Perfusion MRI

M A Oghabian

Perfusion MRI

Exogenous

- Dynamic Contrast Enhanced (DCE, bolus passage)
  –GRE-EPI (T2* weighted)

- Dynamic Susceptibility Contrast (DSC, bolus tracking)
  –Spoiled Fast Gradient Echo (T1 Weighted)

Endogenous

- Arterial spin labeling (ASL)

Perfusion Weighted Imaging (DSC)

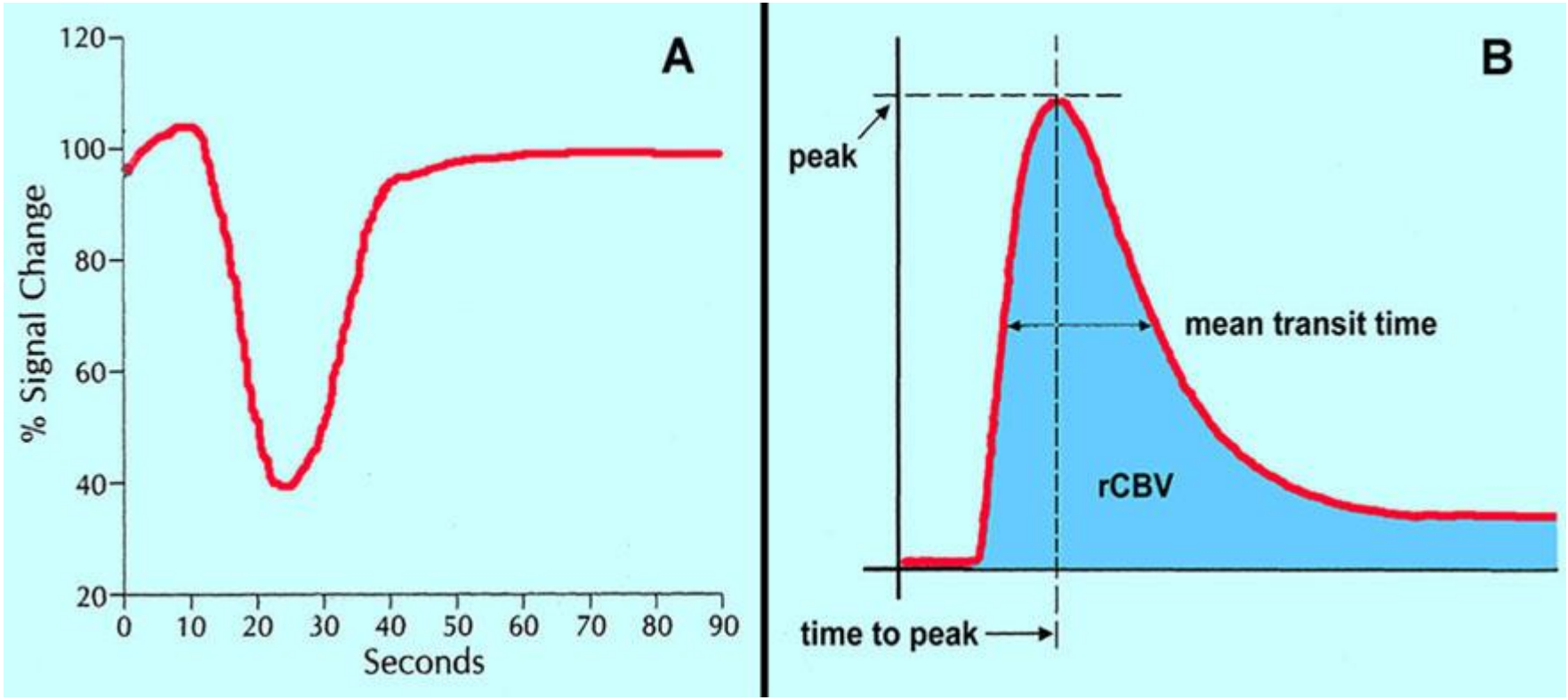
- Perfusion MRI techniques are sensitive to microscopic levels of blood flow.

- T2* susceptibility effects of gadolinium, rather than the T1 shortening effects make gadolinium a suitable agent.

- Susceptibility here refers to the loss of MR signal, most marked on T2* (gradient echo)- and T2 (SE), caused by the magnetic field-distorting effects of paramagnetic substances.

Perfusion Weighted Imaging (DSC)

- The ultimate goal of perfusion MRI is to measure the blood flow perfused in organ
- This flow corresponds to microcirculatory tissue perfusion rather than the flow of the main vascular axes
- This is expressed in milliliters per 100 gram of tissue per minute.



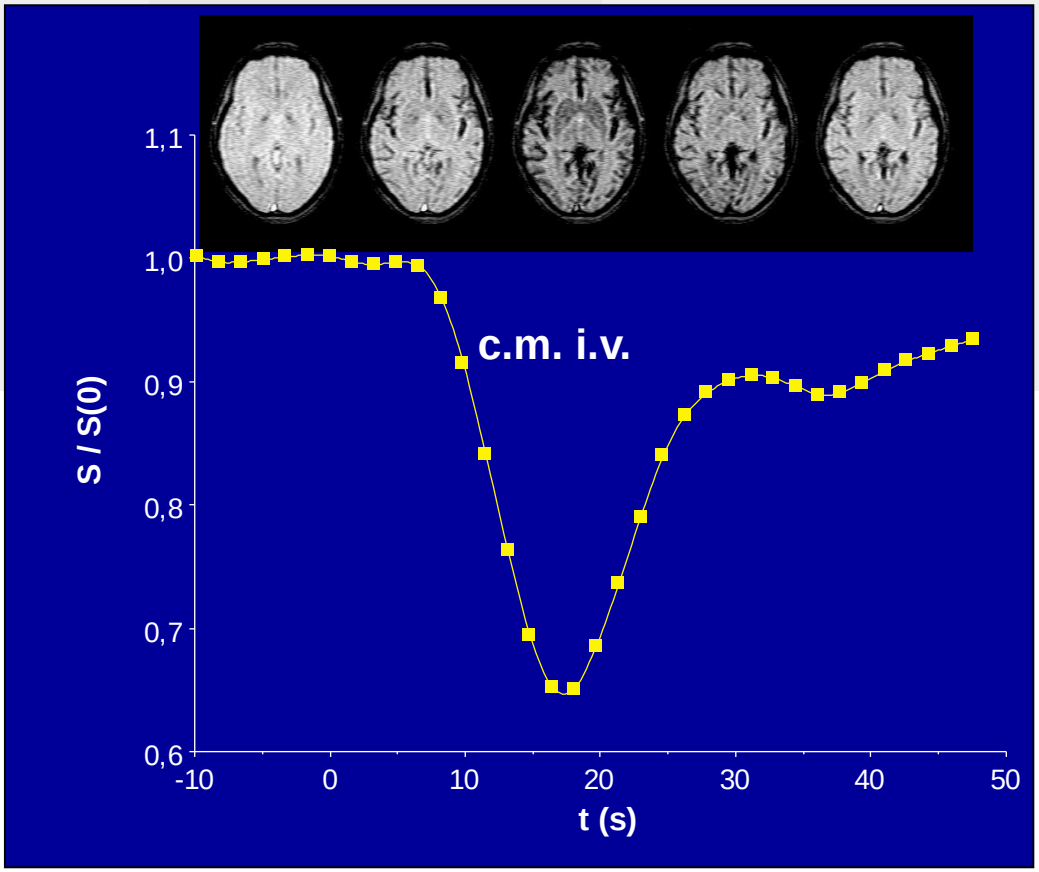
Cerebral perfusion MRI (Graph A) CT perfusion imaging (Graph B).

Graph A shows the effect of a bolus injection of a paramagnetic contrast agent, such as a gadolinium-based agent, as it passes through a single voxel as a function of time.

Graph B shows a similar but inverted response on CT perfusion study with the transit of iodinated contrast material through a sample, resulting in increased attenuation.

Perfusion-weighted MRI (PWI) measurement

Dynamic-susceptibility-weighted (DSC) MR imaging



Fast, repetitive T2*-weighted Sequences (GE) to follow the capillary passage of c.m.

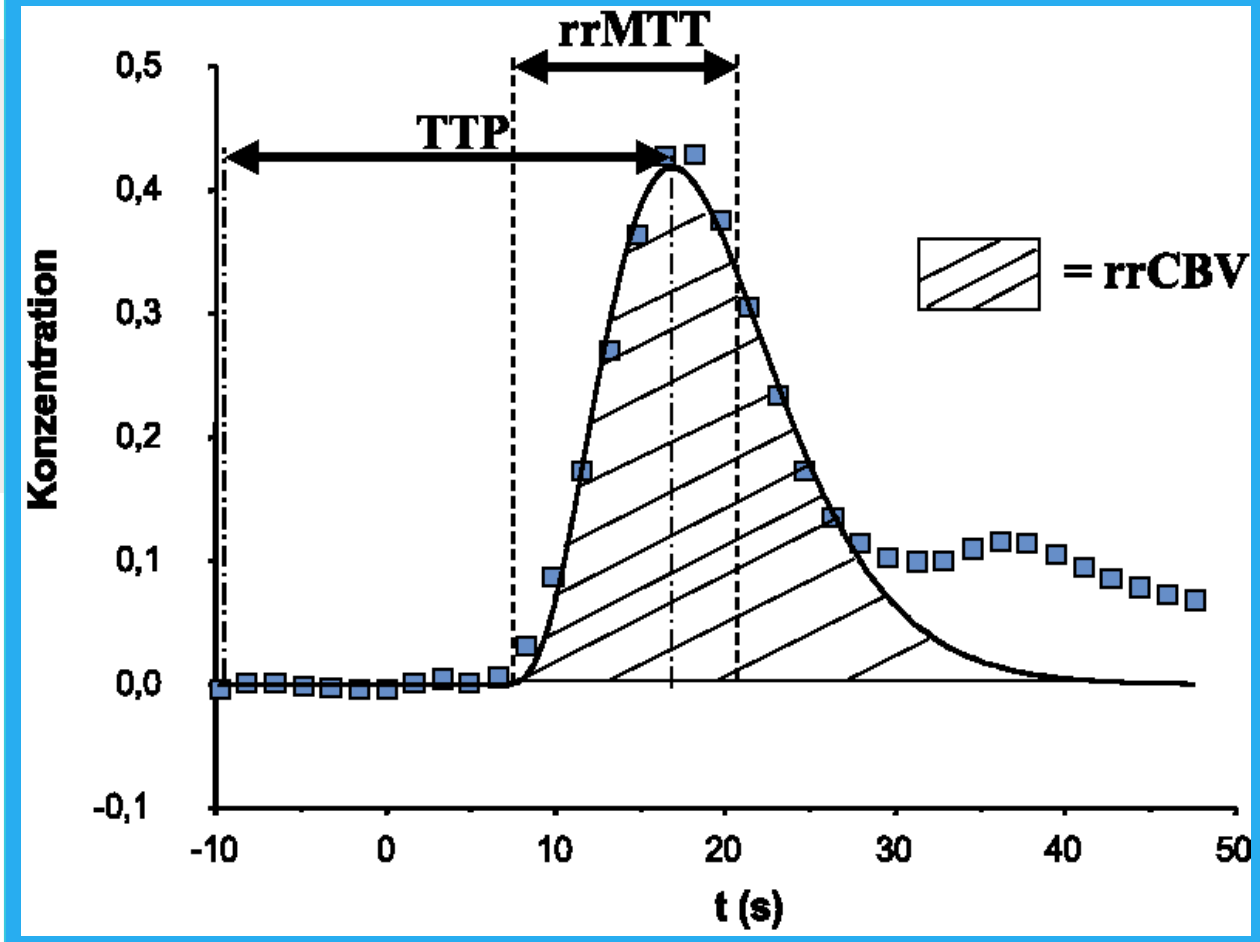
Susceptibility-derived signal decrease

Calculation of RELATIVE hemodynamic parameter maps

(a) Time: TTP, MTT
(b) Perfusion: rCBF, rCBV

Böck et al. 1992

Perfusion-weighted MRI (DSC-PWI) measurement



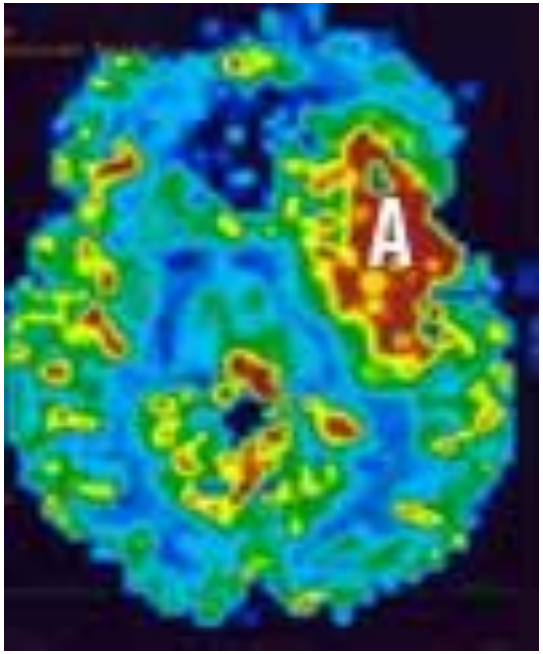
$$rCBF = \frac{rCBV}{MTT}$$

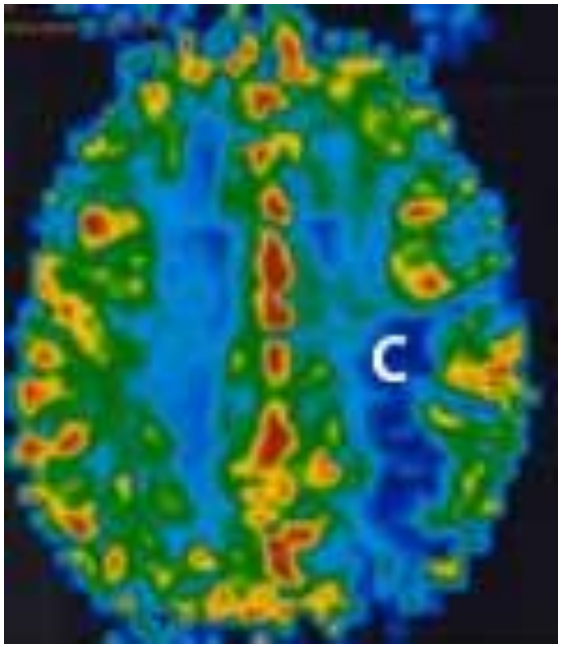
Comparison to contralateral side → regional relative CBF/CBV

Perfusion parameters

- These parameters are extracted by post-processing the signal curves, and are:
- TA: time of arrival of the contrast agent in the slice after injection
- TTP (Time To Peak): time corresponding to the maximum contrast variation
- MTT (mean transit time)
- Peak amplitude: percentage loss of intensity of the maximal signal
- rCBV (regional cerebral blood volume): The area below the decreasing signal curve
- rCBF (regional cerebral blood flow): The ratio rCBV/MTT.
- RCBV and rCBF are relative measurements, giving the calculation of ratios between pathological zone and healthy zone (which serves as a reference).

