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Imaging Stroke:
Is There a Stroke Equivalent of the ECG?

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Disclosures

- **Penumbra, Inc.**
  - research grant (significant) for core imaging lab activities
- **Remedy Pharmaceuticals, Inc.**
  - research support (significant) for core imaging lab for GAMES Pilot trial
- **NIH/NINDS**
  - MR RESCUE

Overview

- The target population & cerebrovascular physiology
- The need for better patient selection
- Key imaging questions

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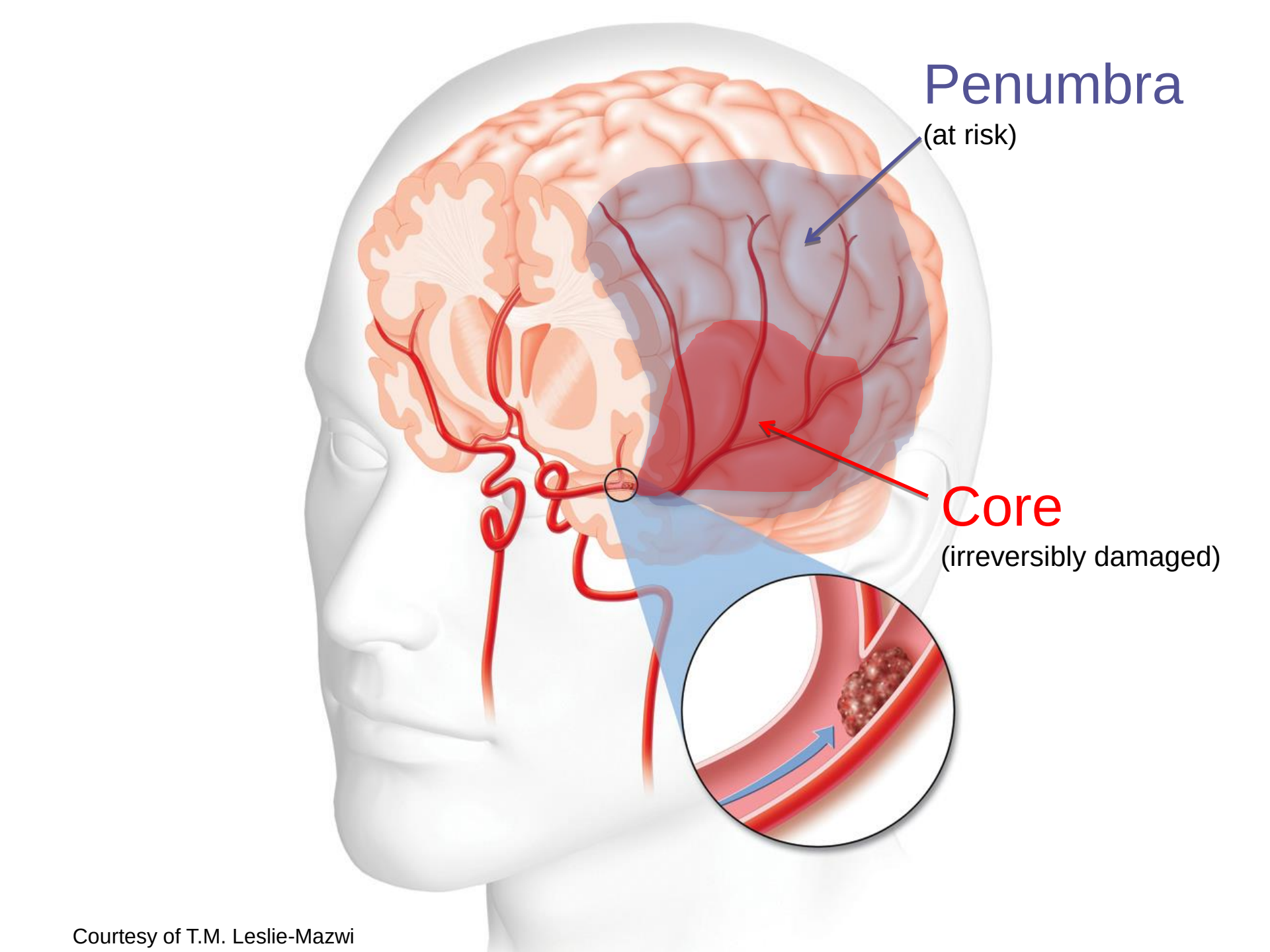
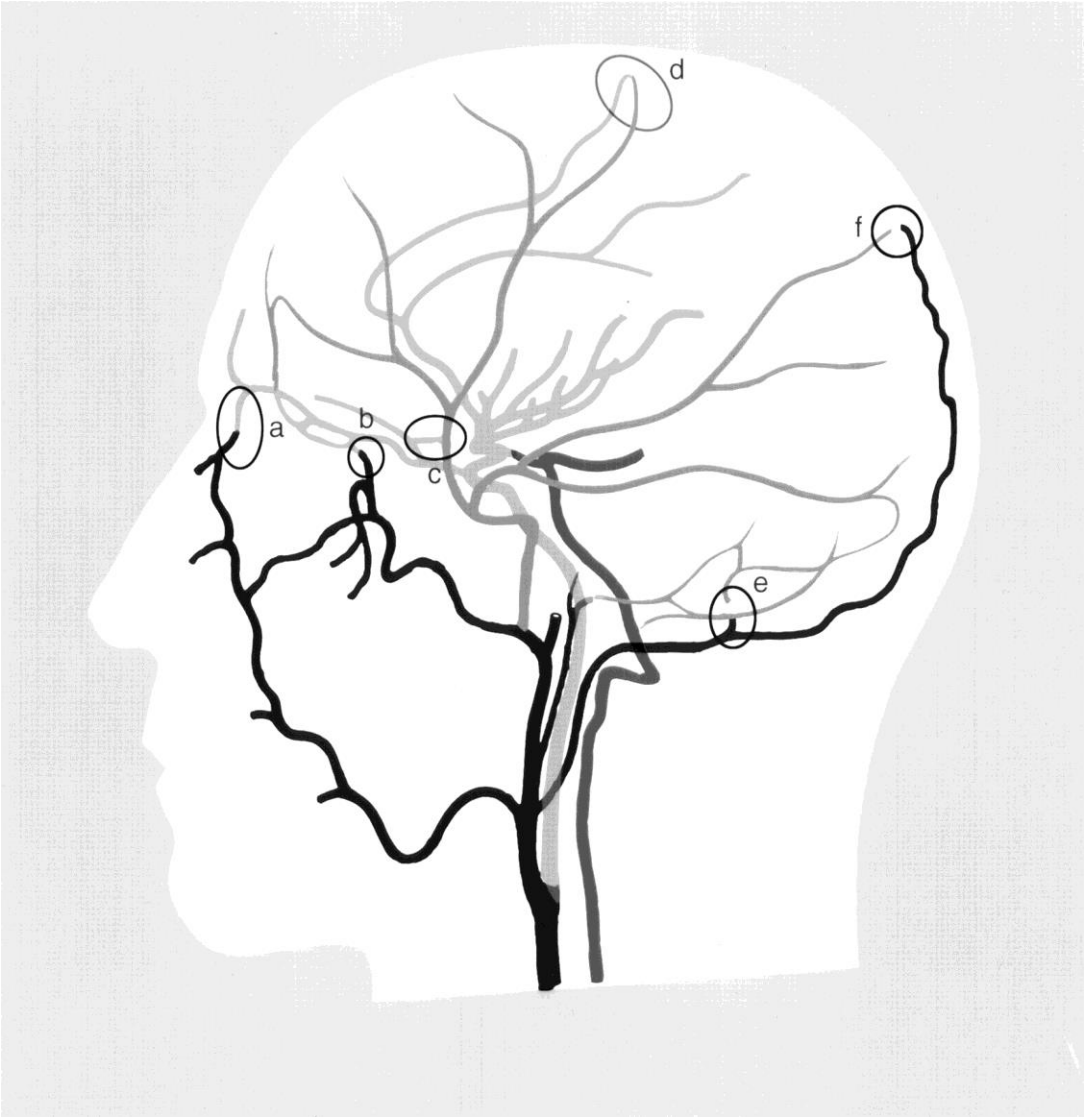


