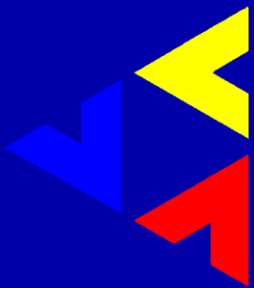


Perfusion

Uwe Klose



MR Research Group
Department for Neuroradiology
Eberhard-Karls-University Tübingen, Germany



Overview

Perfusion measurements need a tracer within the blood system
(like O15 in PET-measurements)

This can be a exogenous tracer like paramagnetic contrast agent

DSC-MRI (dynamic susceptibility contrast magnetic resonance imaging)

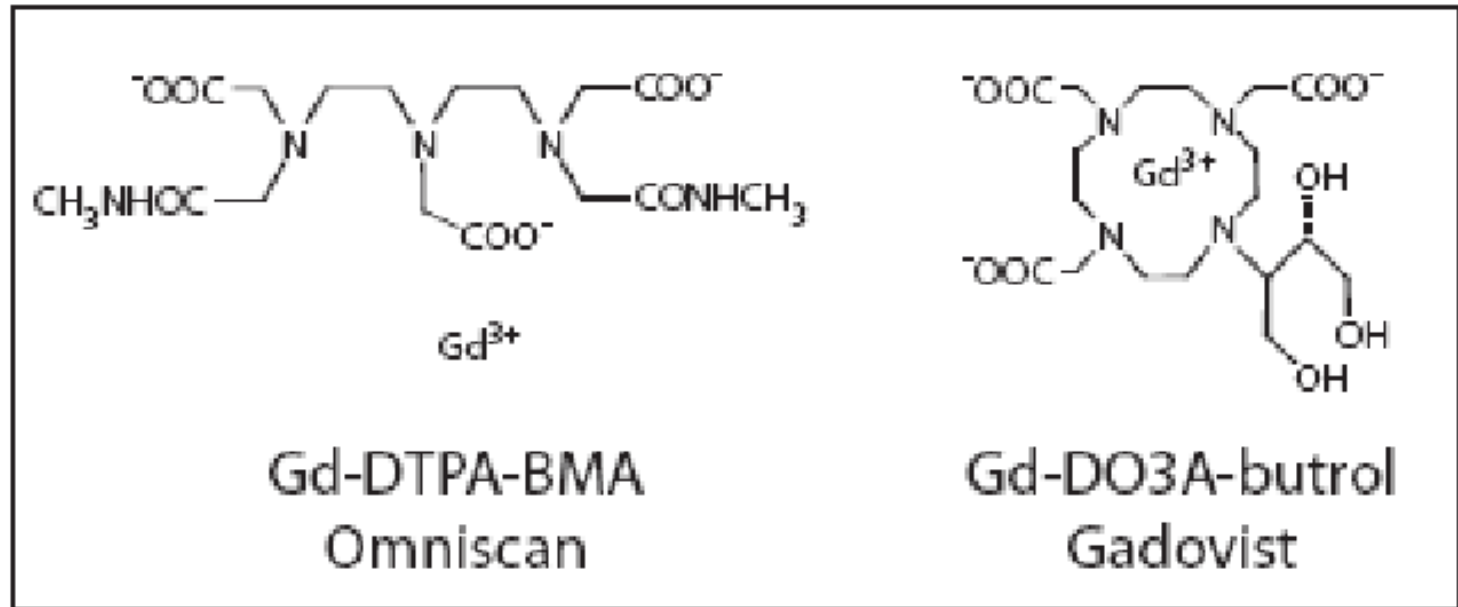
or

with an endogenous tracer: magnetic labeled blood

ASL (Arterial spin labeling)

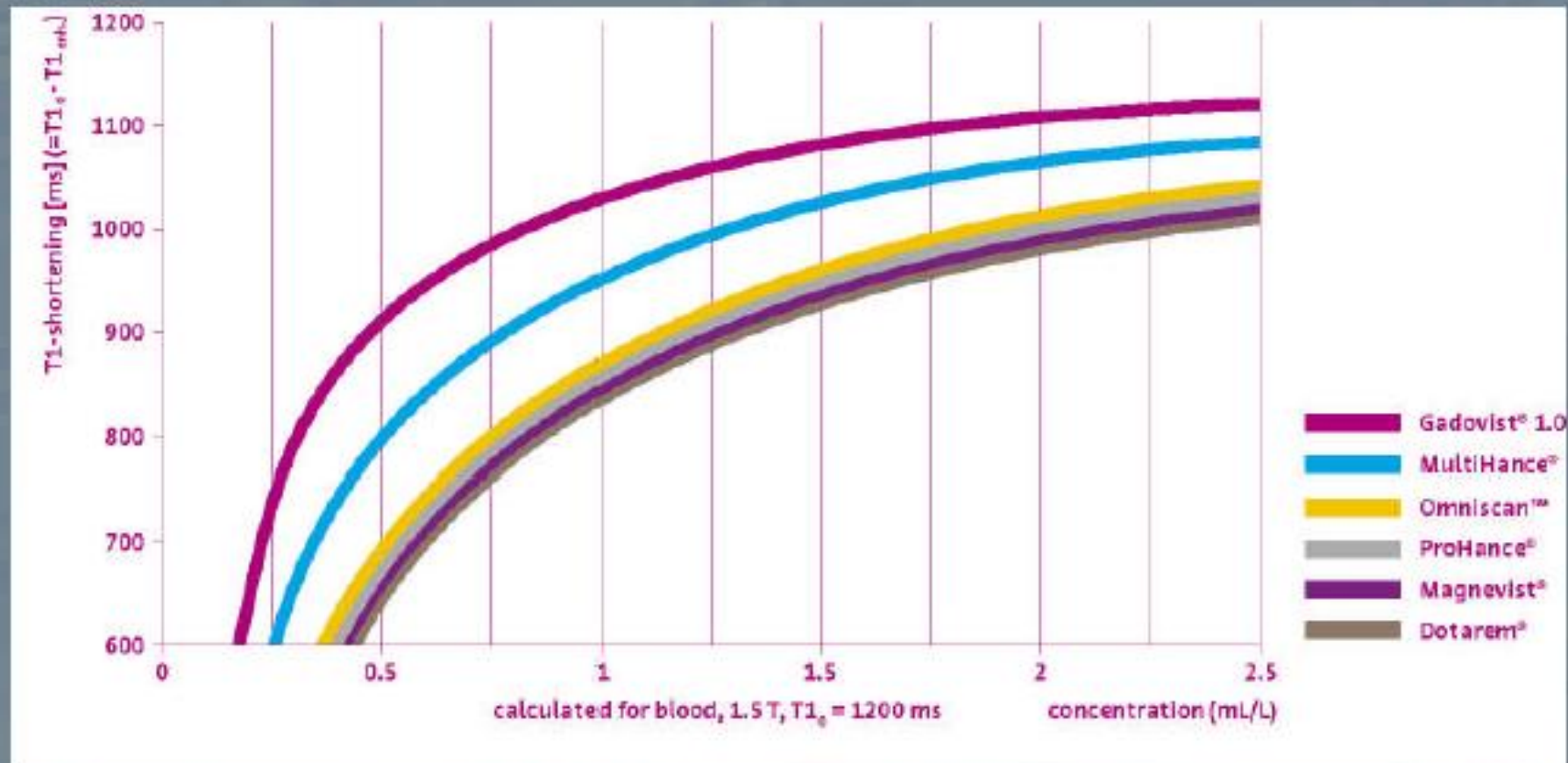
The Use of Paramagnetic Contrast Agent in MRI

GD-containing contrast agents are widely used in clinical MRI



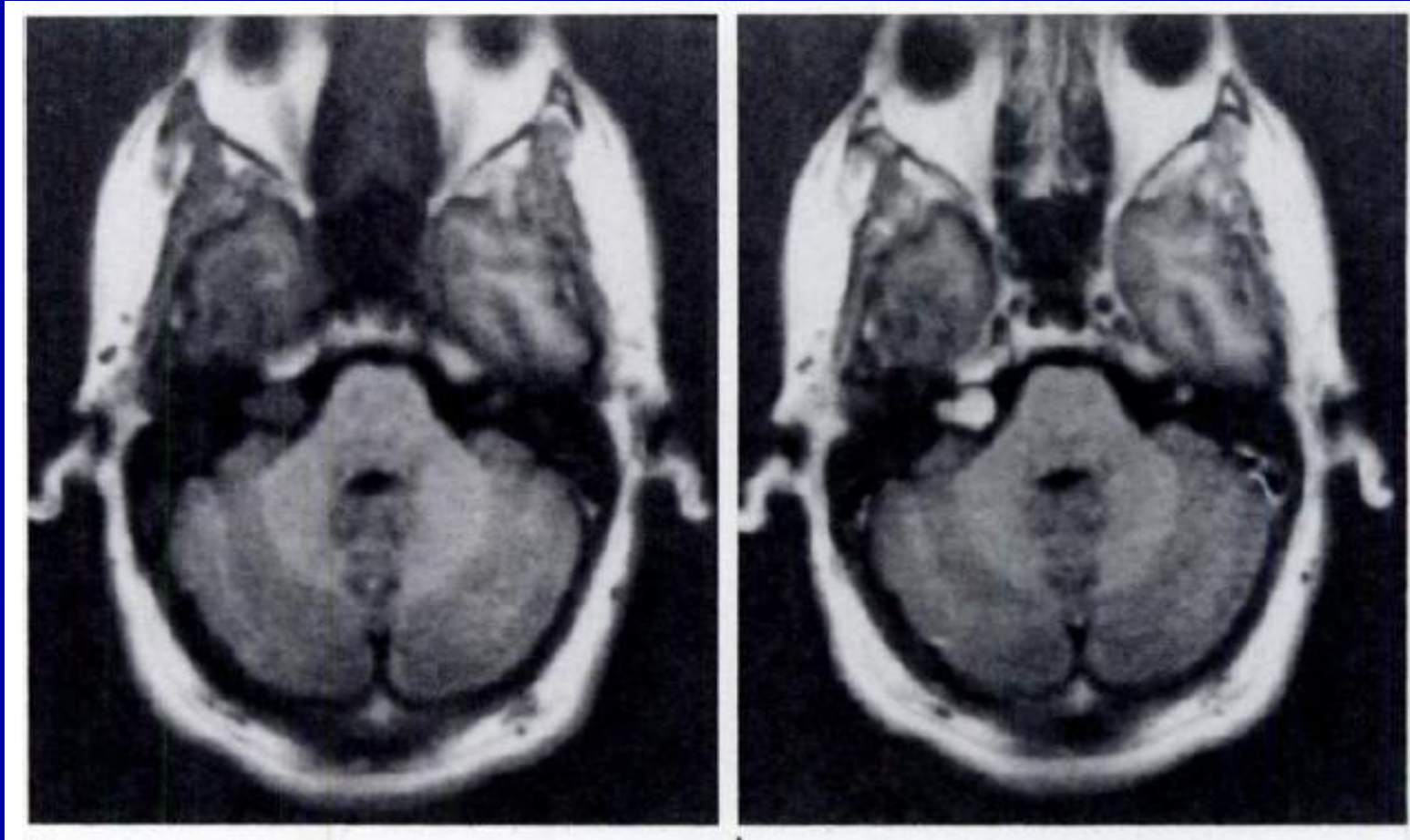
Examples of linear and macrocyclic contrast agents. Omniscan (linear) and Gadovist (macrocyclic) possess similar r_1 relaxivities of 3.8 and 3.7, respectively, in water and human serum albumin at 37°C and 0.47T, but they differ in stability of bond between gadolinium ion and chelate.²

The Use of Paramagnetic Contrast Agent in MRI



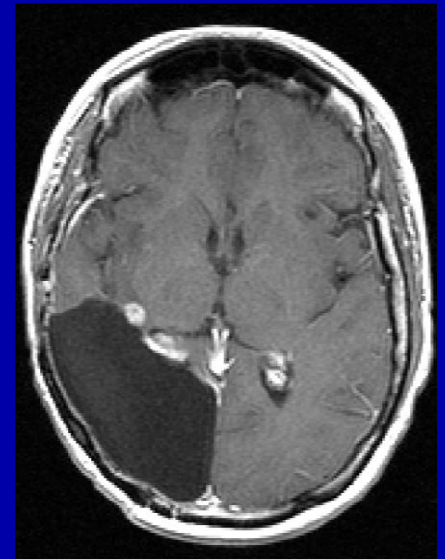
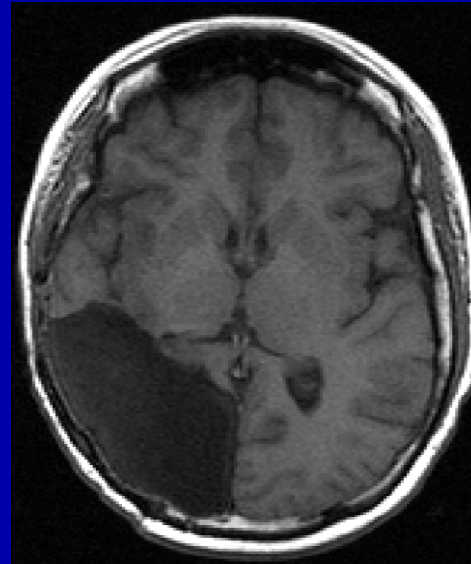
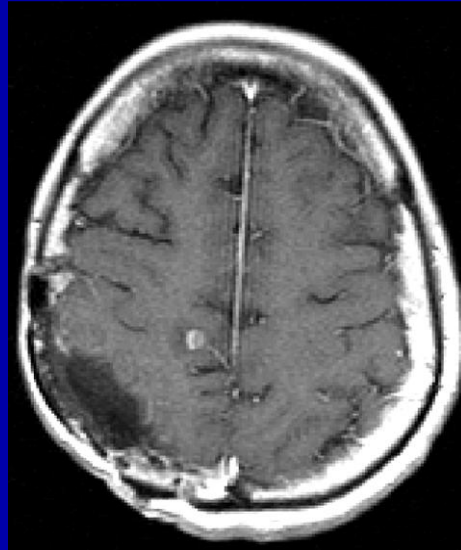
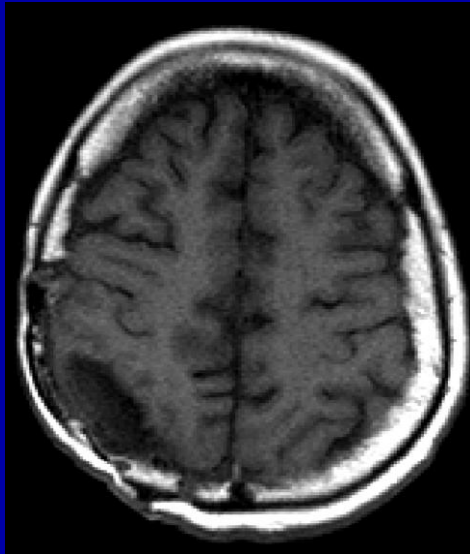
Based on Rohrer M, Bauer H, Mintorovitch J, Requardt M, Weinmann HJ. Invest Radiol 2005; 40:715-724