Perfusion MRI



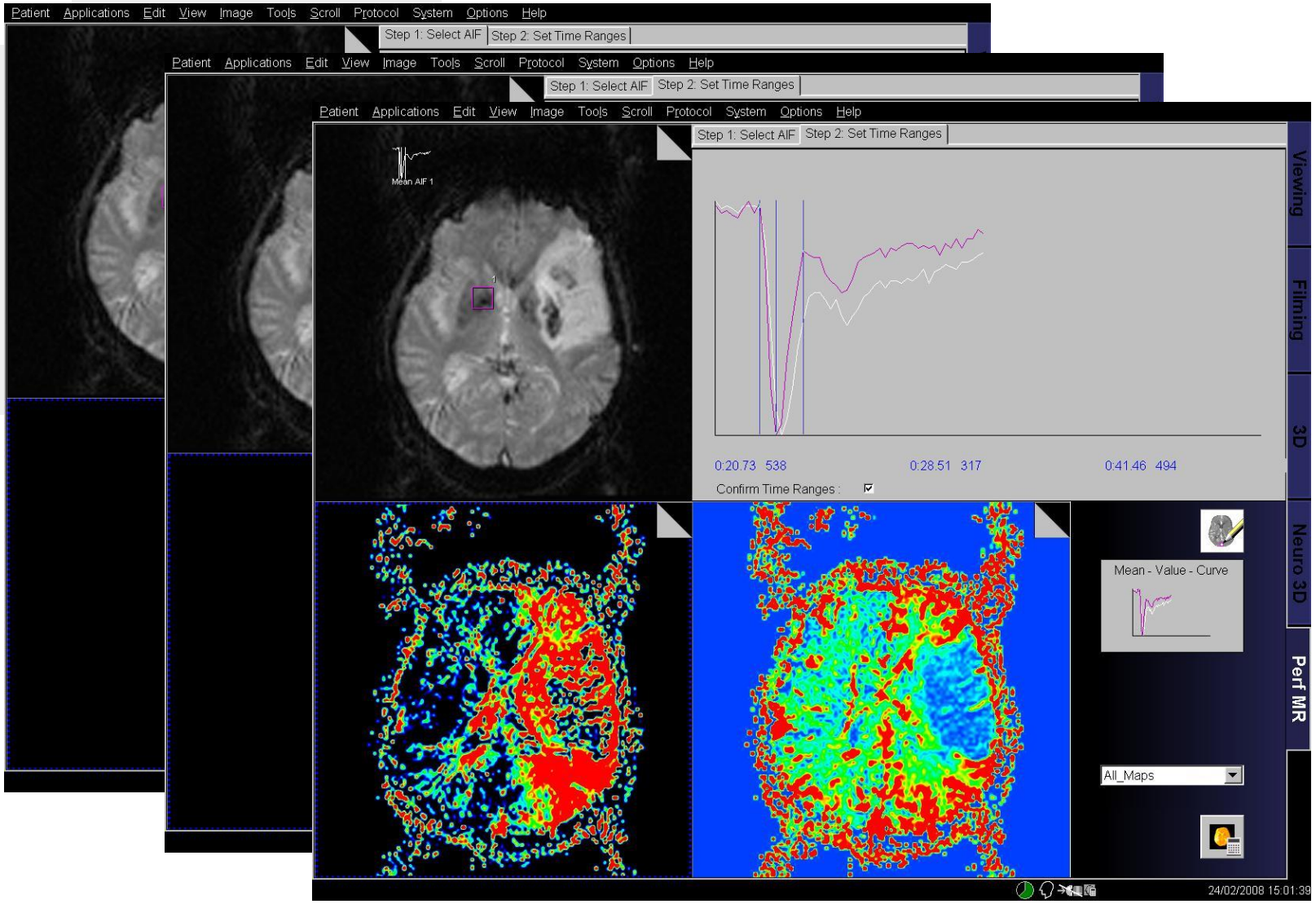


- Perfusion MRI is a technique for evaluation of microscopic blood flow in cerebral capillaries and venules.

- (Left) Perfusion of a high grade brain tumor demonstrates areas of increased capillary blood volume in tumor (red)

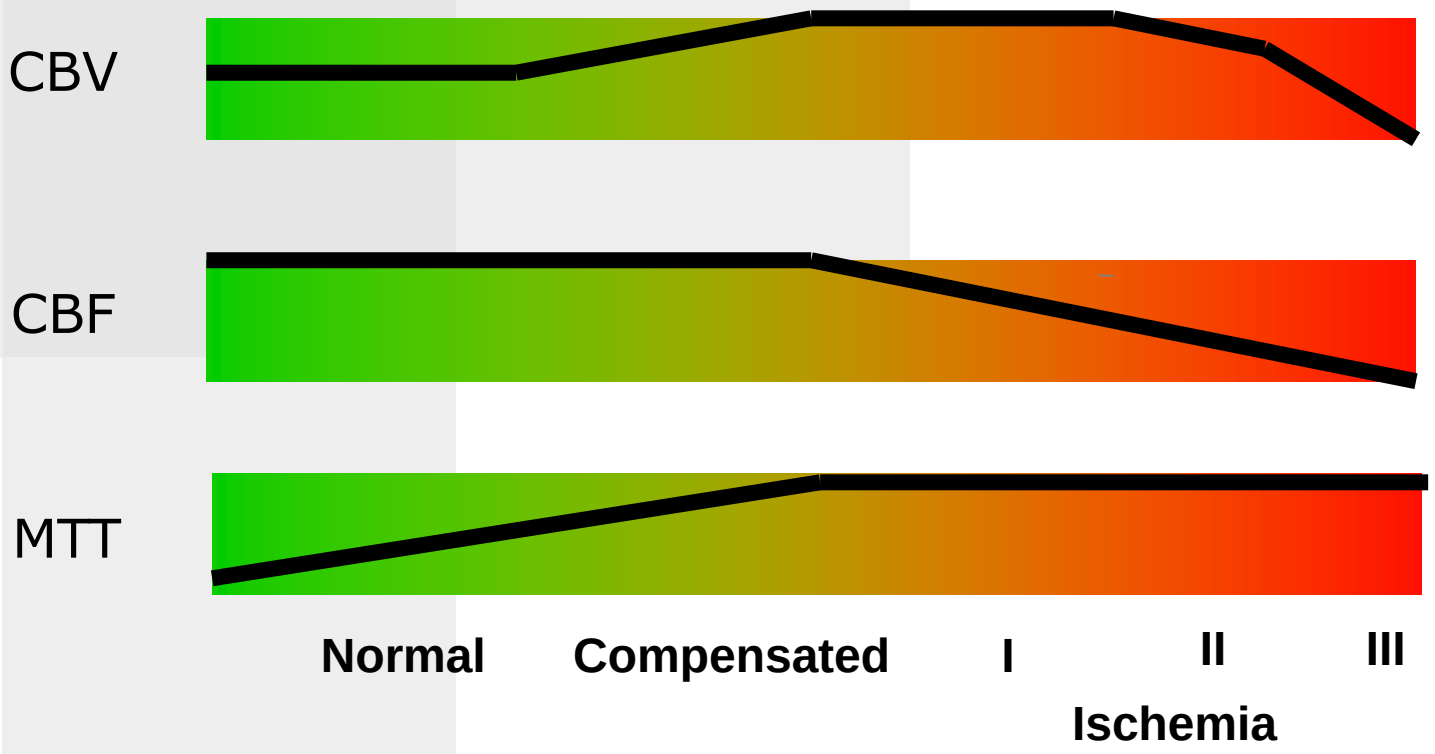
- (Right) Loss of perfusion due to Stroke

Perfusion-weighted MRI (PWI)



Perfusion-weighted MRI (PWI)

Relative CBV, CBF & MTT in ischemia



Powers. Ann Neurol, 1991

Perfusion-weighted MRI protocol for DSC

– Single dose of gadobenate dimeglumine

– Better S/N with 1-molar c.m. (> to 0.5-molar c.m.)

– T2*w-GRE; TR/TE, 1440/50 ms

– 20 slices, 60 measurements, 1.5min

Interfering effect of T1 in DSC

- Gadolinium chelates do not cross the normal blood-brain barrier. But in pathological conditions they cross.

- This effect reduce the T1 of the tissues and increase signal which contaminates the perfusion signal

- This leads to the risk of underestimating cerebral blood volume.

Non-contrast-agent based Perfusion: Arterial Spin Labeling (ASL)

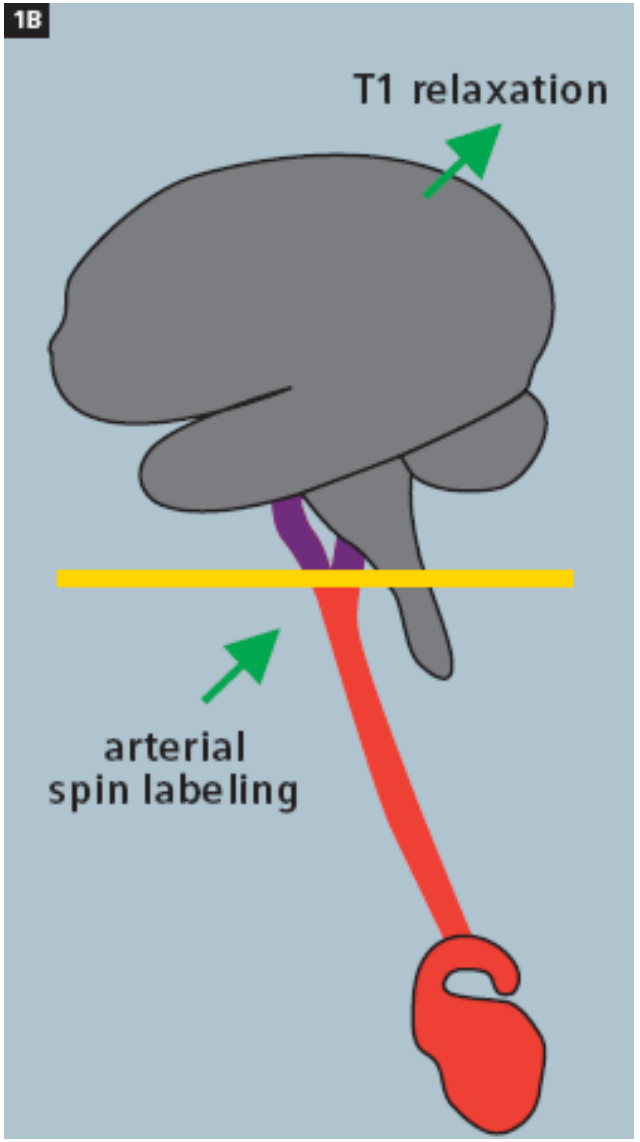
- In ASL, spins of inflowing blood are sensitized to have different magnetic state to that of the static tissue, when flowing into the slices of interest.

- Contrast agents are not required for these techniques.

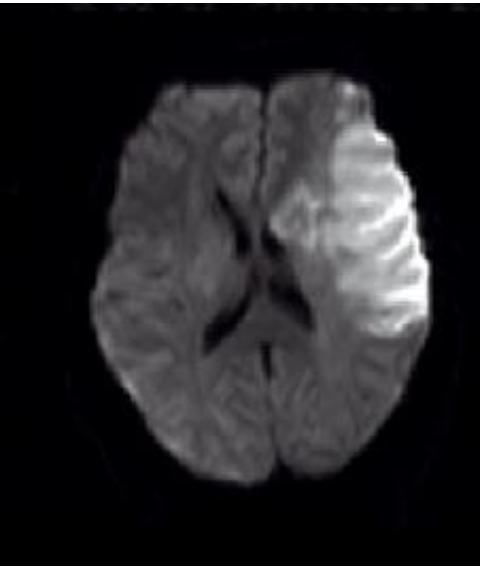
- A perfusion-weighted image can be generated by the subtraction of an image in which inflowing spins have been labeled from an image in which spin labeling has not been performed.

