Prognostic value of CT Perfusion

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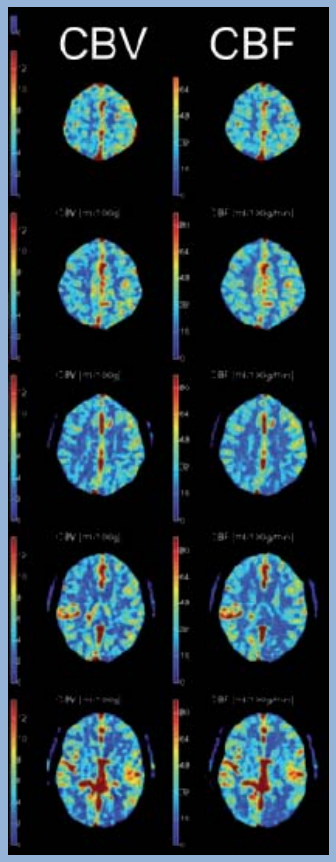
UNIVERSITÀ DEGLI STUDI FIRENZE

SST Servizio Sanitario della Toscana

CTP outcome prediction in the selection setting



Neuroimaging

REVIEW

Utility of perfusion imaging in acute stroke treatment: a systematic review and meta-analysis

Won Hyung A Ryu,[1] Michael B Avery,[1] Navjit Dharampal,[2] Isabel E Allen,[3] Steven W Hetts[4]

J Neurointervent surg 2017; 9:1012-1016

Review

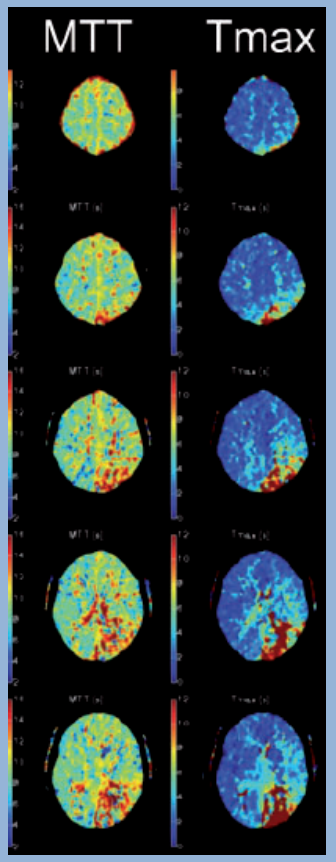
International Journal of Stroke WSO

International Journal of Stroke
2018, Vol. 13(6) 554–567

DOI: 10.1177/1747493018765235
journals.sagepub.com/home/wso
SAGE

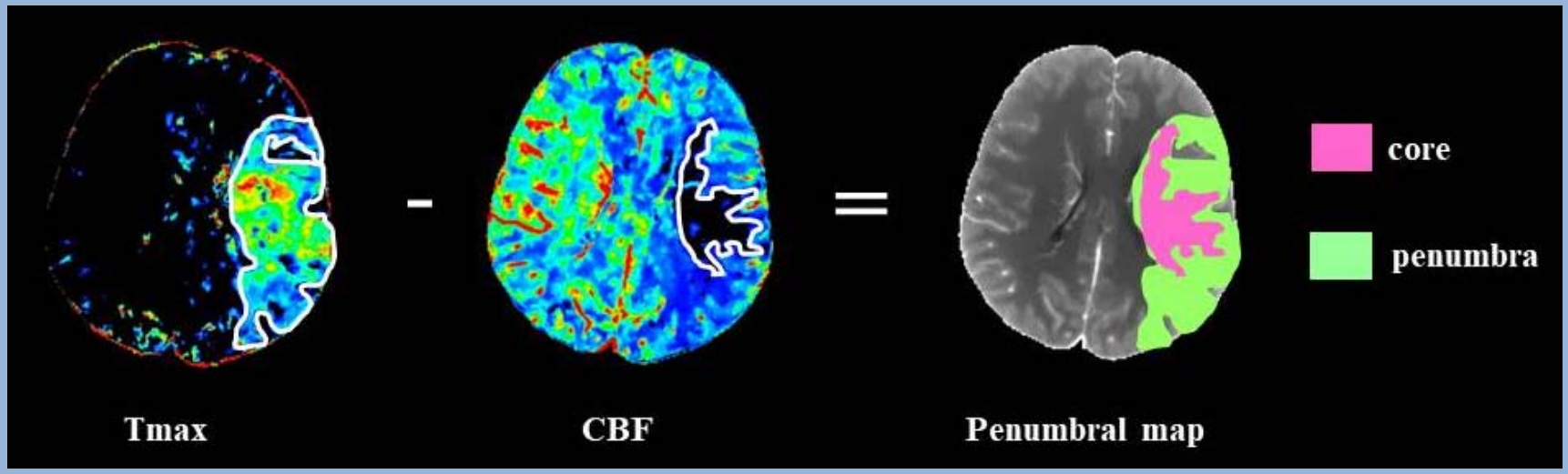
Imaging selection for acute stroke intervention

Bruce CV Campbell[1] and Mark W Parsons[1,2]



pretreatment CTP is a strong predictor of outcome

Tmax - CBF mismatch



target mismatch automatically measured according with corresponding threshold values

↓

infarct core = rCBF < 30%; total hypoperfusion = Tmax > 6 sec

↓

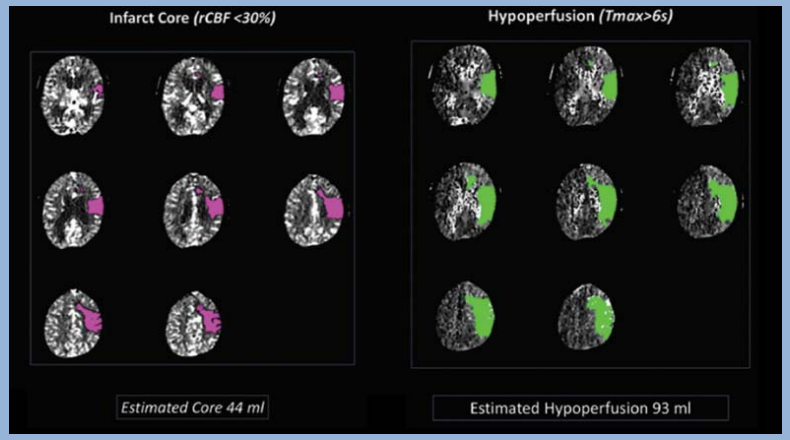
target mismatch slightly differs across the studies

EXTEND-IA

ORIGINAL ARTICLE

Endovascular Therapy for Ischemic Stroke with Perfusion-Imaging Selection

B.C.V. Campbell, P.J. Mitchell, T.J. Kleinig, H.M. Dewey, L. Churilov, N. Yassi, B. Yan, R.J. Dowling, M.W. Parsons, T.J. Oxley, T.Y. Wu, M. Brooks, M.A. Simpson, F. Miteff, C.R. Levi, M. Krause, T.J. Harrington, K.C. Faulder, B.S. Steinfort, M. Priglinger, T. Ang, R. Scroop, P.A. Barber, B. McGuinness, T. Wijeratne, T.G. Phan, W. Chong, R.V. Chandra, C.F. Bladin, M. Badve, H. Rice, L. de Villiers, H. Ma, P.M. Desmond, G.A. Donnan, and S.M. Davis, for the EXTEND-IA Investigators*



N Engl J Med 2015; 372: 1009-1018

- **70 patients admitted ≤ 4.5 hours**

- **core volume < 70 ml**
- **penumbra volume > 10 ml**
- **mismatch ratio > 1.2**

good prognosis was more common in patients treated with thrombectomy than in controls treated with iv thrombolysis alone

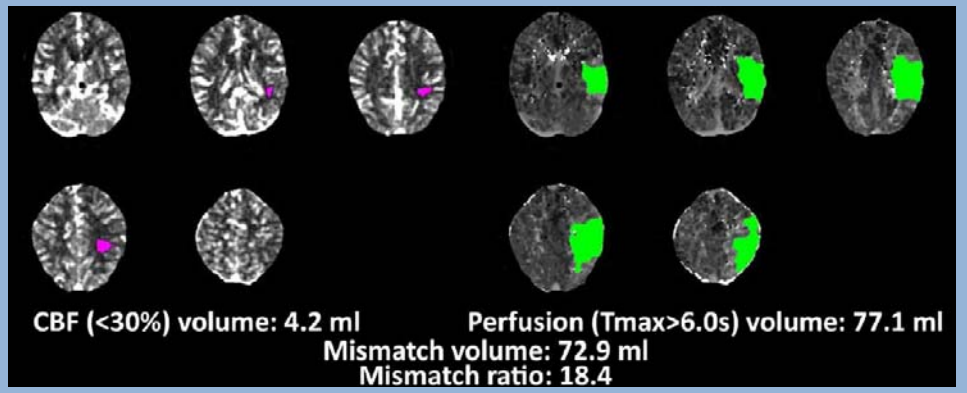
SWIFT PRIME

The NEW ENGLAND JOURNAL of MEDICINE

ESTABLISHED IN 1812 JUNE 11, 2015 VOL. 372 NO. 24

Stent-Retriever Thrombectomy after Intravenous t-PA vs. t-PA Alone in Stroke

Jeffrey L. Saver, M.D., Mayank Goyal, M.D., Alain Bonafe, M.D., Hans-Christoph Diener, M.D., Ph.D., Elad I. Levy, M.D., Vitor M. Pereira, M.D., Gregory W. Albers, M.D., Christophe Cognard, M.D., David J. Cohen, M.D., Werner Hacke, M.D., Ph.D., Olav Jansen, M.D., Ph.D., Tudor G. Jovin, M.D., Heinrich P. Mattle, M.D., Raul G. Nogueira, M.D., Adnan H. Siddiqui, M.D., Ph.D., Dileep R. Yavagal, M.D., Blaise W. Baxter, M.D., Thomas G. Devlin, M.D., Ph.D., Demetrius K. Lopes, M.D., Vivek K. Reddy, M.D., Richard du Mesnil de Rochemont, M.D., Oliver C. Singer, M.D., and Reza Jahan, M.D., for the SWIFT PRIME Investigators*



↓

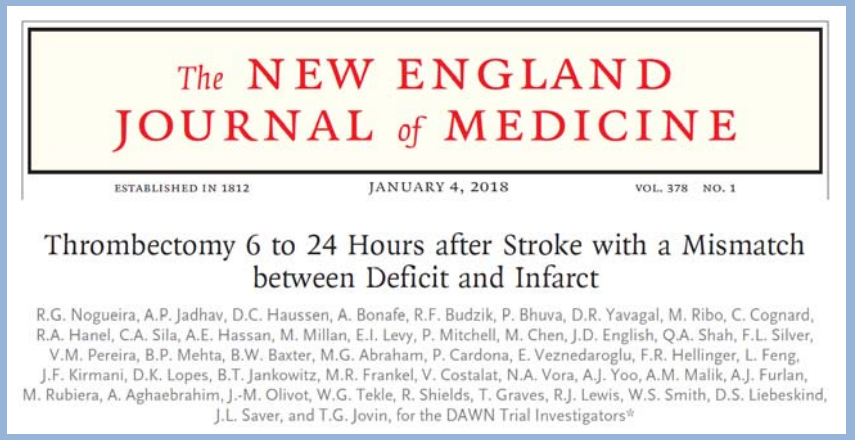
- 196 patients admitted ≤ 6 hours

↓

- core volume < 50 ml
- penumbra volume > 15 ml
- mismatch ratio > 1.8

favorable outcome was more frequent in patients treated with combined thrombectomy and iv thrombolysis than in controls treated with iv thrombolysis alone

