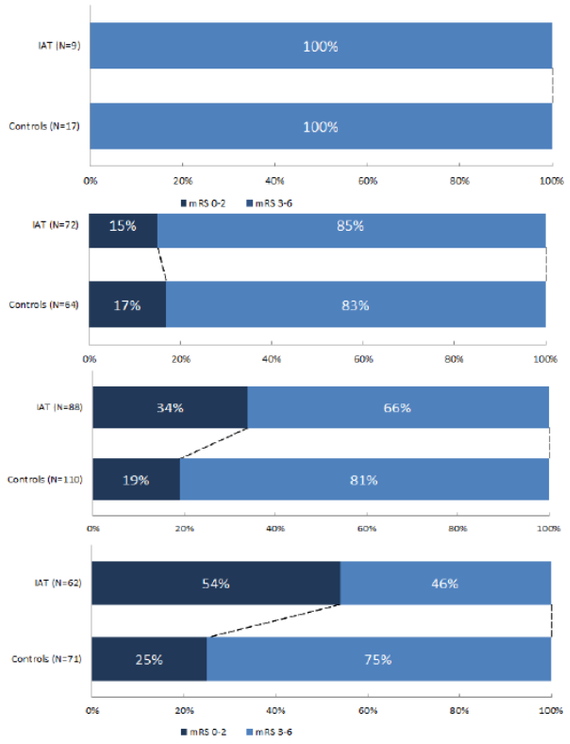


Figure 1. Representative images of collateral status on dual-phase CT. A, Some collaterals to the right MCA territory on CTA with persistence of some defects on CECT (Grade 1). B, Collaterals in part of the left MCA territory on CTA with complete filling on CECT (Grade 2). The collaterals show lower attenuation on CTA with equal to higher attenuation on CECT than unaffected vessels, suggesting slow inflow and washout of collaterals. C, Collaterals in the entire right MCA territory on both CTA and delayed CECT (Grade 3). The collateral vessels show attenuation similar to unaffected vessels on both phase images, suggesting fast velocity of collaterals.
doi:10.1371/journal.pone.0107379.g001

MR CLEAN CTA…

Effect of collateral grade on functional outcome (■mRS 0-2)