Concept of Arterial Spin Labeling (ASL)

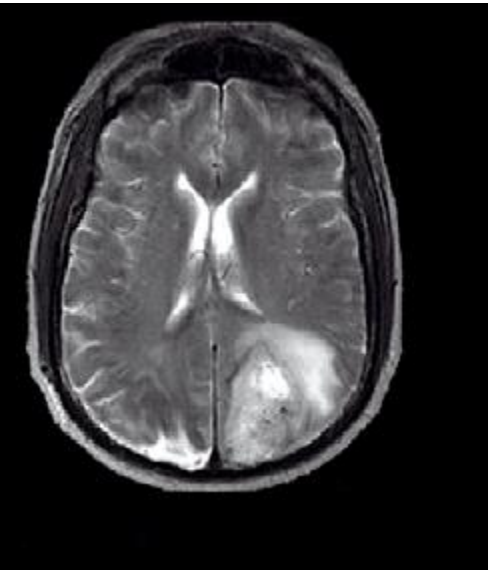
- In ASL, endogenous arterial blood water is magnetically labeled instead of exogenously administered tracer, and the magnetic label decays with T1 instead of radioactive decay

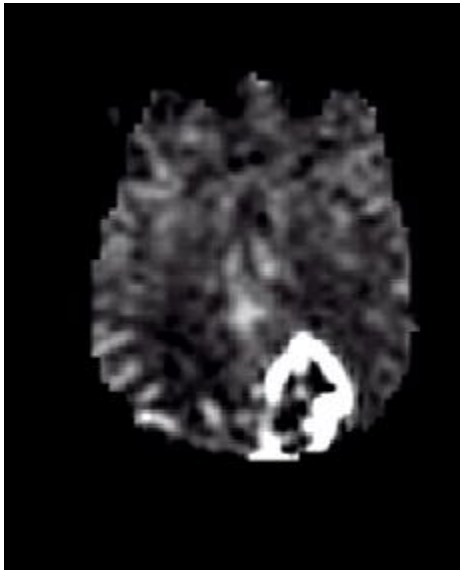


clinical applications of ASL



- **(A)**- Hypo-perfusion in an acute stroke (DWI and ASL)

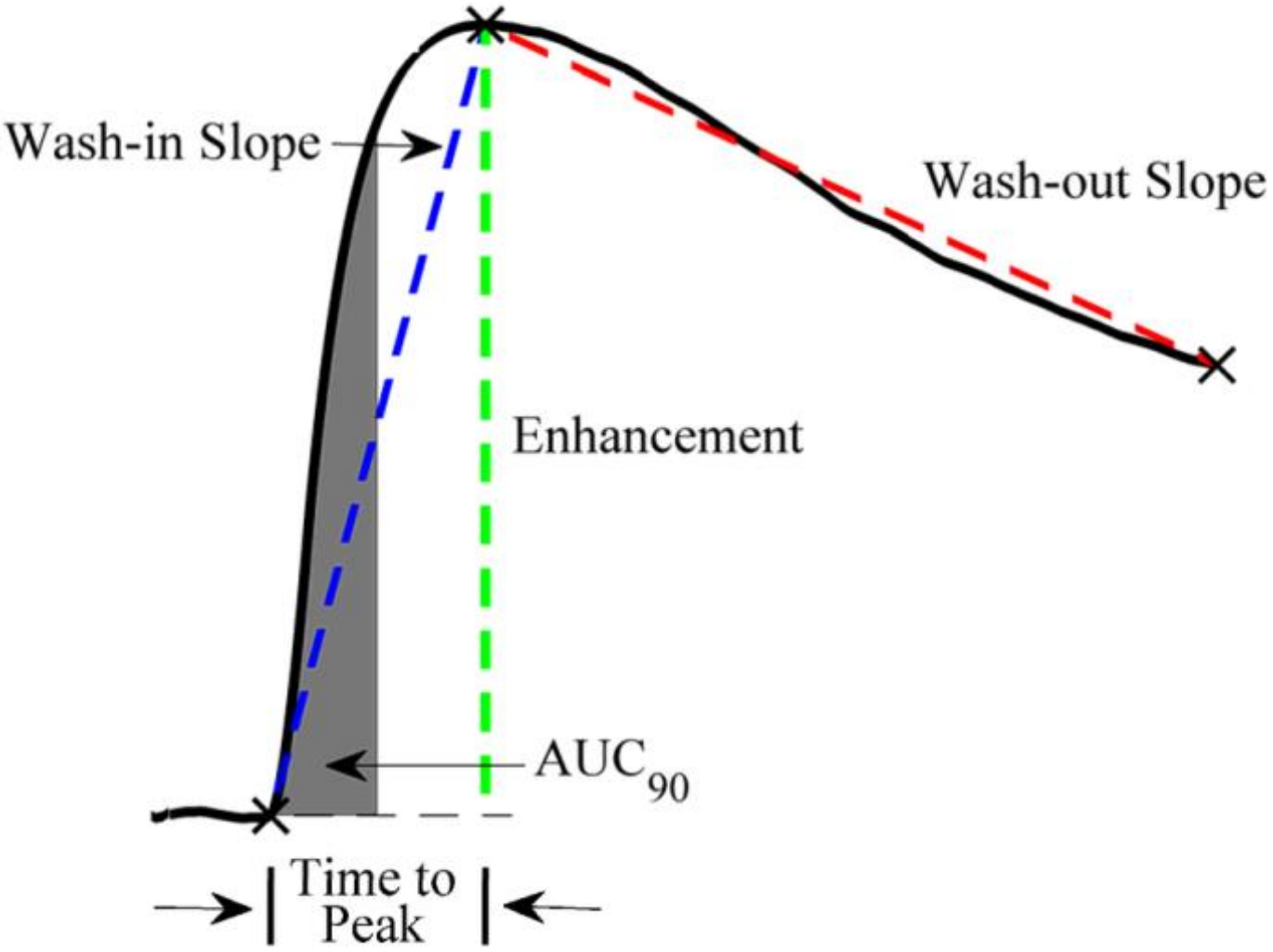




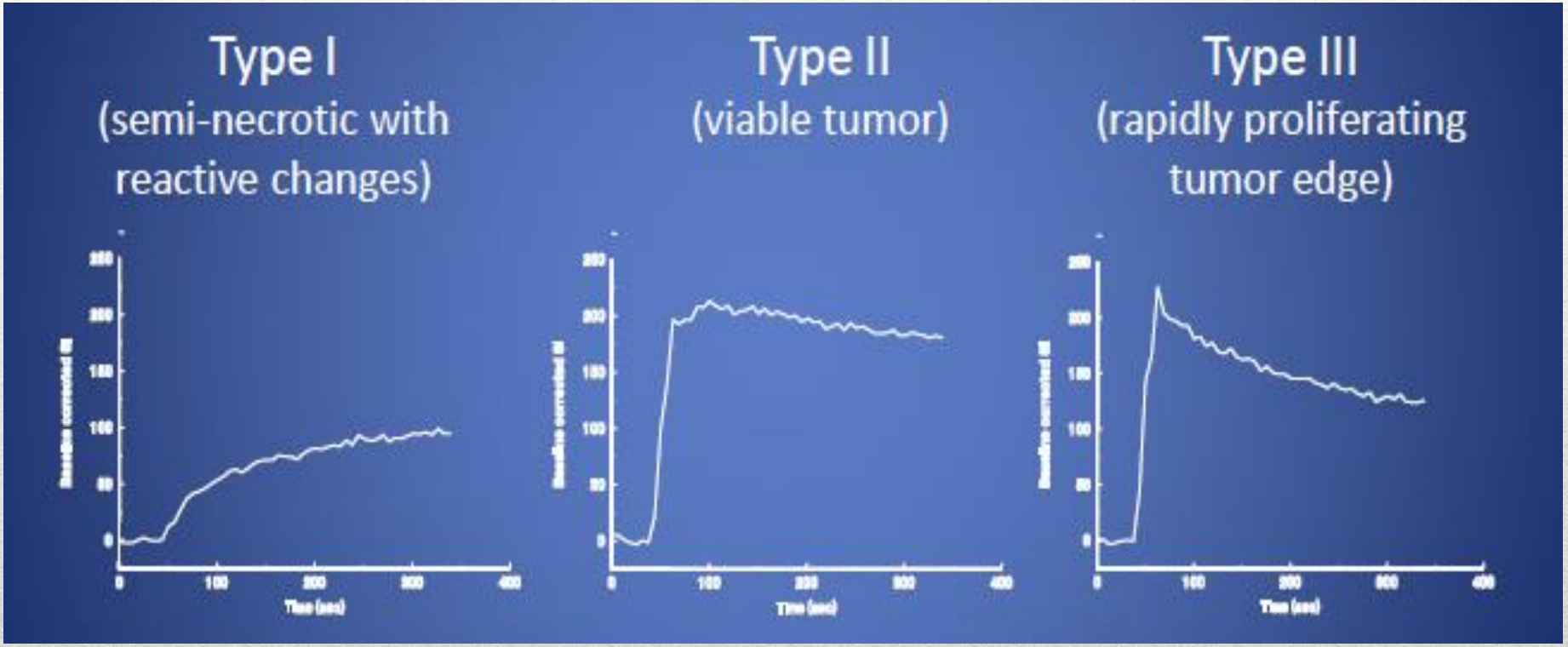
- **(B)-** Hyper-perfusion in a glioblastoma (T2 and ASL)

Dynamic contrast enhanced imaging (DCE)

T1-weighted imaging with c.m. injection



Qualitative - shape of signal intensity (SI) data curve



Taylor and Reddick, Adv Drug Del Rev, 2000

DCE Perfusion Imaging

1. Contrast Injection Protocols
2. DCE MRI Acquisition Protocols
3. DCE MRI Quantification
    1. **Arterial Input Function**
    2. **Relationship between T1 value and Contrast Concentration**
    3. **Pharmacokinetic Modeling**

DCE imaging protocol

– Single dose of gadobenate dimeglumine

– 2D-T1w-GRE; TR/TE, 84/4.34 ms

– Repetitive measurements over 5min

Arterial Input Function (AIF)

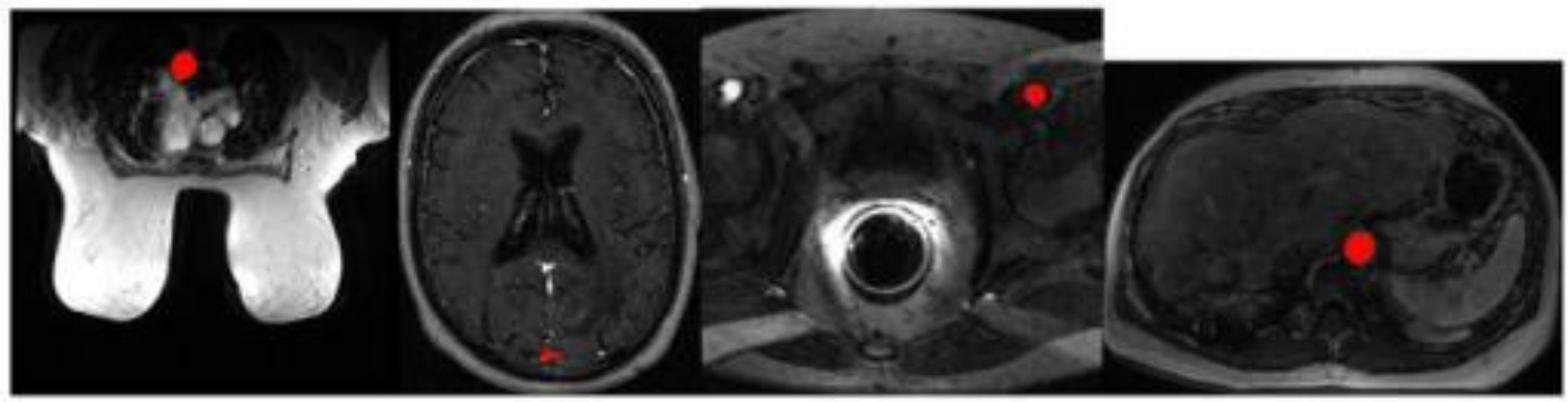
Signal intensity change over time and location in the feeding artery.

AIF needs to be specified by user

AIF Can be averaged over multiple pixels and slices

Automatic Search for AIF

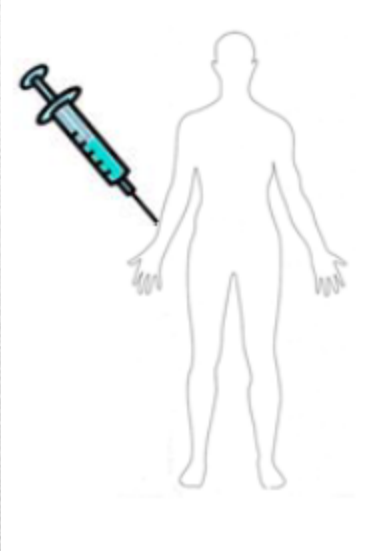
- Global search within the imaging volume:
  - Select pixels based peak signal intensity, and uptake slope
- Select AIF from known Arteries