The Use of Paramagnetic Contrast Agent in MRI



Contrast-enhanced MRI in the brain: acoustic neuroma

The Use of Paramagnetic Contrast Agent in MRI

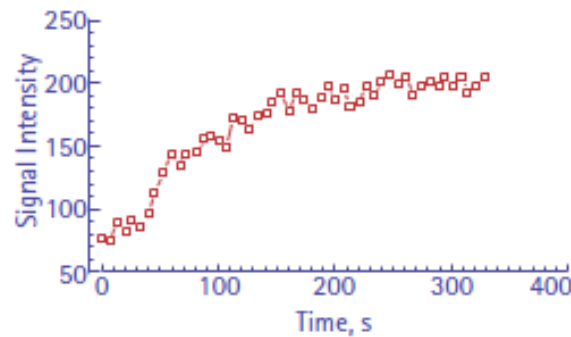


Contrast-enhanced MRI in the brain:

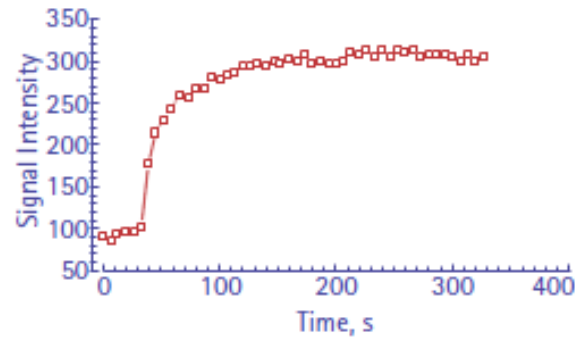
Relapse several months after
resection of a brain tumor

The Use of Paramagnetic Contrast Agent in MRI

FIG. 3. Types of SI-time curves: Type 1 shows a slow SI rise with no subsequent washout (left); type 2 shows a rapid rise in SI and subsequent steady line with no rapid washout (middle); and type 3 curve shows a rapid uptake in SI and rapid washout (right).



Normal tissue

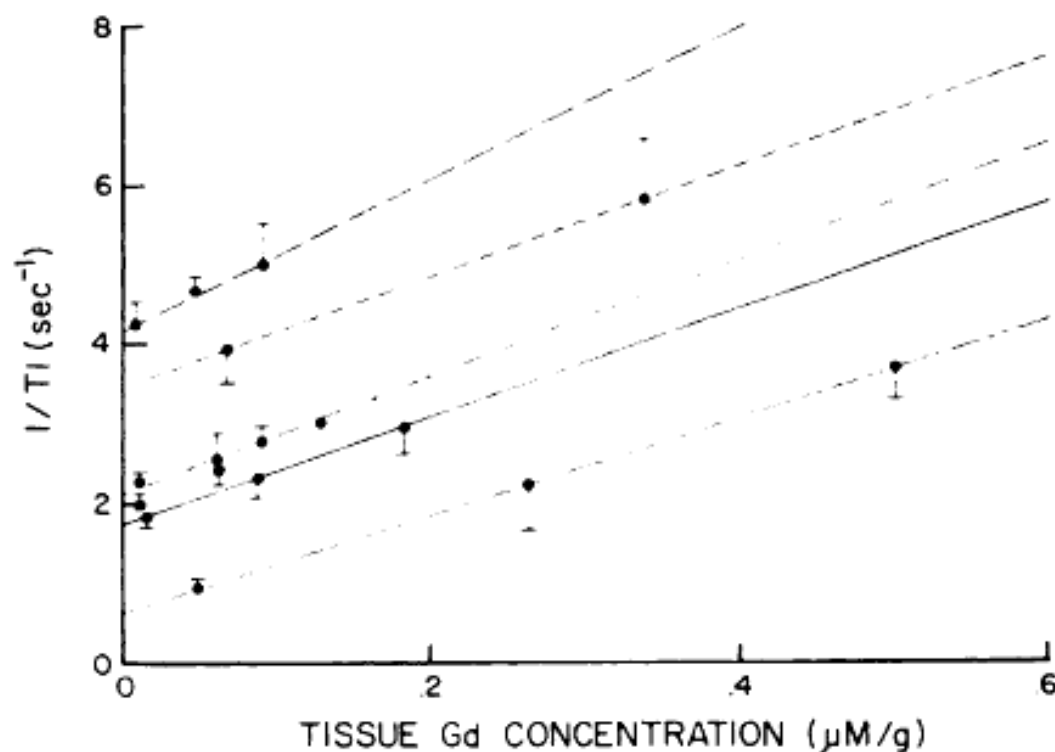


Cancer tissue

Dynamic Contrast-enhanced MRI (DCE-MRI)
allow a differentiation of tissue types

Paramagnetic Contrast Agent in MRI

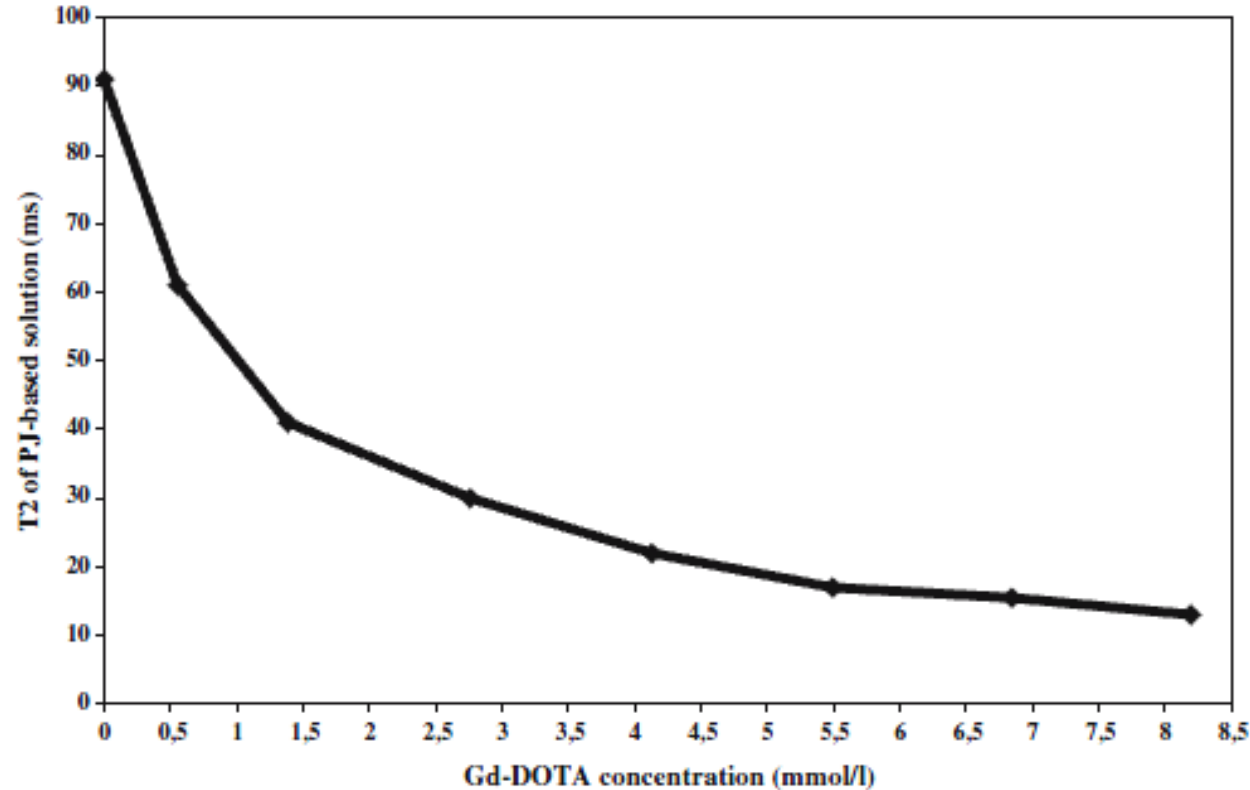
Figure 3



SYMBOL	TISSUE
— — —	LIVER
.....	HEART
- . - .	SPLEEN
- - - -	KIDNEY
————	LUNG
- . . . -	SERUM

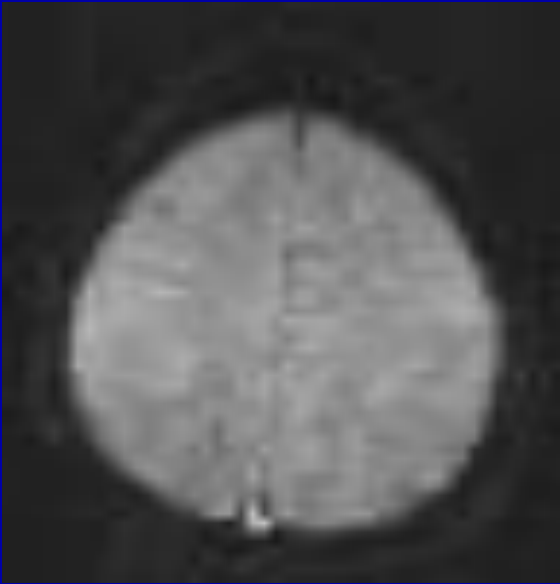
Decreasing T_1 with increasing Gd-DTPA concentration
In different tissues

Paramagnetic Contrast Agent in MRI

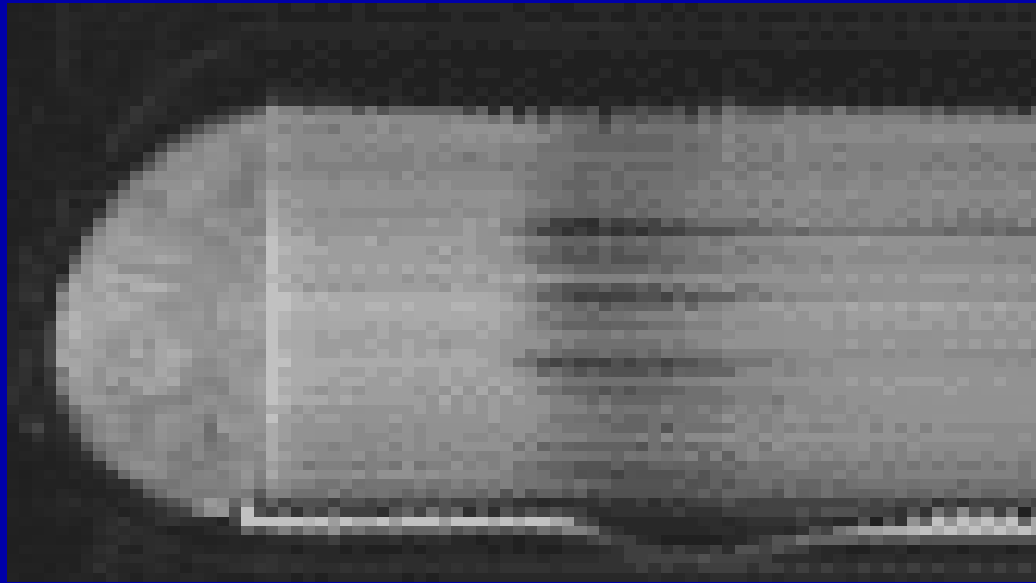


Decreasing T2 with increasing Gd-DOTA concentration
(measured in fruit juice for oral application)