DAWN

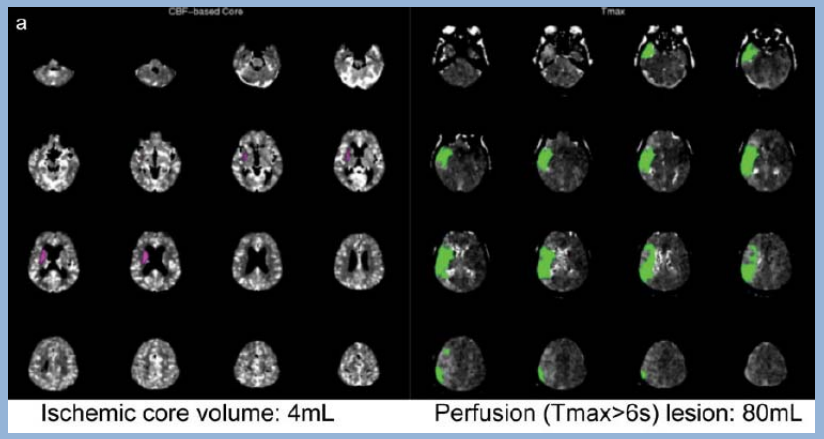


The NEW ENGLAND JOURNAL of MEDICINE

ESTABLISHED IN 1812 JANUARY 4, 2018 VOL. 378 NO. 1

Thrombectomy 6 to 24 Hours after Stroke with a Mismatch between Deficit and Infarct

R.G. Nogueira, A.P. Jadhav, D.C. Haussen, A. Bonafe, R.F. Budzik, P. Bhuva, D.R. Yavagal, M. Ribo, C. Cognard, R.A. Hanel, C.A. Sila, A.E. Hassan, M. Millan, E.I. Levy, P. Mitchell, M. Chen, J.D. English, Q.A. Shah, F.L. Silver, V.M. Pereira, B.P. Mehta, B.W. Baxter, M.G. Abraham, P. Cardona, E. Veznedaroglu, F.R. Hellinger, L. Feng, J.F. Kirmani, D.K. Lopes, B.T. Jankowitz, M.R. Frankel, V. Costalat, N.A. Vora, A.J. Yoo, A.M. Malik, A.J. Furlan, M. Rubiera, A. Aghaebrahim, J.-M. Olivot, W.G. Tekle, R. Shields, T. Graves, R.J. Lewis, W.S. Smith, D.S. Liebeskind, J.L. Saver, and T.G. Jovin, for the DAWN Trial Investigators*



- 206 patients admitted at 6-24 hours

- ≥ 80 years; NIHSS = ≥10; core volume < 21 ml
- < 80 years; NIHSS = ≥10; core volume < 31 ml
- < 80 years; NIHSS = ≥20; core volume < 31-51 ml

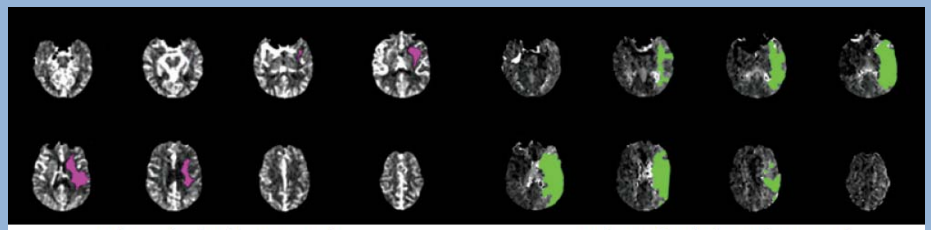
thrombectomy improved outcome in treated patients compared to controls treated with standard medical therapy

DEFUSE 3

ORIGINAL ARTICLE

Thrombectomy for Stroke at 6 to 16 Hours with Selection by Perfusion Imaging

G.W. Albers, M.P. Marks, S. Kemp, S. Christensen, J.P. Tsai, S. Ortega-Gutierrez, R.A. McTaggart, M.T. Torbey, M. Kim-Tenser, T. Leslie-Mazwi, A. Sarraj, S.E. Kasner, S.A. Ansari, S.D. Yeatts, S. Hamilton, M. Mlynash, J.J. Heit, G. Zaharchuk, S. Kim, J. Carrozzella, Y.Y. Palesch, A.M. Demchuk, R. Bammer, P.W. Lavori, J.P. Broderick, and M.G. Lansberg, for the DEFUSE 3 Investigators*



N Engl J Med 2018; 378: 708-718

- **182 patients admitted at 6-16 hours**

- **core volume < 70 ml**
- **penumbra volume > 15 ml**
- **mismatch ratio > 1.8**

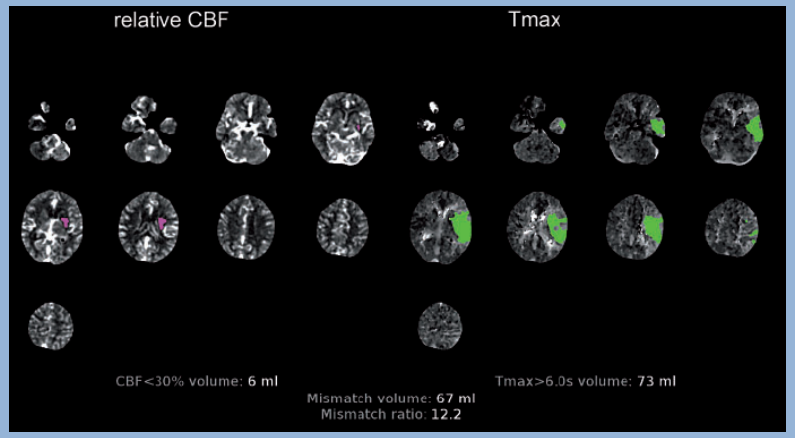
prognosis was better in patients treated with thrombectomy than in controls treated with standard medical therapy

DEFUSE 3 criteria

DEFUSE 3 Non-DAWN Patients
A Closer Look at Late Window Thrombectomy Selection

Thabele M. Leslie-Mazwi, MD; Scott Hamilton, PhD; Michael Mlynash, MD, MS; Aman B. Patel, MD; Lee H. Schwamm, MD; Maarten G. Lansberg, MD; Michael Marks, MD; Joshua A. Hirsch, MD; Gregory W. Albers, MD

Stroke 2019; 50: 618-625



DEFUSE 3 criteria are currently considered more reliable to avoid an overselection

↓

patients with pretreatment core infarct volume < 70 ml but too large for inclusion by DAWN criteria demonstrated benefit from endovascular therapy

DEFUSE 3 criteria

Computed Tomographic Perfusion to Predict Response to Recanalization in Ischemic Stroke

Maarten G. Lansberg, MD, PhD,[1] Soren Christensen, PhD,[1] Stephanie Kemp,[1] Michael Mlynash, MD, MS,[1] Nishant Mishra, MD, PhD,[1] Christian Federau, MD,[1] Jenny P. Tsai, MD,[1] Sun Kim, MD,[1] Raul G. Nogueria, MD,[2] Tudor Jovin, MD,[3] Thomas G. Devlin, MD,[4] Naveed Akhtar, MD,[5] Dileep R. Yavagal, MD,[6] Diogo Haussen, MD,[2] Seena Dehkharghani, MD,[7] Roland Bammer, PhD,[8] Matus Straka, PhD,[9] Greg Zaharchuk, MD,[8] Michael P. Marks, MD,[8] and Gregory W. Albers, MD[1] for the CT Perfusion to Predict Response to Recanalization in Ischemic Stroke Project (CRISP) Investigators

Ann Neurol 2017; 81 :849-856

Computed Tomographic Perfusion Predicts Poor Outcomes in a Randomized Trial of Endovascular Therapy

Robert Wannamaker, BSc; Taurian Guinand, BSc; Bijoy K. Menon, MD; Andrew Demchuk, MD; Mayank Goyal, MD; Donald Frei, MD; Aditya Bharatha, MD; Tudor G. Jovin, MD; Jai Shankar, MD; Timo Krings, MD, PhD; Blaise Baxter, MD; Christine Holmstedt, DO; Richard Swartz, MD, PhD; Dar Dowlatshahi, MD, PhD; Richard Chan, MBBS; Donatella Tampieri, MD; Hana Choe, MD; Paul Burns, MD; Nina Gentile, MD; Jeremy Rempel, MD; Ashfaq Shuaib, MD; Brian Buck, MD, MSc; Andrew Bivard, PhD; Michael Hill, MD; Kenneth Butcher, MD, PhD

Stroke 2018; 49: 1426-1433

- **190 patients admitted ≤ 18 hours treated with thrombectomy**

- **138 patients admitted ≤ 12 hours treated and not treated with thrombectomy**

DEFUSE 3 target mismatch was associated with good outcome between treated patients and in treated compared to not treated patients

EXTEND and meta-analysis

Thrombolysis Guided by Perfusion Imaging up to 9 Hours after Onset of Stroke

H. Ma, B.C.V. Campbell, M.W. Parsons, L. Churilov, C.R. Levi, C. Hsu, T.J. Kleinig, T. Wijeratne, S. Curtze, H.M. Dewey, F. Miteff, C.-H. Tsai, J.-T. Lee, T.G. Phan, N. Mahant, M.-C. Sun, M. Krause, J. Sturm, R. Grimley, C.-H. Chen, C.-J. Hu, A.A. Wong, D. Field, Y. Sun, P.A. Barber, A. Sabet, J. Jannes, J.-S. Jeng, B. Clissold, R. Markus, C.-H. Lin, L.-M. Lien, C.F. Bladin, S. Christensen, N. Yassi, G. Sharma, A. Bivard, P.M. Desmond, B. Yan, P.J. Mitchell, V. Thijs, L. Carey, A. Meretoja, S.M. Davis, and G.A. Donnan, for the EXTEND Investigators*

N Engl J Med 2019; 380: 1795-803

Extending thrombolysis to 4·5–9 h and wake-up stroke using perfusion imaging: a systematic review and meta-analysis of individual patient data

Bruce C V Campbell, Henry Ma*, Peter A Ringleb*, Mark W Parsons, Leonid Churilov, Martin Bendszus, Christopher R Levi, Chung Hsu, Timothy J Kleinig, Marc Fatar, Didier Leys, Carlos Molina, Tissa Wijeratne, Sami Curtze, Helen M Dewey, P Alan Barber, Kenneth S Butcher, Deidre A De Silva, Christopher F Bladin, Nawaf Yassi, Johannes A R Pfaff, Gagan Sharma, Andrew Bivard, Patricia M Desmond, Stefan Schwab, Peter D Schellinger, Bernard Yan, Peter J Mitchell, Joaquín Serena, Danilo Toni, Vincent Thijs, Werner Hacke†, Stephen M Davis†, Geoffrey A Donnan†, on behalf of the EXTEND, ECASS-4, and EPITHET Investigators‡*

Lancet 2109; 13; 394: 139-147

- **225 patients admitted at 4.5-9 hours**
- **414 patients admitted at 4.5-9 hours (EXTEND, ECASS4 and EPITHET)**

- **core volume < 70 ml**
- **penumbra volume > 10 ml**
- **mismatch ratio > 1.2**

favorable outcome was more frequent in patients treated with iv thrombolysis than in controls treated with placebo