J. Chen et al Med Image Comput Comput Assist Interv. 2008; 11(Pt 1): 594–601

Calculation: T1w DCE MRI

Contrast Agent Injection



Concentrations

Interaction Gd+ - H

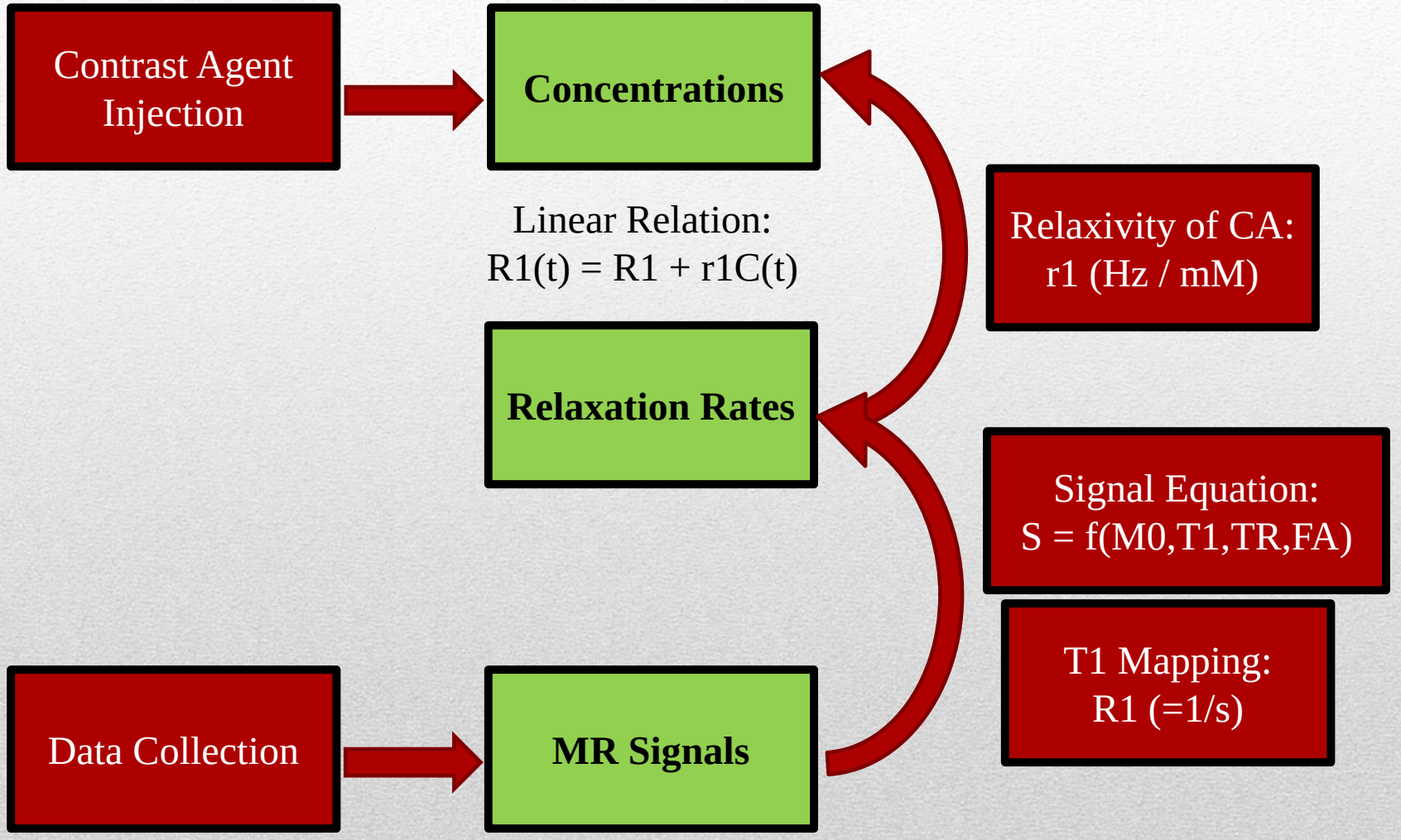
Relaxation Rates

T1-weighted MRI

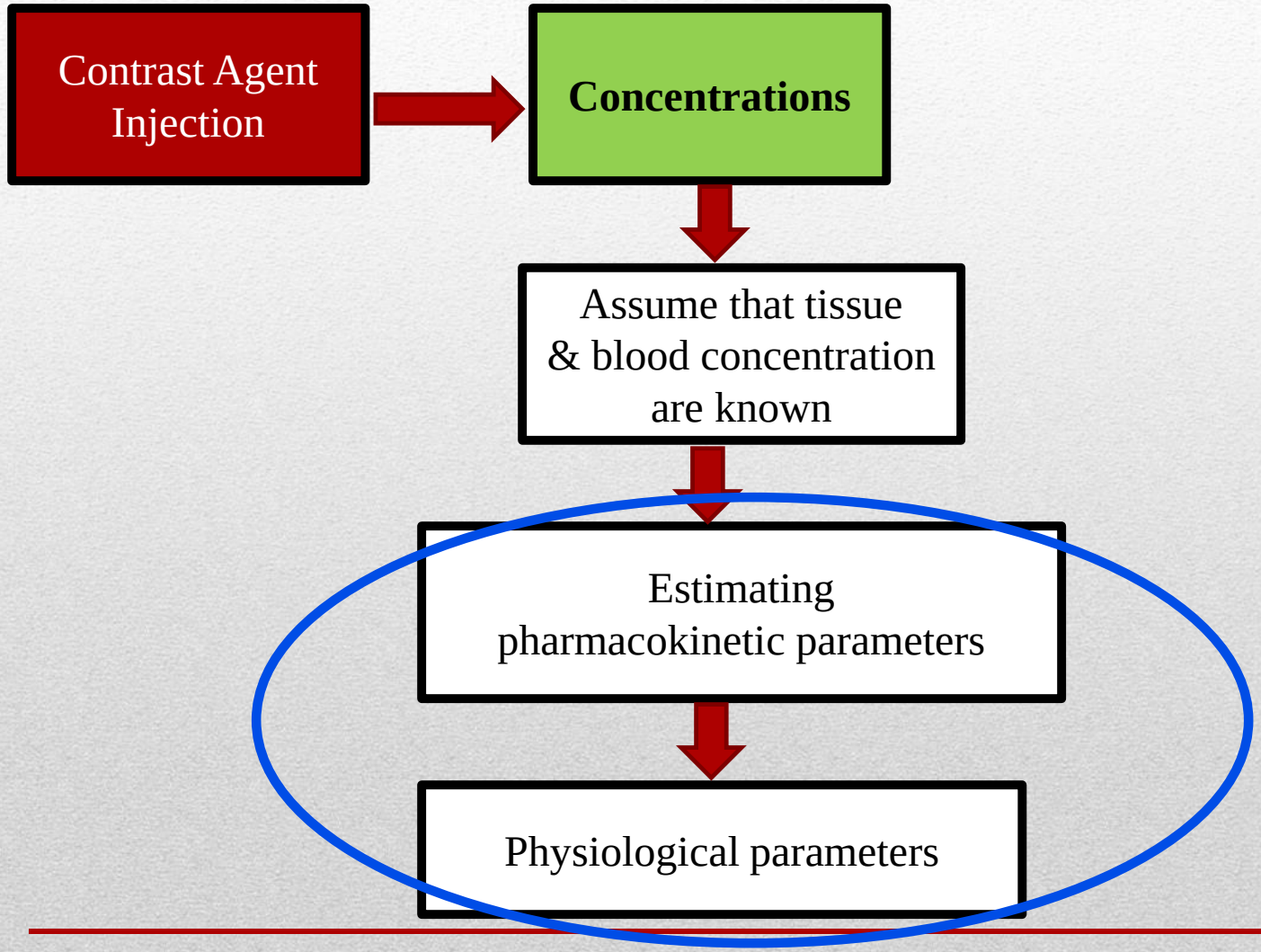
MR Signals

Data Collection

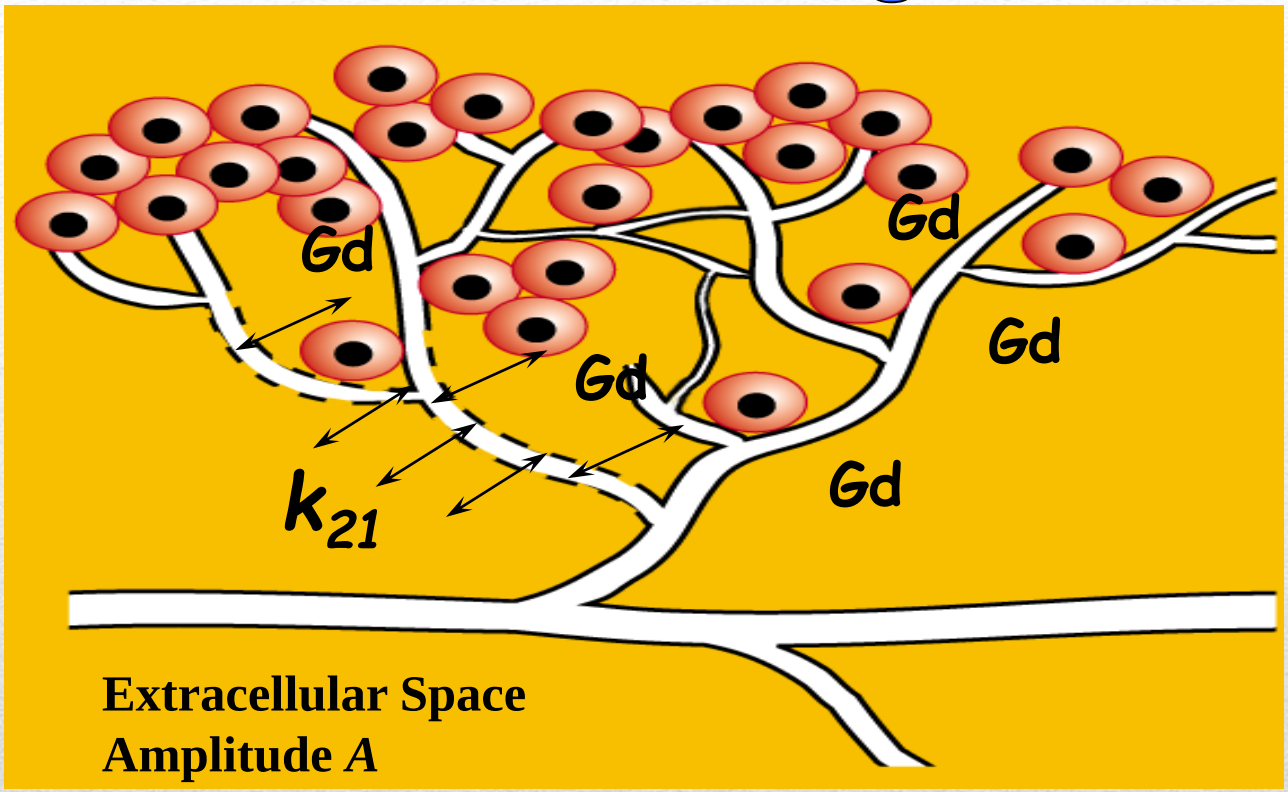
Calculation: T1w DCE MRI

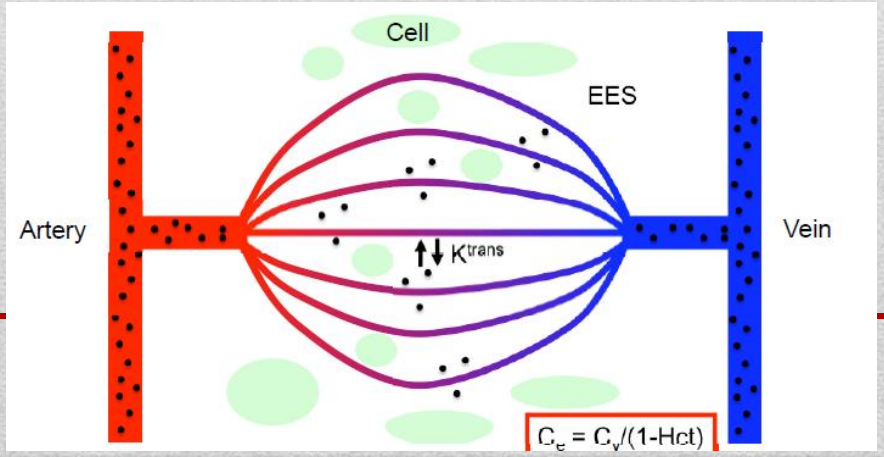


Calculation: T1w DCE MRI



Pharmacokinetic Modelling (Tofts Model)





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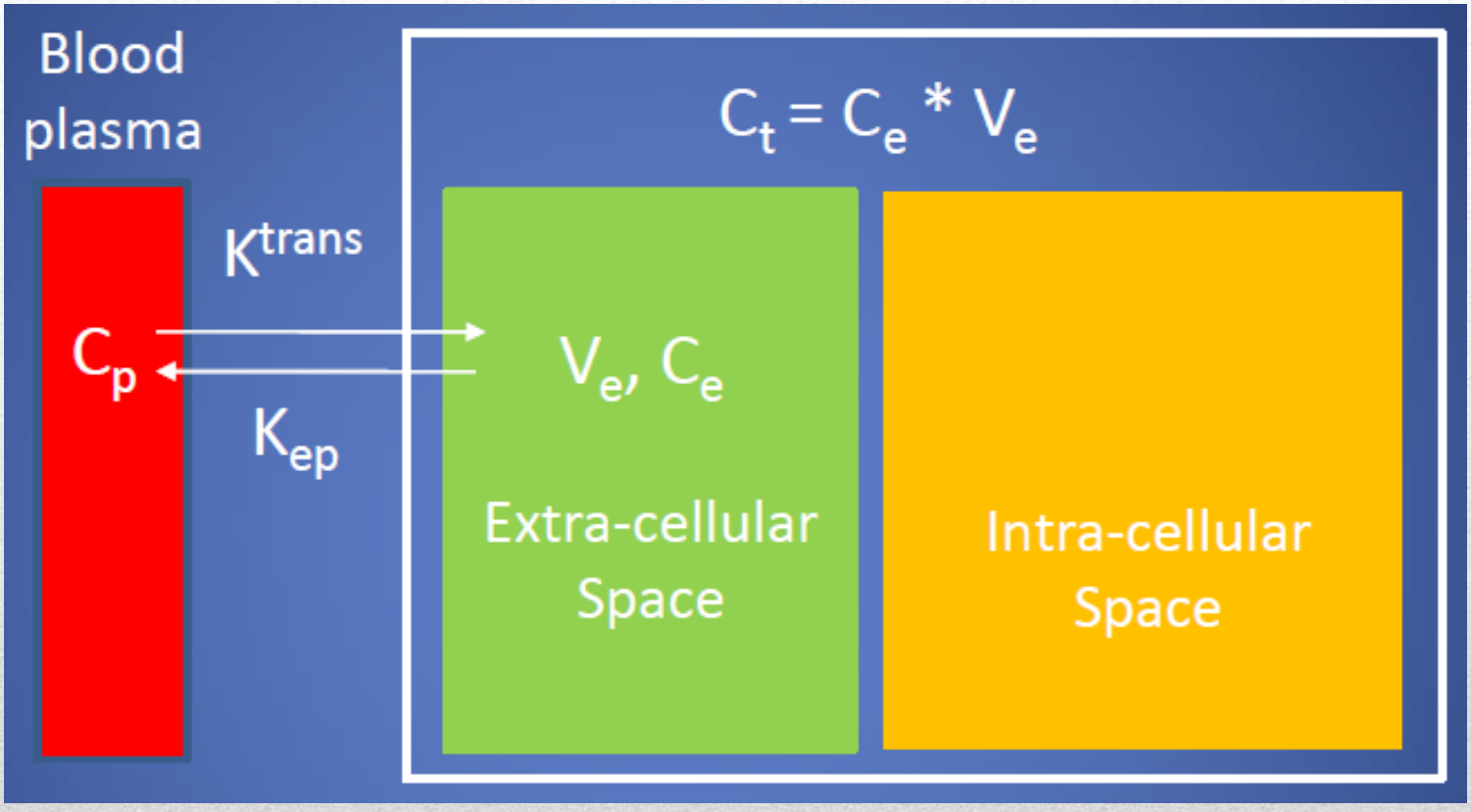