Paramagnetic Contrast Agent in MRI



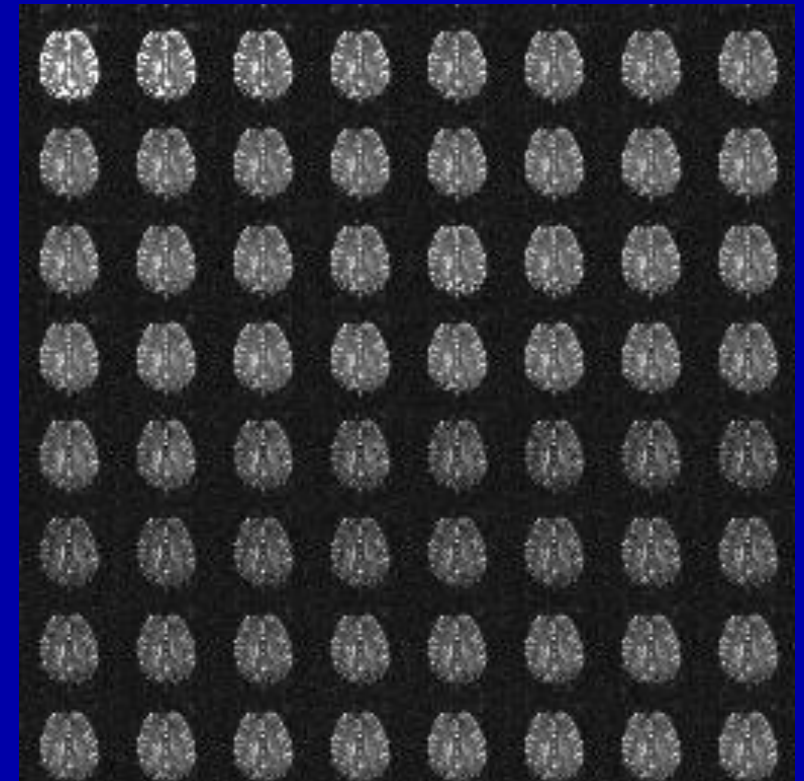
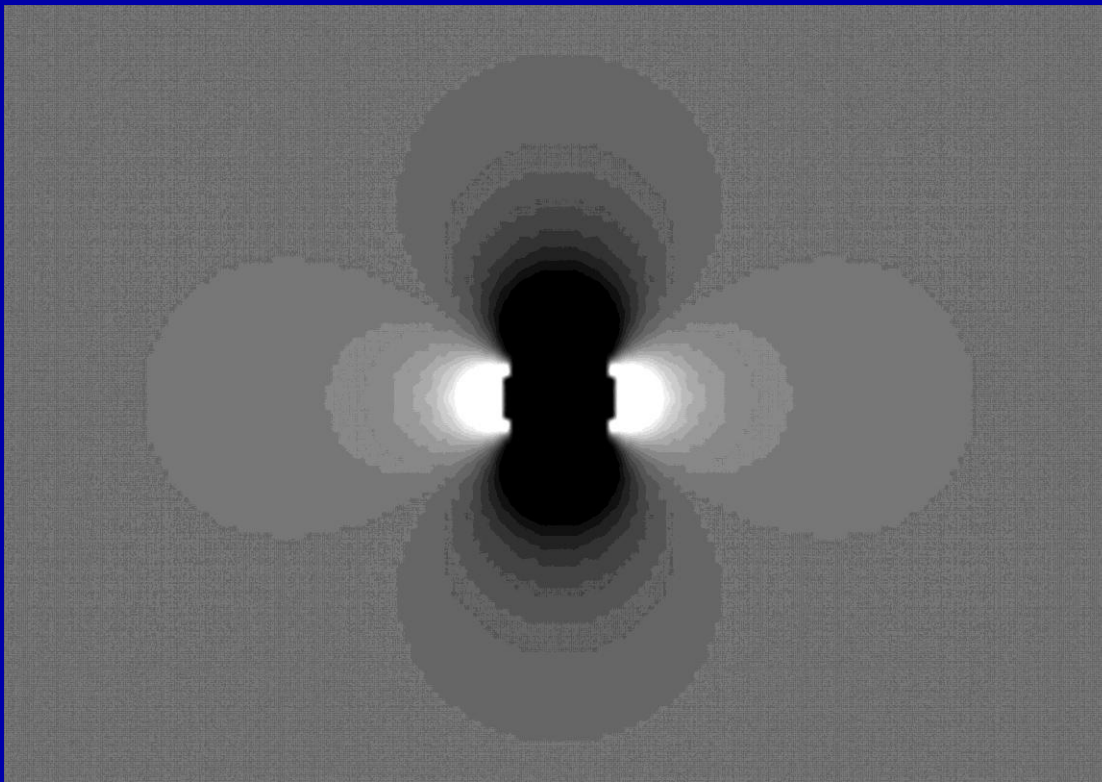
Single EPI-image



EPI-image with time development of a single column

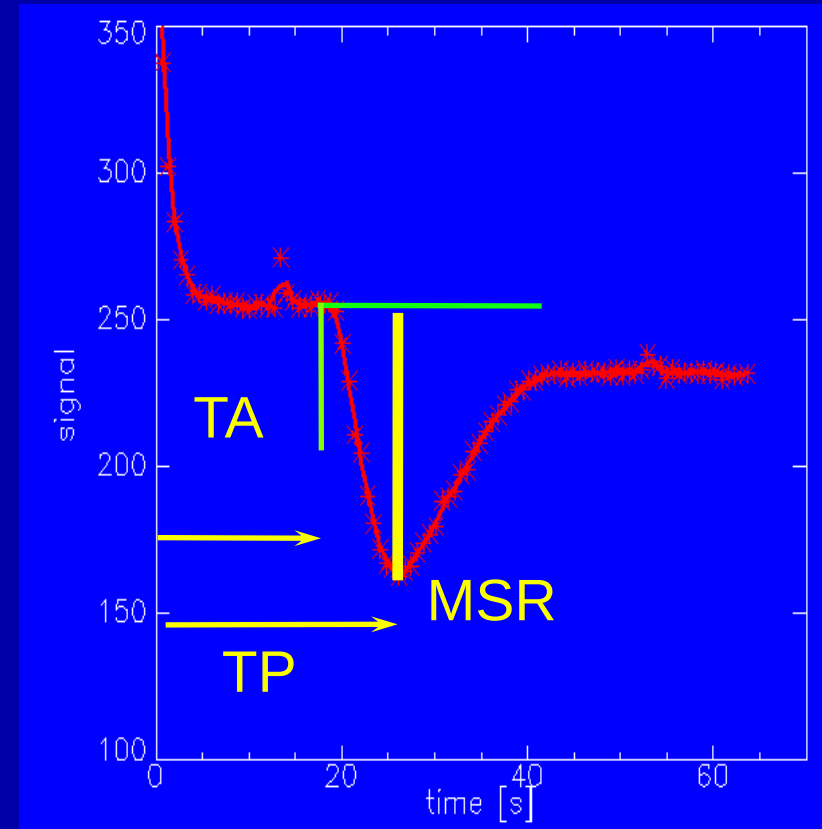
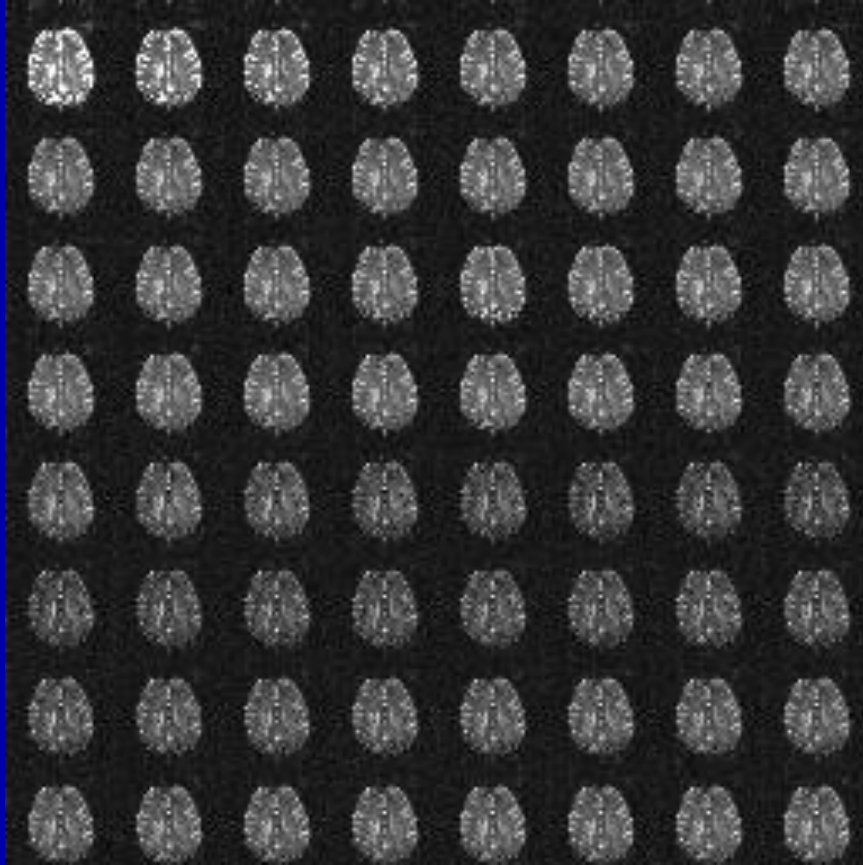
High concentration of gadolinium leads to a frequency shift and signal drop

Dynamic Contrast Enhancement (DCE)

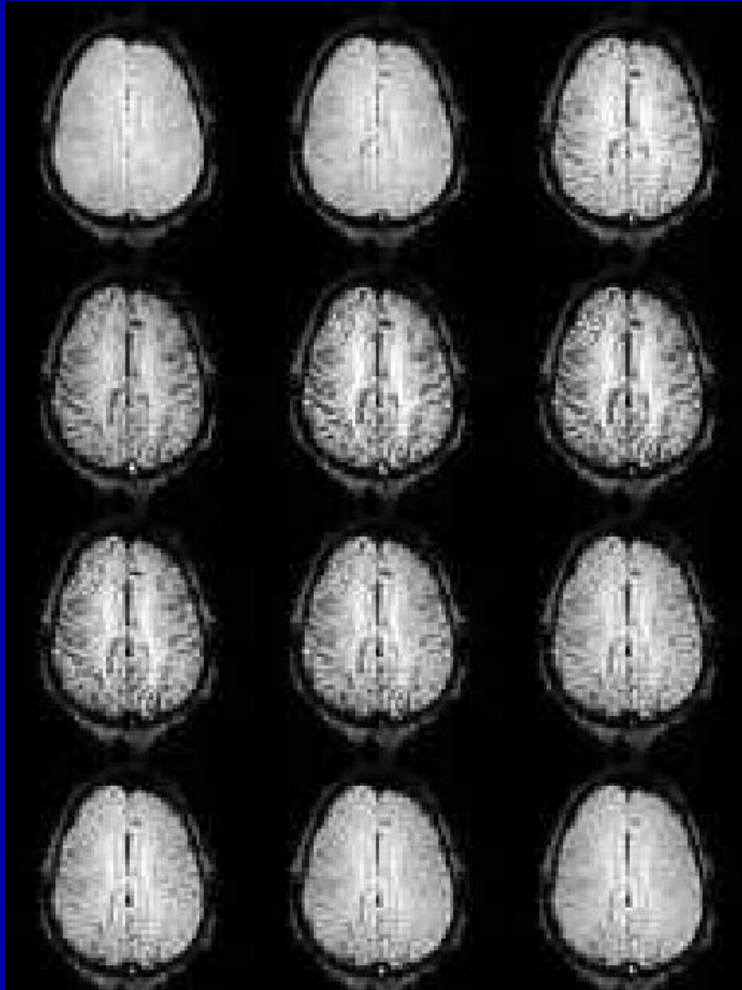


Frequency distribution around a tube with high concentrated contrast agent

Direct Parameters in Dynamic Contrast Enhancement (DCE)

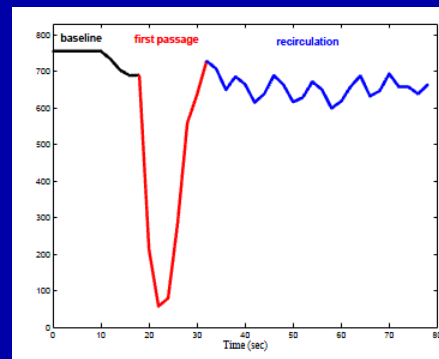


Direct Parameters in Dynamic Contrast Enhancement (DCE)

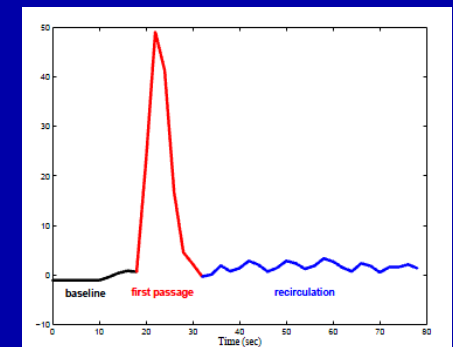


$$S(t) = S_0 = e^{TE \Delta R_2(t)}; \quad R_2 = 1/T_2$$

$$C(t) = \kappa \Delta R_2 = -\frac{\kappa}{TE} \ln \left(\frac{S(t)}{S_0} \right)$$