Disability after thrombolysis

doi:10.1093/brain/aww338 BRAIN 2017: 140; 684–691 | 684

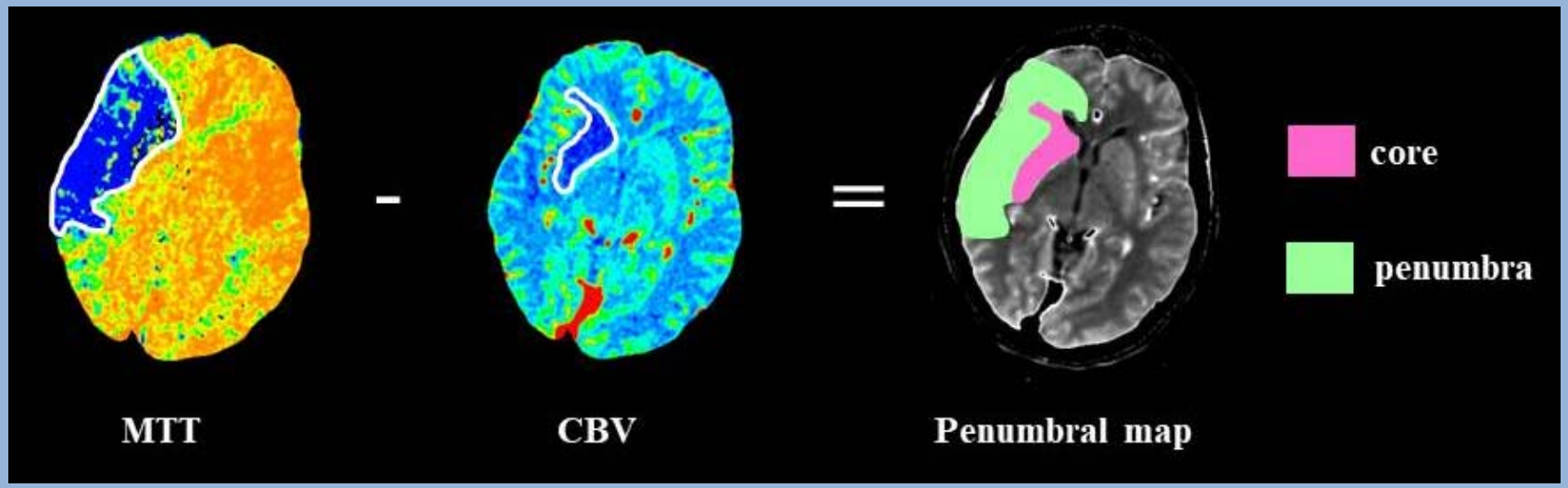
BRAIN
A JOURNAL OF NEUROLOGY

Perfusion computed tomography in patients with stroke thrombolysis

Hiroyuki Kawano,[1] Andrew Bivard,[1] Longting Lin,[1] Henry Ma,[2] Xin Cheng,[3] Richard Aviv,[4] Billy O'Brien,[5] Kenneth Butcher,[6] Min Lou,[7] Jingfen Zhang,[8] Jim Jannes,[9] Qiang Dong,[3] Christopher R. Levi[1] and Mark W. Parsons[1]

core volume and salvaged penumbra calculated with Tmax - rCBF mismatch thresholds were strong predictors of disability in patients treated with iv thrombolysis

MTT - CBV mismatch



automatically measured relative threshold values

↓

infarct core = CBV < 2 ml/100gr; total hypoperfusion = rMTT > 145%

↓

high predictive values for outcome

Prognostic value

Perfusion CT: is it clinically useful?

Mark W. Parsons

Parsons MV. Int J Stroke 2008; 3: 41-50

Computed Tomography Workup of Patients Suspected of Acute Ischemic Stroke

Perfusion Computed Tomography Adds Value Compared With Clinical Evaluation, Noncontrast Computed Tomography, and Computed Tomography Angiogram in Terms of Predicting Outcome

Guangming Zhu, MD, PhD; Patrik Michel, MD; Amin Aghaebrahim, MD; James T. Patrie, MS; Wenjun Xin, MS; Ashraf Eskandari; Weiwei Zhang, MD, PhD; Max Wintermark, MD

Stroke. 2013; 44:1049-1055

Acute Stroke Triage to Intravenous Thrombolysis and Other Therapies with Advanced CT or MR Imaging: Pro CT[1]

Wintermark M et al. Radiology 2009; 251: 619-626

Perfusion-Based Selection for Endovascular Reperfusion Therapy in Anterior Circulation Acute Ischemic Stroke

S. Prabhakaran, M. Soltanolkotabi, A.R. Honarmand, R.A. Bernstein, V.H. Lee, J.J. Conners, F. Dehkordi-Vakil, A. Shaibani, M.C. Hurley, and S.A. Ansari

Am J Neuroradiol 2014; 35: 1303-1308

MTT - CBV mismatch is able to identify favorable outcome in patients treated with iv thrombolysis and/or endovascular therapy < 12 hours

The failure of clinical trials

Intravenous desmoteplase in patients with acute ischaemic stroke selected by MRI perfusion–diffusion weighted imaging or perfusion CT (DIAS-2): a prospective, randomised, double-blind, placebo-controlled study

Werner Hacke, Anthony J Furlan, Yasir Al-Rawi, Antoni Davalos, Jochen B Fiebach, Franz Gruber, Markku Kaste, Leslie J Lipka, Salvador Pedraza, Peter A Ringleb, Howard A Rowley, Dietmar Schneider, Lee H Schwamm, Joaquin Serena Leal, Mariola Söhngen, Phil A Teal, Karin Wilhelm-Ogunbiyi, Max Wintermark, Steven Warach

Lancet Neurol 2009; 8: 141-150

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*

N Engl J Med 2013; 368: 914-923

after iv thrombolysis ≤ 9 hours from onset and endovascular treatment ≤ 8 hours from onset

↓

patients with and without MTT - CBV mismatch had similar outcome

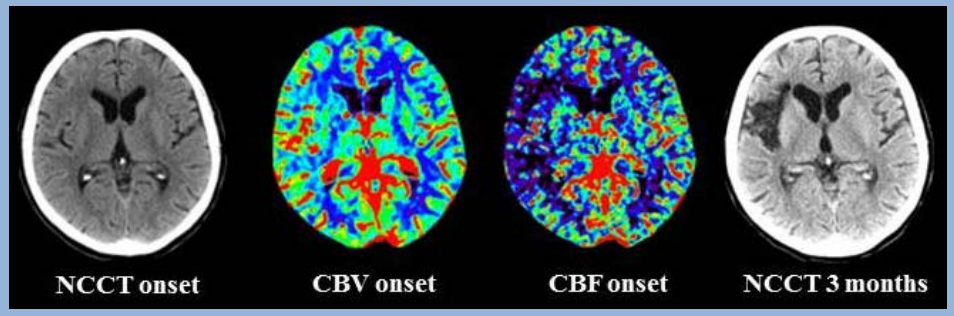
Inaccuracy of CBV and MTT

Neurol Sci (2015) 36:1777–1783
DOI 10.1007/s10072-015-2244-8

ORIGINAL ARTICLE

CT perfusion cerebral blood volume does not always predict infarct core in acute ischemic stroke

Christopher D. d'Esterre[1,2] · Gloria Roversi[3] · Marina Padroni[3] · Andrea Bernardoni[4] · Carmine Tamborino[3] · Alessandro De Vito[5] · Cristiano Azzini[5] · Onofrio Marcello[6] · Andrea Saletti[6] · Stefano Ceruti[6] · Ting Yim Lee[1,2,7] · Enrico Fainardi[6]



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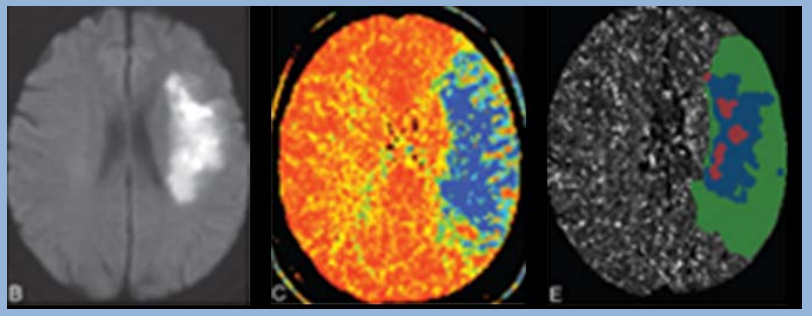
hyperemia occurring in penumbra region can mask infarct core = underestimation of CBV lesion

CT Perfusion Mean Transit Time Maps Optimally Distinguish Benign Oligemia from True "At-Risk" Ischemic Penumbra, but Thresholds Vary by Postprocessing Technique

Kamalian S A et al. Am J Neuroradiol 2012; 33: 545-549



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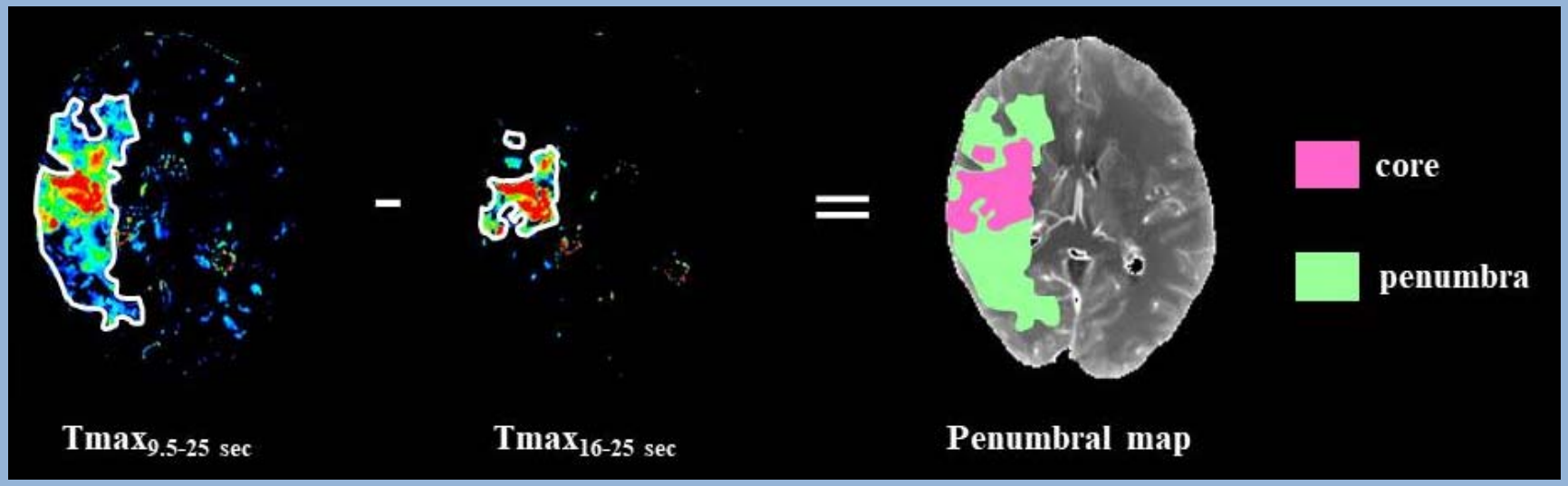
MTT lesion includes hypoperfused regions of benign oligoemia = overestimation of penumbra extent

Tmax - Tmax mismatch



infarct core = Tmax > 16 sec; total hypoperfusion = Tmax > 9.5 sec as threshold values

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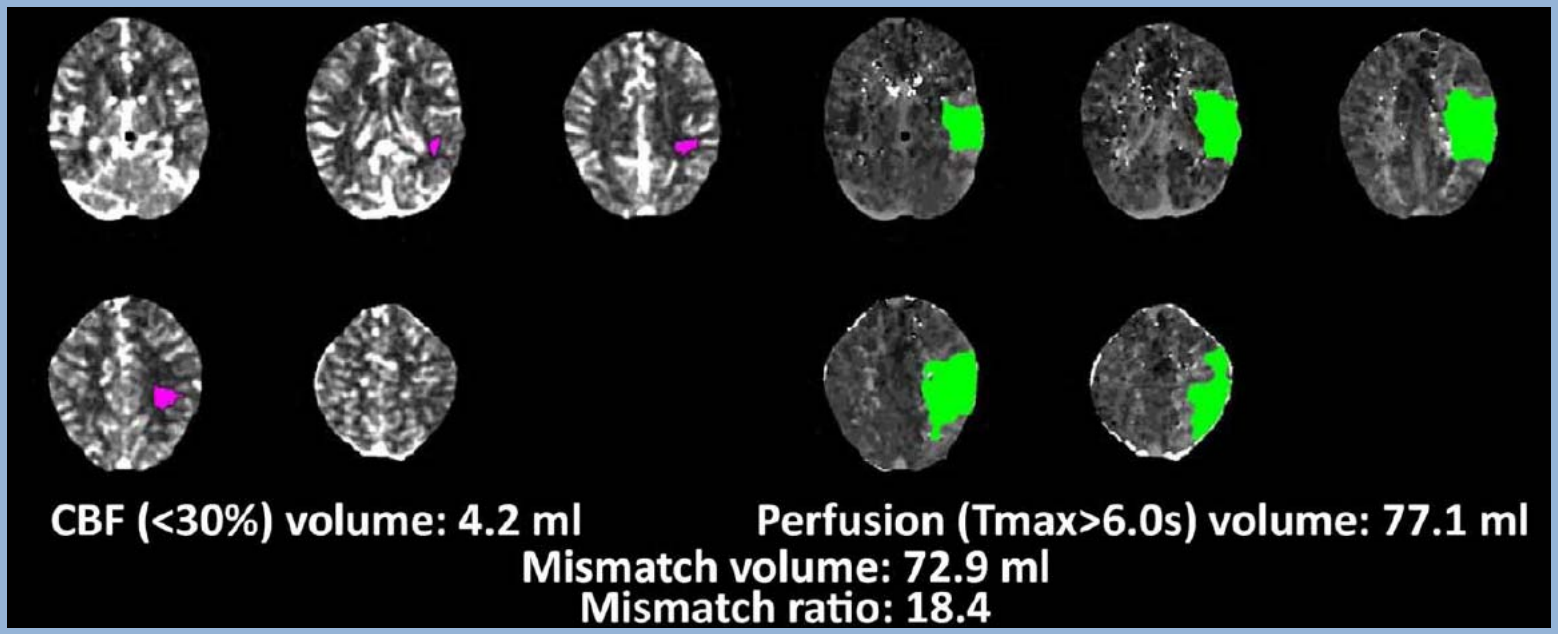
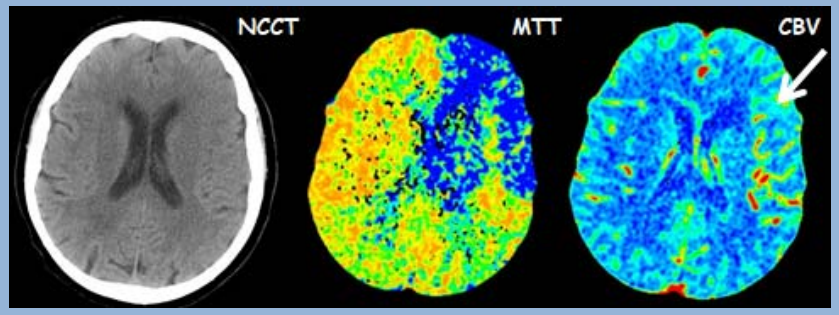
no data are currently available on its ability in predicting outcome