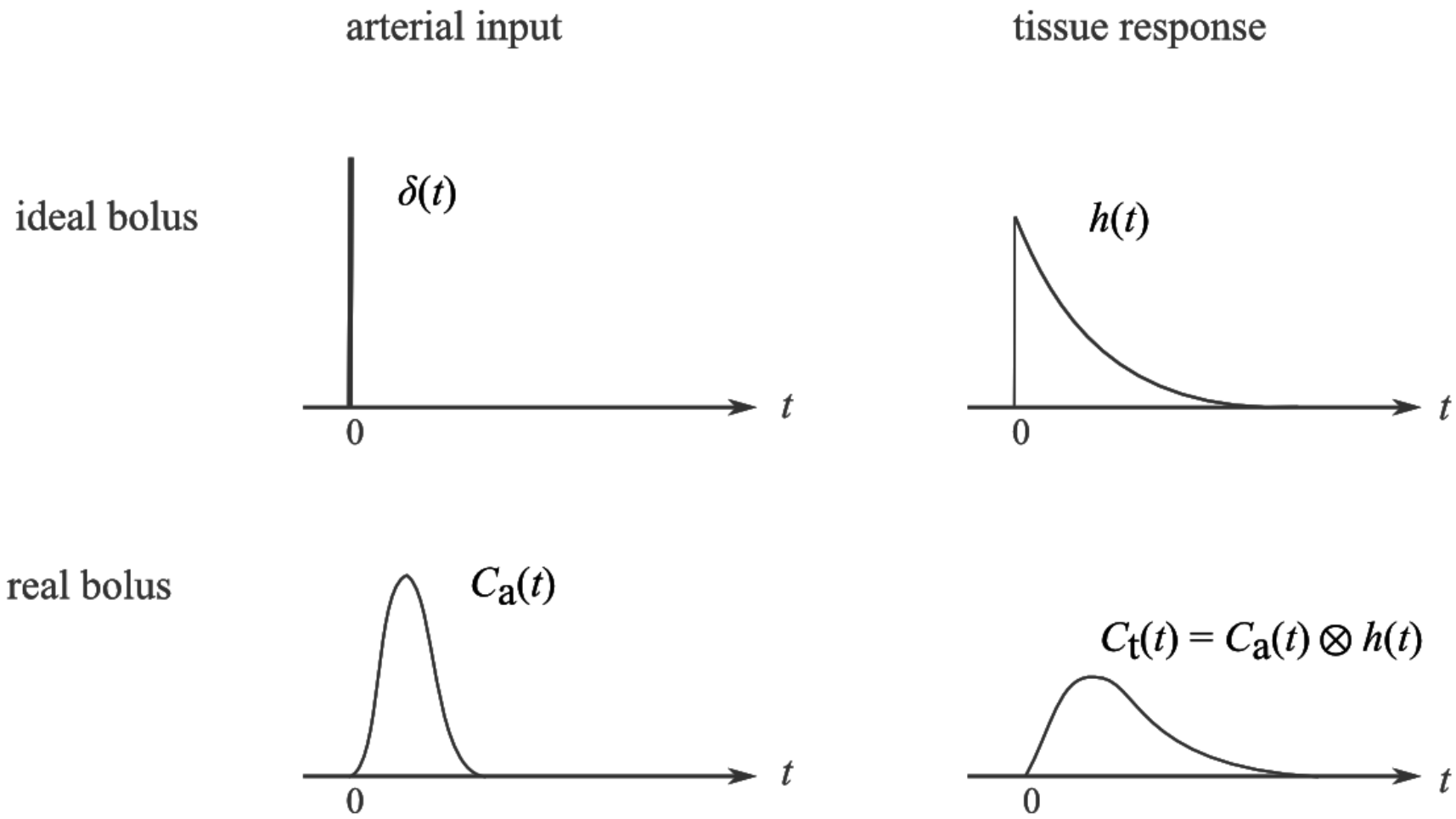
Physiological parameter:

Ktrans : transfer constant (Vessel Permeability)

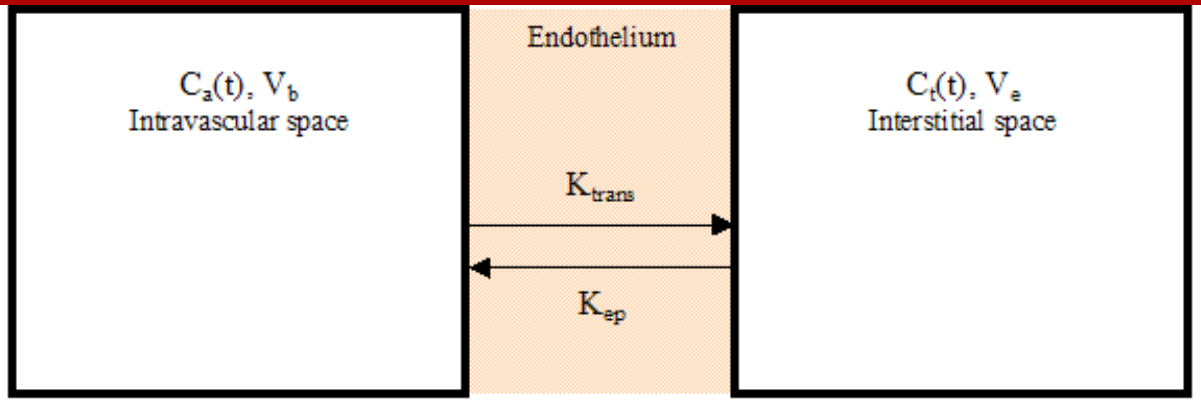
Kep : reflux constant

Ve : extra-vascular, extra-cellular volume fraction (Cellular Density)

Diagram of a linear stationary system



- The Response to an ideal impulse $\delta(t)$ at the entrance is h(t). The real bolus of an infusion is of a broadened form and thus the outflow response is given by a convolution of $C_a(t)$ and h(t). (Modication of Brix et al).

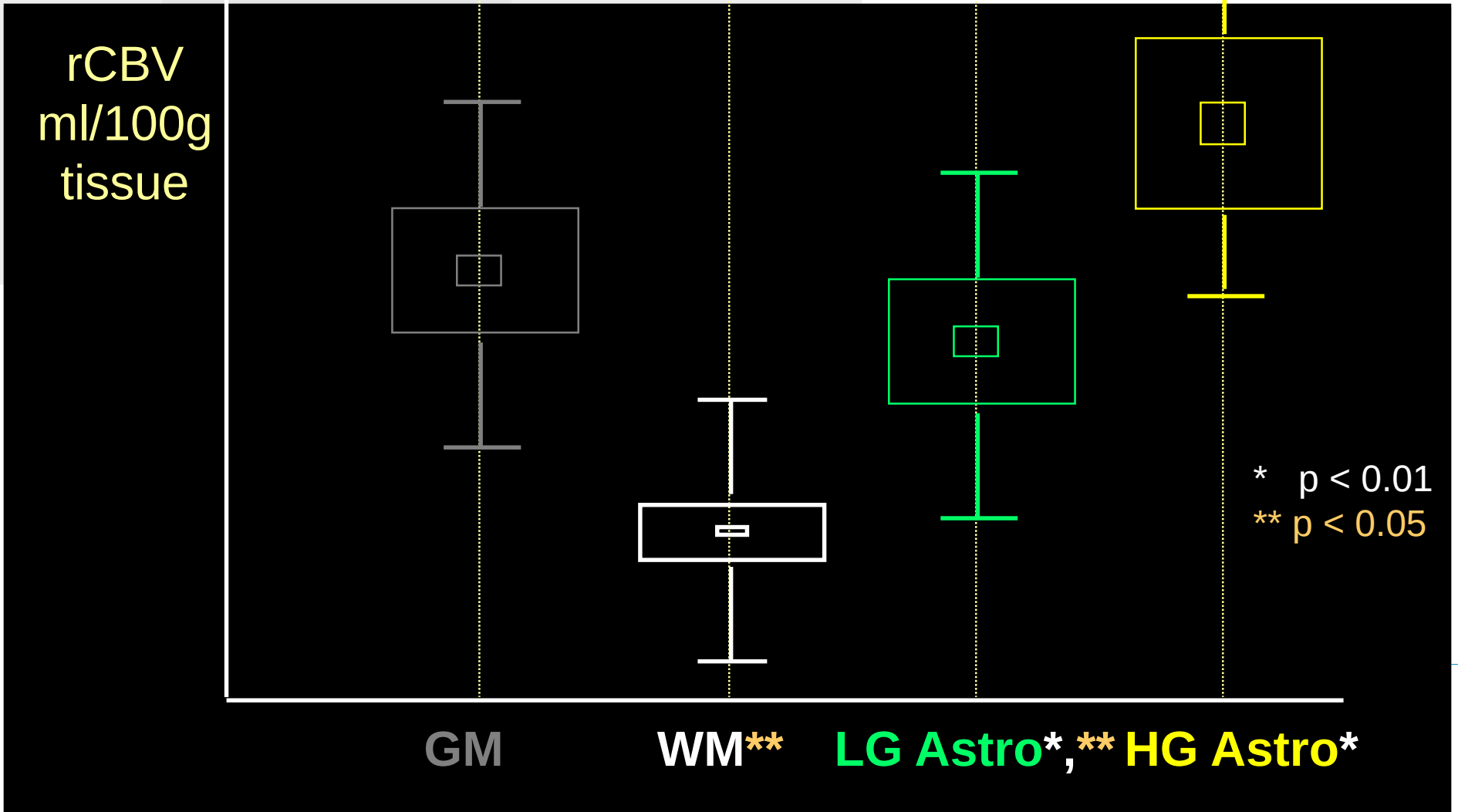


Quantity	Definition	Unit
Ca(t)	Arterial concentration as a function of time	HU or mM
Ct(t)	Tissue concentration as a function of time	HU or mM
Hct	Hematocrit value	Dimensionless
Ktrans	Transfer constant from the blood plasma into the EES	mL/g/min
kep	Transfer constant from the EES back to the blood plasma	1/min
t	Onset time of arterial contrast uptake	sec
Vb	Whole blood volume per unit of tissue	mL/g
Ve	Total EES volume (Ve = Ktrans/kep)	mL/g

$$C_t(t) = \frac{K_{trans}}{1 - Hct}\left(C_a(t) \otimes e^{-k_{ep}(t-\tau)}\right)$$

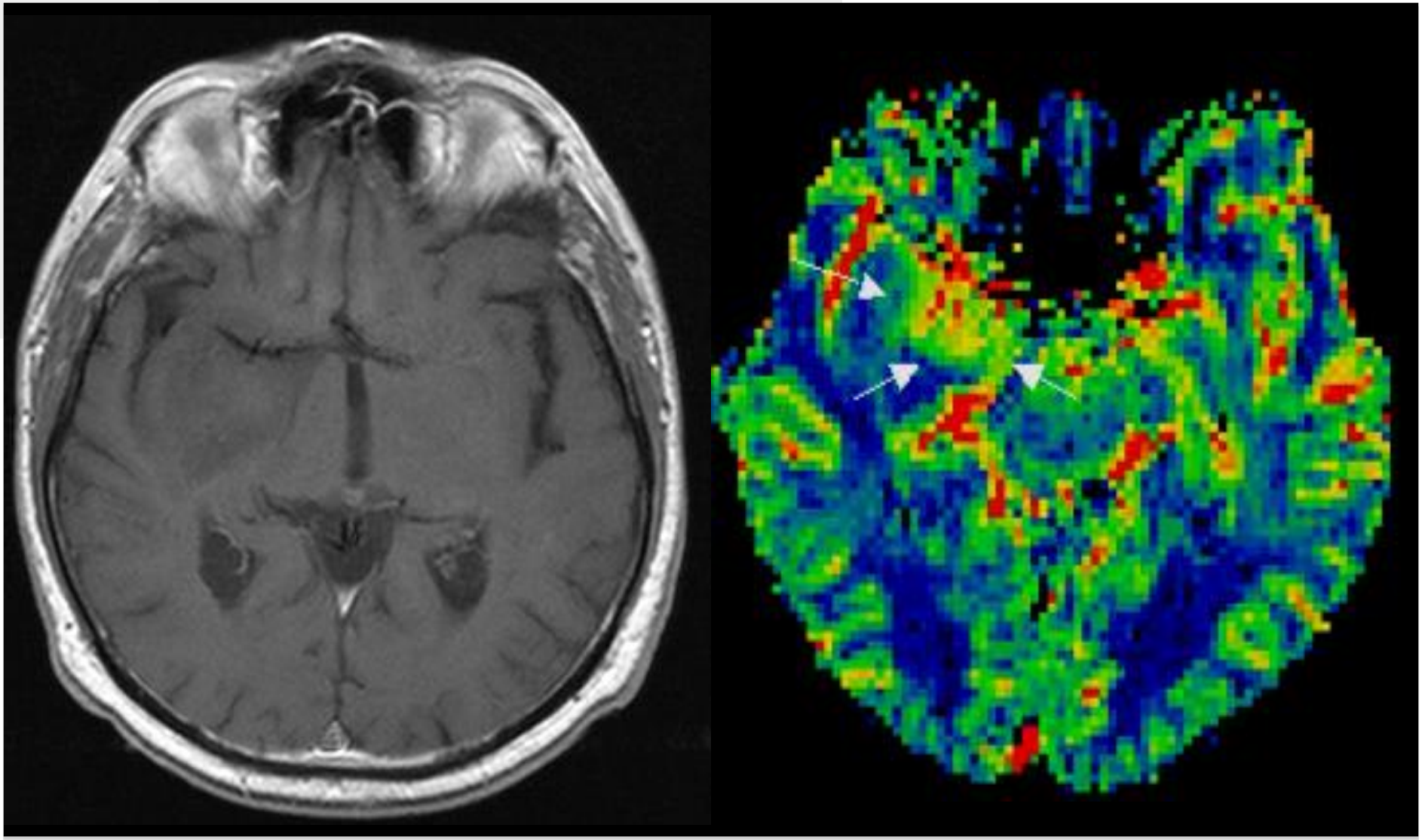
DSC & DCE in neuro-oncological imaging

- Vascularity and vessel permeability of tumors
- Amplitude & exchange rates (k_{trans})
- Grading of primary brain tumors