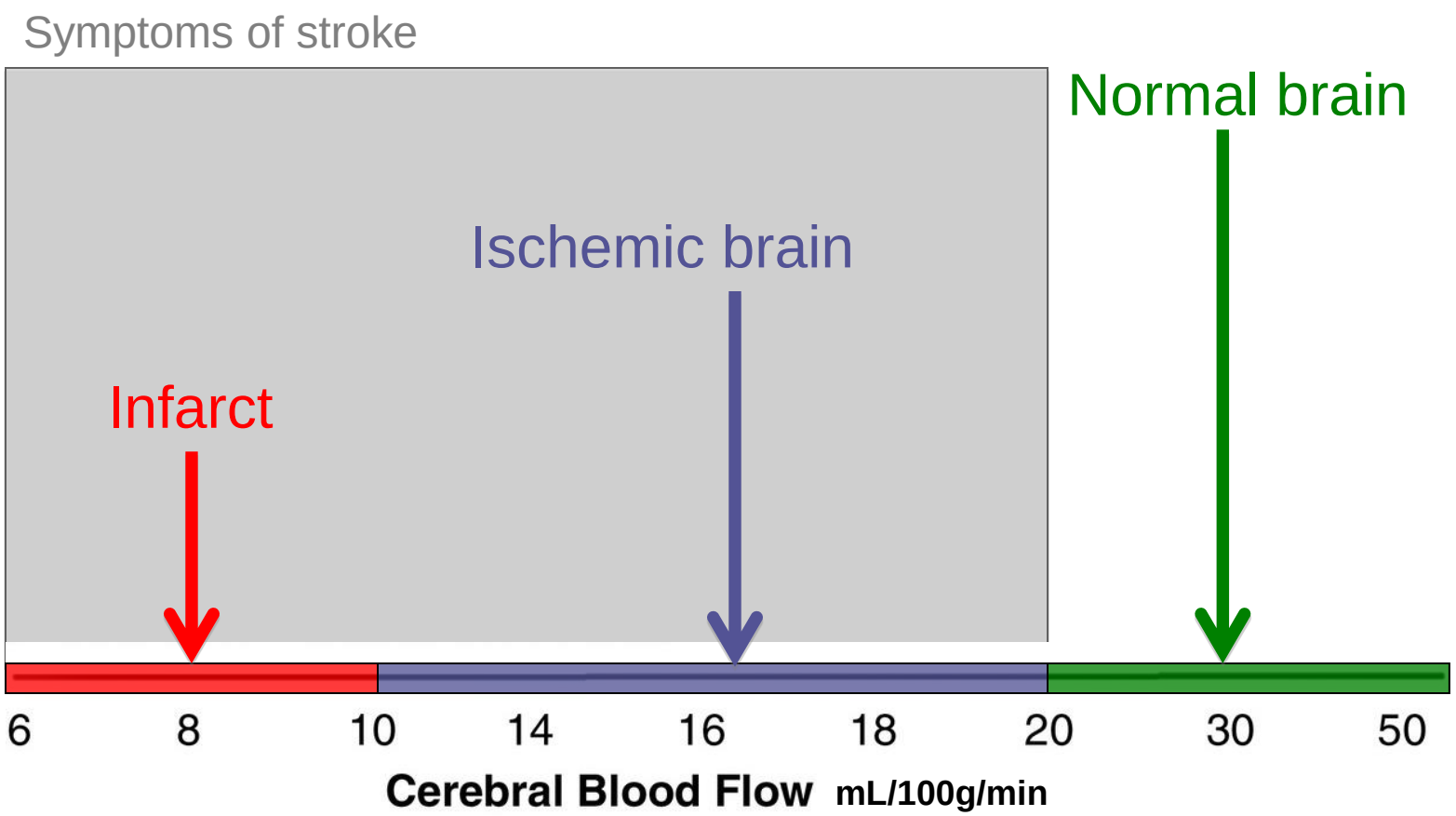
Courtesy of T.M. Leslie-Mazwi

You’re Only As Good As Your Collaterals



Liebeskind,Stroke 2003

The Penumbra Concept

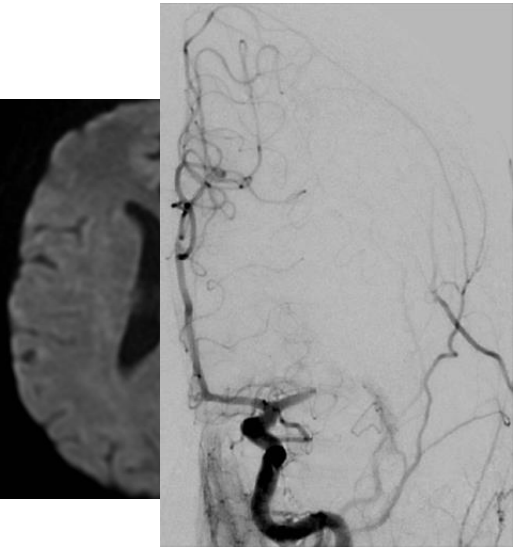


Courtesy of T.M. Leslie-Mazwi

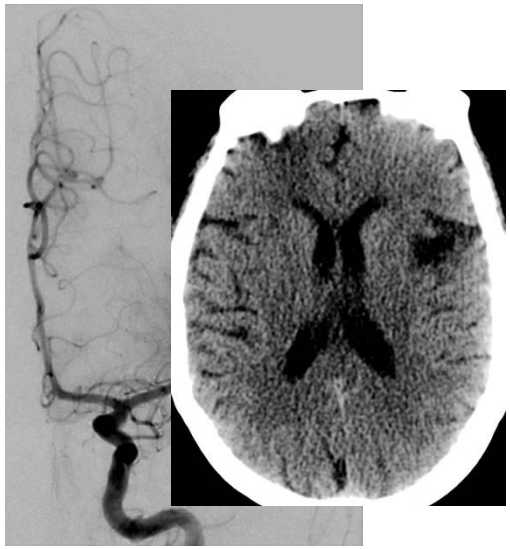
The Basis of Acute Stroke Therapy

- Recanalization hypothesis
  - i.e. reopening of occluded vessels improves clinical outcome in acute ischemic stroke through reperfusion and salvage of threatened tissues.

Ideal case



IAT



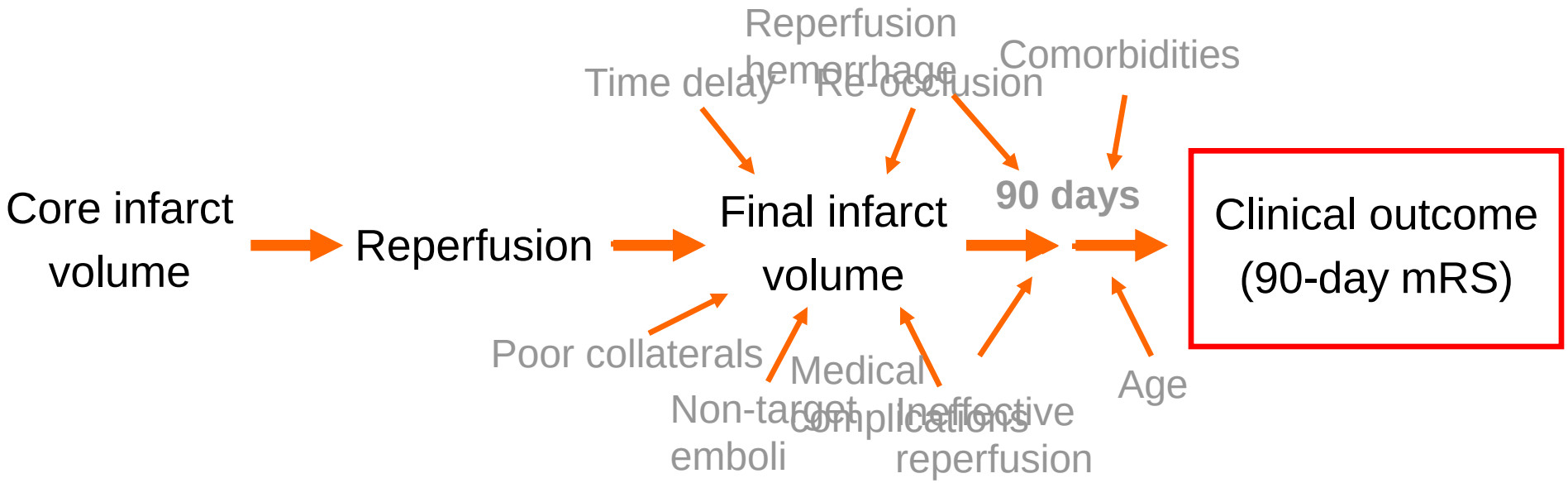
Small baseline infarct volume → Reperfusion → Small final infarct volume → 90 days → Good clinical outcome (90-day mRS 0-2)

The Basis of Acute Stroke Therapy

- Recanalization hypothesis**
  - i.e. reopening of occluded vessels improves clinical outcome in acute ischemic stroke through reperfusion and salvage of threatened tissues.

- **Several biologic factors weaken the relationship of recanalization to outcome in acute ischemic stroke patients:
  - time
  - collateral circulation
  - reperfusion injury
  - no-reflow phenomenon

“Real world” case



Overview

- The target population & cerebrovascular physiology
- The need for better patient selection
- Key imaging questions

Recent RCTs

ORIGINAL ARTICLE

Endovascular Therapy after Intravenous t-PA versus t-PA Alone for Stroke

Joseph P. Broderick, M.D., Yuko Y. Palesch, Ph.D., Andrew M. Demchuk, M.D., Sharon D. Yeatts, Ph.D., Pooja Khatri, M.D., Michael D. Hill, M.D., Edward C. Jauch, M.D., Tudor G. Jovin, M.D., Bernard Yan, M.D., Frank L. Silver, M.D., Rüdiger von Kummer, M.D., Carlos A. Molina, M.D., Bart M. Demaerschalk, M.D., Ronald Budzik, M.D., Wayne M. Clark, M.D., Osama O. Zaidat, M.D., Tim W. Malisch, M.D., Mayank Goyal, M.D., Wouter J. Schonewille, M.D., Mikael Mazighi, M.D., Ph.D., Stefan T. Engelter, M.D., Craig Anderson, M.D., Ph.D., Judith Spilker, R.N., B.S.N., Janice Carrozzella, R.N., B.A., R.T.(R.), Karla J. Ryckborst, R.N., B.N., L. Scott Janis, Ph.D., Renée H. Martin, Ph.D., Lydia D. Foster, M.S., and Thomas A. Tomsick, M.D., for the Interventional Management of Stroke (IMS) III Investigators

ABSTRACT

BACKGROUND

Endovascular therapy is increasingly used after the administration of intravenous tissue plasminogen activator (t-PA) for patients with moderate-to-severe acute ischemic stroke, but whether a combined approach is more effective than intravenous t-PA alone is uncertain.

METHODS

We randomly assigned eligible patients who had received intravenous t-PA within 3 hours after symptom onset to receive additional endovascular therapy or intravenous t-PA alone, in a 2:1 ratio. The primary outcome measure was a modified Rankin scale score of 2 or less (indicating functional independence) at 90 days (scores range from 0 to 6, with higher scores indicating greater disability).

RESULTS

The study was stopped early because of futility after 656 participants had undergone randomization (434 patients to endovascular therapy and 222 to intravenous t-PA alone). The proportion of participants with a modified Rankin score of 2 or less at 90 days did not differ significantly according to treatment (40.8% with endovascular therapy and 38.7% with intravenous t-PA; absolute adjusted difference, 1.5 percentage points; 95% confidence interval [CI], −6.1 to 9.1, with adjustment for the National Institutes of Health Stroke Scale [NIHSS] score [8–19, indicating moderately severe stroke, or ≥20, indicating severe stroke]), nor were there significant differences for the predefined subgroups of patients with an NIHSS score of 20 or higher (6.8 percentage points; 95% CI, −4.4 to 18.1) and those with a score of 19 or lower (−1.0 percentage point; 95% CI, −10.6 to 8.6). Findings in the endovascular-therapy and intravenous t-PA groups were similar for mortality at 90 days (19.1% and 21.6%, respectively; P=0.52) and the proportion of patients with symptomatic intracerebral hemorrhage within 30 hours after initiation of t-PA (6.2% and 5.9%, respectively; P=0.83).

CONCLUSIONS

The trial showed similar safety outcomes and no significant difference in functional independence with endovascular therapy after intravenous t-PA, as compared with intravenous t-PA alone. (Funded by the National Institutes of Health and others; ClinicalTrials.gov number, NCT00359424.)

IMS-III

ORIGINAL ARTICLE

A Trial of Imaging Selection and Endovascular Treatment for Ischemic Stroke

Chelsea S. Kidwell, M.D., Reza Jahan, M.D., Jeffrey Gornbein, Dr.P.H., Jeffry R. Alger, Ph.D., Val Nenov, Ph.D., Zahra Ajani, M.D., Lei Feng, M.D., Ph.D., Brett C. Meyer, M.D., Scott Olson, M.D., Lee H. Schwamm, M.D., Albert J. Yoo, M.D., Randolph S. Marshall, M.D., Philip M. Meyers, M.D., Dileep R. Yavagal, M.D., Max Wintermark, M.D., Judy Guzy, R.N., Sidney Starkman, M.D., and Jeffrey L. Saver, M.D., for the MR RESCUE Investigators*

ABSTRACT

BACKGROUND

Whether brain imaging can identify patients who are most likely to benefit from therapies for acute ischemic stroke and whether endovascular thrombectomy improves clinical outcomes in such patients remains unclear.

METHODS

In this study, we randomly assigned patients within 8 hours after the onset of large-vessel, anterior-circulation strokes to undergo mechanical embolectomy (Merci Retriever or Penumbra System) or receive standard care. All patients underwent pretreatment computed tomography or magnetic resonance imaging of the brain. Randomization was stratified according to whether the patient had a favorable penumbral pattern (substantial salvageable tissue and small infarct core) or a nonpenumbral pattern (large core or small or absent penumbra). We assessed outcomes using the 90-day modified Rankin scale, ranging from 0 (no symptoms) to 6 (dead).

RESULTS

Among 118 eligible patients, the mean age was 65.5 years, the mean time to enrollment was 5.5 hours, and 58% had a favorable penumbral pattern. Revascularization in the embolectomy group was achieved in 67% of the patients. Ninety-day mortality was 21%, and the rate of symptomatic intracranial hemorrhage was 4%; neither rate differed across groups. Among all patients, mean scores on the modified Rankin scale did not differ between embolectomy and standard care (3.9 vs. 3.9, P=0.99). Embolectomy was not superior to standard care in patients with either a favorable penumbral pattern (mean score, 3.9 vs. 3.4; P=0.23) or a nonpenumbral pattern (mean score, 4.0 vs. 4.4; P=0.32). In the primary analysis of scores on the 90-day modified Rankin scale, the [illegible] between the pretreatment imaging pattern and treatment assignment (P=0.14).

CONCLUSIONS

A favorable penumbral pattern on neuroimaging did not identify patients who would differentially benefit from endovascular therapy for acute ischemic stroke, nor was embolectomy shown to be superior to standard care. (Funded by the National Institute of Neurological Disorders and Stroke; MR RESCUE ClinicalTrials.gov number, NCT00389467.)

MR RESCUE

ORIGINAL ARTICLE

Endovascular Treatment for Acute Ischemic Stroke

Alfonso Ciccone, M.D., Luca Valvassori, M.D., Michele Nichelatti, Ph.D., Annalisa Sgoifo, Psy.D., Michela Ponzio, Ph.D., Roberto Sterzi, M.D., and Edoardo Boccardi, M.D., for the SYNTHESIS Expansion Investigators*

ABSTRACT

BACKGROUND

In patients with ischemic stroke, endovascular treatment results in a higher rate of recanalization of the affected cerebral artery than systemic intravenous thrombolytic therapy. However, comparison of the clinical efficacy of the two approaches is needed.