CTP outcome prediction beyond the selection

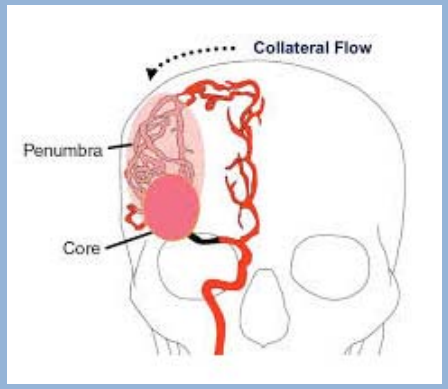


pretreatment CTP predictive value is not only associated with the selection of patients candidates for reperfusion therapies

CBV and collaterals



high CBV values are a marker of good CTA and DSA collaterals in patients treated with iv thrombolysis and thrombectomy



CBV maps indicate collateral status

Relative Cerebral Blood Volume as a Marker of Durable Tissue-at-Risk Viability in Hyperacute Ischemic Stroke

Elisa Cortijo, MD; Ana Isabel Calleja, PhD; Pablo García-Bermejo, MD; Patricia Mulero, MD; Santiago Pérez-Fernández, MD; Javier Reyes, BS; Mª Fe Muñoz, MD; Mario Martínez-Galdámez, MD; Juan Francisco Arenillas, PhD

Stroke 2014; 45: 113-118

ORIGINAL RESEARCH

CT perfusion and angiographic assessment of pial collateral reperfusion in acute ischemic stroke: the CAPRI study

Arturo Consoli,[1] Tommy Andersson,[2,3] Ake Holmberg,[3] Luca Verganti,[4] Andrea Saletti,[5] Stefano Vallone,[4] Andrea Zini,[6] Alfonso Cerase,[7] Daniele Romano,[7] Sandra Bracco,[7] Svetlana Lorenzano,[8] Enrico Fainardi,[5] Salvatore Mangiafico,[1] on behalf of the CAPRI Collaborative Group

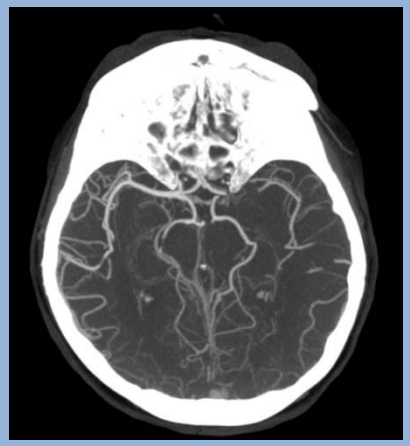
J Neurointerv Surg 2016; 8:1211-1216

Relative cerebral blood volume is associated with collateral status and infarct growth in stroke patients in SWIFT PRIME

Juan F Arenillas[1,2], Elisa Cortijo[1,2], Pablo García-Bermejo[1], Elad I Levy[3], Reza Jahan[4], Mayank Goyal[5], Jeffrey L Saver[4] and Gregory W Albers[6]

J Cereb Blood Flow Metab 2018; 38: 1839-1847

Collaterals and outcome



ORIGINAL RESEARCH

F. McVerry
D.S. Liebeskind
K.W. Muir

Systematic Review of Methods for Assessing Leptomeningeal Collateral Flow

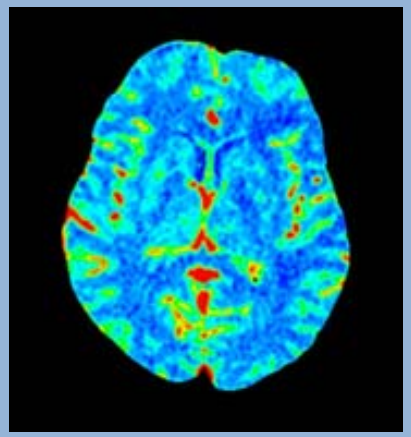
BACKGROUND AND PURPOSE: The importance of LMF in the outcome after acute ischemic stroke is increasingly recognized, but imaging presents a wide range of options for identification of collaterals and there is no single system for grading collateral flow. The aim of this study was to systematically review the literature on the available methods for measuring LMF adequacy.

AJNR Am J Neuroradiol 2012; 33: 576-582

Collateral Circulation in Ischemic Stroke
Assessment Tools and Therapeutic Strategies

Oh Young Bang, MD, PhD; Mayank Goyal, MD; David S. Liebeskind, MD

Stroke 2015; 46: 3302-3309



collateral extent is correlated with prognosis

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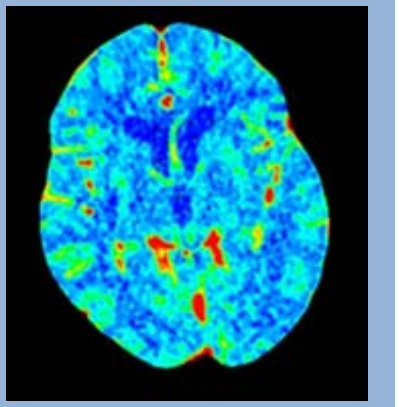
good collaterals = good outcome

↓

CBV may be useful for predicting outcome

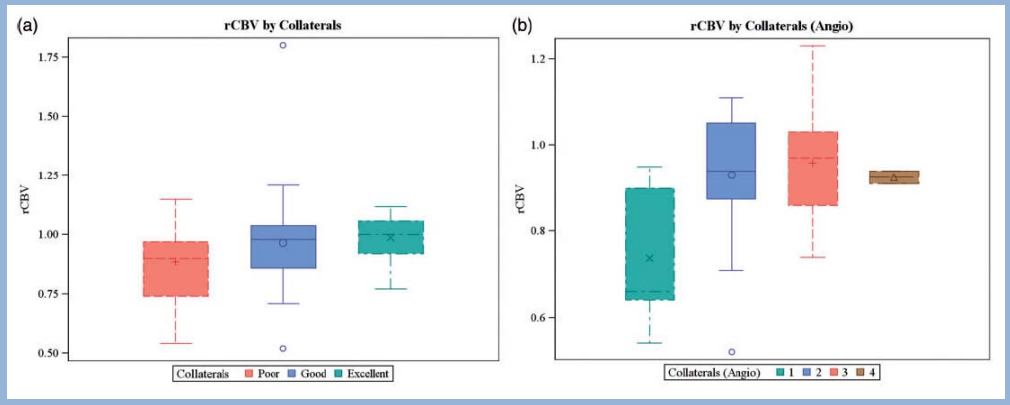


HIR and collaterals

Relative cerebral blood volume is associated with collateral status and infarct growth in stroke patients in SWIFT PRIME

Juan F Arenillas[1,2], Elisa Cortijo[1,2], Pablo García-Bermejo[1], Elad I Levy[3], Reza Jahan[4], Mayank Goyal[5], Jeffrey L Saver[4] and Gregory W Albers[6]

J Cereb Blood Flow Metab 2018; 38: 1839-1847



the same consideration is valid for Hypoperfusion Intensity Ratio (HIR)

↓

severe hypoperfused tissue volume (Tmax > 10 sec)/any hypoperfused tissue volume (Tmax > 6 sec)

↓

severity of hypoperfusion

↓

low HIR correlates with good collaterals in patients treated with thrombectomy

HIR and outcome

Hypoperfusion Intensity Ratio Predicts Infarct Progression and Functional Outcome in the DEFUSE 2 Cohort

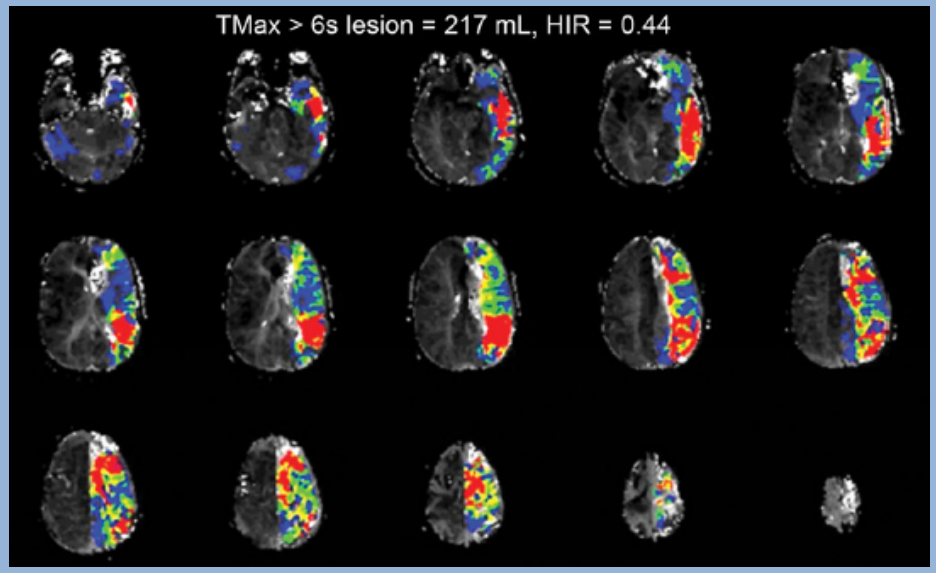
Jean Marc Olivot, MD, PhD; Michael Mlynash, MD, MS; Manabu Inoue, MD, PhD; Michael P. Marks, MD; Hayley M. Wheeler, BS; Stephanie Kemp, BS; Matus Straka, PhD; Gregory Zaharchuk, MD, PhD; Roland Bammer, PhD; Maarten G. Lansberg, MD, PhD; Gregory W. Albers, MD; on behalf of the DEFUSE 2 Investigators*