Signal



Concentration

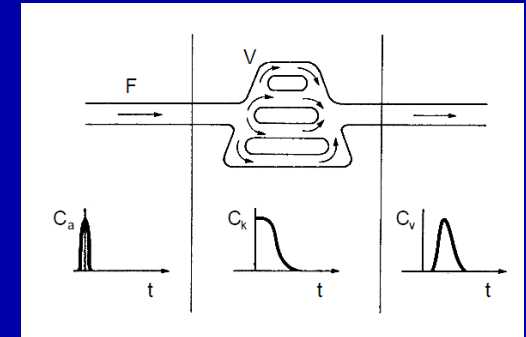
Intravascular indicator dilution theory

Concentration of contrast agent in the tissue:

$$C(t) = \kappa \Delta R_2 = -\frac{\kappa}{TE} \ln \left(\frac{S(t)}{S_0} \right)$$

total mass of contrast agent:

$$m = \int_0^{\infty} F \cdot C_{out}(t) dt.$$



F : flow within the artery

f : relation blood/tissue = CBV

$$\int_0^{\infty} F \cdot C_a(t) dt = \int_0^{\infty} F \cdot C_{out}(t) dt = \frac{1}{f} \int_0^{\infty} F \cdot C_g(t) dt.$$

$$f = \frac{\int_0^{\infty} C_g(t) dt}{\int_0^{\infty} C_a(t) dt}.$$

Intravascular indicator dilution theory

$$CBV = \frac{\kappa}{\rho} \cdot \frac{\int C_m(t) dt}{\int AIF(t) dt}$$

$$\kappa = (1 - HCT_{LV}) / (1 - HCT_{SV})$$

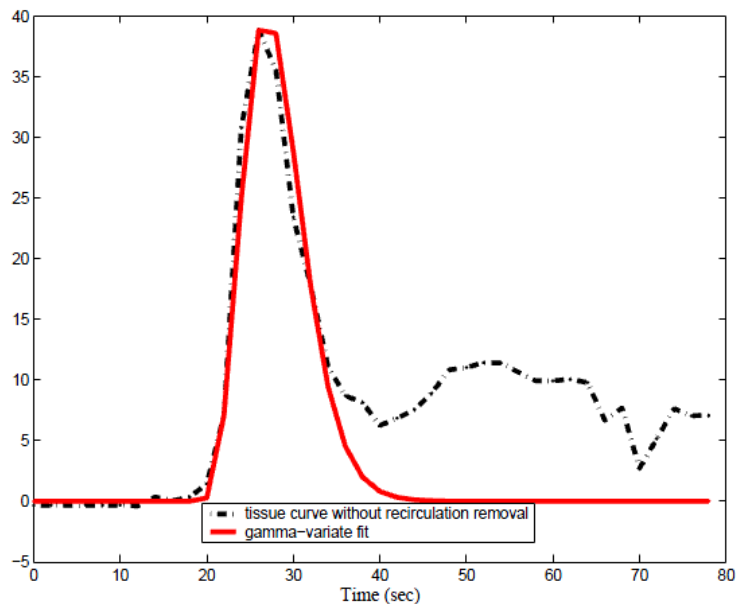
$$C(t) = C_m(t) \otimes^{-1} AIF(t)$$

$$\frac{CBV}{CBF} = \frac{\int C(t) dt}{C_{max}},$$

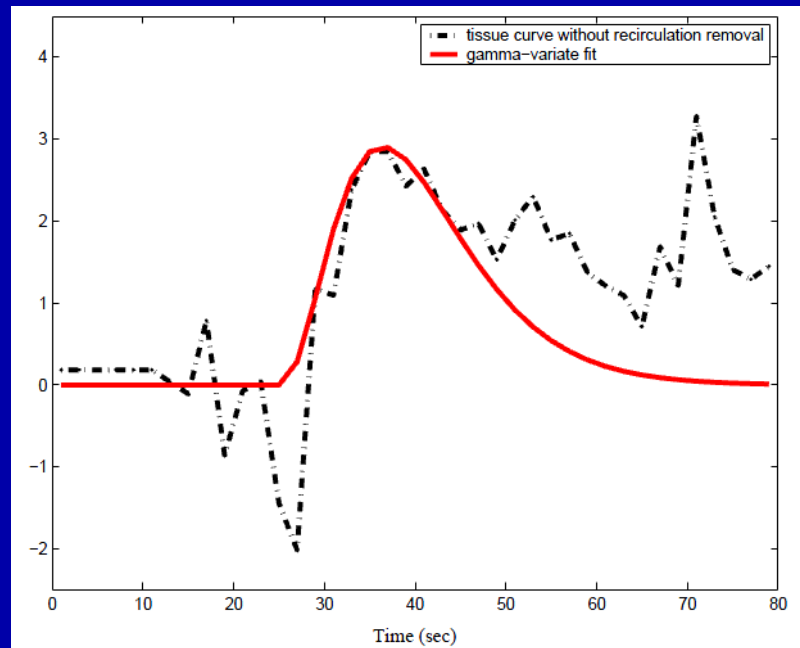
$$MTT = \frac{CBV}{CBF}$$

Gamma-Variate Function Fitting

$$C_{\Gamma}(t) = \begin{cases} A(t - t_0)^B e^{-D(t-t_0)} & t_0 \leq t \\ 0 & \text{otherwise,} \end{cases}$$



Fitting the tissue curve with a gamma-variate function to remove recirculation



(b) Removing recirculation using gamma-variate fitting

DSC Perfusion Imaging

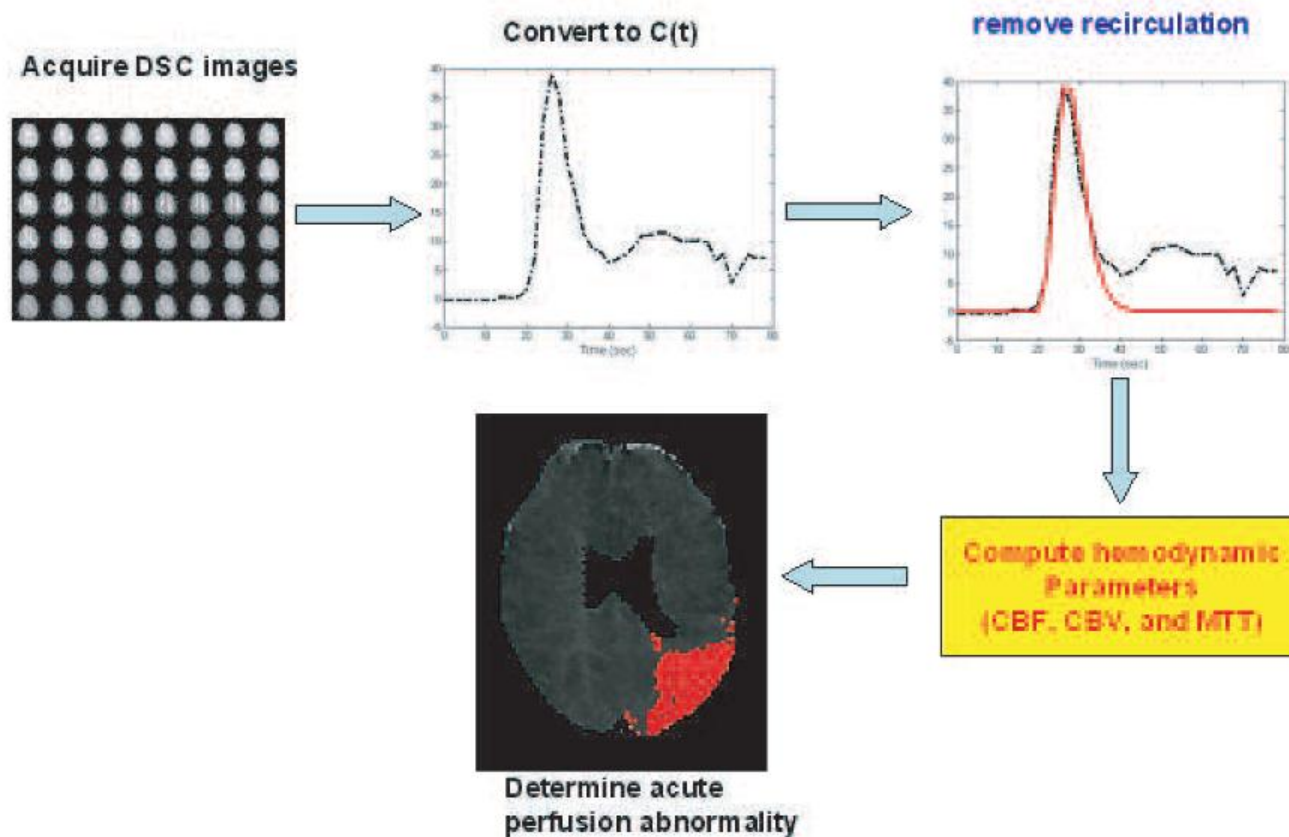
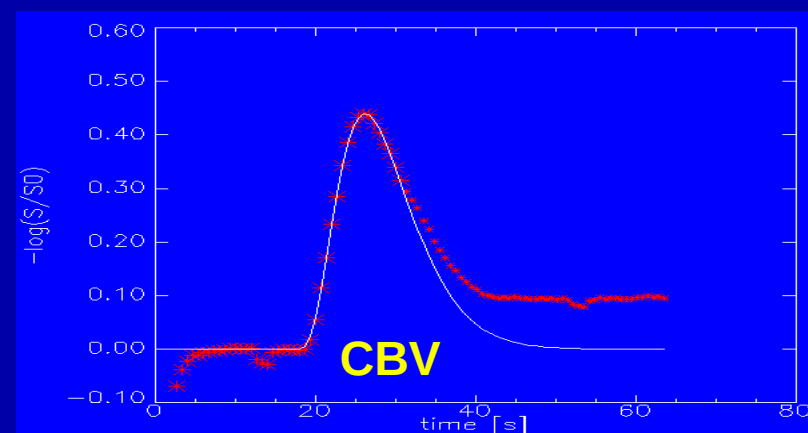
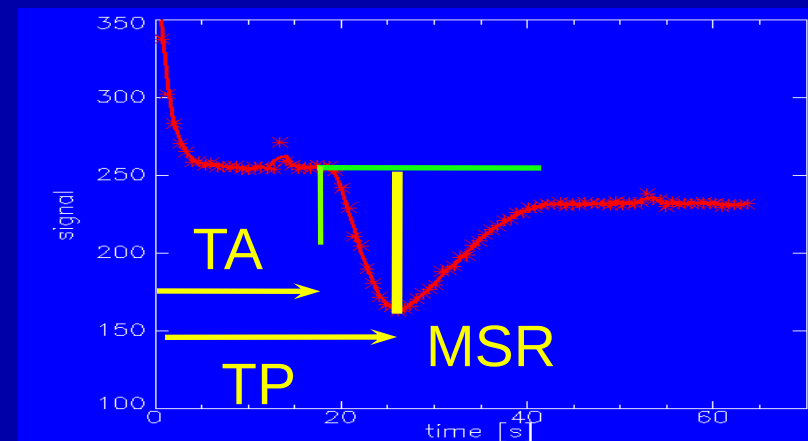
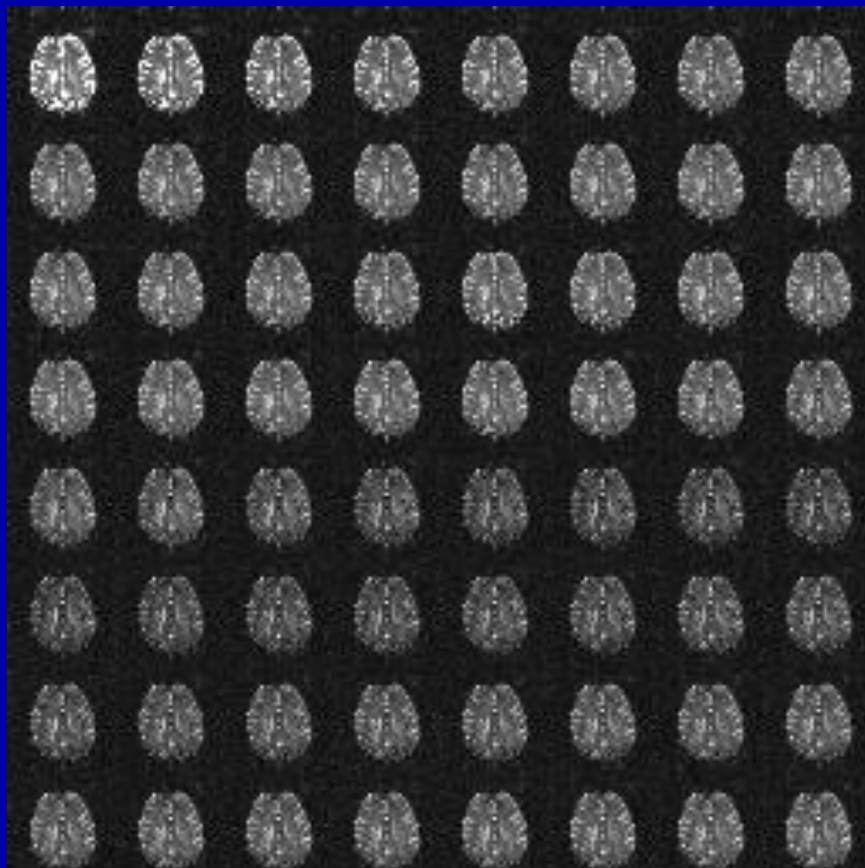
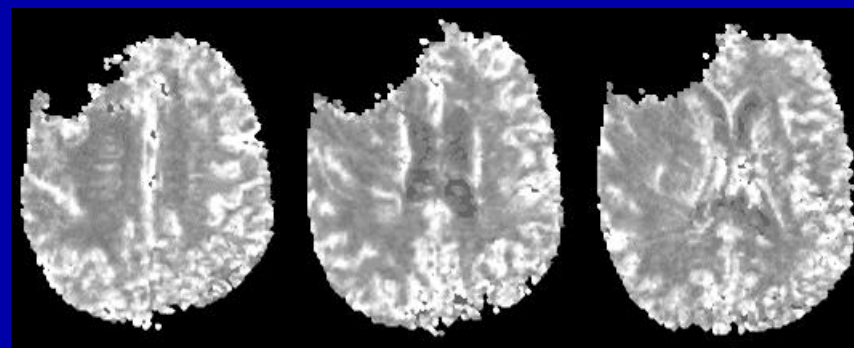
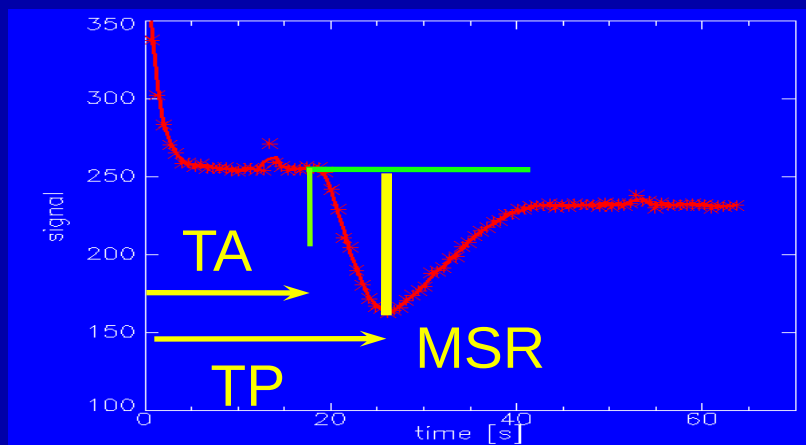