METHODS

We randomly assigned 362 patients with acute ischemic stroke, within 4.5 hours after onset, to endovascular therapy (intraarterial thrombolysis with recombinant tissue plasminogen activator [t-PA], mechanical clot disruption or retrieval, or a combination of these approaches) or intravenous t-PA. Treatments were to be given as soon as possible after randomization. The primary outcome was survival free of disability (defined as a modified Rankin score of 0 or 1 on a scale of 0 to 6, with 0 indicating no symptoms, 1 no clinically significant disability despite symptoms, and 6 death) at 3 months.

RESULTS

A total of 181 patients were assigned to receive endovascular therapy, and 181 intravenous t-PA. The median time from stroke onset to the start of treatment was 3.75 hours for endovascular therapy and 2.75 hours for intravenous t-PA (P<0.001). At 3 months, 55 patients in the endovascular-therapy group (30.4%) and 63 in the intravenous t-PA group (34.8%) were alive without disability (odds ratio adjusted for age, sex, stroke severity, and atrial fibrillation status at baseline, 0.71; 95% confidence interval, 0.44 to 1.14; P=0.16). Fatal or nonfatal symptomatic intracranial hemorrhage within 7 days occurred in 6% of the patients in each group, and there were no significant differences between groups in the rates of other serious adverse events or the case fatality rate.

CONCLUSIONS

The results of this trial in patients with acute ischemic stroke indicate that endovascular therapy is not superior to standard treatment with intravenous t-PA. (Funded by the Italian Medicines Agency, ClinicalTrials.gov number, NCT00640367.)

SYNTHESIS

NEJM 2013

Recent RCTs

	Patients	Treatments	Clinical Selection
IMS III	656 (target 900)	IAT + IVtPA *vs.* IVtPA alone	NIHSS ≥10, IVtPA <3hrs, IAT <5hrs (complete by 7hrs). Ant and post circulation.
MR RESCUE	127 (118 analyzed)	IAT *vs.* Standard care	NIHSS 6-29, randomization within 8hrs of LSW. Ant circulation only.
SYNTHESIS Expansion	362	IAT *vs.* IVtPA	IVtPA <4.5hrs, IAT <6 hrs

Recent RCTs

	Imaging Selection	Primary Outcome	Results
IMS III	NCCT. <1/3rd of MCA territory affected	90 day mRS 0-2	Terminated due to futility analysis. Good outcome of 40.8% IAT, 38.7% IVtPA, no difference. sICH equivalent.
MR RESCUE	Multimodal CT/MRI. LVO (ICA→M2).	90 day mRS Shift analysis	IAT versus standard care for non-penumbral *or* penumbral imaging patterns showed no difference. sICH equivalent.
SYNTHESIS Expansion	NCCT. No established hypodensity	90 day mRS 0-1	Good outcome of 30.8% IAT, 34.8% IVtPA, no difference. sICH equivalent.

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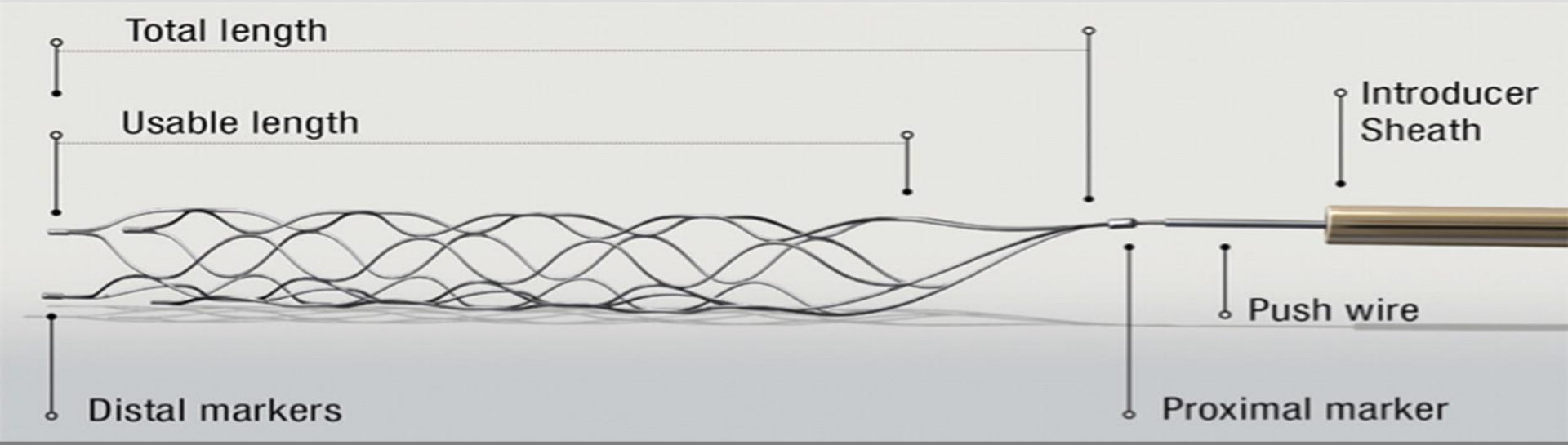
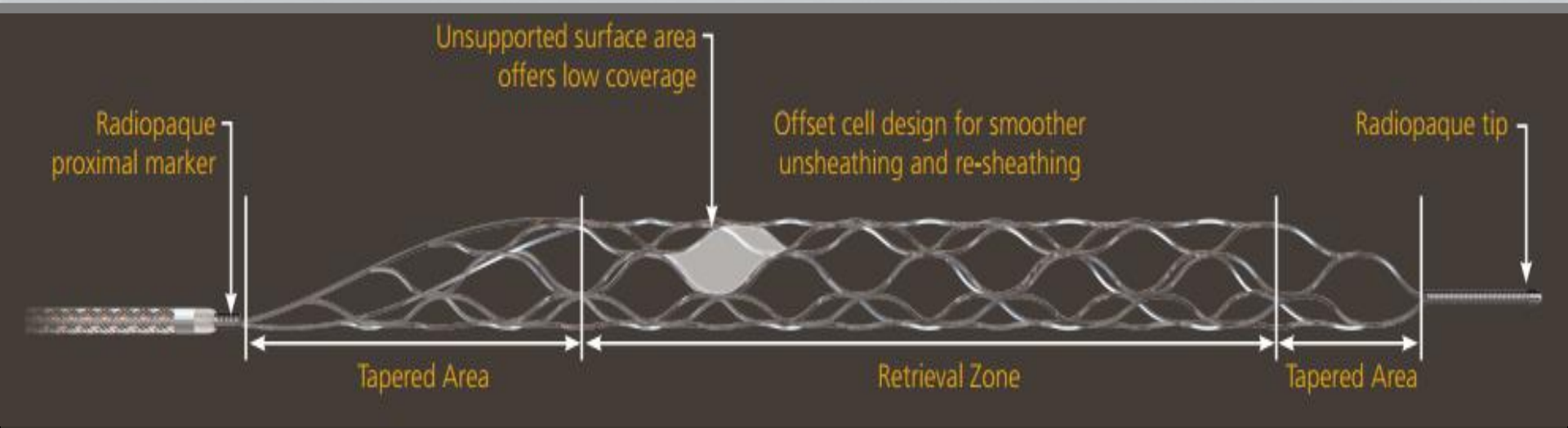
Solitaire





Trevo

Machi P et al. J NeuroIntervent Surg 2012;4:62-66
Nogueira R G et al. J NeuroIntervent Surg 2012;4:295-300

SWIFT and Trevo 2

Two RCTs comparing stent retrievers vs. first-generation Merci device

Stentriever benefit*	SWIFT	Trevo 2
Higher reperfusion rate	✔	✔
-Faster reperfusion	✔	
-Fewer passes	✔	
Better clinical outcomes	✔	✔
Safe (SAEs, SICH, mortality)	✔	✔

** compared to Merci device*

Saver JL, et al, Lancet 2012
Nogueira RN, et al, Lancet 2012

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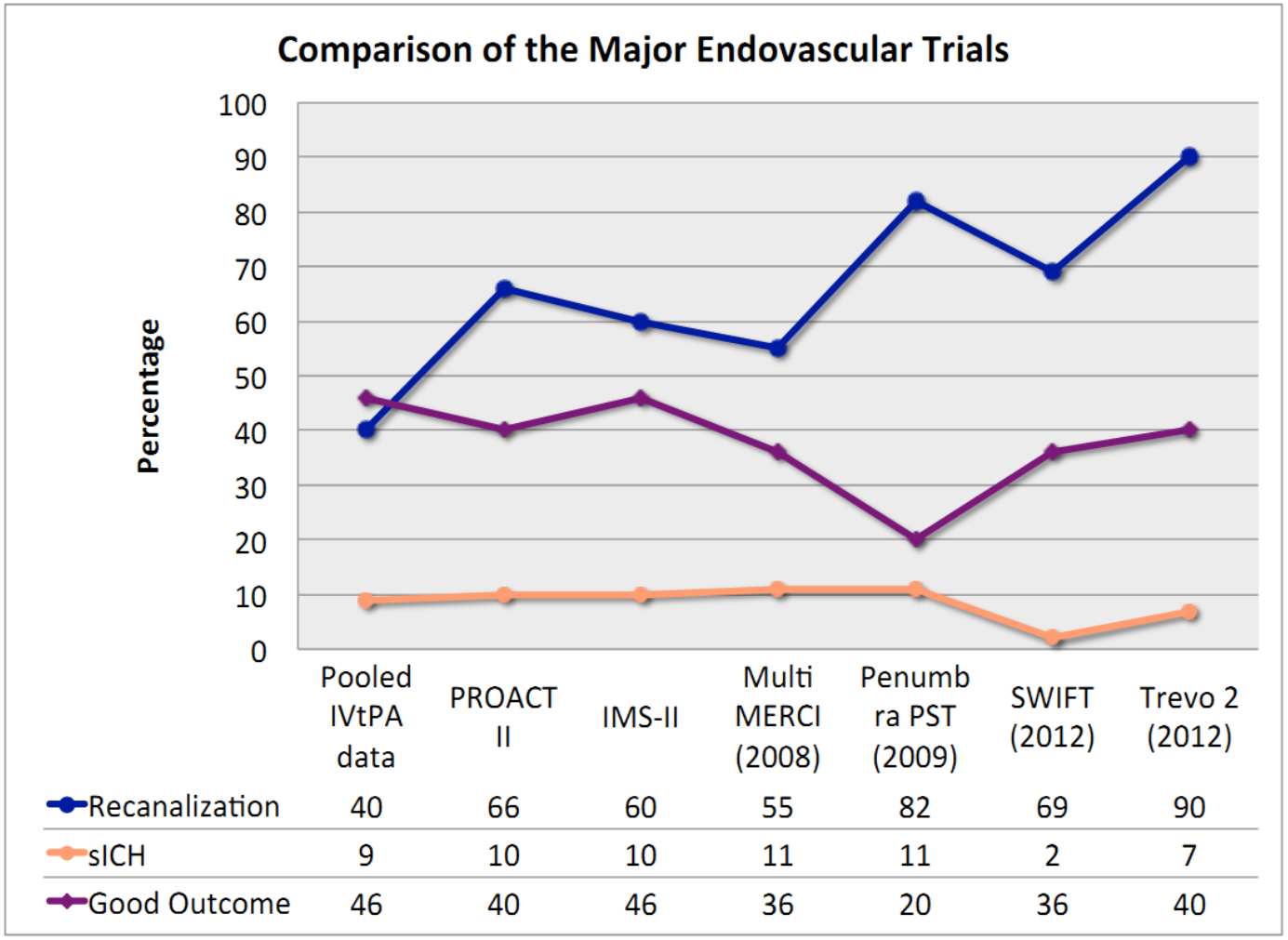
SWIFT and Trevo 2