Stroke 2014; 45: 1018-1023

given its ability to assess collateral status

↓

- **HIR is a predicting factor for outcome**



HIR and selection

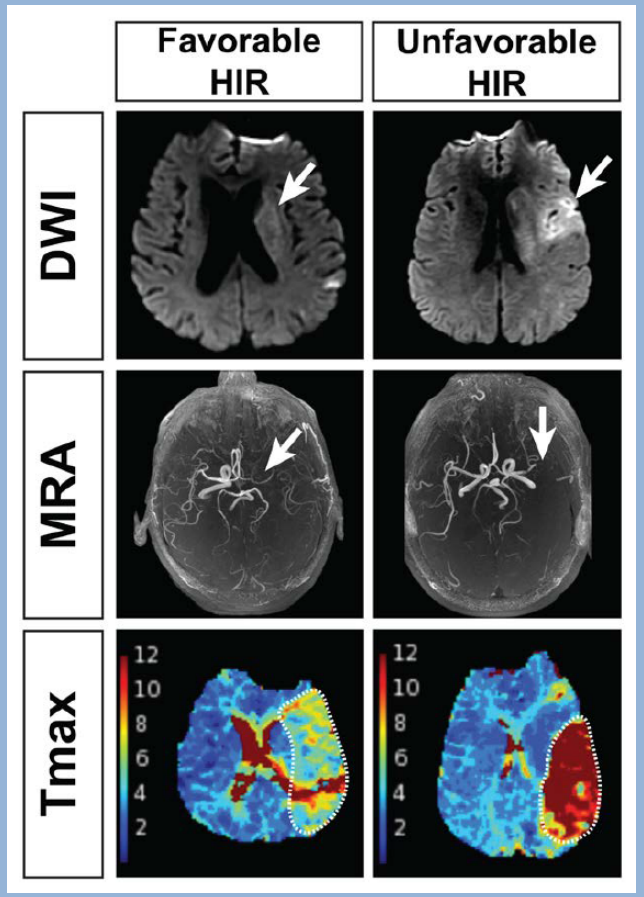
Hypoperfusion Intensity Ratio Is Correlated With Patient Eligibility for Thrombectomy

Adrien Guenego, MD; David G. Marcellus, BS; Blake W. Martin, BS; Soren Christensen, PhD; Gregory W. Albers, MD; Maarten G. Lansberg, MD, PhD; Michael P. Marks, MD; Max Wintermark, MD, PhD; Jeremy J. Heit, MD, PhD

Stroke 2019; 50: 917-922

↓

- **HIR may be useful for the selection of patients who could benefit from endovascular treatment**

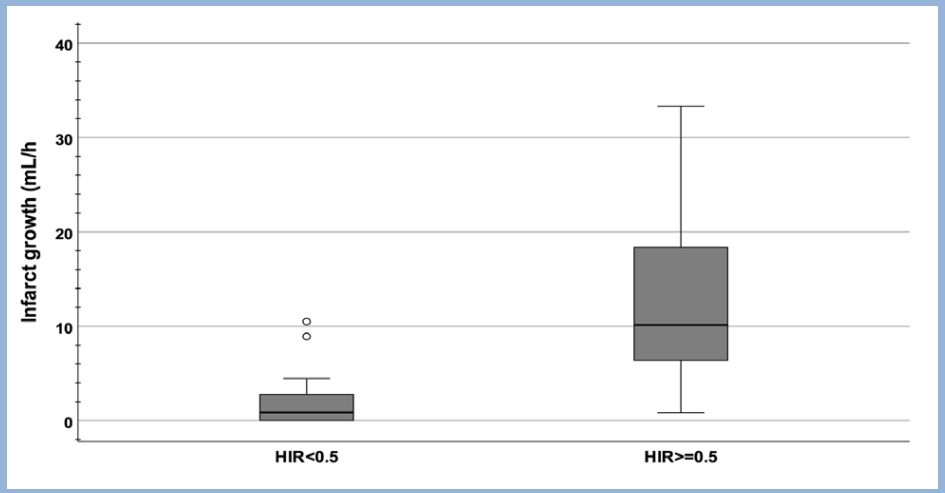


HIR and infarct growth

Hypoperfusion Ratio Predicts Infarct Growth during Transfer for Thrombectomy

Adrien Guenego, MD,[1]
Michael Mlynash, MD, MS,[1]
Soren Christensen, PhD,[1]
Stephanie Kemp, BS,[1]
Jeremy J. Heit, MD, PhD,[2]
Maarten G. Lansberg, MD, PhD,[1] and
Gregory W. Albers, MD[1]

Ann Neurol 2018;84:616–620



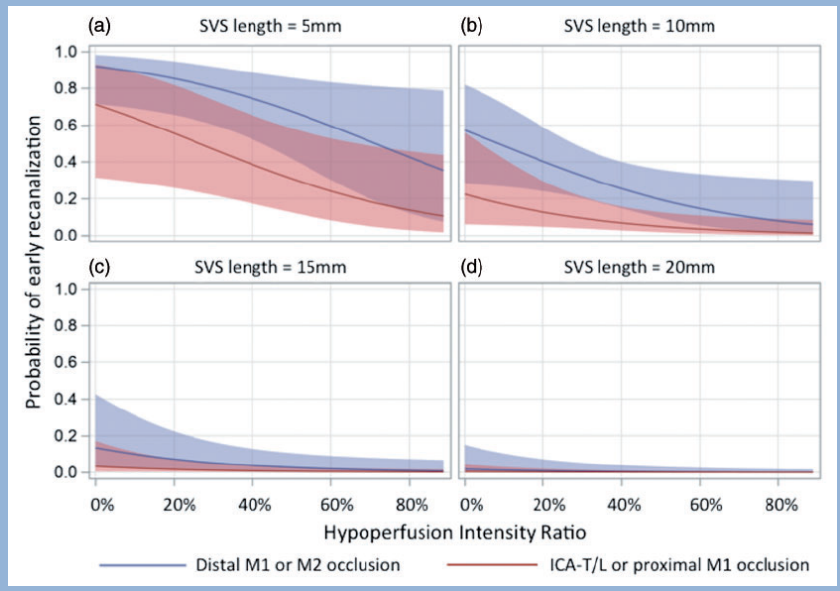
- **HIR ≤ 5 is associated with core expansion**

HIR and recanalization

Relationships between brain perfusion and early recanalization after intravenous thrombolysis for acute stroke with large vessel occlusion

Pierre Seners[1], Guillaume Turc[1], Stéphanie Lion[2], Jean-Philippe Cottier[3], Tae-Hee Cho[4], Caroline Arquizan[5], Serge Bracard[6], Canan Ozsancak[7], Laurence Legrand[2], Olivier Naggara[2], Séverine Debiais[8], Yves Berthezene[9], Vincent Costalat[10], Sébastien Richard[11], Christophe Magni[12], Norbert Nighoghossian[4], Ana-Paula Narata[3], Cyril Dargazanli[10], Benjamin Gory[6], Jean-Louis Mas[1], Catherine Oppenheim[2,*] and Jean-Claude Baron[1,*]

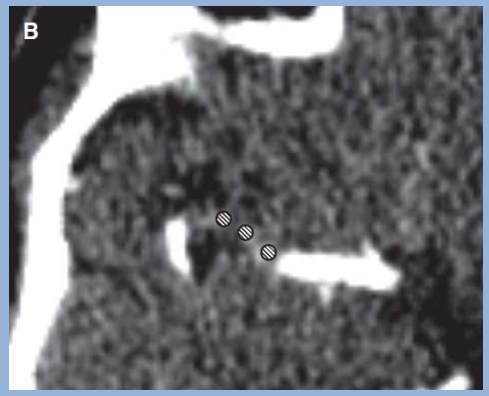
J Cereb Blood Flow Metab 2019 Mar 19 [Epub ahead of print]



↓

- **HIR is correlated with post-thrombolysis recanalization**

Thrombus permeability



thrombus permeability is associated with:

↓

- **good outcome**
- **recanalization after thrombolysis and thrombectomy**
- **good collaterals**

Thrombus Permeability Is Associated With Improved Functional Outcome and Recanalization in Patients With Ischemic Stroke

Emilie M.M. Santos, MSc*; Henk A. Marquering, PhD*; Mark D. den Blanken, MSc; Olvert A. Berkhemer, MD, MSc; Anna M.M. Boers, MSc; Albert J. Yoo, MD; Ludo F. Beenen, MD; Kilian M. Treurniet, MD, MSc; Carrie Wismans, BSc; Kim van Noort, BSc; Hester F. Lingsma, PhD; Diederik W.J. Dippel, MD, PhD; Aad van der Lugt, MD; Wim H. van Zwam, MD, PhD; Yvo B.W.E.M. Roos, MD, PhD; Robert J. van Oostenbrugge, MD; Wiro J. Niessen, PhD; Charles B. Majoie, MD, PhD; on behalf of the MR CLEAN Investigators†

Stroke 2016;47: 732-7 41

Permeable Thrombi Are Associated With Higher Intravenous Recombinant Tissue-Type Plasminogen Activator Treatment Success in Patients With Acute Ischemic Stroke

Emilie M.M. Santos, MSc; Jan Willem Dankbaar, MD, PhD; Kilian M. Treurniet, MD, MSc; Alexander D. Horsch, MD, MSc; Yvo B. Roos, MD, PhD; L. Jaap Kappelle, MD, PhD; Wiro J. Niessen, PhD; Charles B. Majoie, MD, PhD; Birgitta Velthuis, MD, PhD; Henk A. Marquering, PhD; on behalf of the DUST Investigators*

Stroke 2016; 47: 2058-2065

Value of Thrombus CT Characteristics in Patients with Acute Ischemic Stroke

J. Borst, O.A. Berkhemer, E.M.M. Santos, A.J. Yoo, M. den Blanken, Y.B.W.E.M. Roos, E. van Bavel, W.H. van Zwam, R.J. van Oostenbrugge, H.F. Lingsma, A. van der Lugt, D.W.J. Dippel, H.A. Marquering, and C.B.L.M. Majoie; on behalf of the MR CLEAN investigators

AJNR Am J Neuroradiol 2017; 38:1758-1764

Associations Between Collateral Status and Thrombus Characteristics and Their Impact in Anterior Circulation Stroke

Heitor C. Alves, MD*; Kilian M. Treurniet, MD, MSc*; Bruna G. Dutra, MD; Ivo G. H. Jansen, MD; Anna M.M. Boers, MSC; Emilie M.M. Santos, PhD; Olvert A. Berkhemer, MD, PhD; Diederik W.J. Dippel, MD, PhD; Aad van der Lugt, MD, PhD; Wim H. van Zwam, MD, PhD; Robert J. van Oostenbrugge, MD, PhD; Hester F. Lingsma, PhD; Yvo B.W.E.M. Roos, MD, PhD; Albert J. Yoo, MD; Henk A. Marquering, PhD*; Charles B.L.M. Majoie, MD, PhD*; on behalf of the MR CLEAN trial investigators

Stroke 2018; 49: 391-396

CTP occult anterograde flow

Occult Anterograde Flow Is an Under-Recognized but Crucial Predictor of Early Recanalization With Intravenous Tissue-Type Plasminogen Activator

Seong Hwan Ahn, MD; Christopher D. d'Esterre, PhD; Emmad M. Qazi, BSc; Mohammed Najm, BSc; Marta Rubiera, MD; Enrico Fainardi, MD; Michael D. Hill, MD; Mayank Goyal, MD; Andrew M. Demchuk, MD; Ting Y. Lee, PhD; Bijoy K. Menon, MD

Stroke 2015; 46: 968-975

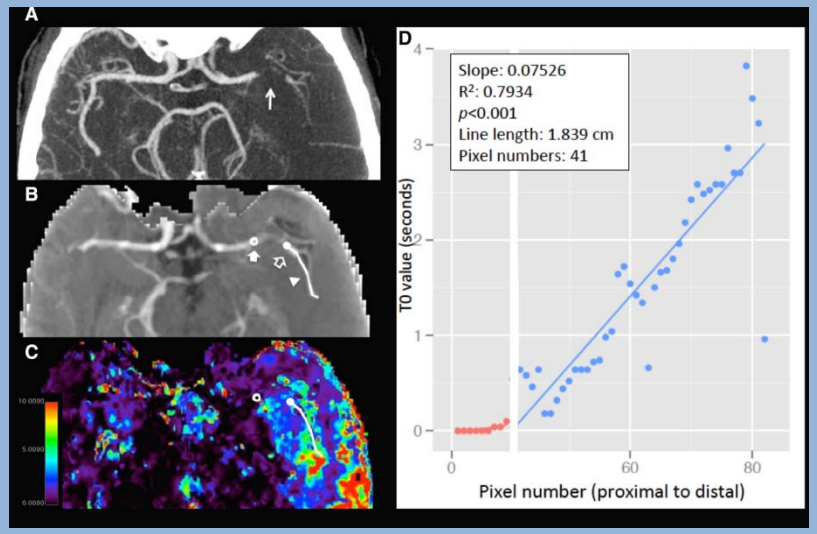
CTP detects thrombus permeability by occult anterograde flow distal to thrombus