Figure 1.11: Clinical application of DSC perfusion imaging

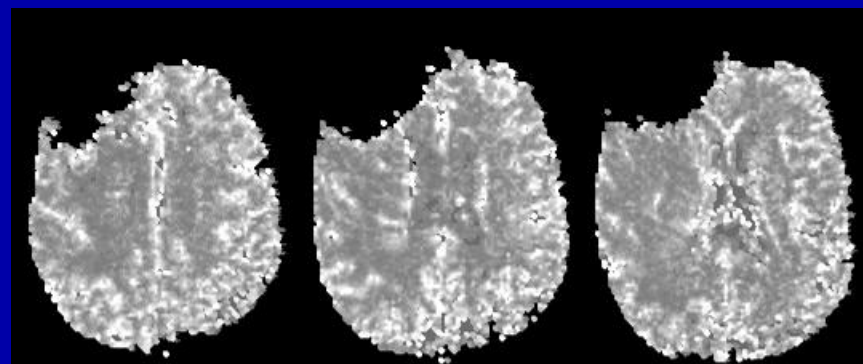
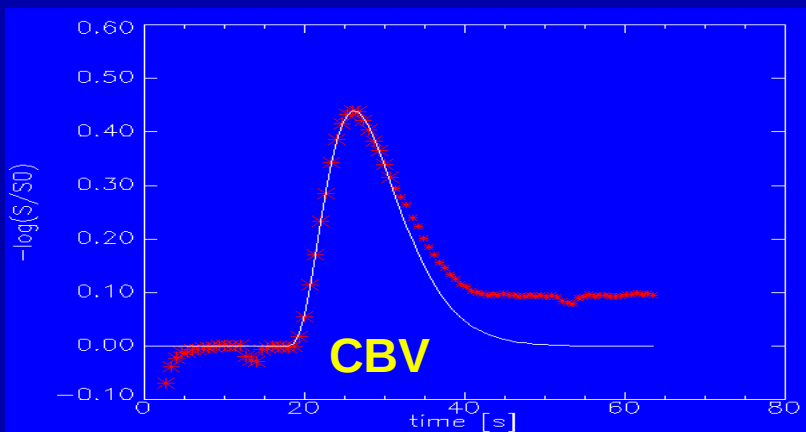
Direct Parameters in Dynamic Contrast Enhancement (DCE)



Direct Parameters in Dynamic Contrast Enhancement (DCE)

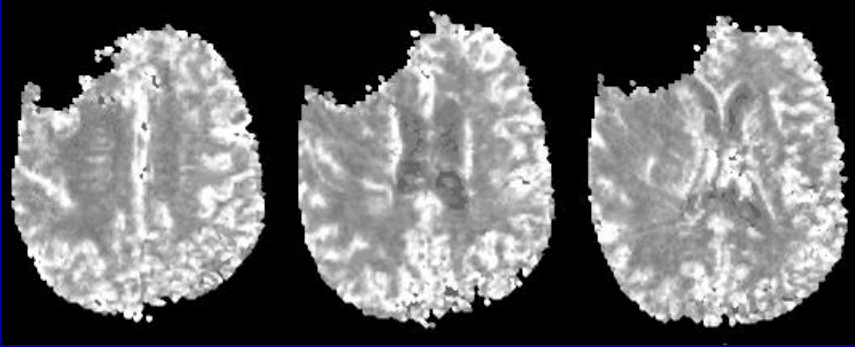


MSR

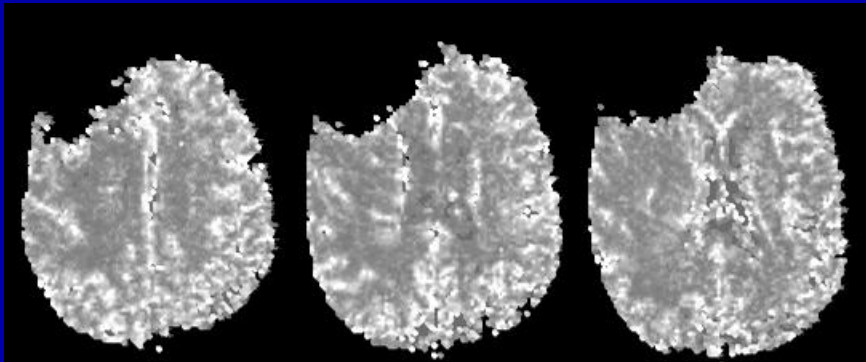
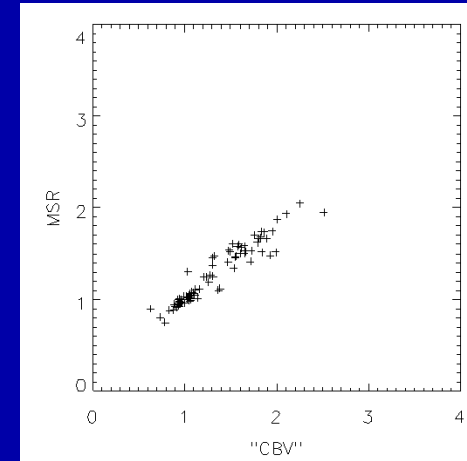


CBV

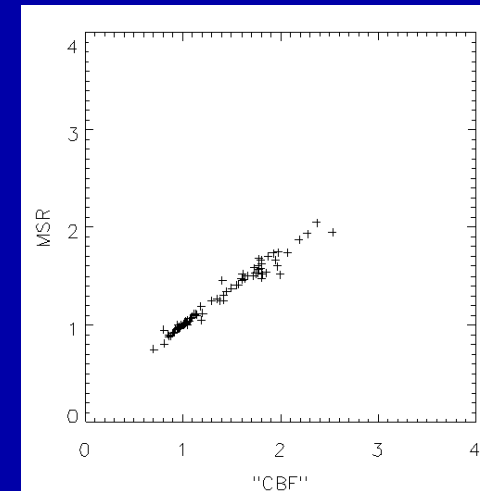
Direct Parameters in Dynamic Contrast Enhancement (DCE)



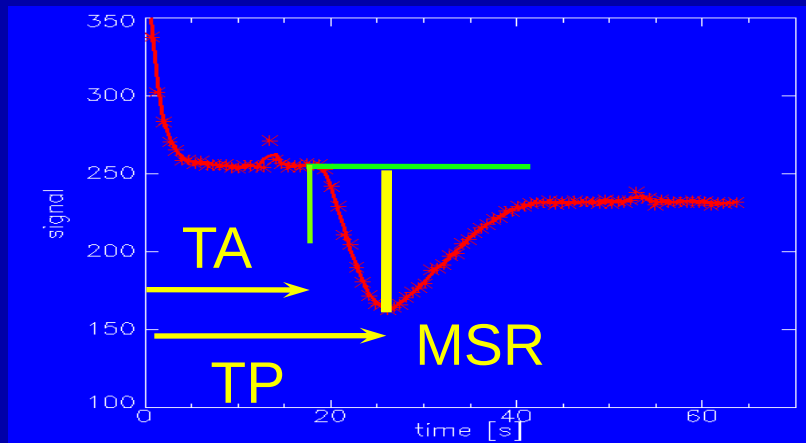
MSR



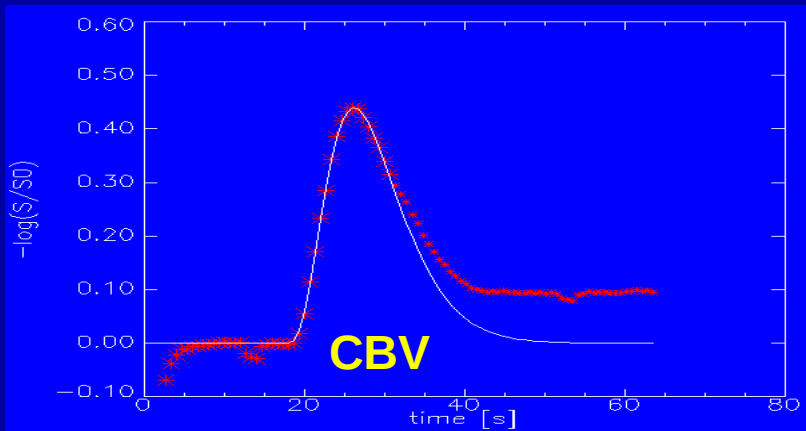
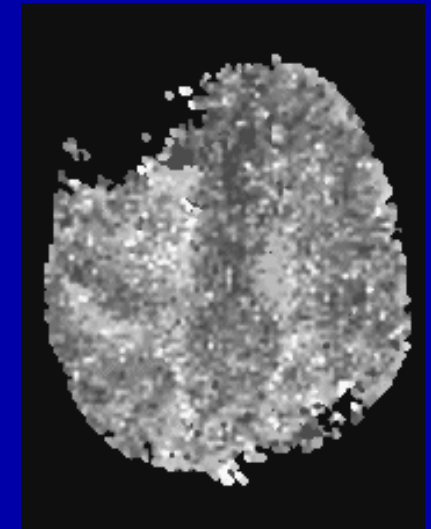
CBV



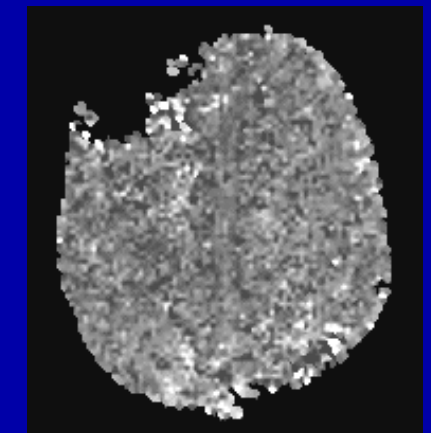
Direct Parameters in Dynamic Contrast Enhancement (DCE)