- **Good news**: Encouraging RCT data
- **Bad news**: Not exactly the RCT data we need
  - Before comparing devices we need to compare device to *standard medical therapy*
  - One step removed from where we need to be

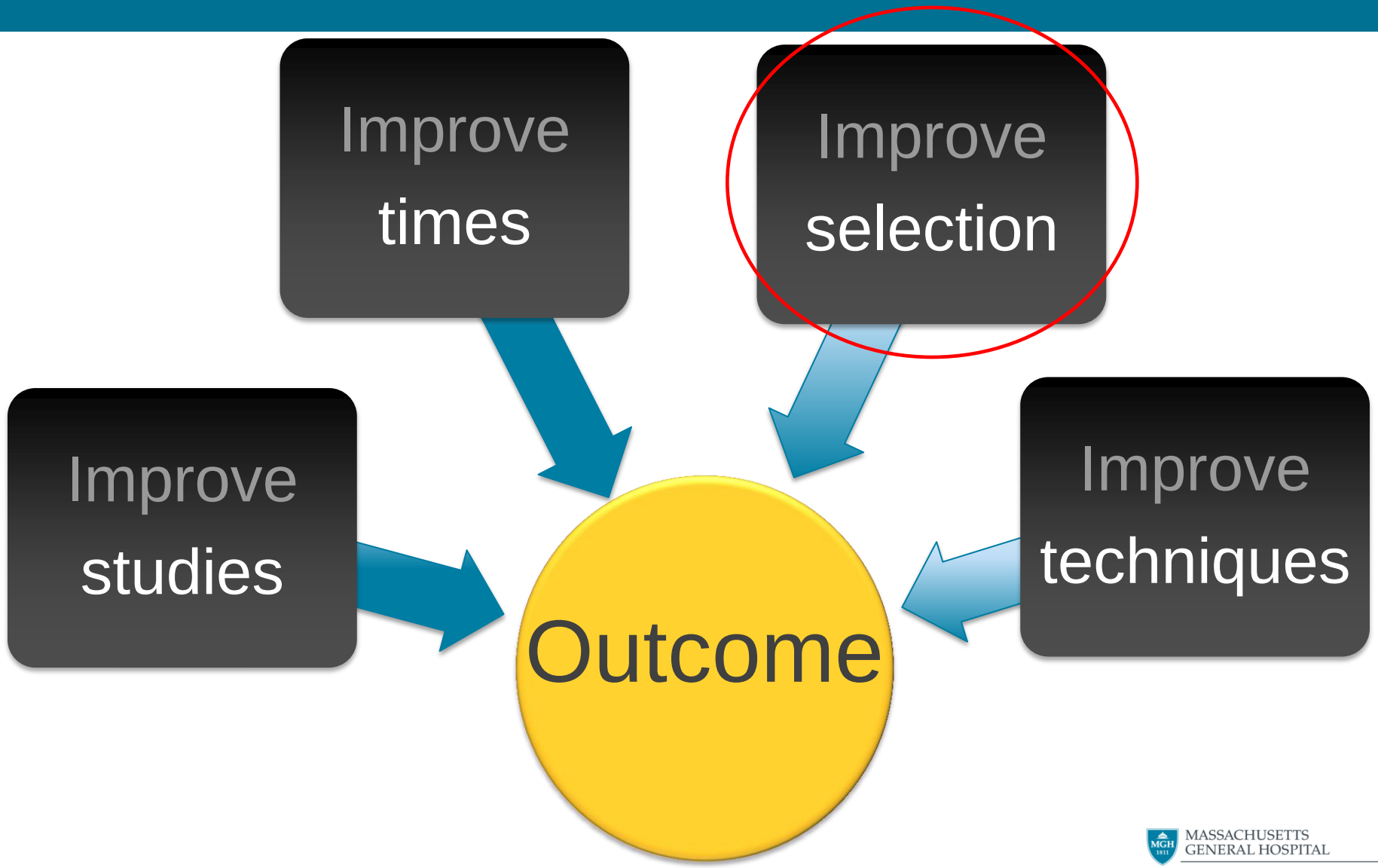
A Worrying Trend…



	Pooled IVtPA data	PROACT II	IMS-II	Multi MERCI (2008)	Penumbra PST (2009)	SWIFT (2012)	Trevo 2 (2012)
Recanalization	40	66	60	55	82	69	90
sICH	9	10	10	11	11	2	7
Good Outcome	46	40	46	36	20	36	40

Courtesy of T.M. Leslie-Mazwi

How Do We Improve Outcomes?



Overview

- The target population & cerebrovascular physiology
- The need for better patient selection
- Key imaging questions

Imaging selection for IAT

- **Major imaging questions:**

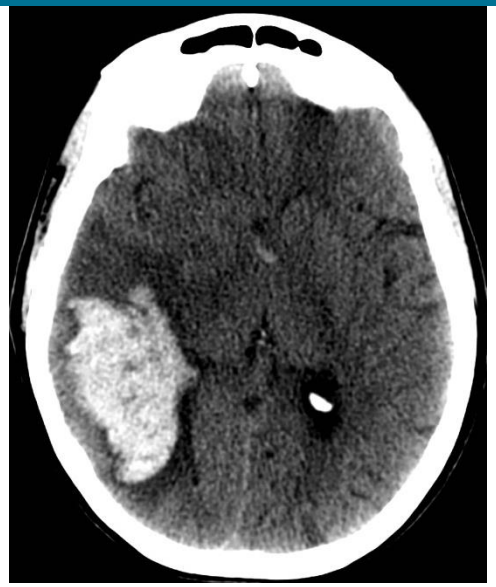
For patients beyond 3 hours from onset of symptoms, either MR-DWI or CTA-SI should be performed along with vascular imaging and perfusion studies, particularly if mechanical thrombectomy or intra-arterial thrombolytic therapy is contemplated (Class I, LOE: A).

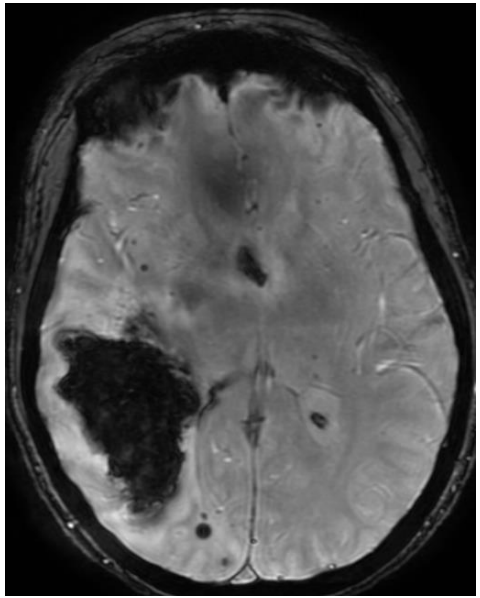
- There is no standard imaging approach for selecting patients for intra-arterial therapy

Stroke 2009; 40:3646-3678.

Rule out hemorrhage

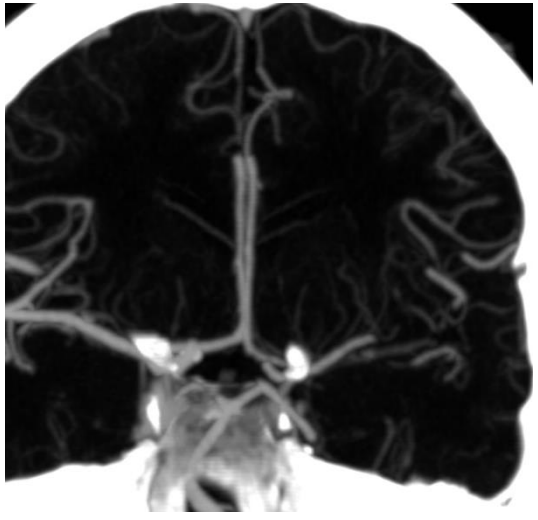
- NCCT = standard imaging for ICH
- MRI appears as good as NCCT for detecting acute hemorrhage
  - GRE imaging → High agreement with NCCT for acute ICH (96% concordance) (*JAMA* 2004; 292:1823-30)
  - T2, T2*, DWI → 100% sensitivity (95%CI: 97.1-100%) and accuracy for NCCT hemorrhage (*Stroke* 2004; 35:502-7)
  - Better than NCCT for detection of chronic hemorrhage (*JAMA* 2004; 292:1823-30)

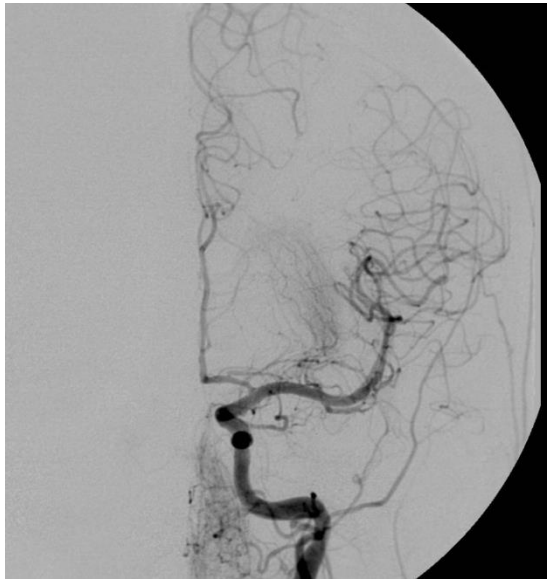


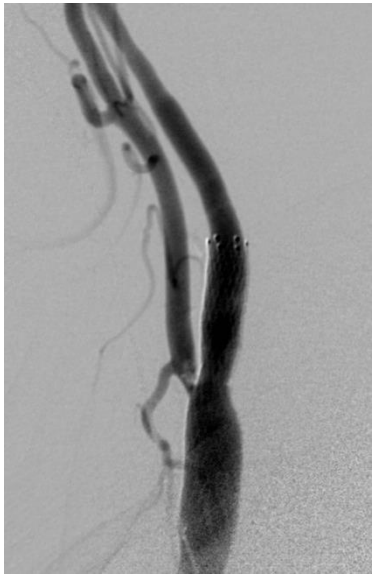


Vessel imaging

- Vascular imaging is necessary as a preliminary step for IAT (**Class IIa, LOE B**)
  - Identify treatment target
  - Plan treatment approach (e.g., ICA stenting)
  - Provide prognostic information (e.g., terminal ICA vs. M1)
  - Predict IV tPA failure
    - ICA-T: 4.4% recanalization
    - M1: 32.3%
    - M2: 30.8%
    - Basilar: 4%