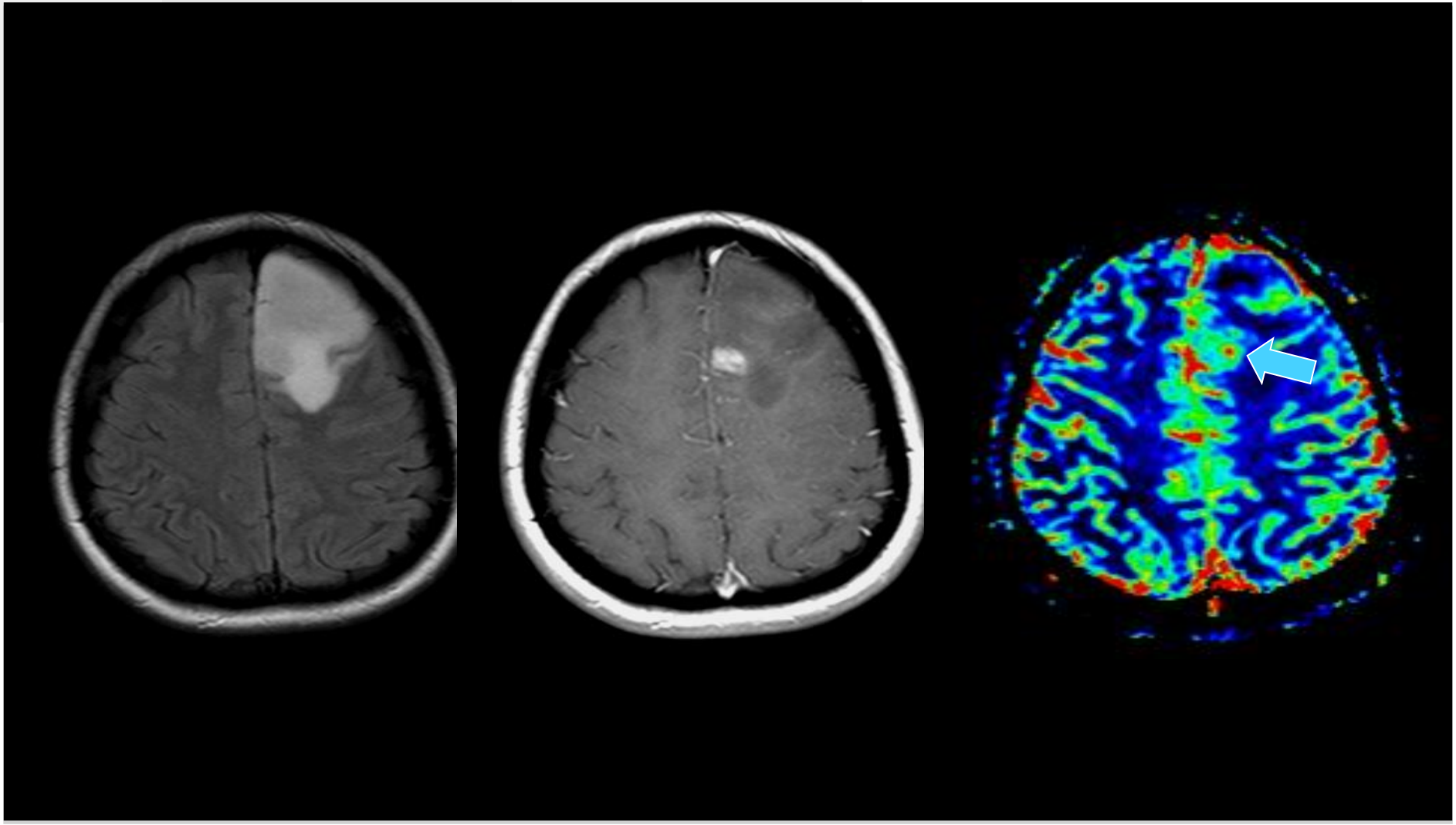
DSC & DCE in neuro-oncological imaging

Grading of primary brain tumors

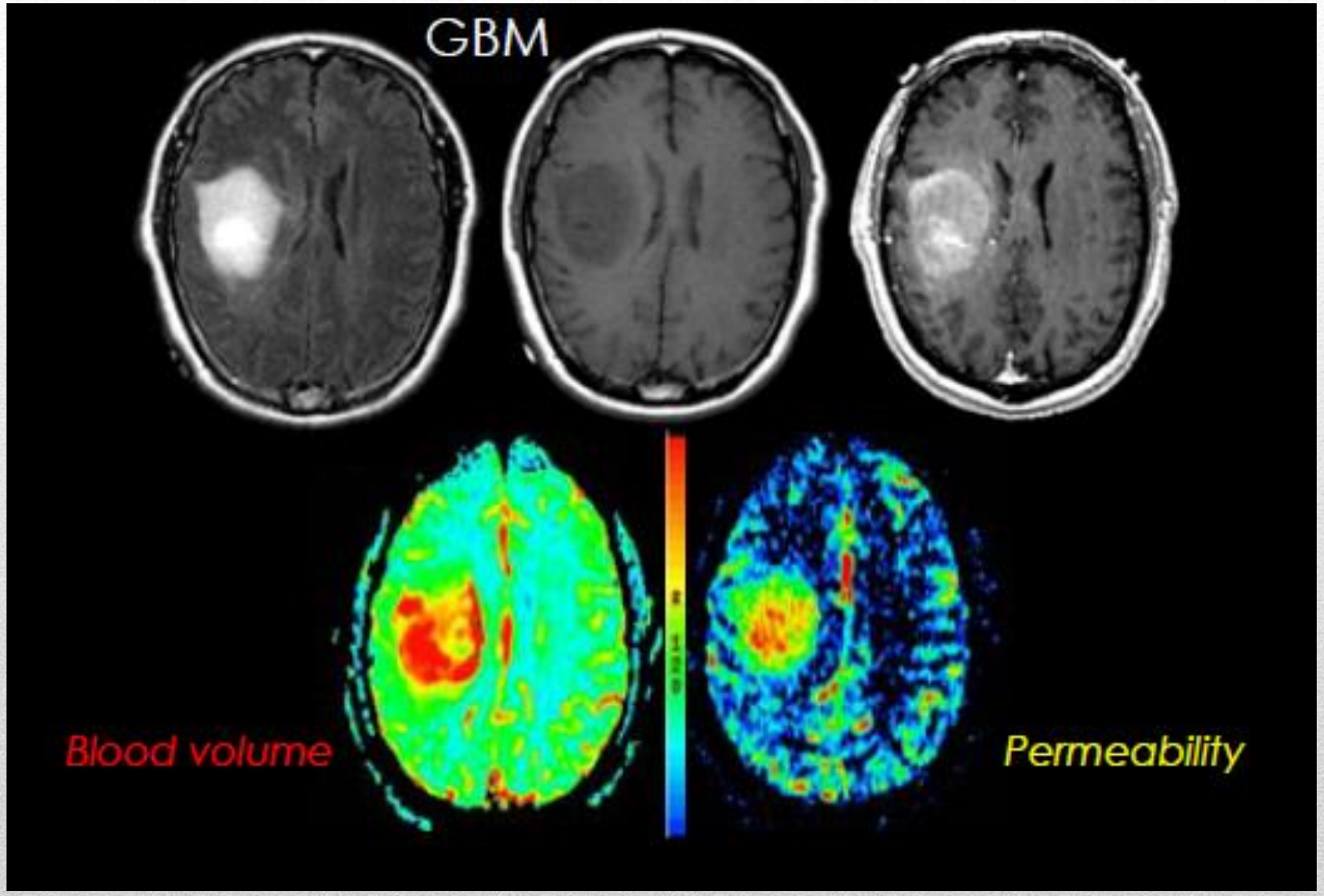


DSC & DCE in neuro-oncological imaging

Detection of recurrent tumor

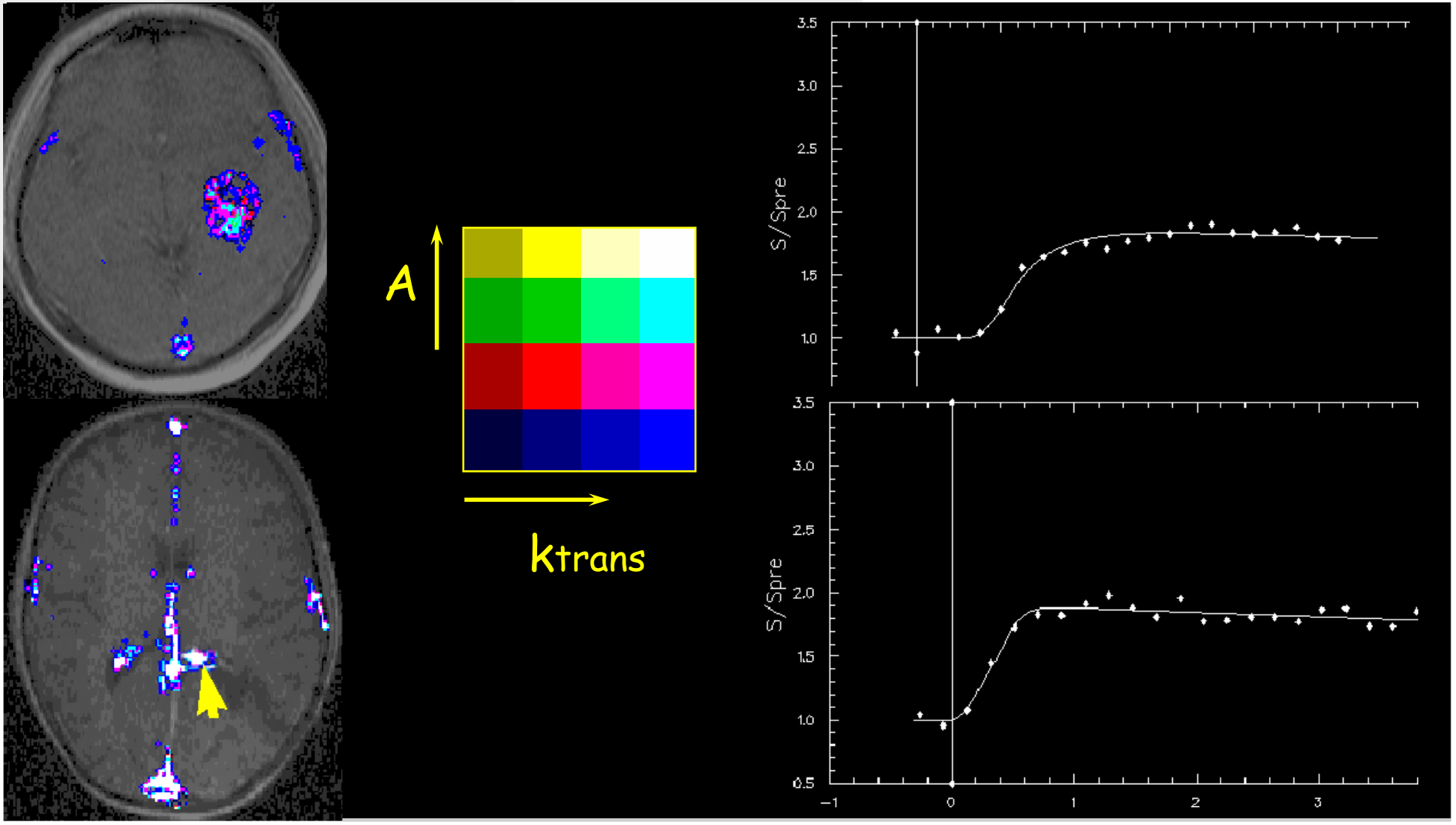


DSC & DCE in neuro-oncological imaging



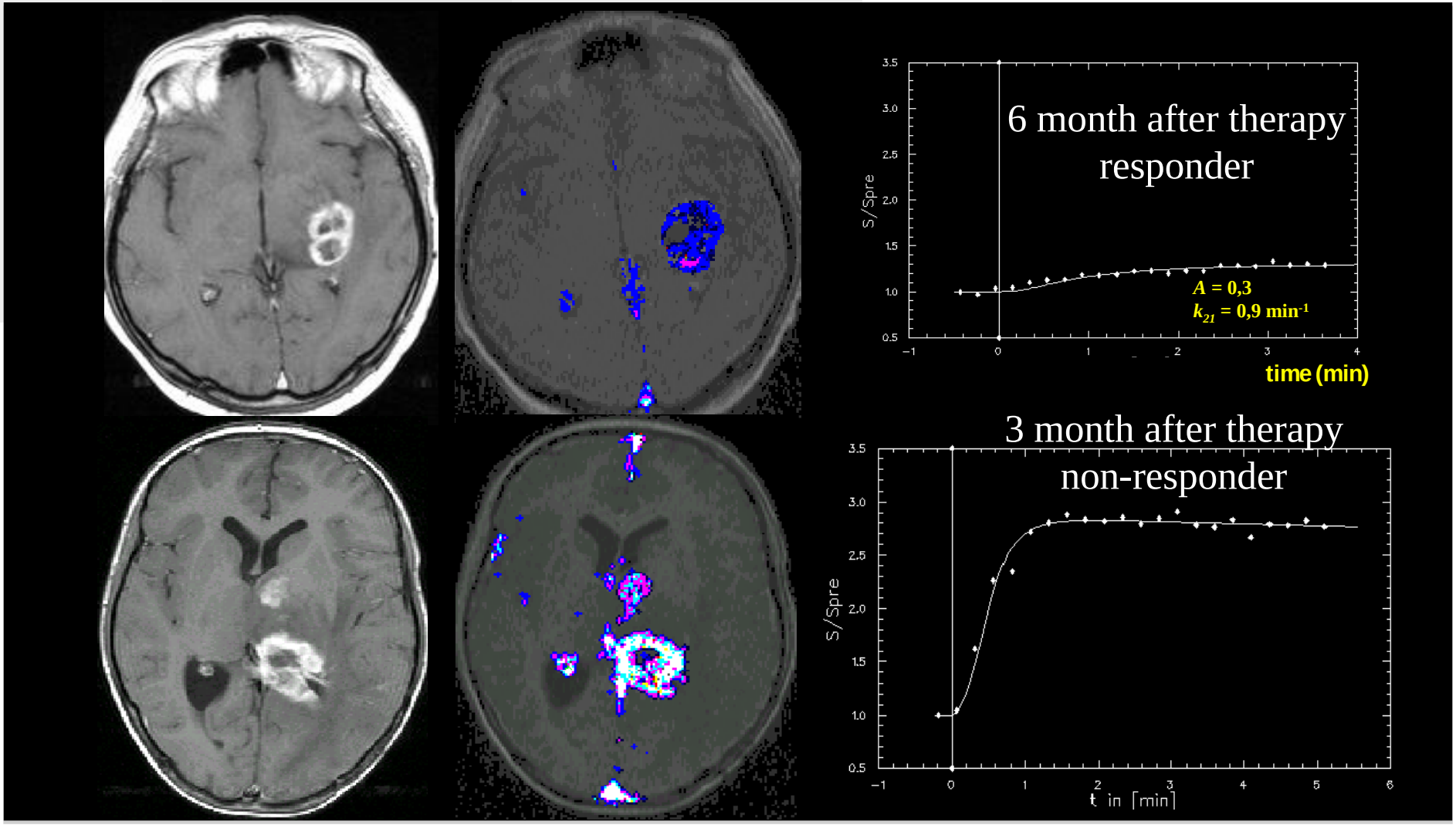