Collateral score*
Grade 0 (absent)
Absent filling of occl territory

Grade 1 (poor)
>0 - ≤50% filling

15%

Grade 2 (moderate)
>50-<100% filling

29%

Grade 3 (good)
100% filling

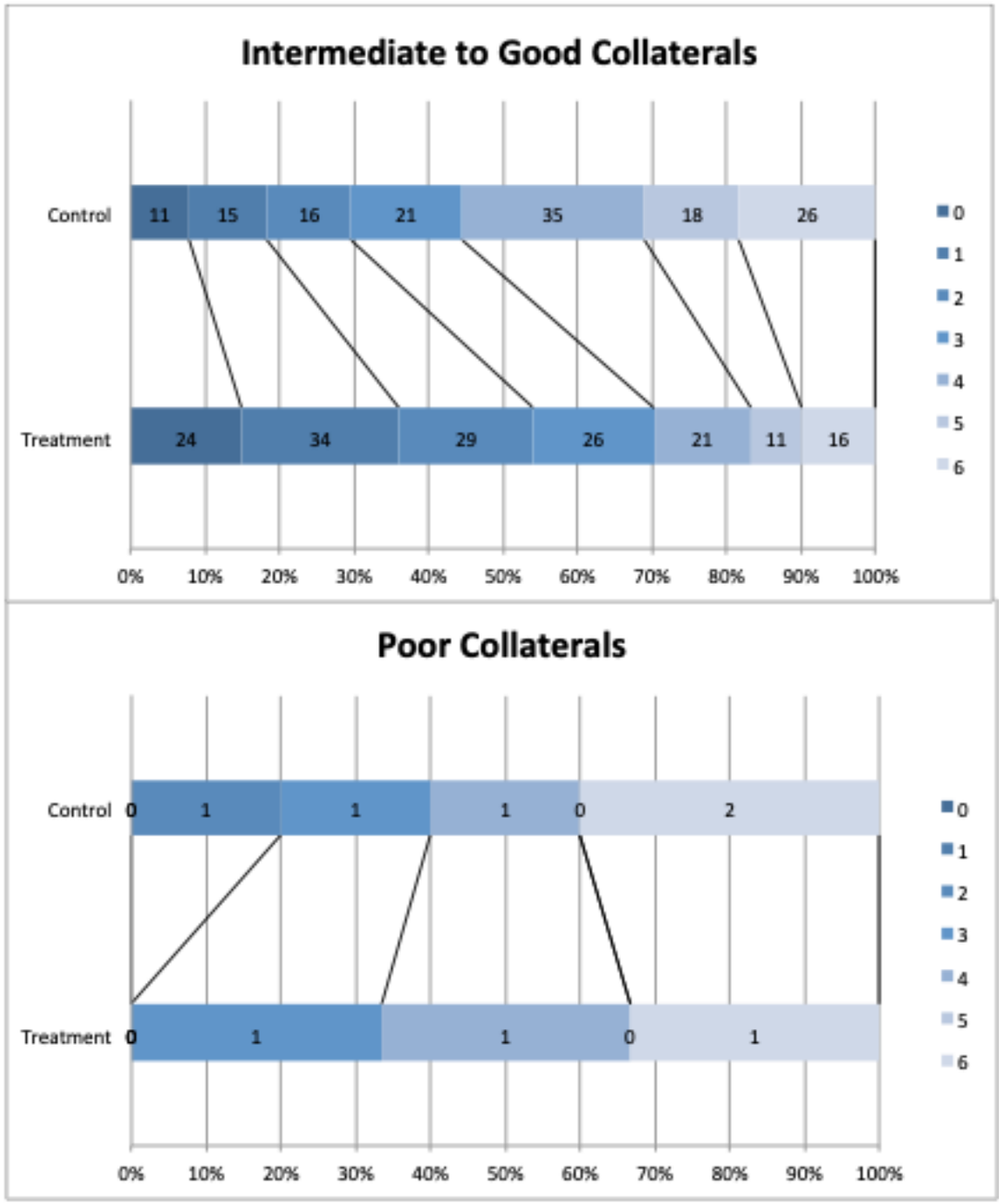
*Tan IY, AJNR 2009

Collaterals: post-hoc analysis safety parameters

Parameter	Grade 0 Absent (n=26)	Grade 1 Poor (n=132)	Grade 2 Moderate (n=198)	Grade 3 Good (n=133)
Death within 7 days - n (%)	10 (38.5%)	27 (19.9)	18 (9.1)	3 (2.3%)
Death within 30 days - n (%)	11 (42.3%)	39 (28.7)	27 (13.6)	14 (10.5%)
Progression of Ischemic Stroke - n (%)	13 (50.0%)	37 (27.2)	30 (15.2)	14 (10.5%)

ESCAPE CTA…

ESCAPE criteria
Collaterals



P<0.0001

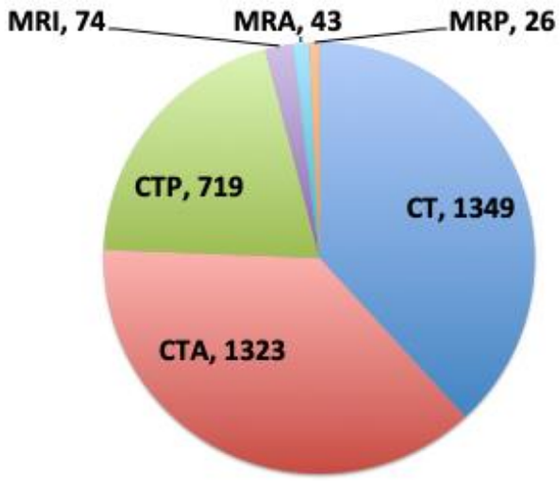
P=0.877

Pooled CTA…

IMAGING STUDIES AVAILABLE

TRIAL	CT	CTA	CTP	MRI	MRA	MRP
MR CLEAN	100% 499	99% 496	67% 333	4% 19	0.5% 2	?
EXTEND-IA	100% 70	100% 70	100% 70	0	0	0
ESCAPE	99% 313	99% 313	44% 138	<1% 2	<1% 2	0
SWIFT-PRIME	~80% ~155	~80%` ~150	~70% ~138	<20% ~39	~20% ~37	~20% ~25
REVASCAT	100% 206	95% 195	31% 64	5%% 11	5% 11	2% 5
THERAPY	98% 106	92% 99	37% 40	3% 3	2% 2	1% 1
TOTALS	1349	1323	719	74	54	31

IMAGING STUDIES VISUALIZED



IMAGING POPULATION

TRIAL	ASPECTS-CT	CORE	PENUMBRA	COLLAT-ERALS	OCCLU-SIONS
MR CLEAN	75% 8-10 19% 5-7 6% 0-4	141/175=81% with <70 cc	TMM 107/175=58% Ratio >1.2 Absolute >10cc	32% poor	28% ICA 64% M1 8% M2
EXTEND-IA	94%=8-10	All <70cc only	+TMM in 100% Ratio >1.2 Absolute >10cc	NA (could be calculated?)	31% ICA 51% M1 17% M2
ESCAPE	Majority 6-10	NA	NA	2.5% poor	28% ICA 68% M1 3% 2-M2
SWIFT-PRIME	75%=8-10 23%=6-7 2%=0-5	10 with 50-70cc Rest all <50 cc	TMM 141/165=85% Ratio >1.8 Absolute >15 cc Tmax>10=<100cc	NA (could be calculated?)	18% ICA 67% M1 14% M2
REVASCAT	54% 8-10 39% 5-7 8% 0-4	NA	NA	NA (could be calculated?)	~27% ICA 64% M1 9% M2
THERAPY	50% 8-10 31% 5-7 6% 0-4	NA	NA	27% poor	28% ICA 62% M1 10% M2

COLLATERALS - ESTIMATE

NOTE DIFFERING DEFINITIONS

	Poor	Good
MR CLEAN 0-1 vs 2-3	162	334
ESCAPE Poor vs good/ intermediate	8	307
THERAPY 0-1 vs 2-4	29	60
TOTALS	**199**	**701**