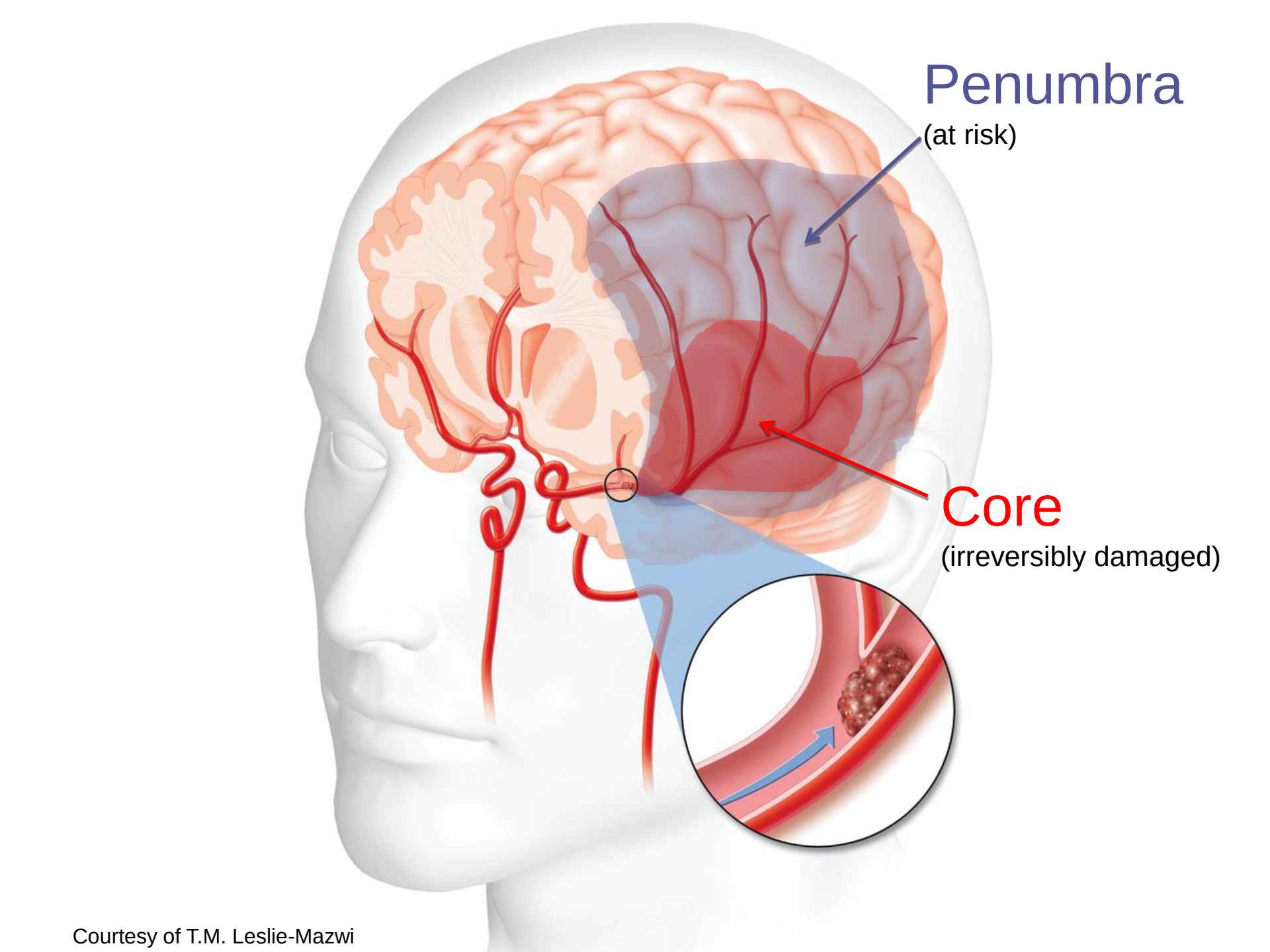


Stroke 2007; 38:1655-1711
Stroke 2010; 41:2254-2258

Vessel imaging: CTA vs. MRA

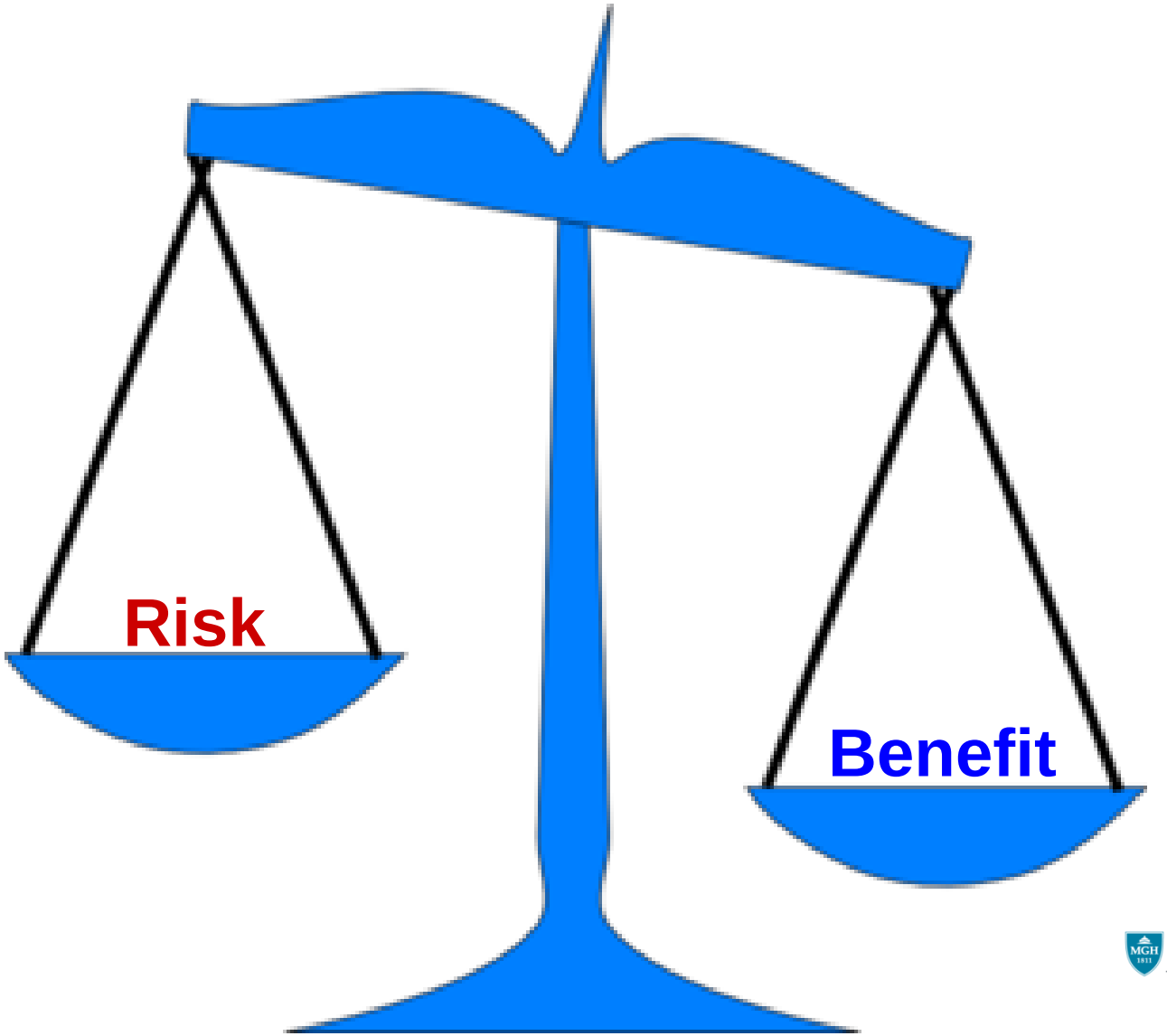
- **CTA**
  - vs. DSA: 98.4% sens, 98.1% spec, 98.2% accuracy for proximal artery occlusion (*JCAT* 2001; 25:520-8)
  - Facilitated by thick section, overlapping MIPs
  - High interobserver reliability
- **MRA**
  - 3D TOF vs. DSA: 84-87% sens, 85-98% spec for PAO (*AJNR* 2005; 26:1012-1021; *Can J Neurol Sci* 2006; 33:58-62)
  - Suboptimal evaluation of M2 branches
  - Prone to motion and flow artifact
  - Moderate interobserver reliability (κ=0.5)
- CTA and MRA → **Class I, LOE A**

Stroke 2009; 40:3646-3678.



Courtesy of T.M. Leslie-Mazwi

Core principle of treatment selection



Benefit vs. Core infarct size

- **For proximal artery occlusions treated with IAT, smaller core infarct volumes → better outcomes**
  - Xe-enhanced CT:
    - Jovin et al, *Stroke*. 2003; 34: 2426-33
  - MRI DWI (reference standard):
    - Yoo et al., *Stroke*. 2009; 40: 2046-54
    - Lansberg et al., *Lancet Neurol*. 2012; 11: 860-7 (DEFUSE 2)
    - Olivot et al., *Stroke*. 2013; In press
  - CT Perfusion CBV:
    - Gasparotti et al., *AJNR*. 2009; 30: 722-7
  - CTA Source Images:
    - Lev et al., *Stroke*. 2001; 32: 2021-28
  - NCCT ASPECTS:
    - Hill et al., *Stroke*. 2003; 34: 1925-31 (PROACT-II)
    - Hill et al., *AJNR*. 2006; 27: 1612-16 (IMS-1)
    - Goyal et al., *Stroke*. 2011; 42:93-7 (Penumbra Pivotal)

Risk of sICH vs. Core infarct size

- In multicenter study of 645 pts treated with IV or IA thrombolysis, (*Ann Neurol.* 2008; 63:52-60.)
  - **Larger baseline DWI lesion volume (i.e. core infarct volume) → independent predictor of sICH**
  - DWI volume >100 mL → 16.1% sICH rate

- DEFUSE post hoc analysis (*Stroke.* 2007; 38:2275-8)
  - **Risk of sICH in large infarcts is further increased by reperfusion**

Impact of Diffusion-Weighted Imaging Lesion Volume on the Success of Endovascular Reperfusion Therapy

Jean-Marc Olivot, MD, PhD; Pascal J. Mosimann, MD; Julien Labreuche, BST; Manabu Inoue, MD; Elena Meseguer, MD; Jean-Philippe Desilles, MD; Aymeric Rouchaud, MD; Isabelle F. Klein, MD, PhD; Matus Straka, MD, PhD; Roland Bammer, MD, PhD; Michael Mlynash MD, MS; Pierre Amarenco, MD; Gregory W. Albers, MD; Mikael Mazighi MD, PhD

Table 2. Impact of DWI Lesion Volume on Clinical Outcomes

	DWI Lesion Volume, cc			
	<8.0 (n=46)	8.0–31.7 (n=47)	>31.7 (n=46)	*P* for Trend or OR per SD*
Favorable outcome				
n, %	29 (64.4)	23 (48.9)	14 (30.4)	0.001
Crude OR (95% CI)	1.00 (ref)	0.53 (0.23–1.22)	0.24 (0.10–0.58)	0.49 (0.33–0.72)
Model 1–adjusted OR (95% CI)	1.00 (ref)	0.32 (0.11–0.90)	0.14 (0.04–0.44)	0.38 (0.23–0.63)
Model 2–adjusted OR (95% CI)	1.00 (ref)	0.53 (0.17–1.66)	0.34 (0.10–1.17)	0.55 (0.31–0.96)
90-day mortality				
n, %	7 (15.6)	10 (21.3)	19 (41.3)	0.005
Crude OR (95% CI)	1.00 (ref)	1.47 (0.51–4.26)	3.82 (1.41–10.36)	2.30 (1.46–3.62)
Model 1–adjusted OR (95% CI)	1.00 (ref)	1.90 (0.53–6.82)	6.29 (1.76–22.46)	2.76 (1.61–4.75)
Model 2–adjusted OR (95% CI)	1.00 (ref)	1.49 (0.39–5.75)	4.65 (1.20–17.94)	2.60 (1.45–4.66)
Intracerebral hemorrhage				
n, %	3 (6.5)	10 (21.3)	18 (39.1)	<0.001
Crude OR (95% CI)	1.00 (ref)	3.87 (0.99–15.14)	9.21 (2.48–34.21)	2.39 (1.47–3.89)
Model 1–adjusted OR (95% CI)	1.00 (ref)	4.42 (1.08–18.04)	11.71 (2.90–47.31)	2.54 (1.51–4.27)
Model 2–adjusted OR (95% CI)	1.00 (ref)	2.98 (0.69–12.84)	6.57 (1.50–28.75)	1.97 (1.11–3.47)

- 139 patients with anterior circulation PAO and pre-treatment DWI
- DWI lesion volume was an independent predictor of dependency, death and HT after IAT

Stroke. 2013; 44:2205-11.

How big is too big?