↓

is indicated by a positive artery profile slope and values ≤ 2 sec between proximal and distal thrombus interface in delay T0 maps

↓

is a strong predictor of early recanalization in patients treated with iv thrombolysis



Recanalization and outcome

Progress in Intravenous Thrombolytic Therapy for Acute Stroke

Randolph S. Marshall, MD, MS

JAMA Neurol 2015; 72: 928-934

Endovascular stent thrombectomy: the new standard of care for large vessel ischaemic stroke

Bruce C V Campbell, Geoffrey A Donnan, Kennedy R Lees, Werner Hacke, Pooja Khatri, Michael D Hill, Mayank Goyal, Peter J Mitchell, Jeffrey L Saver, Hans-Christoph Diener, Stephen M Davis

Lancet Neurol 2015; 14: 846-854

recanalization is a strong predictor of favorable outcome

↓

CTP occult anterograde flow is a promising prognostic factor

HT and outcome

Factors influencing haemorrhagic transformation in ischaemic stroke

José Álvarez-Sabín, Olga Maisterra, Estevo Santamarina, Carlos S Kase

Alvarez-Sabin et al. Lancet Neurol 2013; 12: 689-705

Treatment and Outcome of Hemorrhagic Transformation After Intravenous Alteplase in Acute Ischemic Stroke

A Scientific Statement for Healthcare Professionals From the American Heart Association/American Stroke Association

The American Academy of Neurology affirms the value of this statement as an educational tool for neurologists.

The American Association of Neurological Surgeons/Congress of Neurological Surgeons Joint Cerebrovascular Section affirms the educational benefit of this document.

Shadi Yaghi, MD, Chair; Joshua Z. Willey, MD, MS, FAHA, Vice Chair; Brett Cucchiara, MD, FAHA; Joshua N. Goldstein, MD, PhD, FAHA; Nicole R. Gonzales, MD; Pooja Khatri, MD, MSc, FAHA; Louis J. Kim, MD; Stephan A. Mayer, MD, FAHA; Kevin N. Sheth, MD, FAHA; Lee H. Schwamm, MD, FAHA; on behalf of the American Heart Association Stroke Council; Council on Cardiovascular and Stroke Nursing; Council on Clinical Cardiology; and Council on Quality of Care and Outcomes Research

Stroke 2017; 48: e343-e361

hemorrhagic transformation (HT) classified according to ECASS II criteria

↓

is a determinant of unfavorable outcome

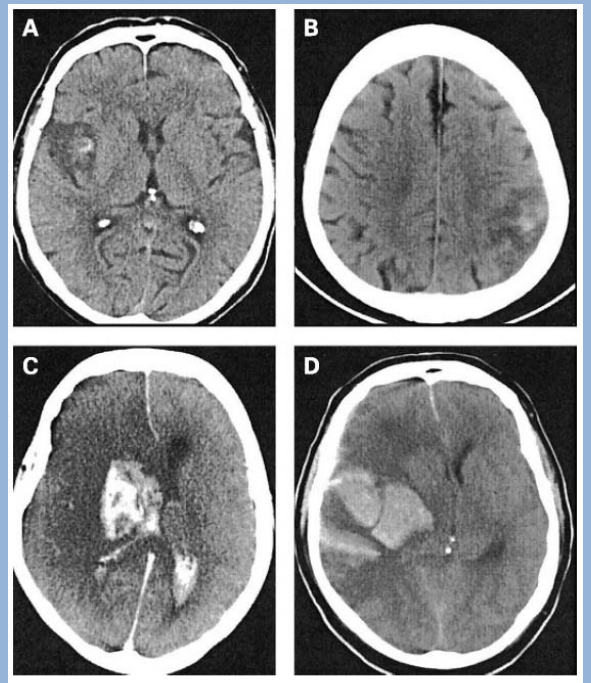


Figure 1 European Cooperative Acute Stroke Study (ECASS) classification of intracerebral haemorrhage (ICH) following thrombolysis (from Berger and colleagues[38]). (A) HI-1; (B) HI-2; (C) PH-1; (D) PH-2 (see text for details).

HI: petechial infarction without space-occupying effect

HI1: small petechiae

HI2: more confluent petechiae

PH: hemorrhage (coagulum) *with* mass effect

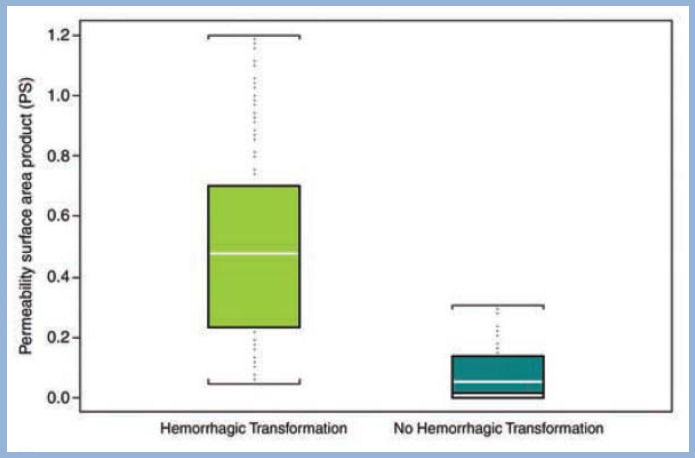
PH1: <30% of the infarcted area *with* mild space-occupying effect

PH2: >30% of the infarcted area *with* significant space-occupying effect

Hacke W et al. Lancet 1998; 352:1245-1251

CTP permeability and HT

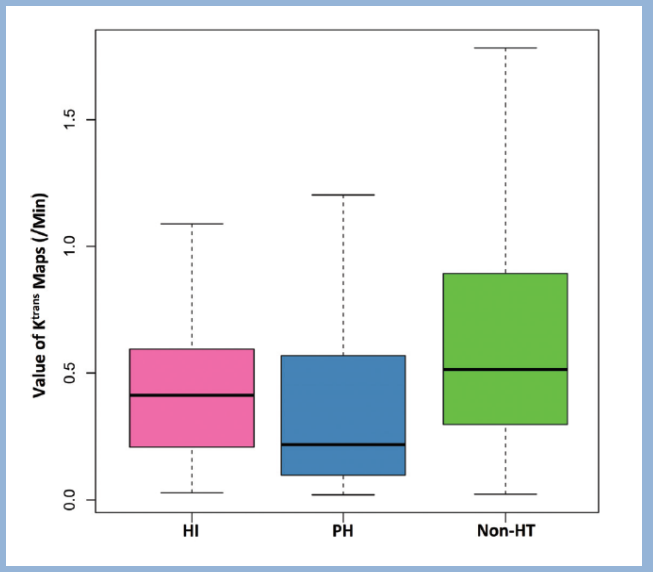
Hemorrhagic Transformation of Ischemic Stroke: Prediction with CT Perfusion[1]



Aviv RI. Radiology 2009; 250: 867-877

Focal Low and Global High Permeability Predict the Possibility, Risk, and Location of Hemorrhagic Transformation following Intra-Arterial Thrombolysis Therapy in Acute Stroke

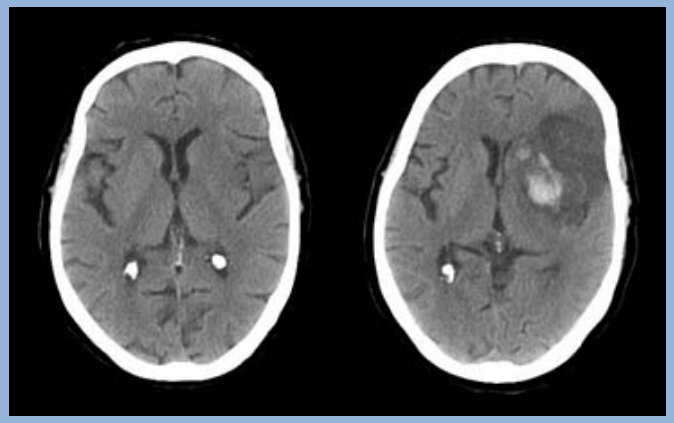
Y. Li, Y. Xia, H. Chen, N. Liu, A. Jackson, M. Wintermark, Y. Zhang, J. Hu, B. Wu, W. Zhang, J. Tu, Z. Su, and G. Zhu

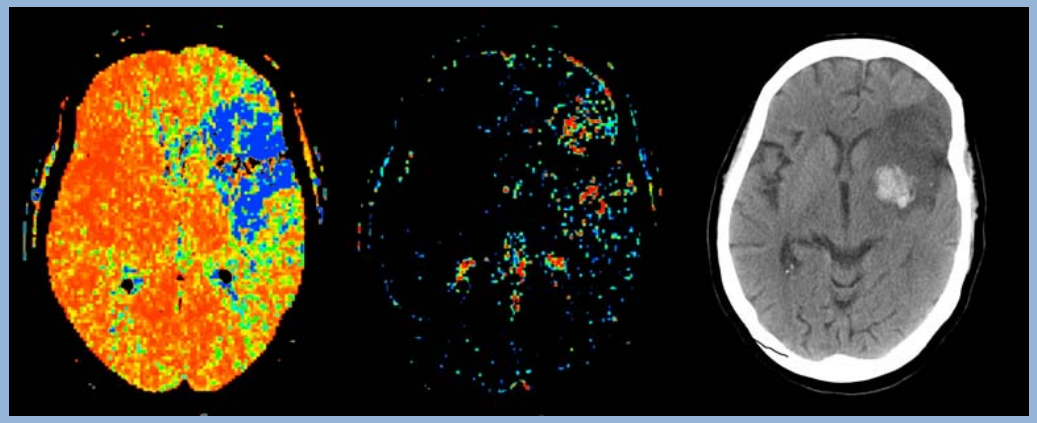


Li Y et al. 2017; AJNR Am J Neuroradiol 38:1730-1736

increased CTP permeability in ischemic area at onset is associated with high risk for developing HT in patients treated with iv thrombolysis and endovascular therapy

CTP permeability and HT

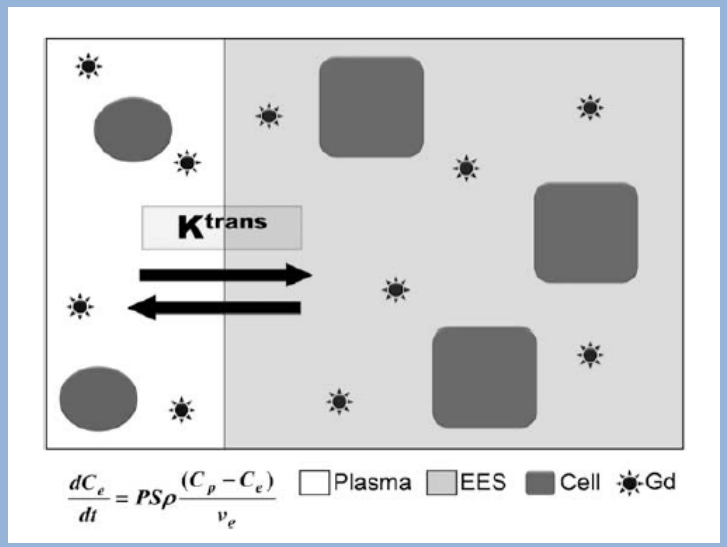




Lin K et al. Am J Neuroradiol 2007; 28:1292-1298; Aviv RI. Radiology 2009; 250: 867-877;
Hom J et al. Am J Neuroradiol 2011; 32: 41-48; ; Ozkul-Wermester O et al. Eur Neurol 2014; 72: 45-53;
Puig G. PLoS One 2017; 12: e0188238; Li Y et al. 2017; AJNR Am J Neuroradiol 38:1730-1736

CTP permeability can be measured with two different maps:

- **permeability surface area product (PS)**
- **transfer rate constant (K^{trans})**



CBV and HT

Association of CT Perfusion Parameters with Hemorrhagic Transformation in Acute Ischemic Stroke

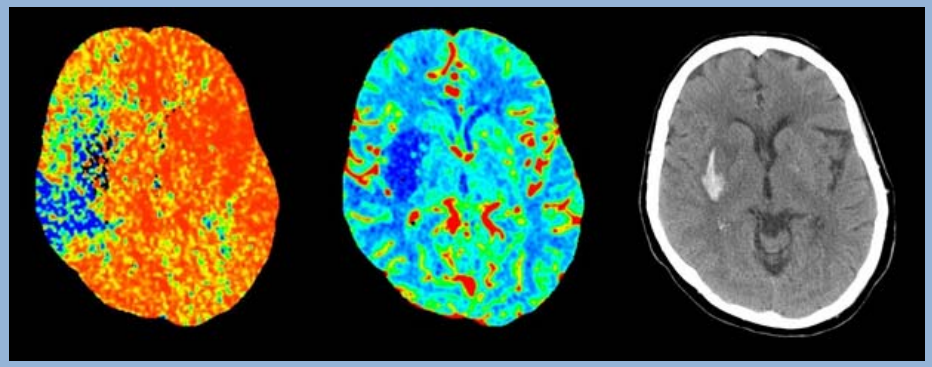
A.R. Jain, M. Jain, A.R. Kanthala, D. Damania, L.G. Stead, H.Z. Wang, and B.S. Jahromi

Jain AR et al. Am J Neuroradiol. 2013; 34: 1895-1900

Use of Noncontrast Computed Tomography and Computed Tomographic Perfusion in Predicting Intracerebral Hemorrhage After Intravenous Alteplase Therapy

Connor Batchelor, MSc; Pooneh Pordeli, PhD; Christopher D. d'Esterre, PhD; Mohamed Najm, BSc; Fahad S. Al-Ajlan, MD; Mari E. Boesen, MSc; Connor McDougall, BSc; Lisa Hur, BSc; Enrico Fainardi, MD; Jai Jai Shiva Shankar, MD; Marta Rubiera, MD; Alexander V. Khaw, MD; Michael D. Hill, MD, MSc; Andrew M. Demchuk, MD; Tolulope T. Sajobi, PhD; Mayank Goyal, MD; Ting-Yim Lee, PhD; Richard I. Aviv, MD; Bijoy K. Menon, MD, MSc

Stroke 2017; 48: 1548-1553



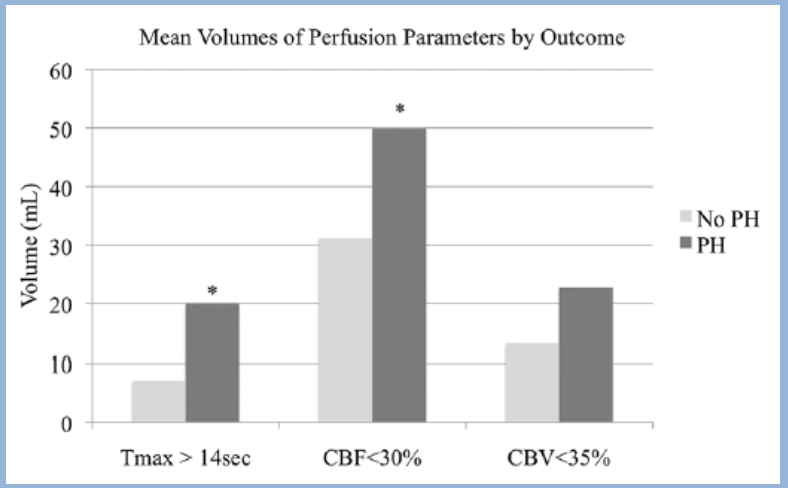
very low CBV values in ischemic area at onset have elevated predictive value for HT in patients treated with iv thrombolysis

Tmax and HT

Prediction of Poststroke Hemorrhagic Transformation Using Computed Tomography Perfusion

Nawaf Yassi, MBBS, BSc (Med), FRACP; Mark W. Parsons, PhD, FRACP; Søren Christensen, PhD; Gagan Sharma, MCA; Andrew Bivard, PhD; Geoffrey A. Donnan, MD, FRACP; Christopher R. Levi, FRACP; Patricia M. Desmond, MD, FRANZCR; Stephen M. Davis, MD, FRACP; Bruce C.V. Campbell, MBBS, BMedSc, PhD, FRACP

Stroke 2013; 44: 3039-3043



↓

prolonged Tmax values > 14 sec in ischemic area at onset are strong predictors for PH in patients treated with iv thrombolysis

CTP and HT

Perfusion CT for prediction of hemorrhagic transformation in acute ischemic stroke: a systematic review and meta-analysis

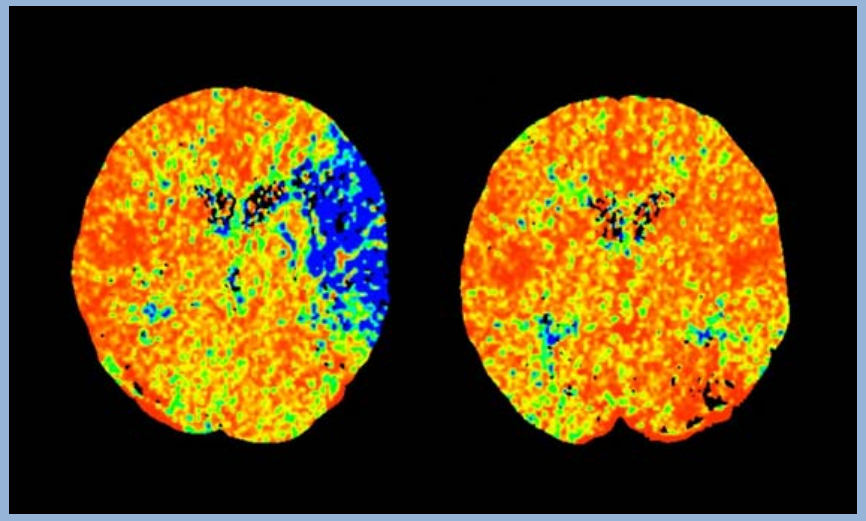
Chong Hyun Suh[1] · Seung Chai Jung[1] · Se Jin Cho[1] · Donghyun Kim[1] · Jung Bin Lee[1] · Dong-Cheol Woo[2] · Woo Yong Oh[3] · Jong Gu Lee[3] · Kyung Won Kim[1,4]

Eur Radiol 2019; 8: 4077-4087

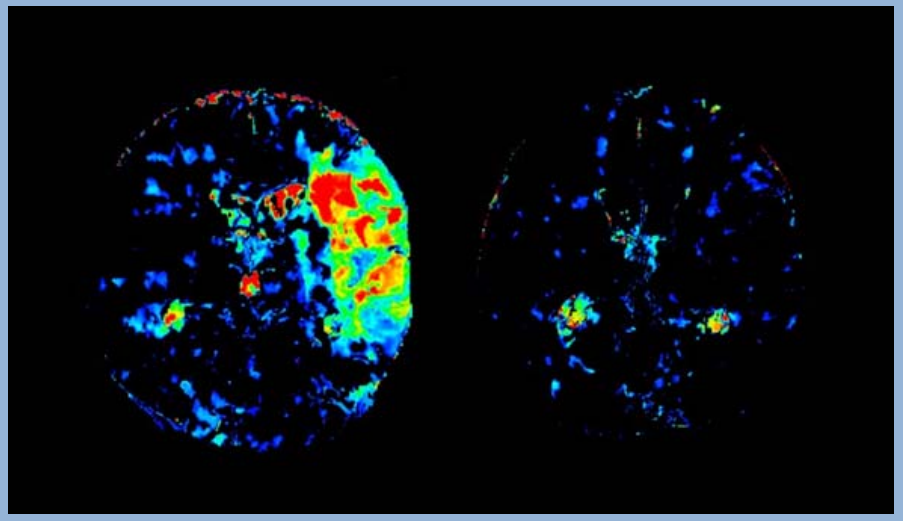
↓

these data suggest an association between pretreatment abnormal CTP parameters and HT

Prognostic value after treatment



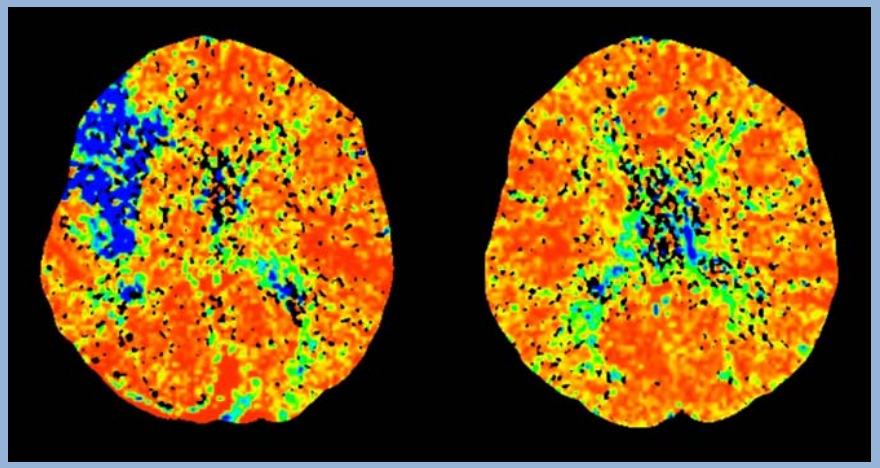
pre-treatment MTT post-treatment MTT



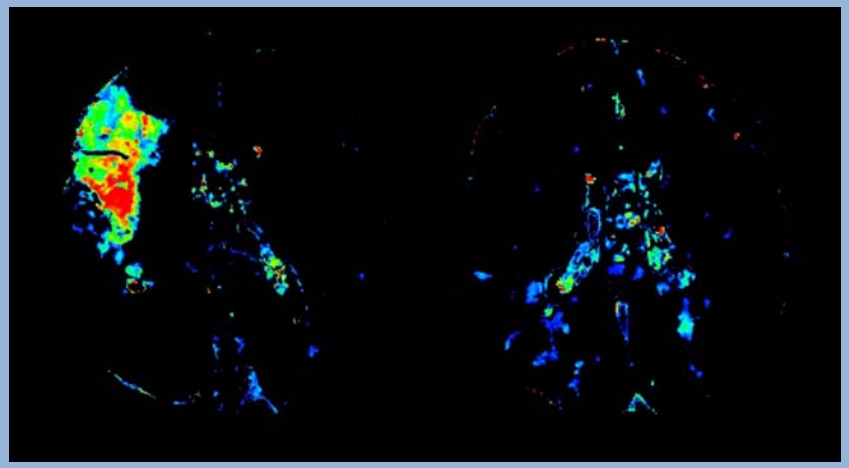
pre-treatment Tmax post-treatment Tmax

additional information comes from post-treatment CTP

Reperfusion



pre-treatment MTT post-treatment MTT



pre-treatment Tmax post-treatment Tmax

a percentage reduction of baseline MTT lesion at 24 hours > 75%

Soares BP et al. Stroke 2010; 41: e34-e40

a percentage reduction of baseline Tmax lesion at 24 hours ≥ 59%

Eilaghi A et al. Radiology 2013; 260: 240-248

Other reperfusion thresholds

Acute ischemic stroke

Imaging-guided tenecteplase treatment in an extended time window

Neurology 2009; 72: 915-921

a percentage reduction of baseline MTT lesion at 24 hours > 80%

Effects of alteplase beyond 3 h after stroke in the Echoplanar Imaging Thrombolytic Evaluation Trial (EPITHET): a placebo-controlled randomised trial

*Stephen M Davis, *Geoffrey A Donnan, Mark W Parsons, Christopher Levi, Kenneth S Butcher, Andre Peeters, P Alan Barber, Christopher Bladin, Deidre A De Silva, Graham Byrnes, Jonathan B Chalk, John N Fink, Thomas E Kimber, David Schultz, Peter J Hand, Judith Frayne, Graeme Hankey, Keith Muir, Richard Gerraty, Brian M Tress, Patricia M Desmond, for the EPITHET investigators†

Lancet Neurol 2008; 7: 299-309

a percentage reduction of baseline Tmax lesion at 24 hours > 90%

MRI profile and response to endovascular reperfusion after stroke (DEFUSE 2): a prospective cohort study

Maarten G Lansberg, Matus Straka, Stephanie Kemp, Michael Mlynash, Lawrence R Wechsler, Tudor G Jovin, Michael J Wilder, Helmi L Lutsep, Todd J Czartoski, Richard A Bernstein, Cherylee W J Chang, Steven Warach, Franz Fazekas, Manabu Inoue, Aaryani Tipirneni, Scott A Hamilton, Greg Zaharchuk, Michael P Marks, Roland Bammer, Gregory W Albers, for the DEFUSE 2 study investigators*

Lancet Neurol 2012; 11: 860-867

a percentage reduction of baseline Tmax lesion at 24 hours > 50%

PWI Tmax vs CTP Tmax

Comparison of Computed Tomographic and Magnetic Resonance Perfusion Measurements in Acute Ischemic Stroke

Back-to-Back Quantitative Analysis

Longting Lin, MMed; Andrew Bivard, PhD; Christopher R. Levi, MD; Mark W. Parsons, MD, PhD

Stroke 2014;45:1727-1732

PWI Tmax and CTP Tmax lesion volumes are equivalent

↓

they can be used interchangeably if Tmax is used for the measurements

Reperfusion vs recanalization

MR and CT Monitoring of Recanalization, Reperfusion, and Penumbra Salvage

Everything That Recanalizes Does Not Necessarily Reperfuse!