DCE in neuro-oncological imaging

Tumor characterisation & therapy response

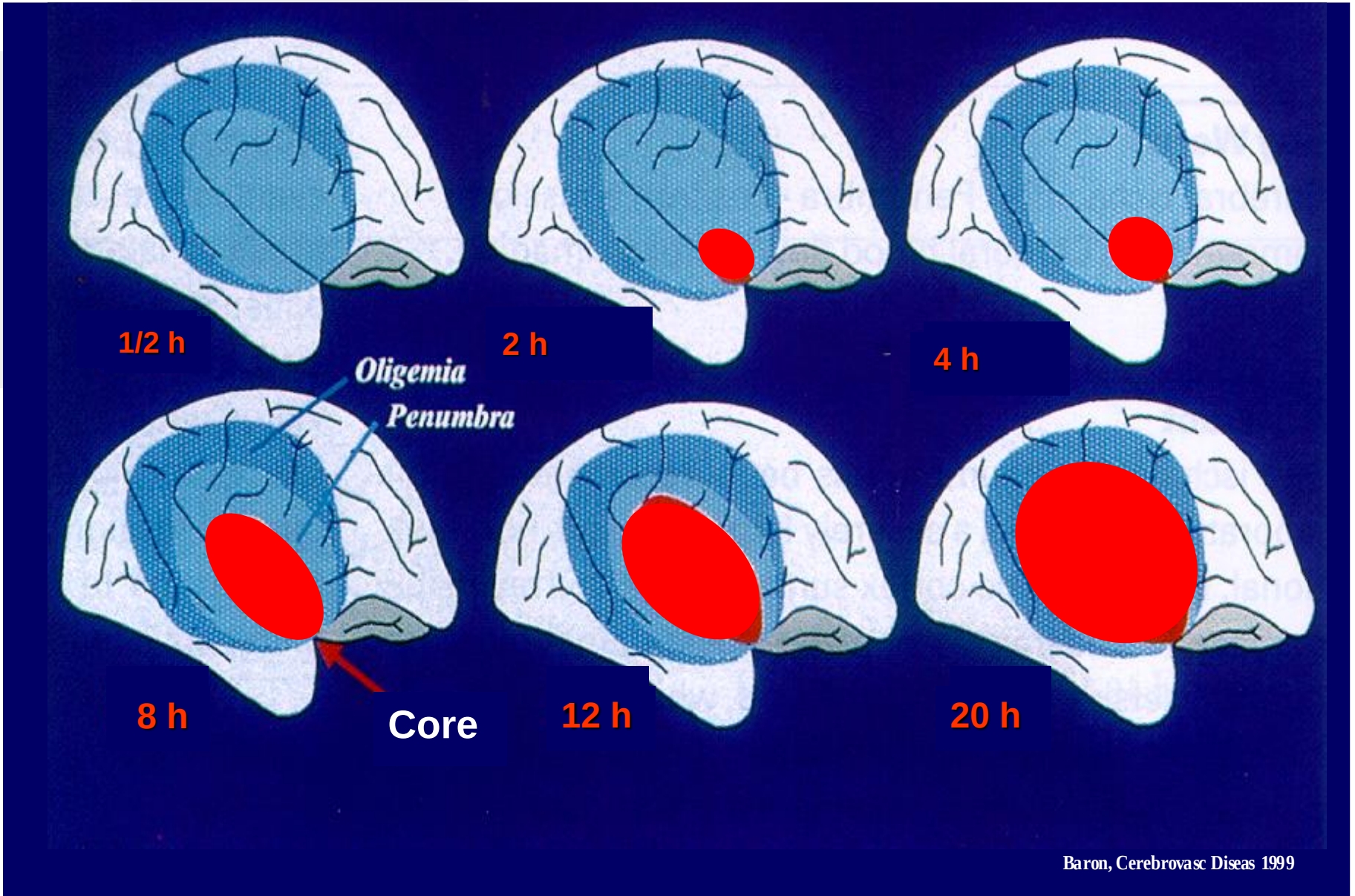


DCE in neuro-oncological imaging

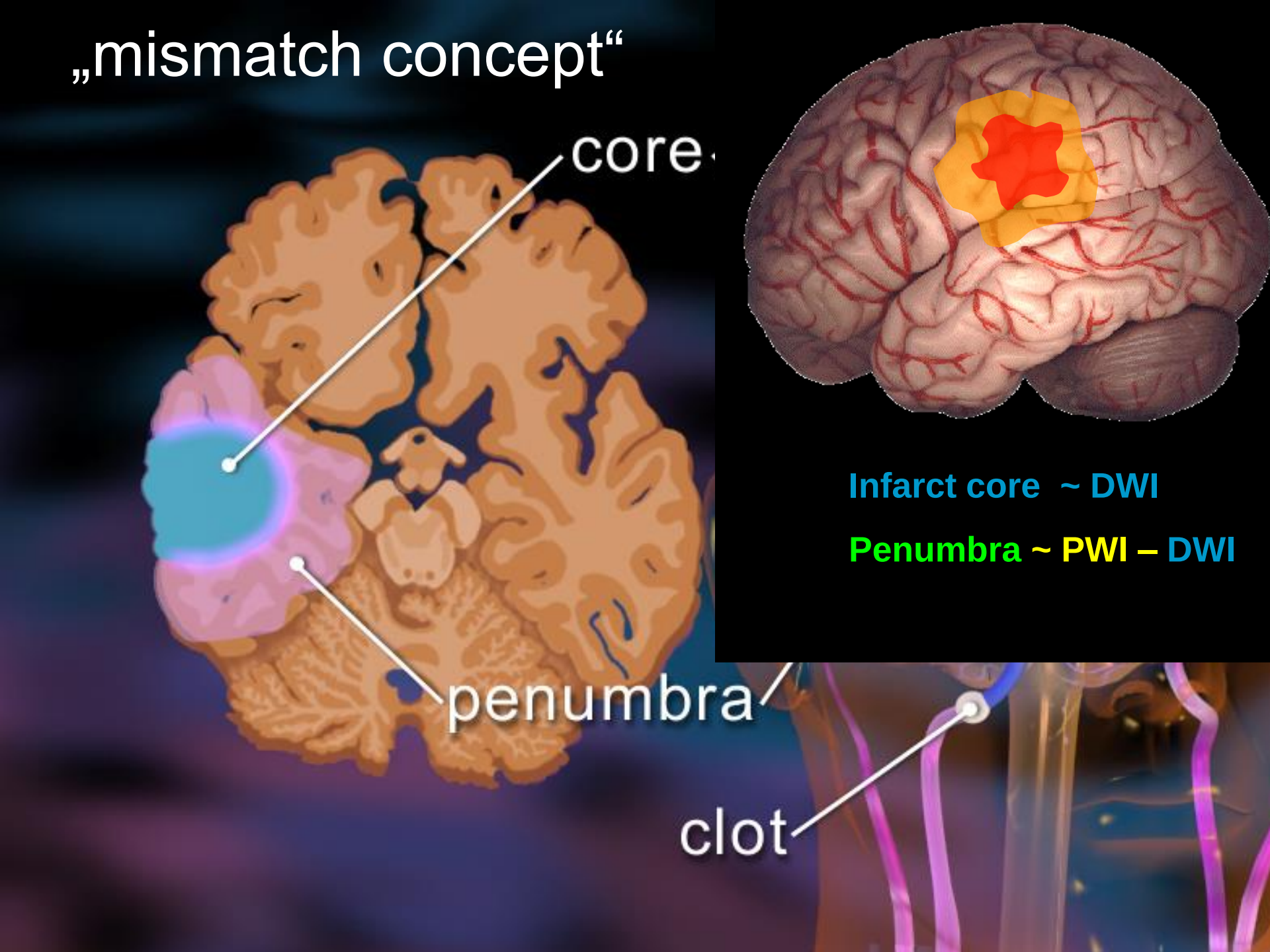
Tumor characterisation & therapy response



Stroke

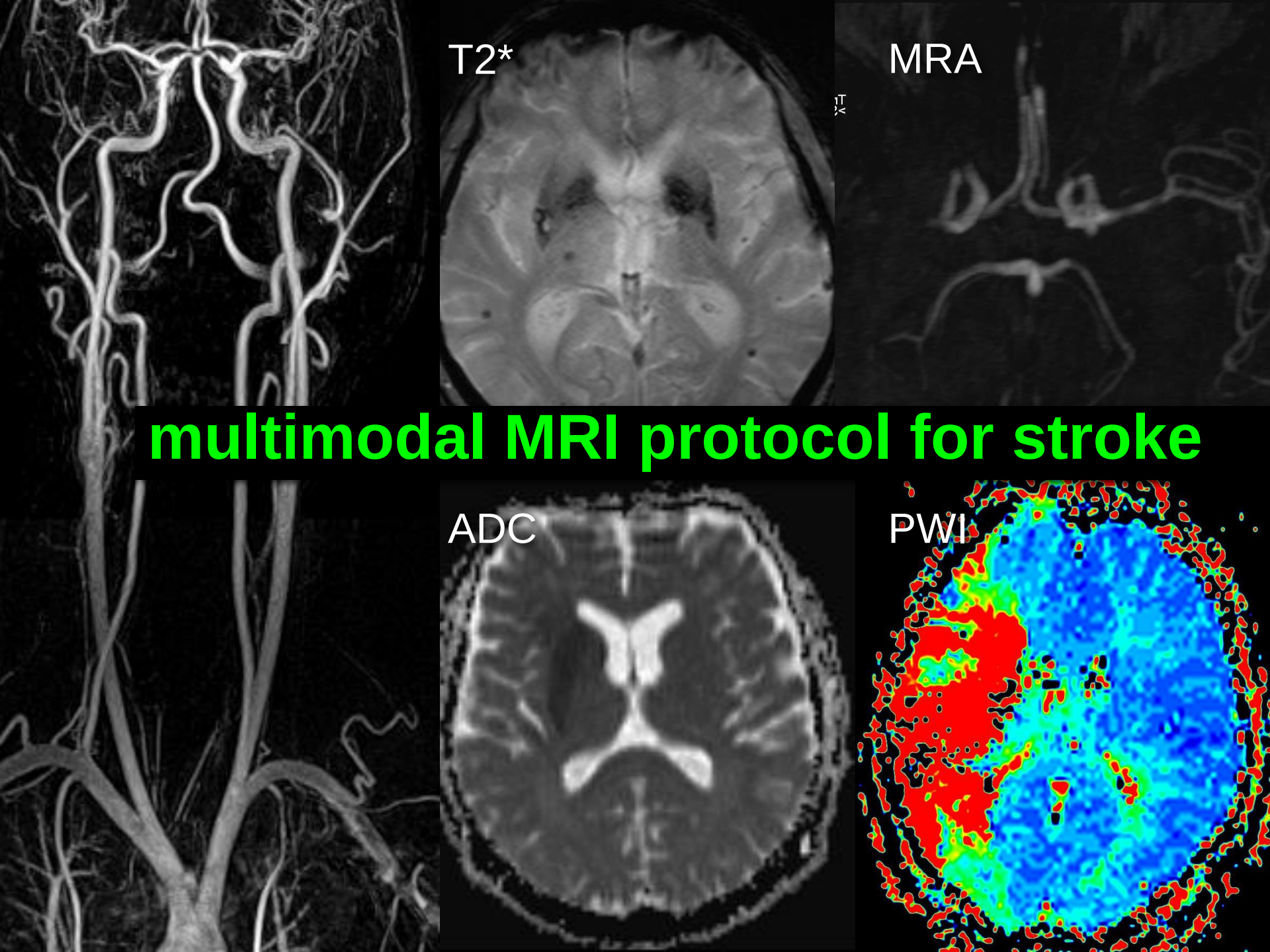

1/2 h
2 h
4 h
Oligemia
Penumbra
8 h
Core
12 h
20 h
Baron, Cerebrovasc Diseas 1999