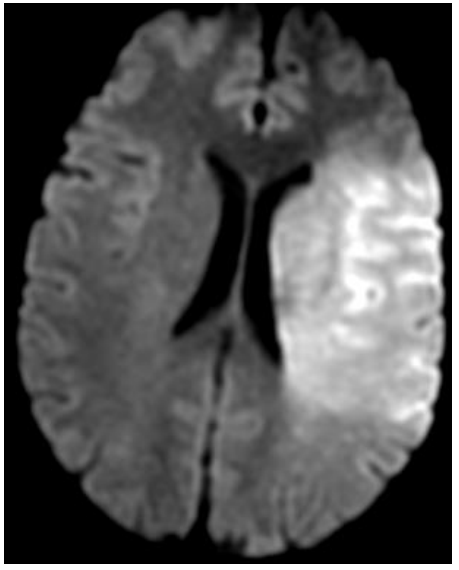
- An acute infarct volume threshold of >70 cm^3 has a high specificity for predicting a poor outcome[1,2]

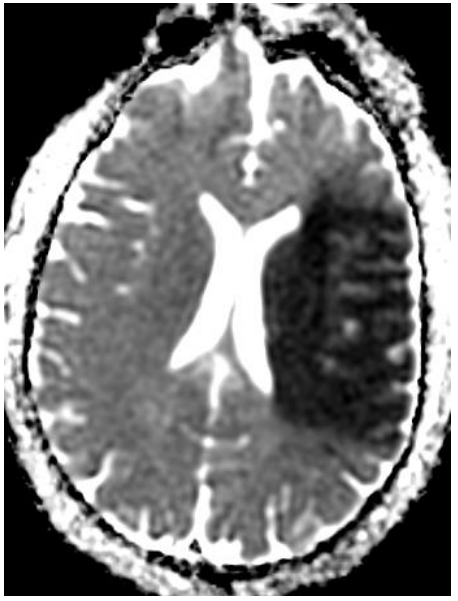
- **Patients with infarcts >70 cm^3 respond poorly to IAT**
  - Yoo AJ et al. *Stroke.* 2009; 40:2046-54.
  - Lansberg MG et al. *Lancet Neurol.* 2012; 11:860-7. (DEFUSE 2)
  - Olivot JM et al. *Stroke.* 2013; 44:2205-11.

[1]Sanak et al. *Neuroradiology*. 2006; 48:632-9.
[2]Yoo et al. *Stroke.* 2010; 41:1728-35.

How should we measure core?

- With the best available method: **diffusion MRI**
- Highly sensitive (91-100%) and specific (86-100%) within the first 6 hrs of stroke onset
  - Similar accuracy to ^{11}C flumazenil PET
- **Allows volumetric quantification**
- Excellent inter-reader agreement
- **Class I, level of evidence A recommendation***

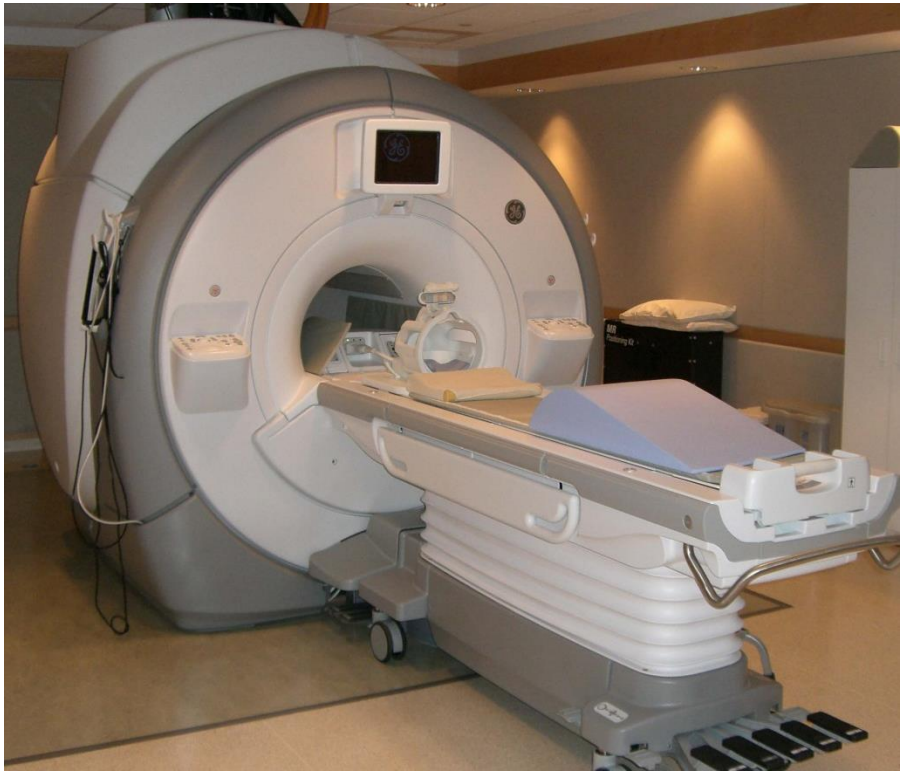




* *Stroke.* 2009; 40:3646-3678.
Neurology. 2010; 75:177-185.

Limitations of MRI

- Limited availability in the acute treatment setting
- Patient contraindications or intolerance
- Time delay



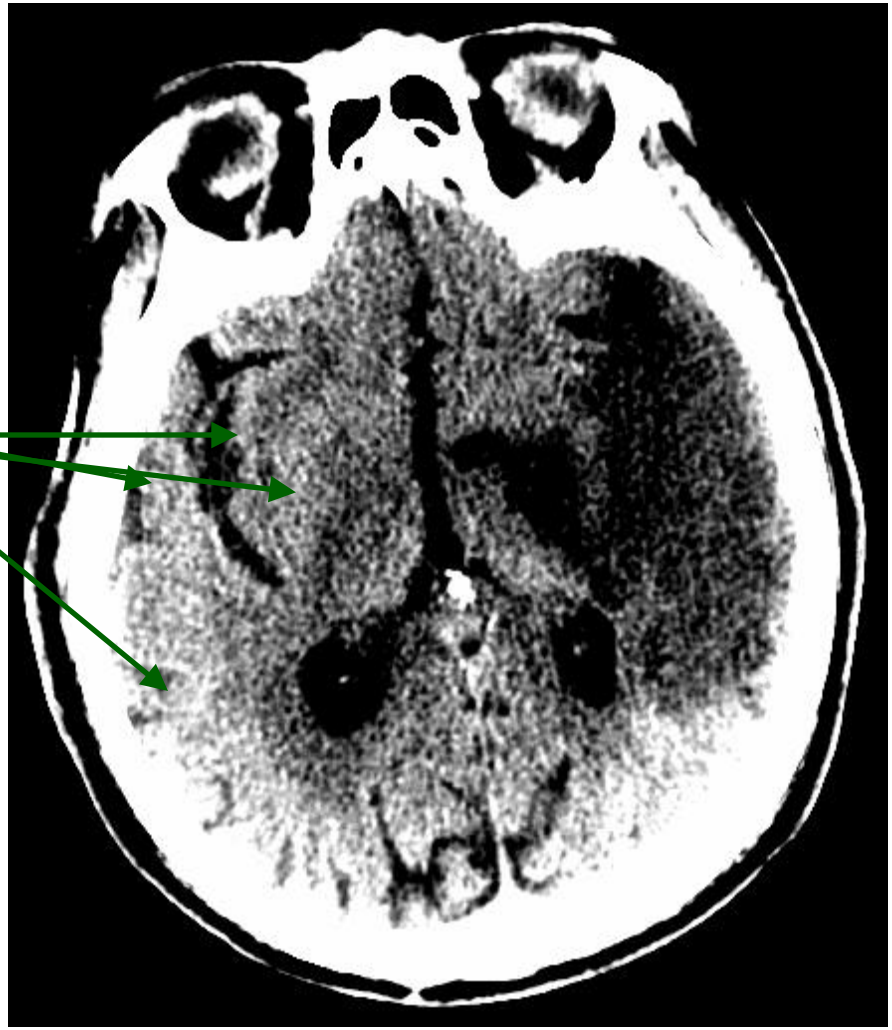
Available CT-based techniques

- CT perfusion
- CTA source imaging

Technique dependent, significant noise → unreliable for infarct detection

- NCCT → Reliable, highly specific for infarction

NCCT signs of acute ischemia



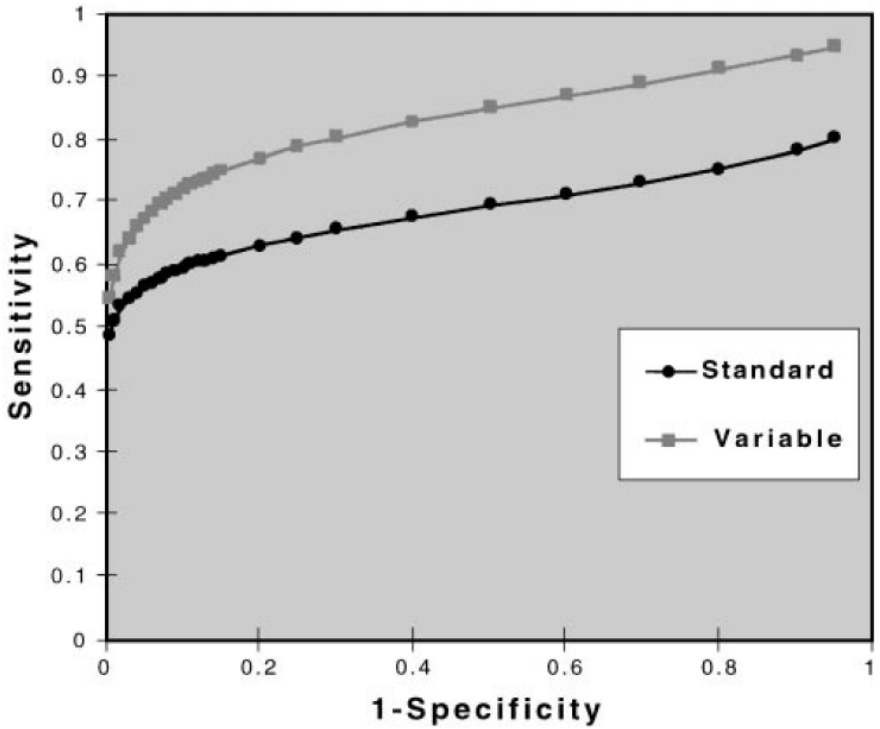
- Loss of gray-white matter differentiation:
  - "Insular ribbon"
  - Basal ganglia
  - Cortex

Michael H. Lev, MD
Jeffrey Farkas, MD
Joseph J. Gemmete, MD
Syeda T. Hossain, BS
George J. Hunter, MD
Walter J. Koroshetz, MD
R. Gilberto Gonzalez, MD, PhD

Index terms:
Brain, CT, 10.781, 174.12111

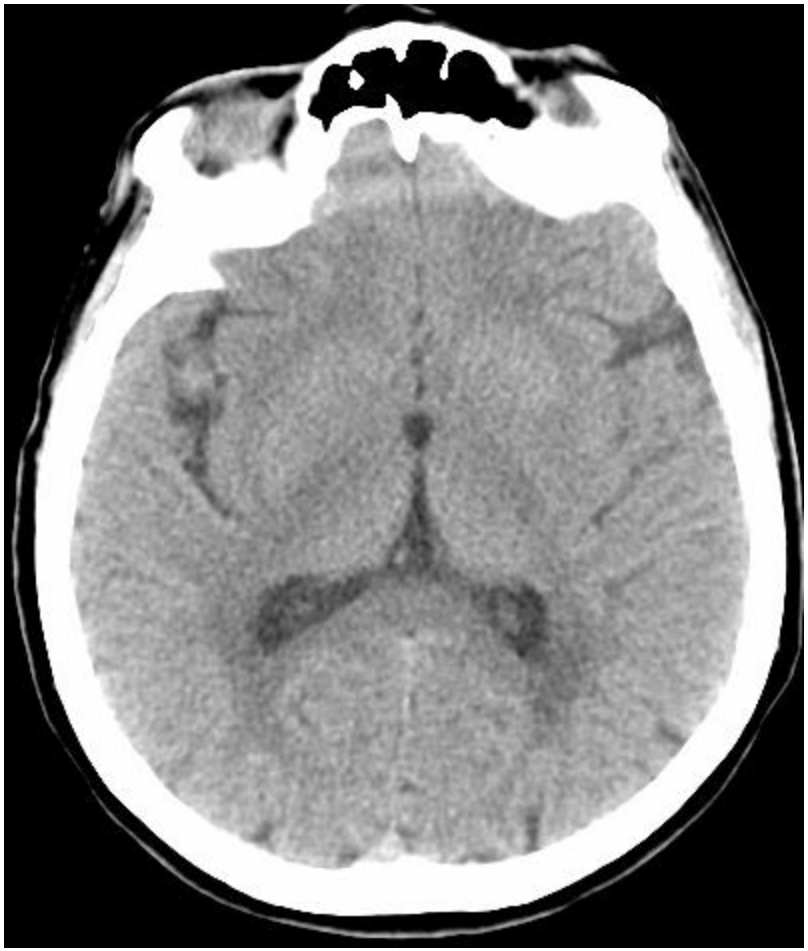
Acute Stroke: Improved Nonenhanced CT Detection—Benefits of Soft-Copy Interpretation by Using Variable Window Width and Center Level Settings[1]