Bruno P. Soares, MD; Jeffrey D. Chien, BA; Max Wintermark, MD

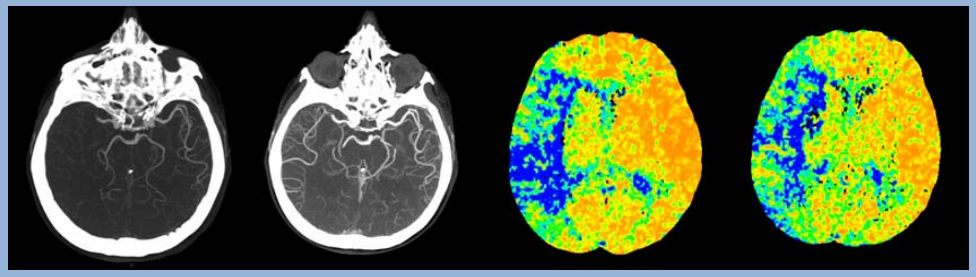
Stroke 2009; 40: S24-S27

reperfusion and recanalization do not have the same meaning:

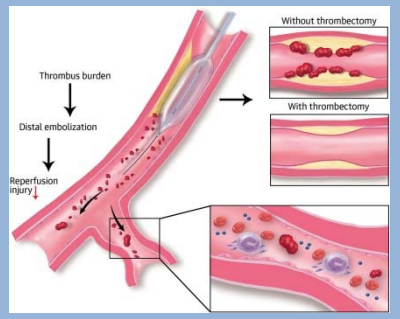
- ***recanalization*** **= reopening of the occluded artery**

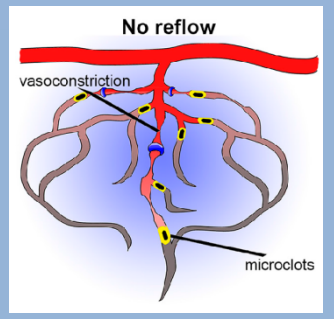
- ***reperfusion*** **= restoring of capillary blood flow downstream the occluded artery**

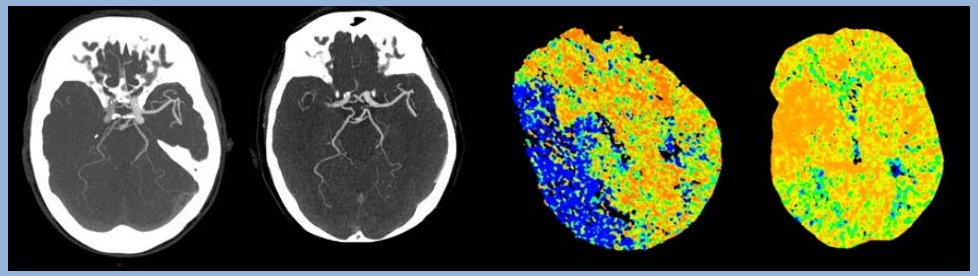
Reperfusion and/or recanalization



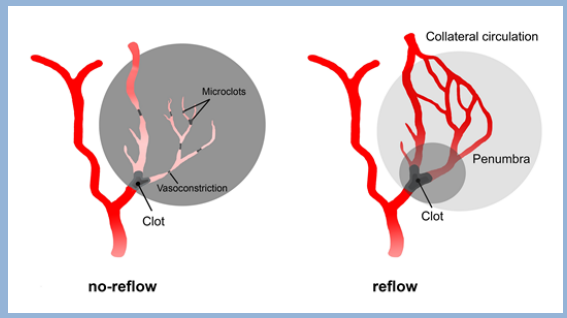
Recanalization without reperfusion







Reperfusion without recanalization



Dalkara T, Arsava EM. J Cereb Blood Flow Metab 2012; 32: 2091-2099

reperfusion and recanalization not always are associated:

- ***recanalization without reperfusion*** **(thrombus distal fragmentation + no-reflow phenomenon = futile recanalization)**

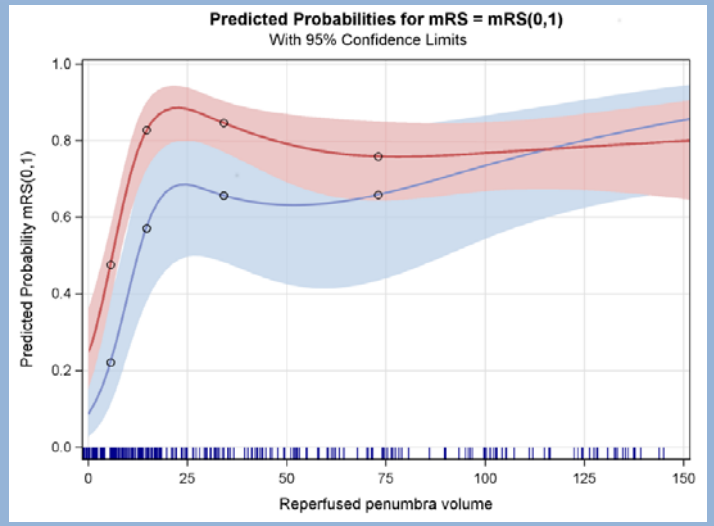
- ***reperfusion without recanalization*** **(retrograde reperfusion through collaterals)**

Reperfusion and outcome

Influence of Penumbral Reperfusion on Clinical Outcome Depends on Baseline Ischemic Core Volume

Chushuang Chen, MMed; Mark W. Parsons, PhD, FRACP; Matthew Clapham, BS; Christopher Oldmeadow, PhD; Christopher R. Levi, FRACP; Longting Lin, PhD; Xin Cheng, FRACP; Min Lou, PhD, FRACP; Timothy J. Kleinig, PhD, FRACP; Kenneth S. Butcher, FRACP; Qiang Dong, FRACP; Andrew Bivard, PhD

Stroke. 2017; 48: 2739-2745



reperfusion is associated with good outcome when baseline infarct core is small in patients receiving iv thrombolysis

↓

reperfusion is effective when penumbral salvageable tissue is large

Reperfusion is superior to recanalization

reperfusion is a stronger predictor of good outcome than recanalization

MR and CT Monitoring of Recanalization, Reperfusion, and Penumbra Salvage

Everything That Recanalizes Does Not Necessarily Reperfuse!

Bruno P. Soares, MD; Jeffrey D. Chien, BA; Max Wintermark, MD

Stroke 2009; 40: S24-S27;

→ **CTP MTT maps at 24 hours from baseline**

Reperfusion Is a Stronger Predictor of Good Clinical Outcome than Recanalization in Ischemic Stroke[1]

Eilaghi A et al. Radiology 2013; 260: 240-248

→ **CTP Tmax maps at 24 hours from baseline**

Reperfusion Within 6 Hours Outperforms Recanalization in Predicting Penumbra Salvage, Lesion Growth, Final Infarct, and Clinical Outcome

Tae-Hee Cho, PhD; Norbert Nighoghossian, PhD; Irene Klærke Mikkelsen, PhD; Laurent Derex, PhD; Marc Hermier, PhD; Salvador Pedraza, MD; Jens Fiehler, MD; Leif Østergaard, PhD; Yves Berthezène, PhD; Jean-Claude Baron, ScD

Stroke 2015; 6: 1582-1589

→ **PWI Tmax maps at 6 hours from baseline**

Reperfusion is superior to recanalization

Radiologic Cerebral Reperfusion at 24 h Predicts Good Clinical Outcome

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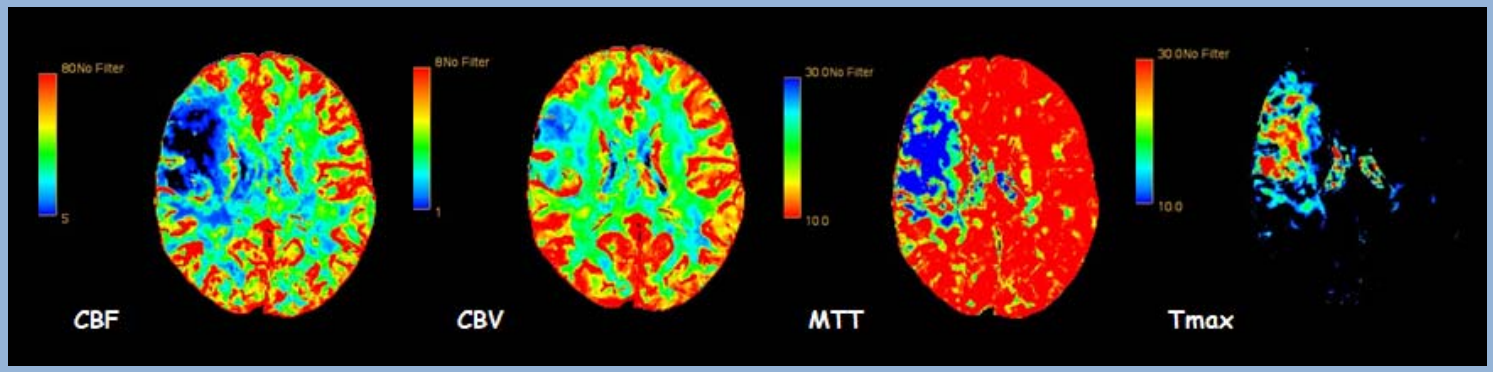
CTP MTT maps at 24 hours from baseline

↓

reperfusion is an independent determinant of favorable outcome, while recanalization is not

	OR (95% CI)	*p* value
Good functional outcome (day 90)		
Age	0.950 (0.854–1.058)	0.0.351
Gender, male	0.348 (0.035–3.471)	0.370
Glycemia	0.968 (0.939–0.998)	0.034
Time window to CT	0.071 (0.004–1.347)	0.078
Intravenous r-tPA	0.050 (0.002–1.054)	0.054
NIHSS at onset	0.734 (0.569–0.949)	0.018
Ischemic core volume	0.964 (0.922–1.007)	0.095
Ischemic penumbra	1.008 (0.985–1.032)	0.507
Recanalization at day 1	1.618 (0.178–14.700)	0.669
Reperfusion at day 1 ≥ 75%	25.801 (1.483–448.840)	0.026

Take-home messages



- **pretreatment target mismatch automatically measured according with Tmax - rCBF mismatch thresholds is a powerful predictor of outcome**
- **pretreatment CBV values indicate collateral status**
- **pretreatment CTP occult anterograde flow predicts early recanalization after thrombolysis**
- **pretreatment CTP permeability, CBV and Tmax values are predictive factors for HT**
- **post-treatment MTT and Tmax reperfusion is a stronger predictor of outcome than recanalization**