Time-to Peak

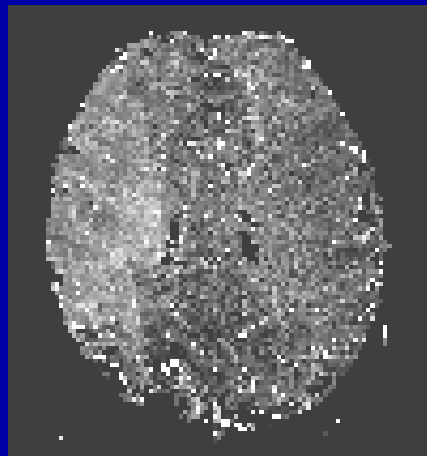


MTT

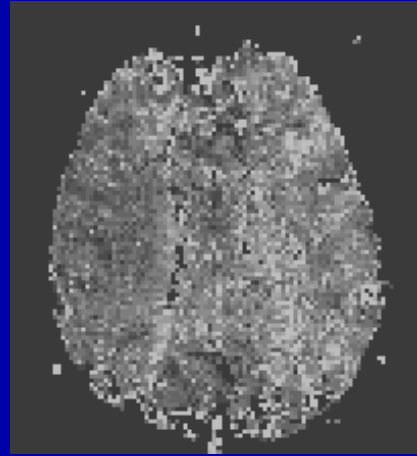


Example: Perfusion Maps in a Patient with Strong Stenosis of the Artery

TTP



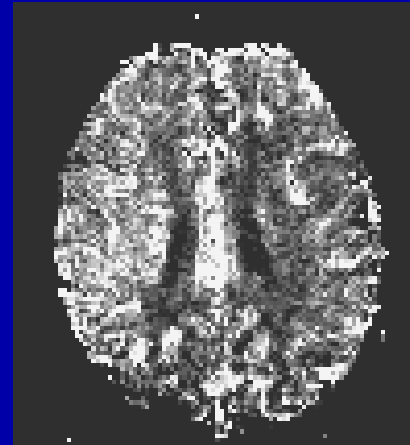
before



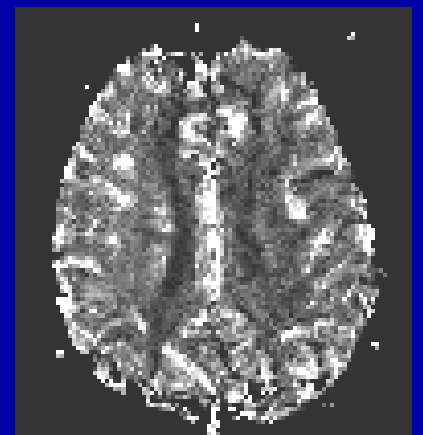
after

surgery

rel. CBV



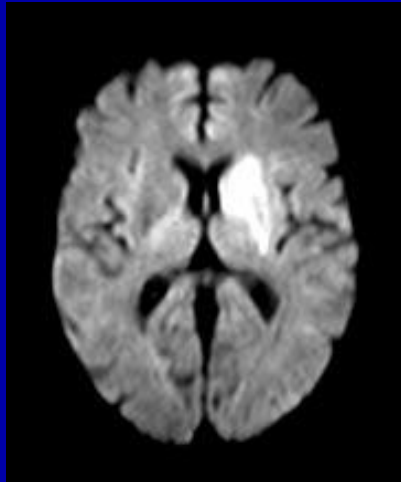
before



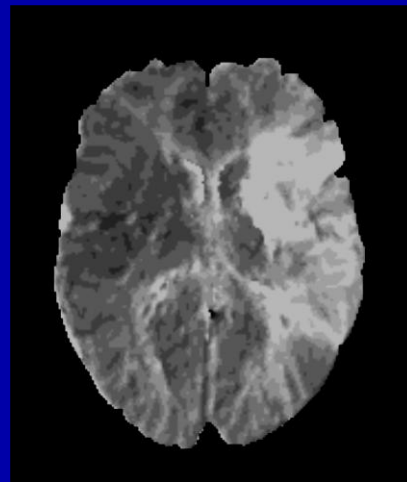
after

surgery

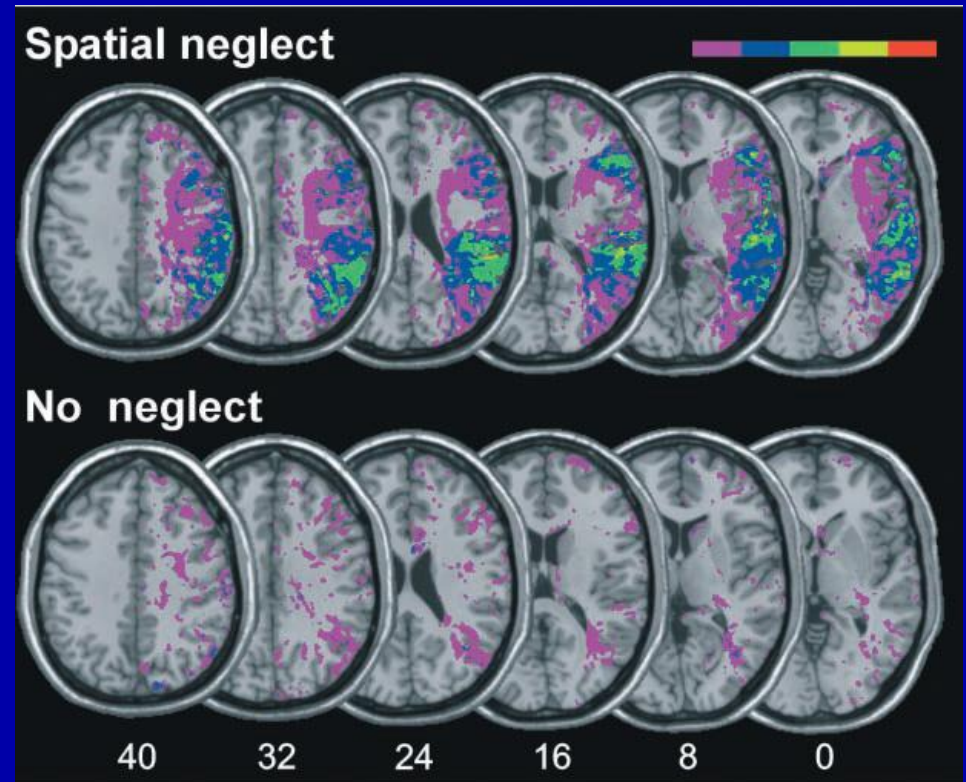
Example: Perfusion/Diffusion Mismatch in Stroke Patients



DWI



TTP



Arterial Spin Labeling

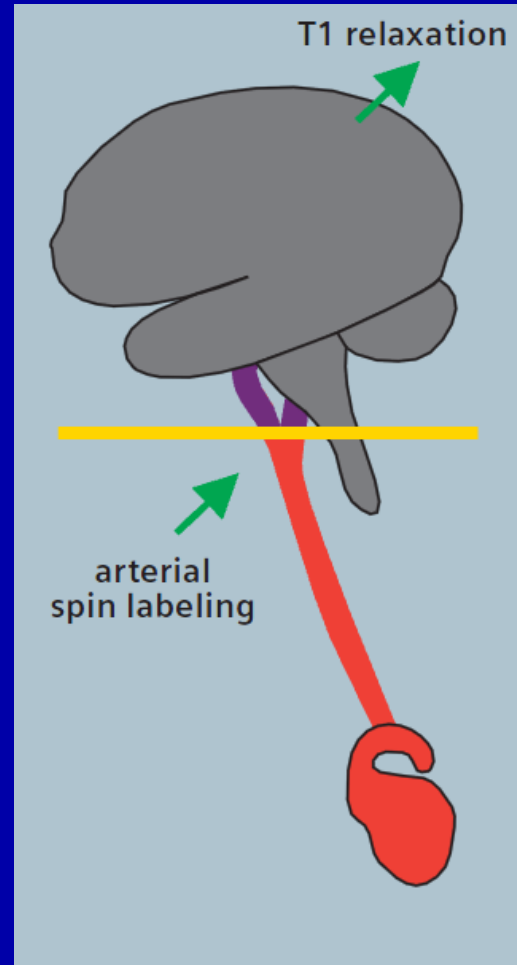
Perfusion measurement
with an endogenous tracer:

Blood, with a magnetization
marked by rf pulses

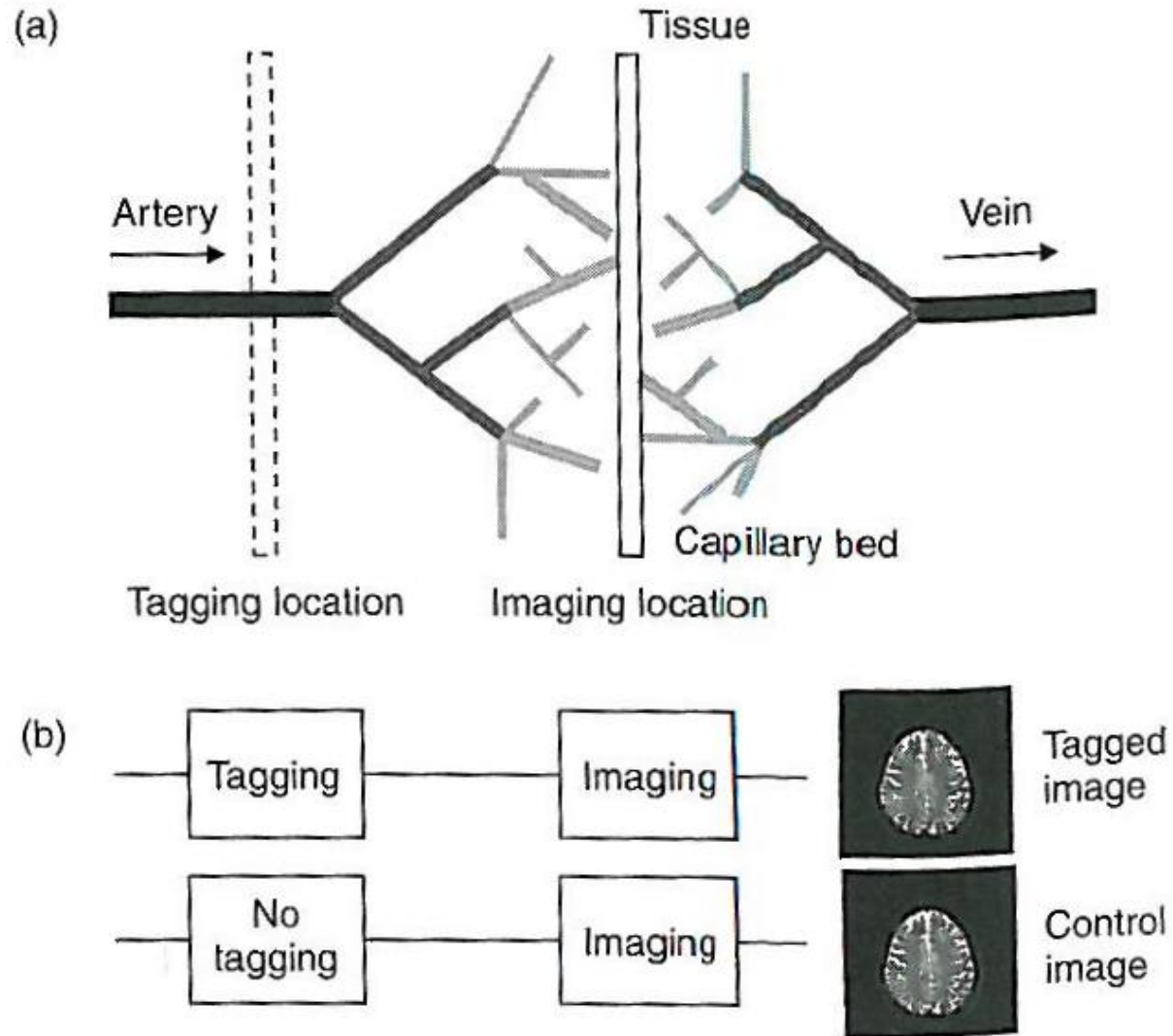
Different techniques proposed:

- EPISTAR
- FAIR
- QUIPPS II

and different techniques to mark the blood

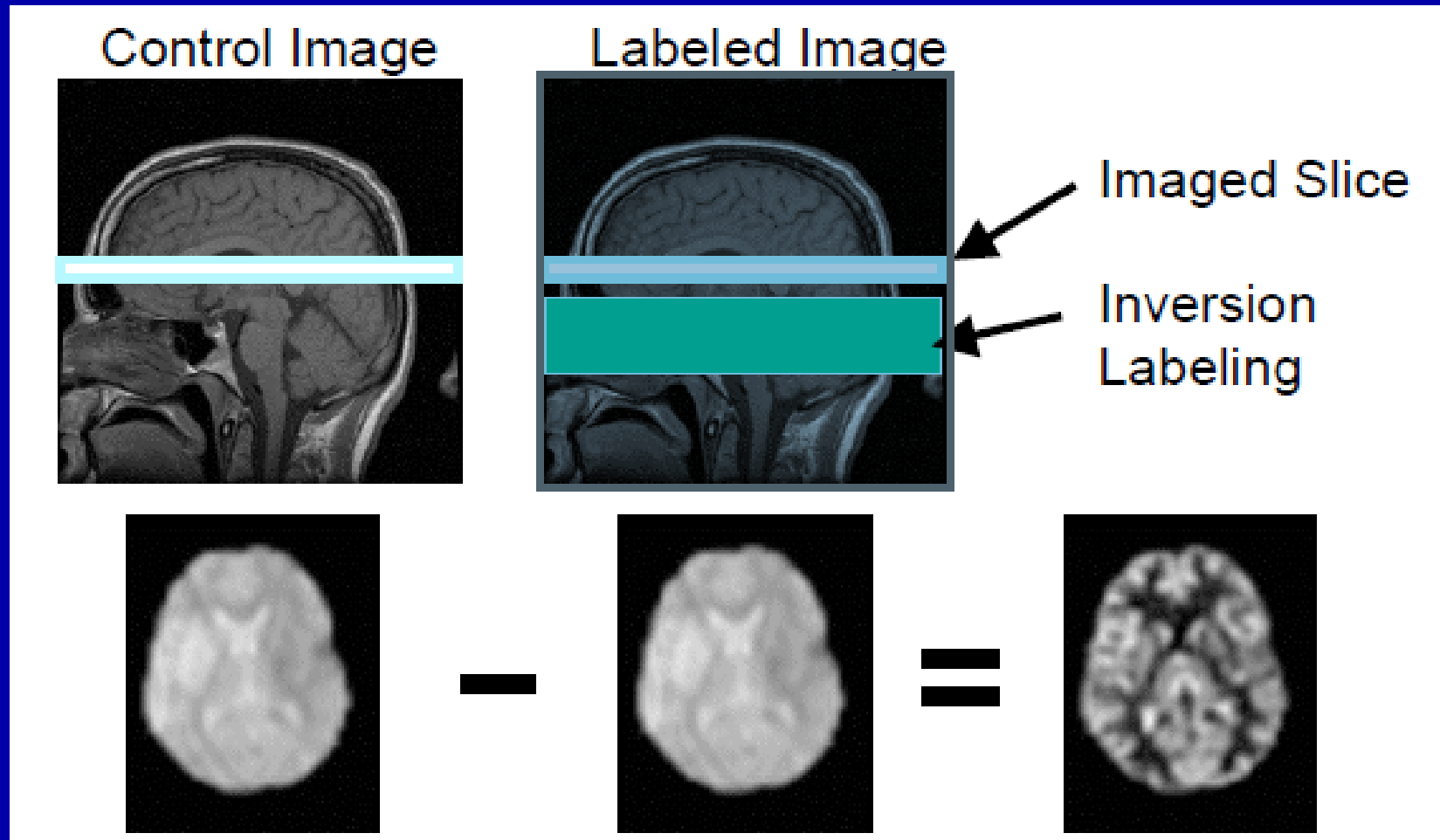


Principle of Arterial Spin Labeling

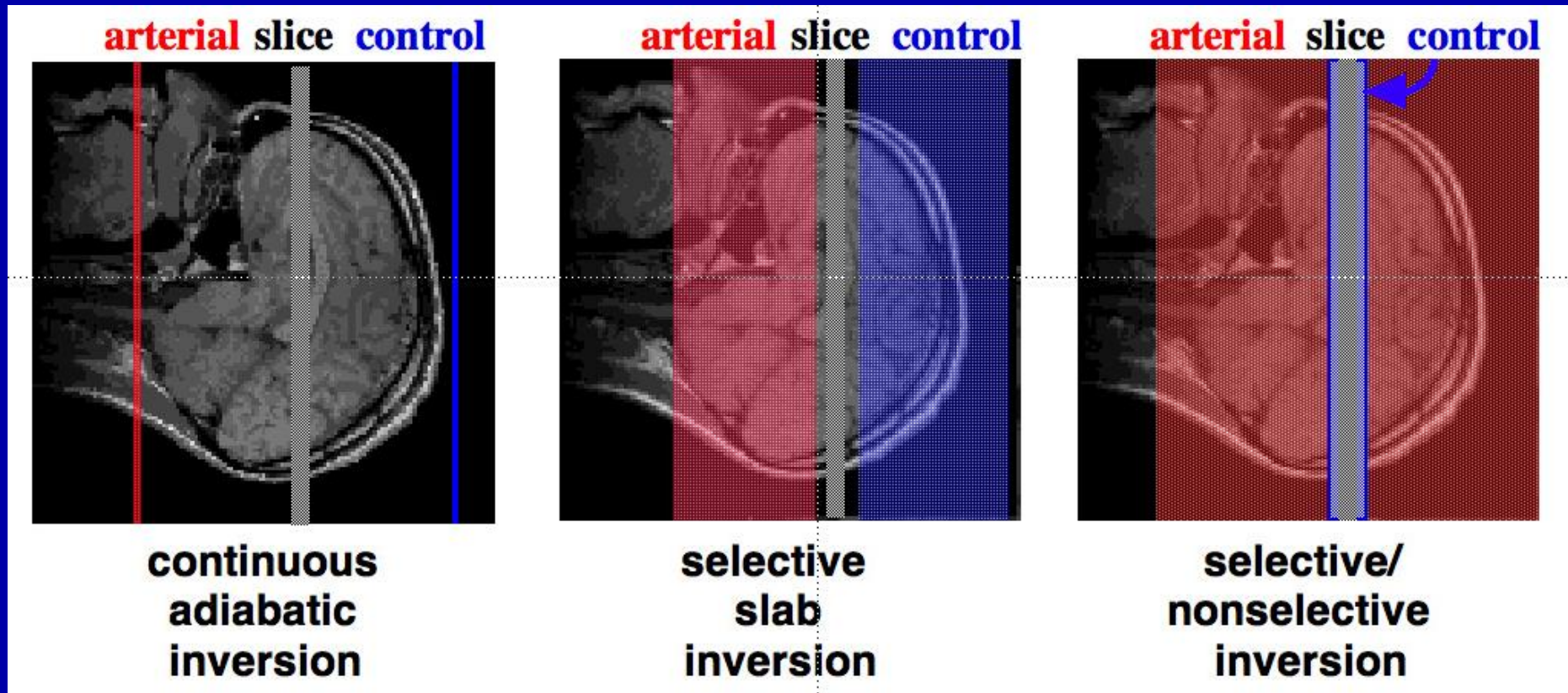


Arterial Spin Labeling

Basic Principle



Arterial Spin Labeling



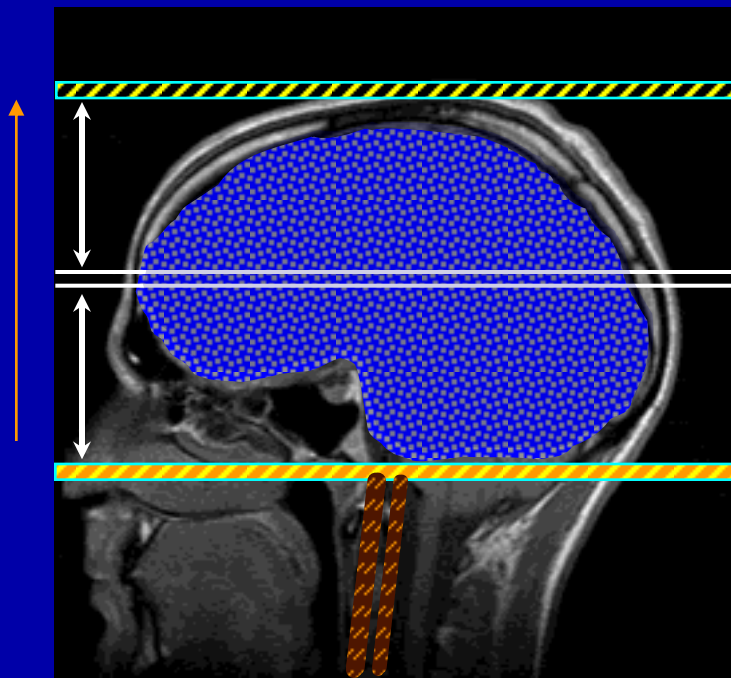
CASL

PASL

PASL

Arterial Spin Labeling

CASL:



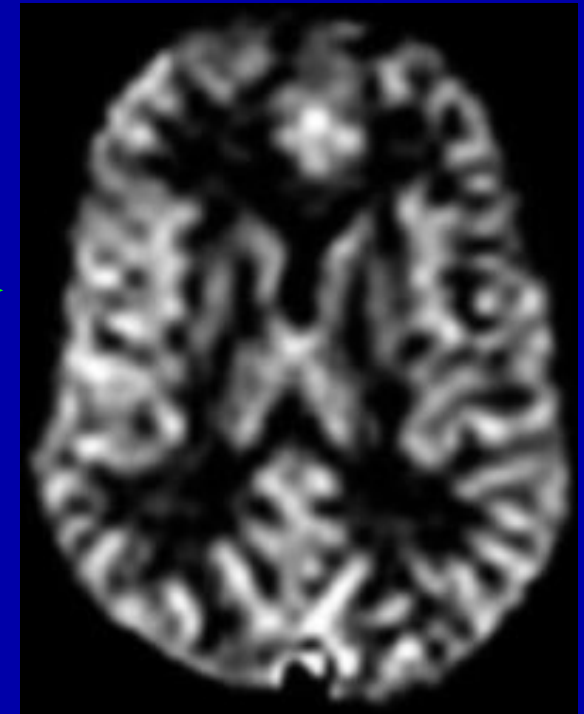
Continuous Adiabatic
Inversion Geometry

Control Inversion
Plane

Imaging Slice

Arterial Tagging
Plane

Control - Label

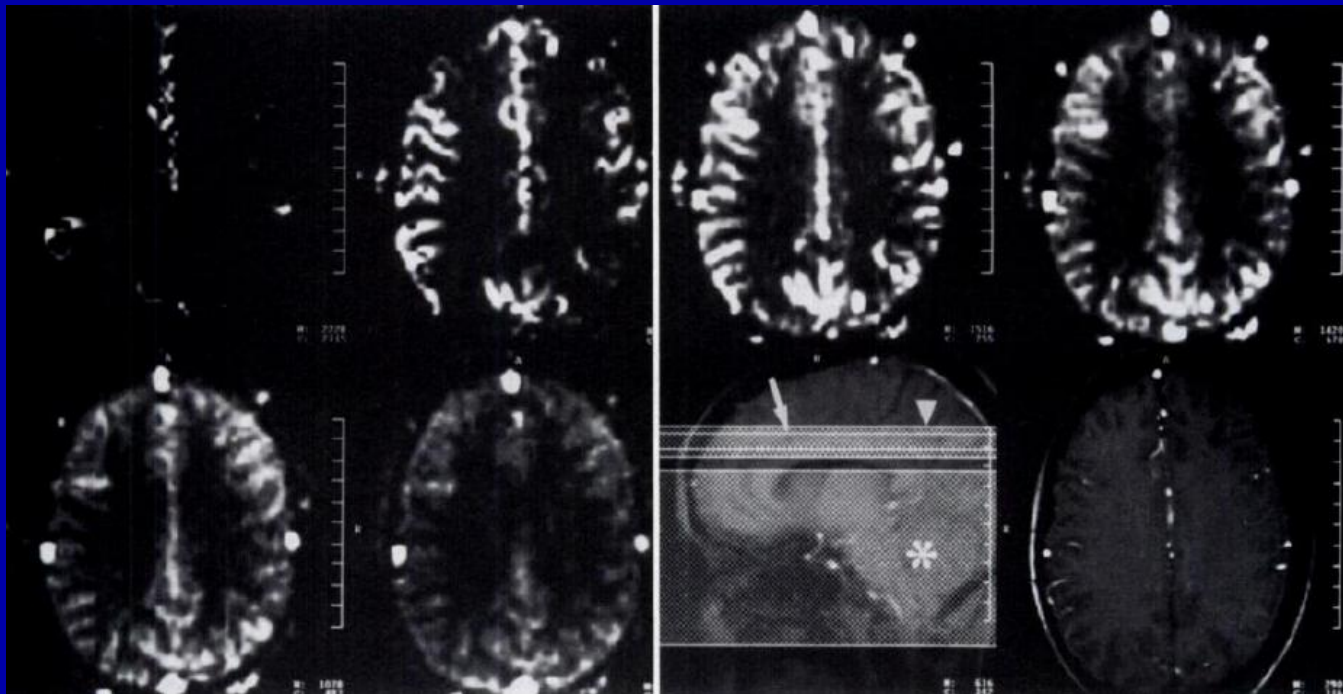


Single Slice
Perfusion Image
about 1% effect

Arterial Spin Labeling

EPISTAR

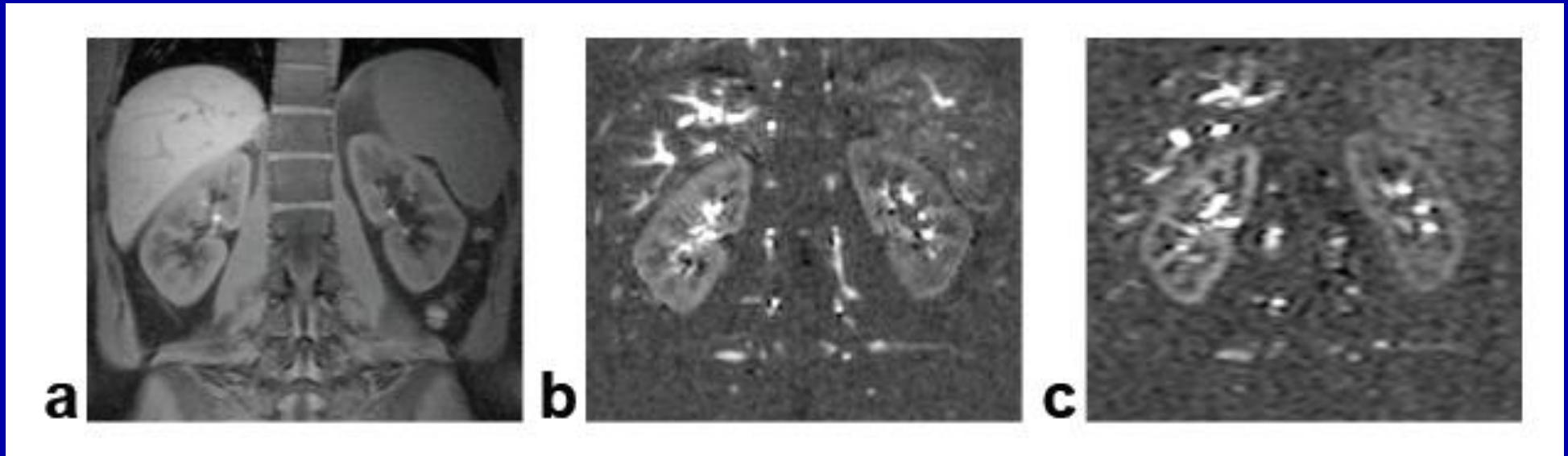
Edelman et al. 1994



TI: 200, 600, 1000, 1400, 1800, and 2200 msec.