„mismatch concept“



Infarct core ~ DWI

Penumbra ~ PWI – DWI


T2*
MRA
multimodal MRI protocol for stroke
ADC
PWI

Stroke

MRI protocol acute stroke

- Diffusion-MRI	0:52 min
- MRA (3D-TOF)	3:03 min
- FLAIR	3:20 min
- GRE T2/T2*	2:52 min
- CE-MRA	1 min
- Perfusion-MRI	1:30 min
- T1 + CA	2:30 min

total ~ 15 min

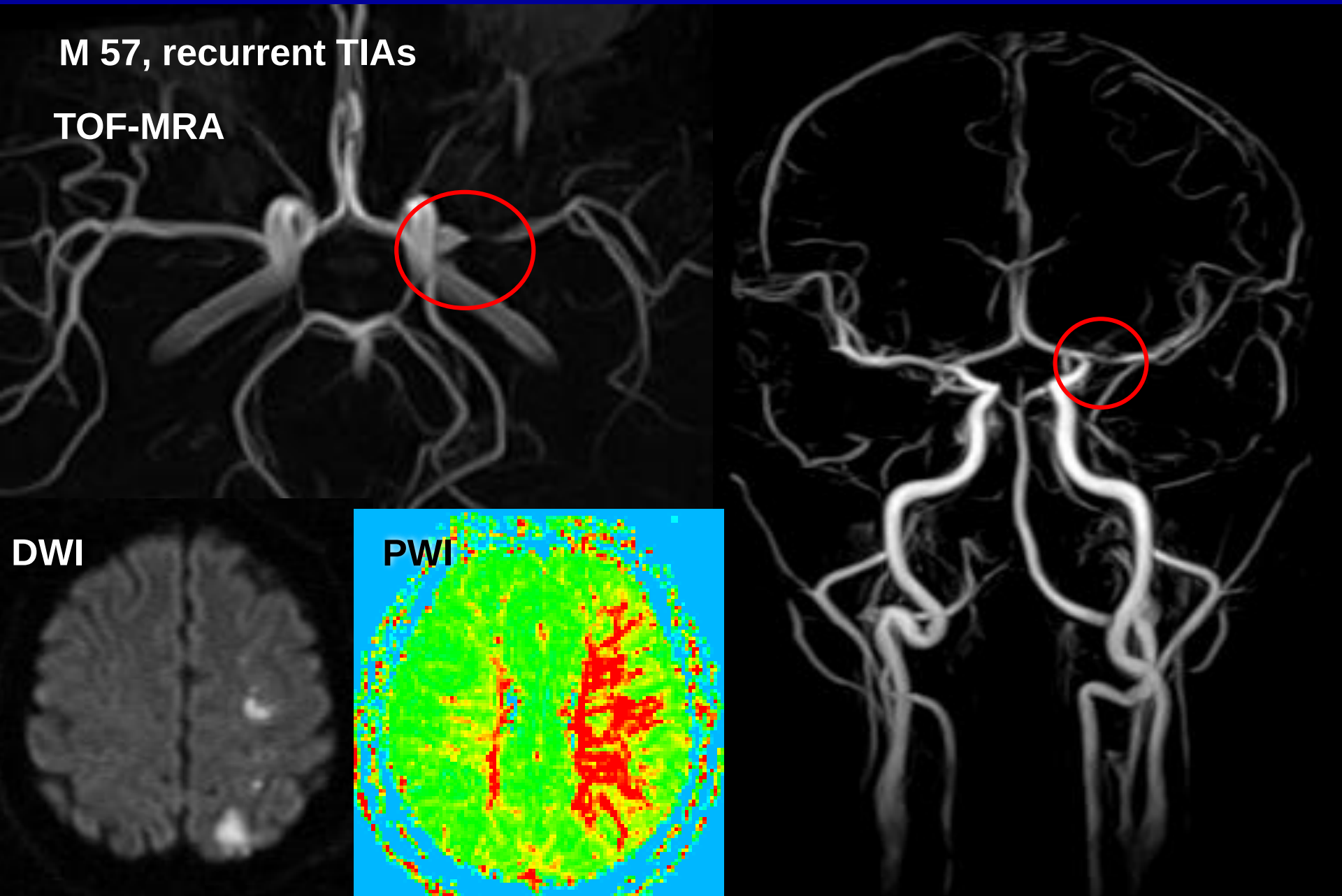
DSC in stroke imaging

How to define critically hypoperfused tissue ?

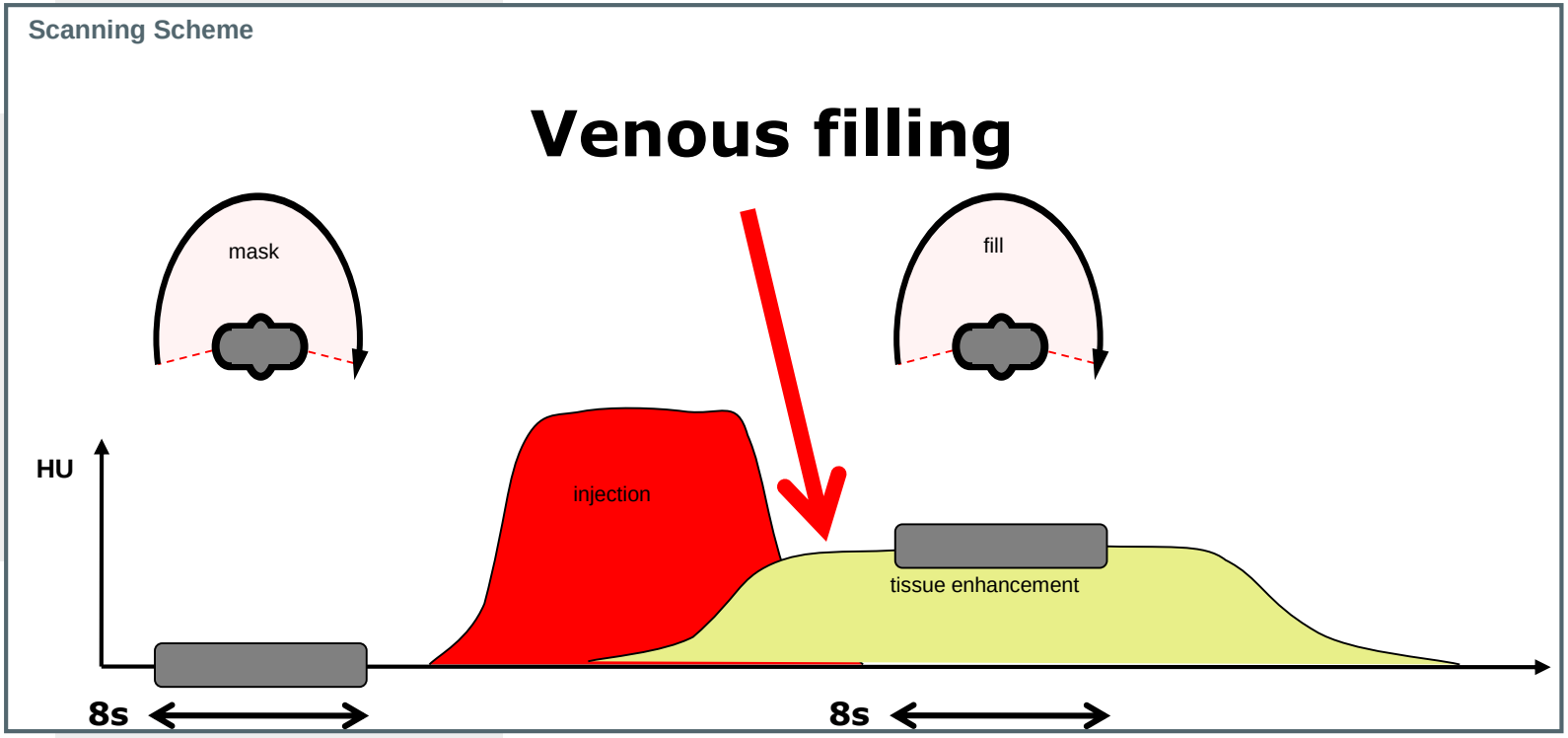
MTT	**> 3s**
TTP	**> 4s**
CBF	**< 40% compared to contra-side**
CBV	**< 45% compared to c.s.**

Ford 2014, Siesjö 2001

DSC in stroke imaging

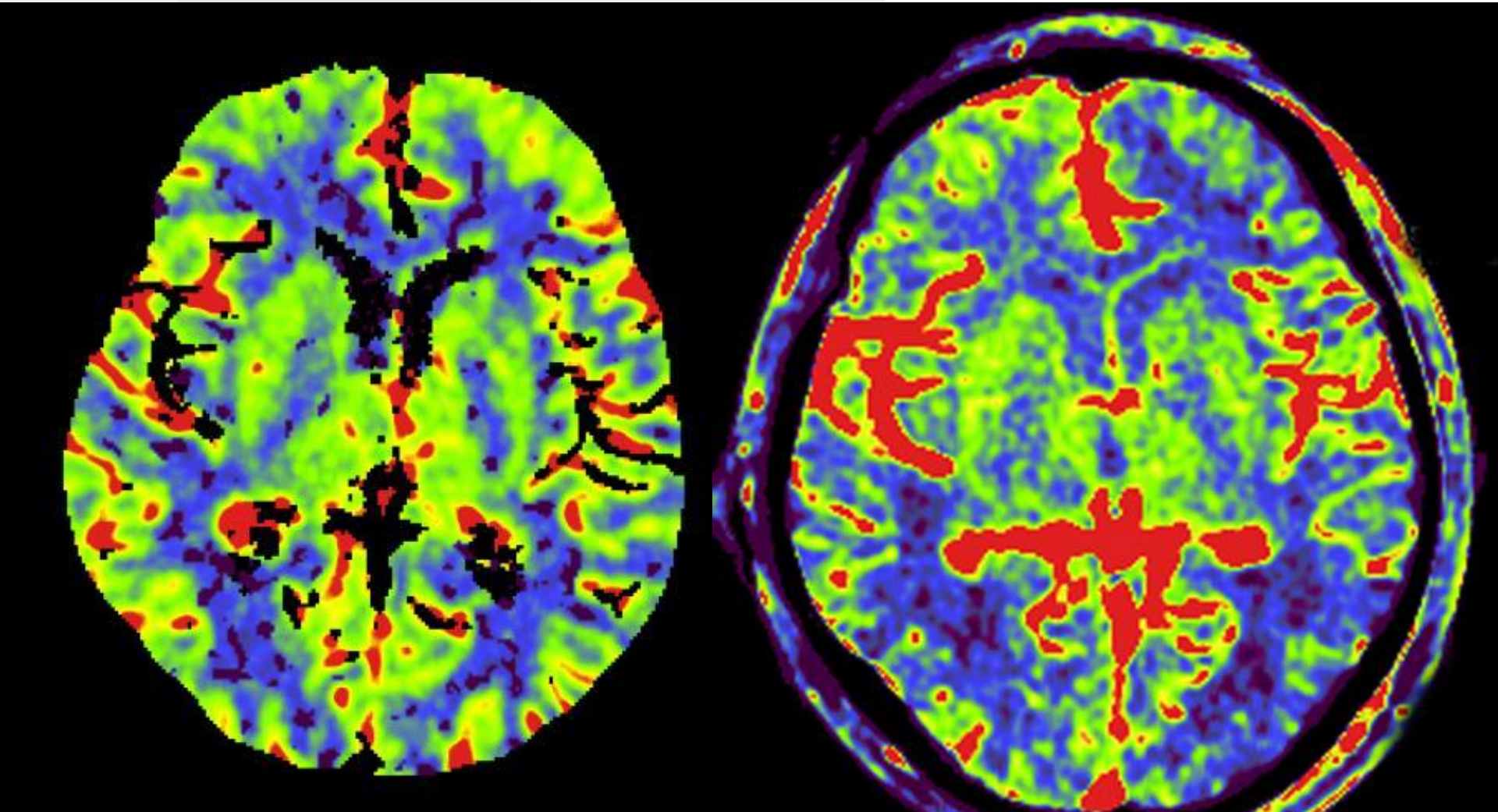


CT or DynaCT Perfusion



Perfusion imaging: CBV
8s_DSA (Neuro PBV IR)

60 ml contrast 300 mg/ml, flow 4ml/s
60 ml saline, flow 4 ml/s

DynaCT Perfusion

Perfusion: visualisation of CBV
MisMatch= MTT - CBV