- Using narrow window and level settings (**8HU W, 32HU L**) can accentuate the small differences in attenuation due to ischemia
  - Sensitivity increases from 57% to 71%
  - Specificity 100%

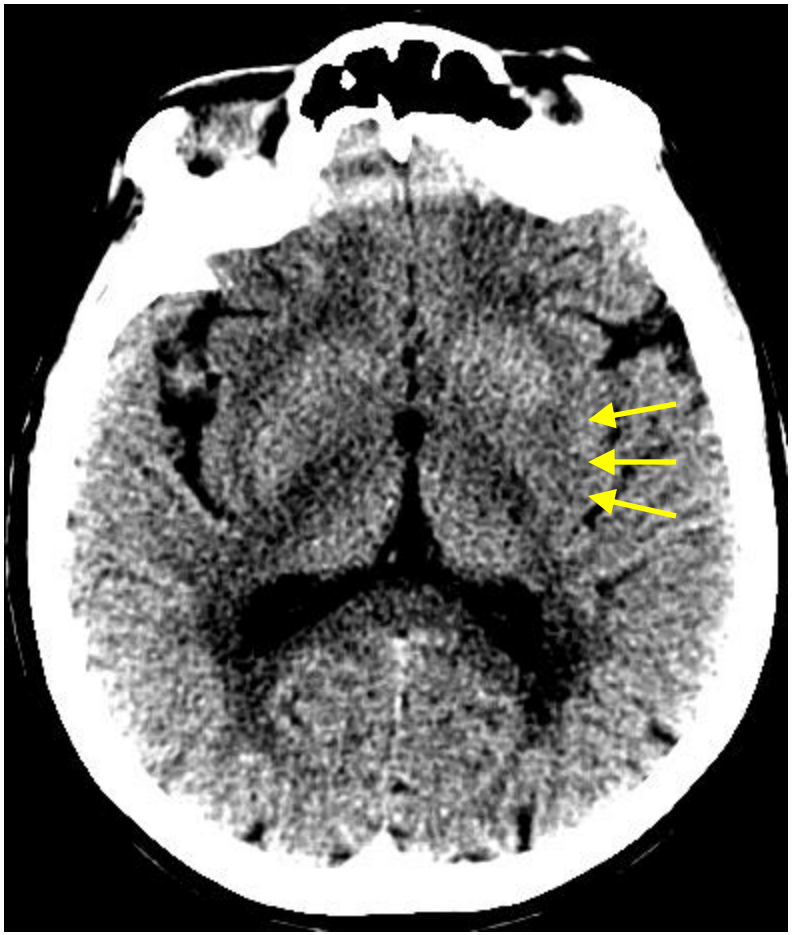


Radiology. 1999; 213: 150-155

Optimizing NCCT detection



Standard



Optimal

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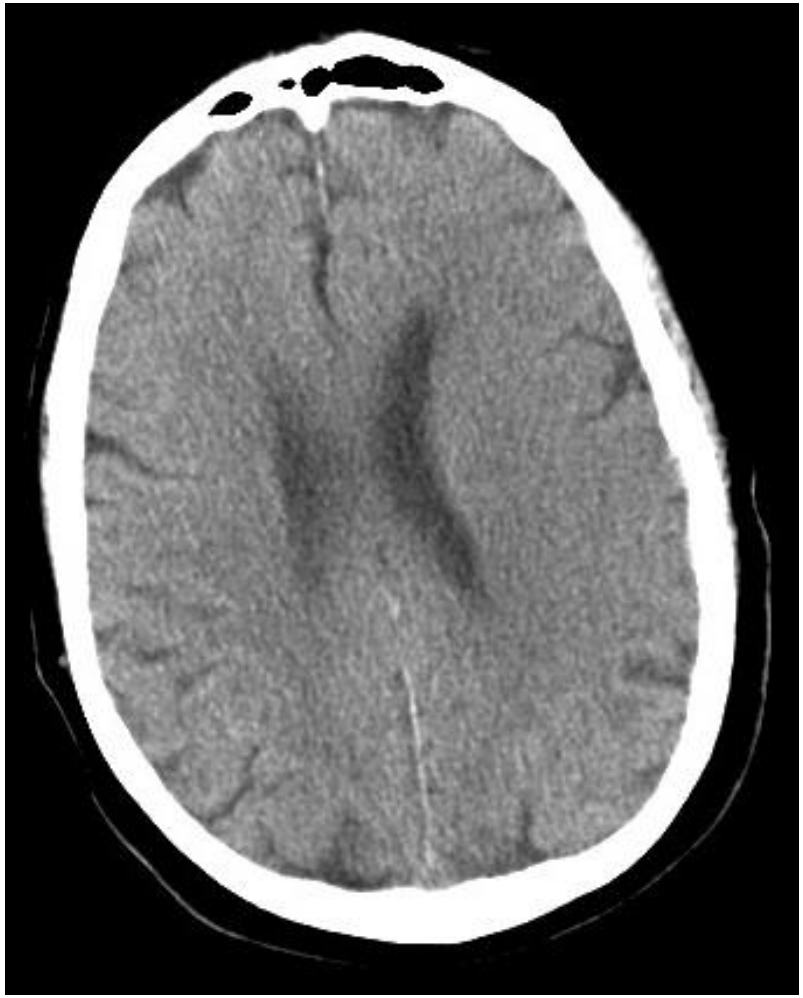
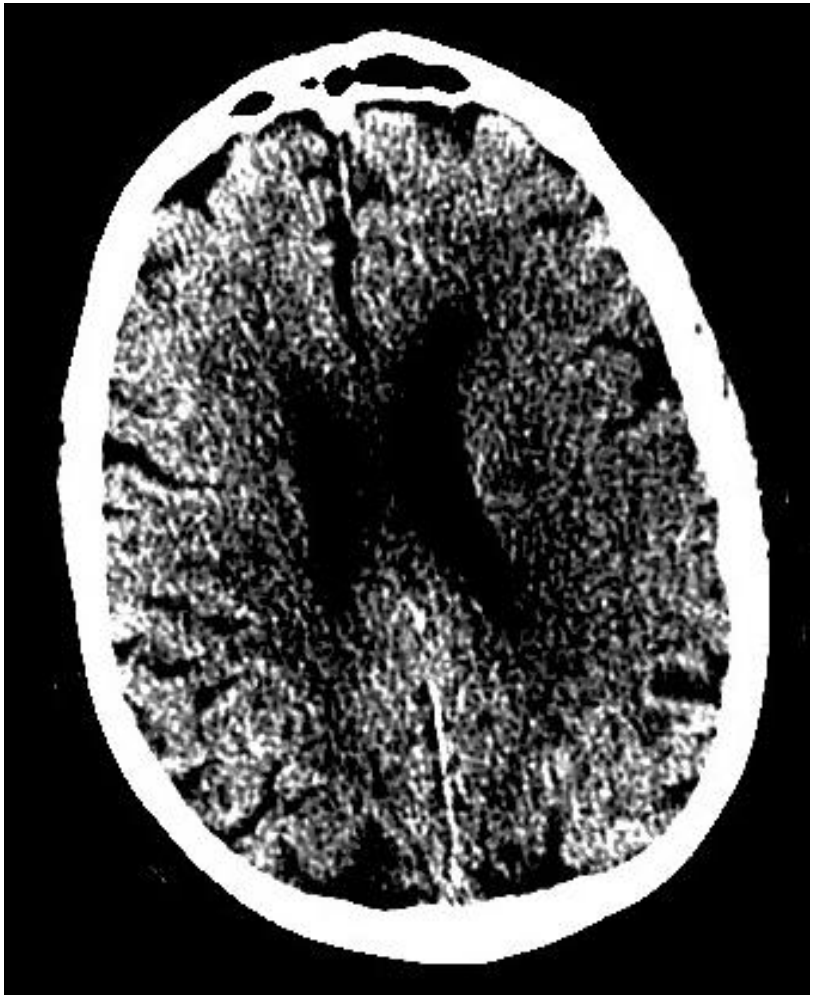
Optimizing NCCT detection

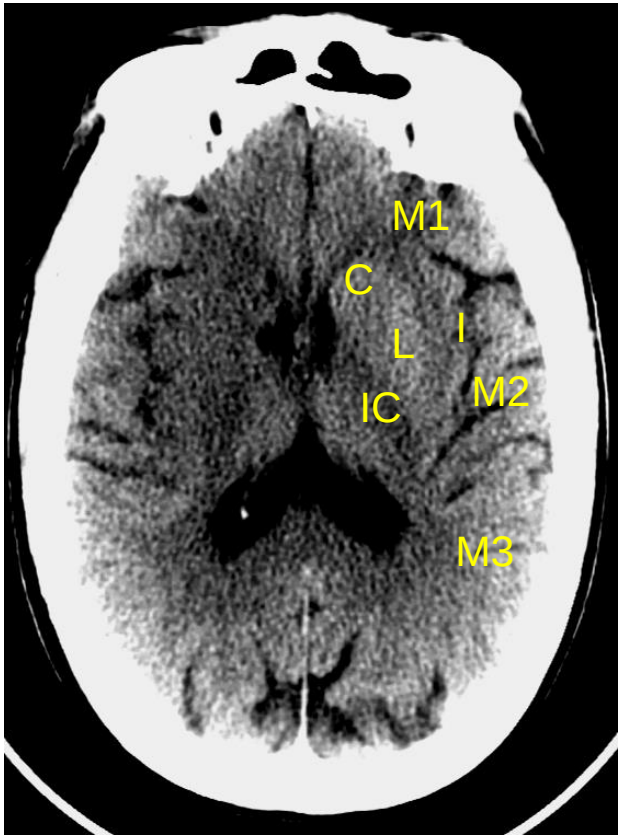


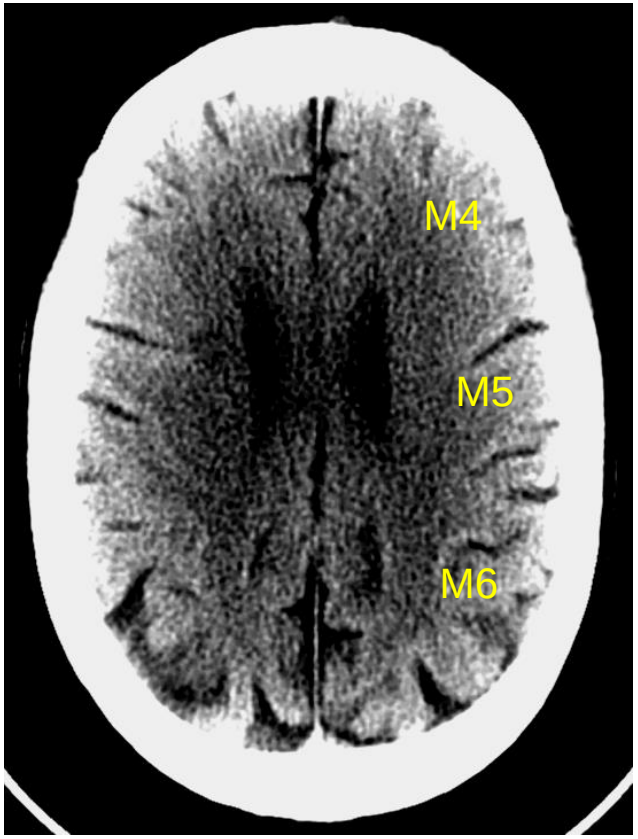


3 hours

Standardizing NCCT evaluation

- Alberta Stroke Program Early CT Score
- Reliable, semi-quantitative
- Scored from 0 to 10 – **lower score indicates a larger infarct**





NCCT ASPECTS predicts IAT response

- **PROACT II (154 pts):**
  - Patients with small infarcts (ASPECTS 8-10) had 5 times higher rate of good outcome with IAT
  - No difference in outcomes between IAT vs. placebo in ASPECTS 0-7

- **PICS-Pivotal (249 pts):**
  - Higher ASPECTS → significantly better 90-day functional outcomes, lower mortality and less symptomatic ICH

JAMA. 1999; 282:2003-11.
Stroke. 2012: 43:A72.

The problem with NCCT

- NCCT is much less sensitive than MRI for detection of acute infarction (75% sensitivity[1]), especially when it is large (>33% of MCA territory: 14-43% sensitivity[2])

[1]*Stroke*. 1999; 30:2059-65.
[2]*Neurology.* 2000; 54:1557-61.

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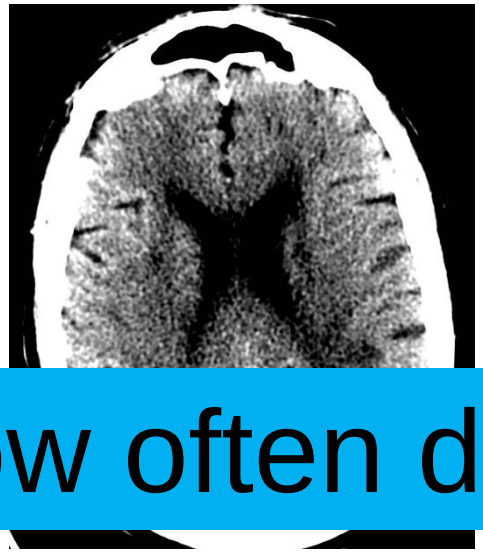
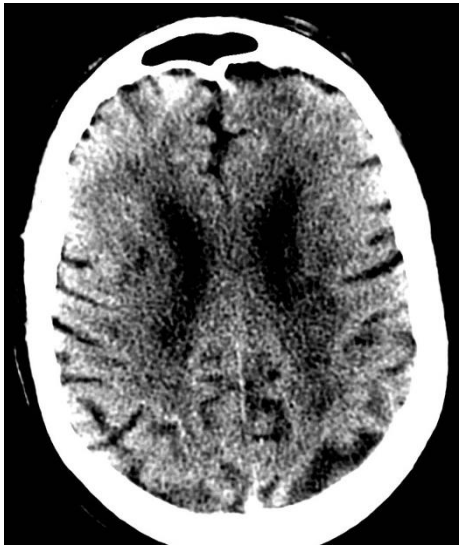
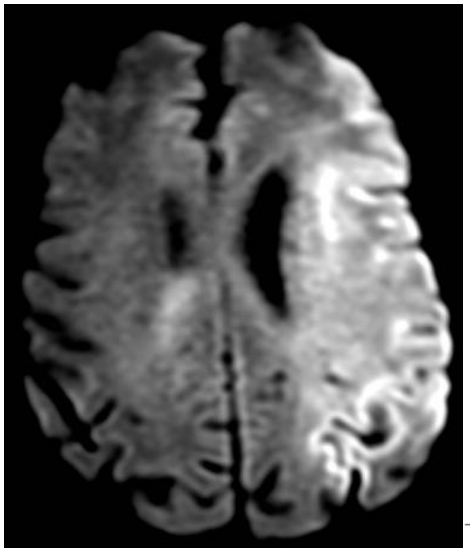
NCCT vs. DWI



How often does this happen?





NCCT ASPECTS vs. DWI

- **Aim:** To evaluate the accuracy of NCCT ASPECTS for identifying large admission DWI volumes

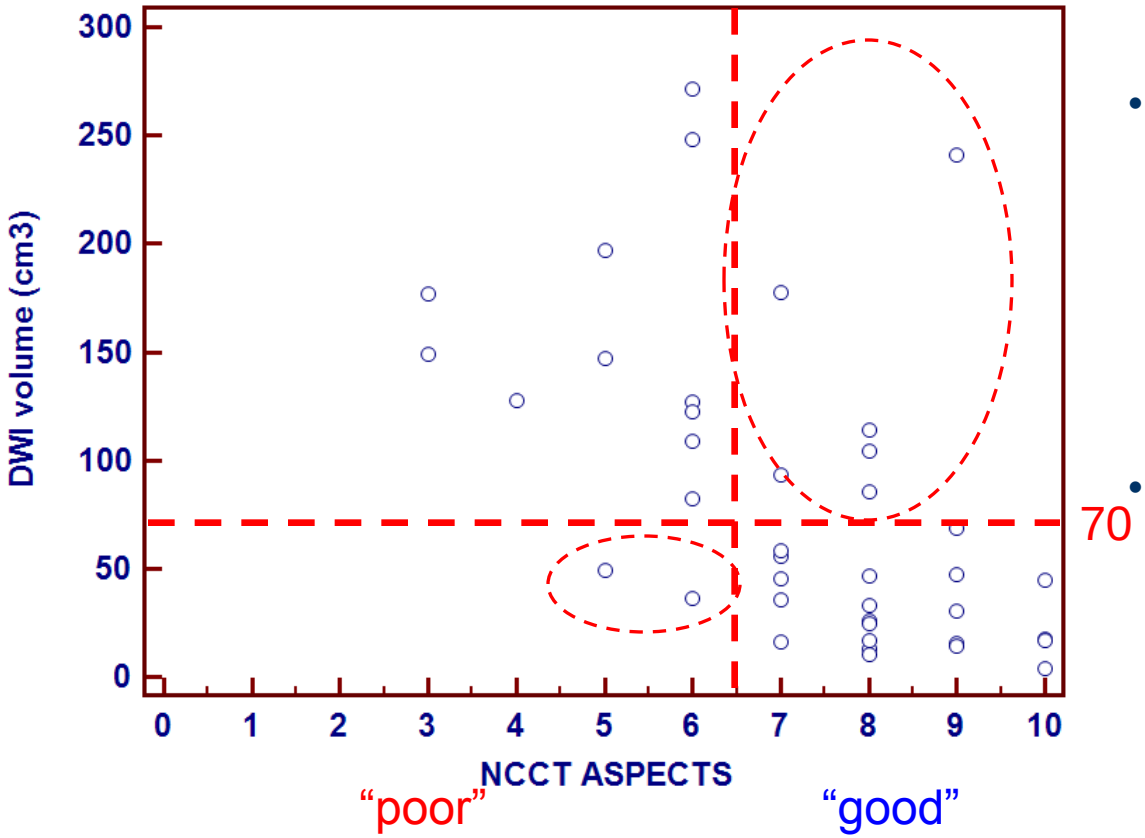
- **Methods:**
  - Single center study
  - Prospective data collection on consecutive AIS patients with NIHSSS ≥10 and presentation within 7 hours of symptom onset
  - November 2011 thru September 2012

NCCT ASPECTS vs. DWI

	n=40 pts
Age (yrs)	66.0 ± 15.6
Baseline NIHSS	19 (14.5-20)
Time, CT to MRI (min)	31.5 (26-39.5)
NCCT ASPECTS	7.5 (6-8.5)
DWI lesion volume (cm^3)	52.7 (25.1-124.9)

42.5% of pts had
DWI lesion ≥70 cm^3

NCCT ASPECTS vs. DWI



- ASPECTS 7-10 (n=27):
  - DWI ≥70 cm^3: 22.2%

    ↓

    Inappropriate tx
- ASPECTS 0-6 (n=13):
  - DWI <70 cm^3: 15.4%

    ↓

    Inappropriate exclusion

MGH 1811

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Conclusion

- Proper patient selection is critical for improved IAT outcomes

- For IAT selection, imaging evaluation is key
  - No standard imaging approach
  - Vessel imaging (CTA or MRA) important to identify proximal occlusion (and evaluate cervical vessels)
  - **Core infarct size predicts clinical response to IAT (i.e., benefit vs. risk)**
    - Diffusion MRI is the best available method
    - NCCT is the best validated CT-based approach but *it misses a significant fraction of large infarcts*

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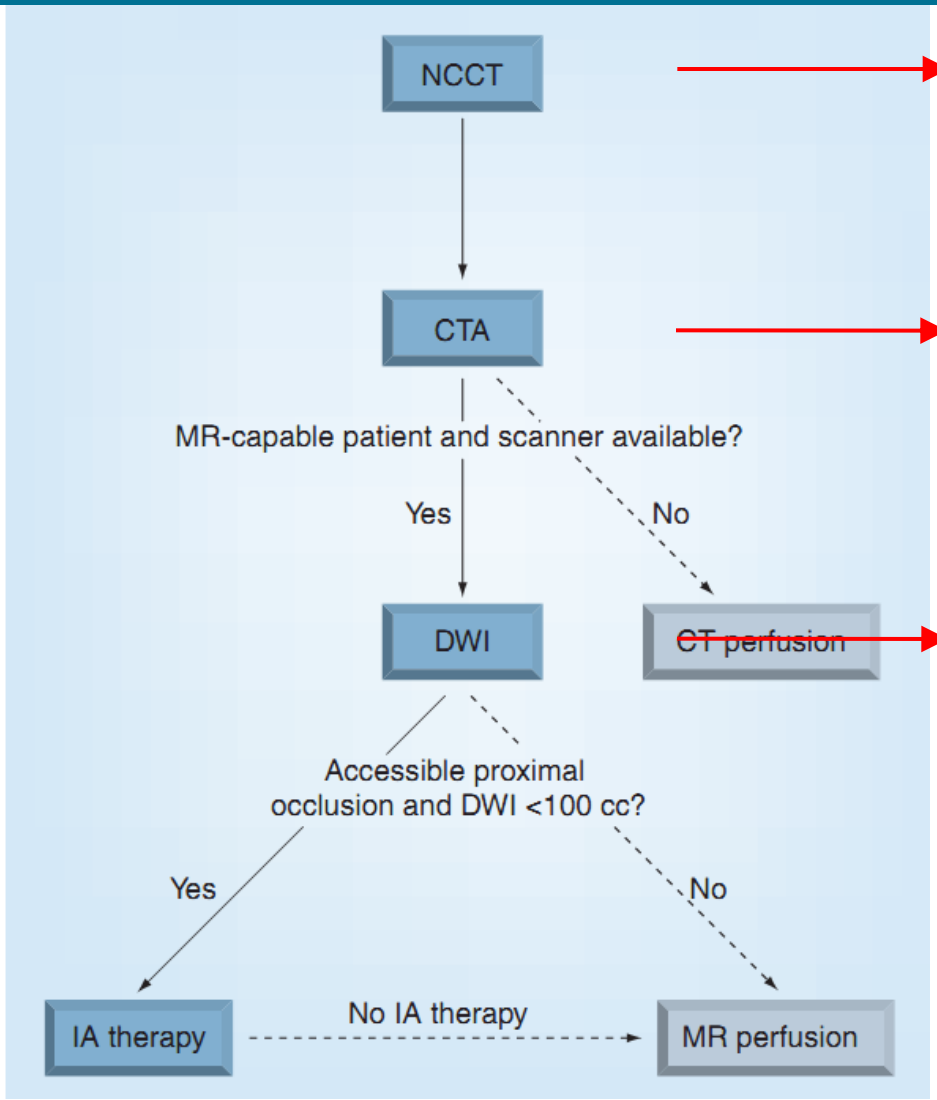
MGH approach to IAT selection



Rule out hemorrhage, IV tPA eligibility

Proximal artery occlusion, cervical disease

Infarct size estimation

Expert Rev Cardiovasc Ther 2011; 9:857-876.