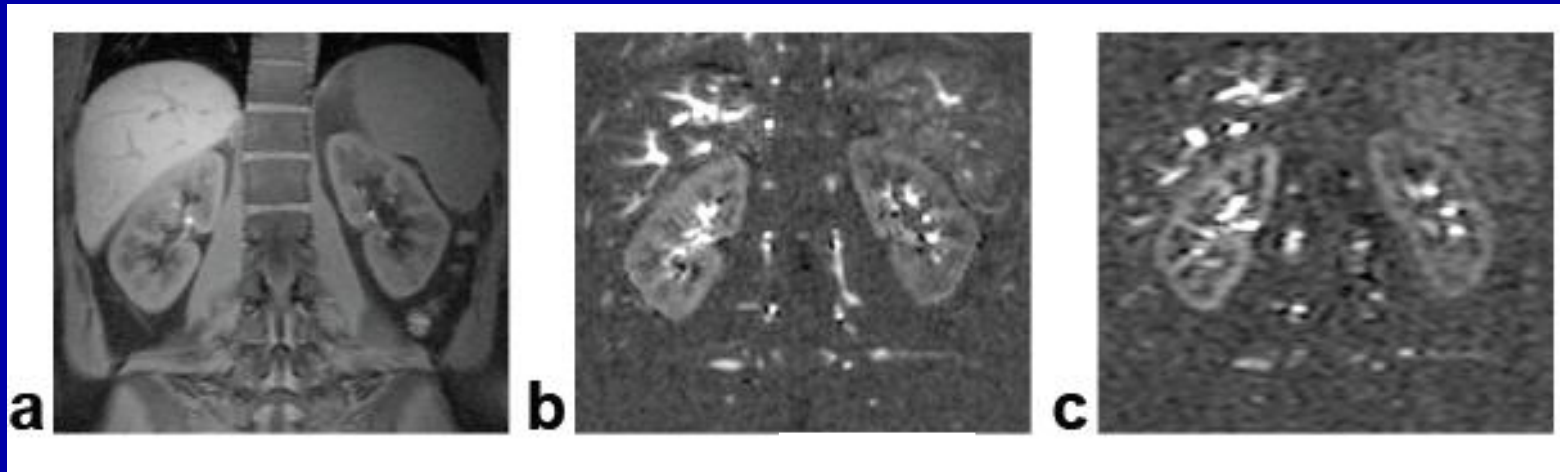
Arterial Spin Labeling

FAIR True-FISP Perfusion Imaging of the Kidney



Arterial Spin Labeling

FAIR True-FISP Perfusion Imaging of the Kidney

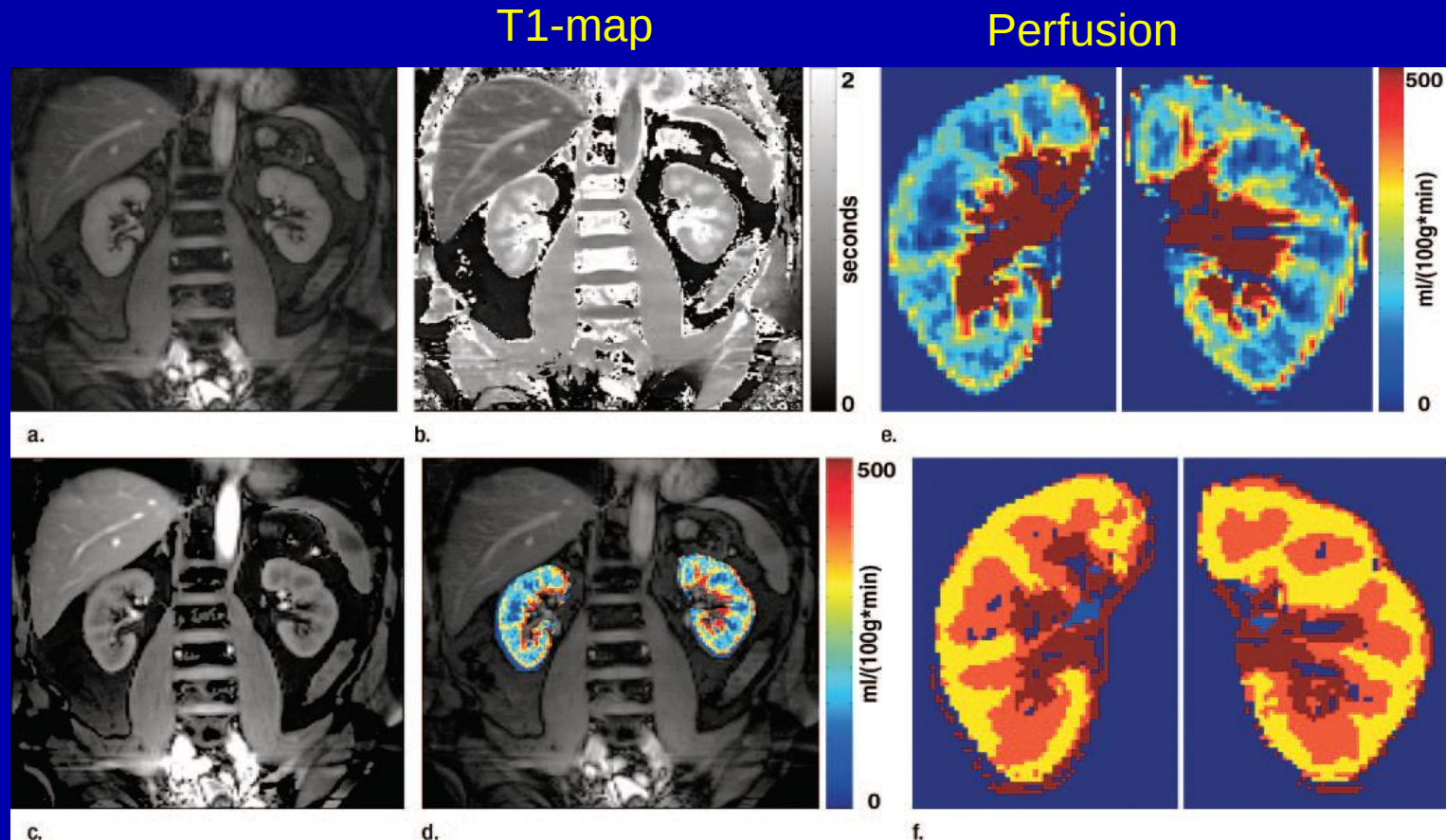


$$\begin{aligned}\Delta M(TI) &= M_{\text{sel}}(TI) - M_{\text{non}}(TI) \\ &= 2M_0 TI \cdot \frac{f}{\lambda} \exp\left(-\frac{TI}{T1}\right),\end{aligned}$$

$$f = \frac{\lambda}{2TI} \cdot \frac{\Delta M(TI)}{M_0} \cdot \exp\left(\frac{TI}{T1}\right).$$

Arterial Spin Labeling

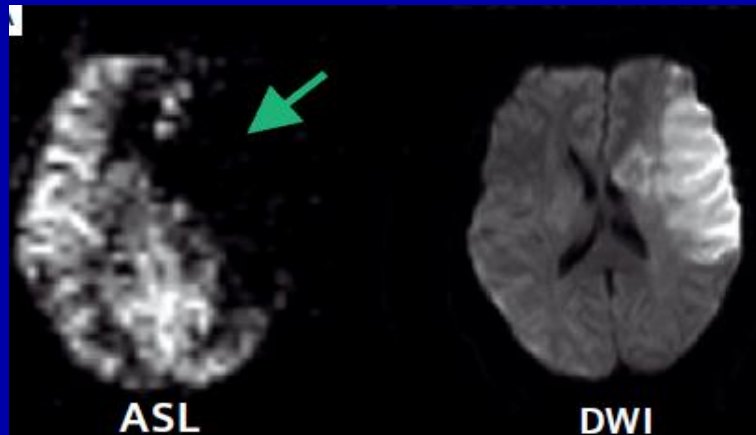
FAIR True-FISP Perfusion Imaging of the Kidney



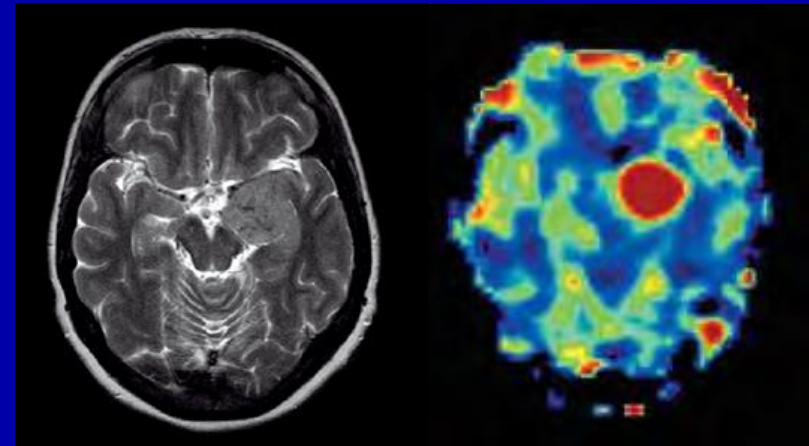
Classification based on T1

Arterial Spin Labeling: Clinical Applications

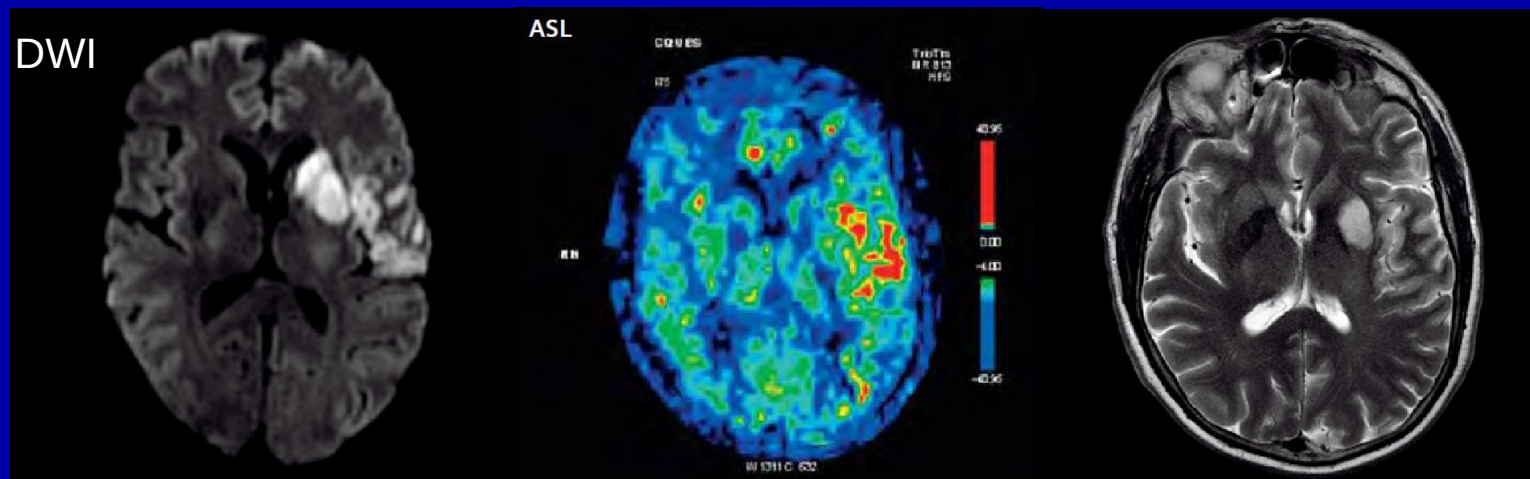
Hypoperfusion in acute stroke



Hypervascularization in a glioma



Reperfusion after acute stroke

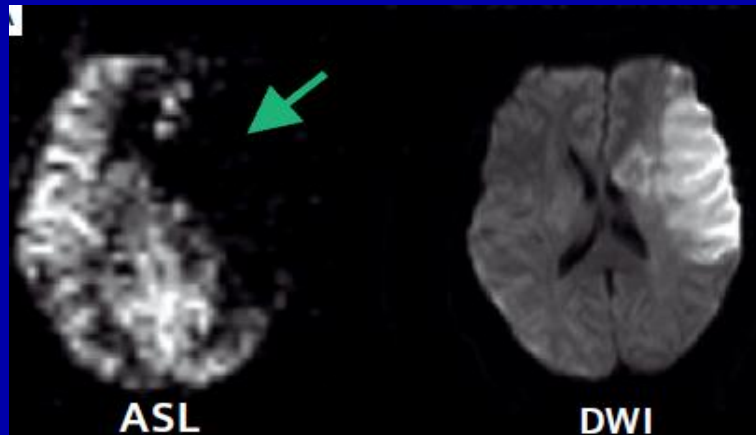


QUIPSII

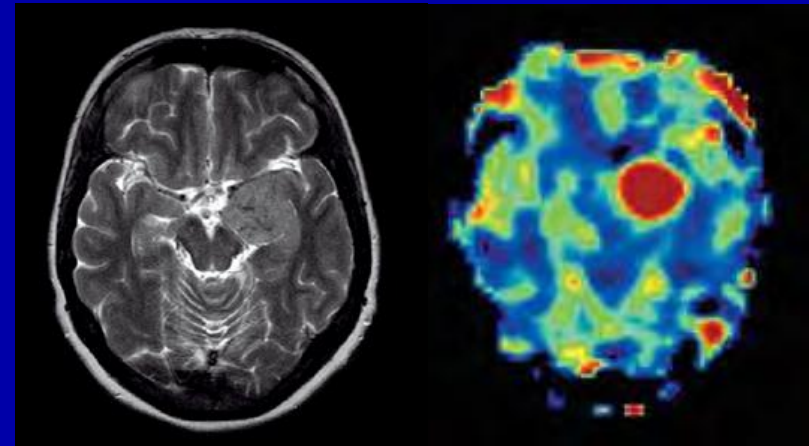
Magnetom Flash 1/2008, 6

Arterial Spin Labeling: Clinical Applications

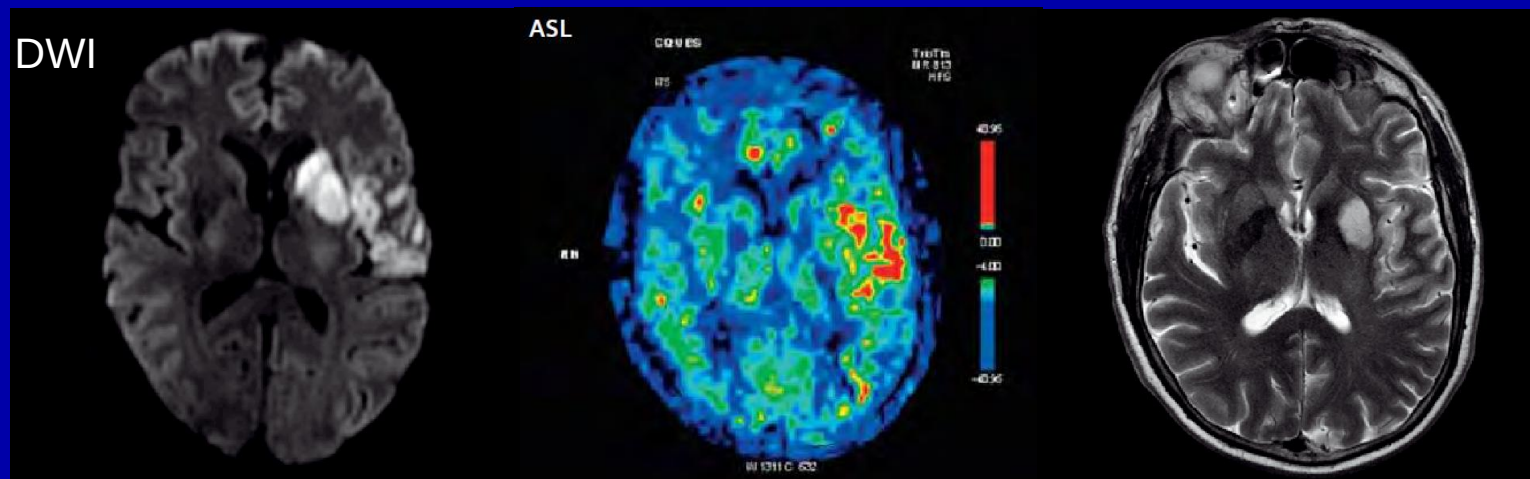
Hypoperfusion in acute stroke



Hypervascularization in a glioma

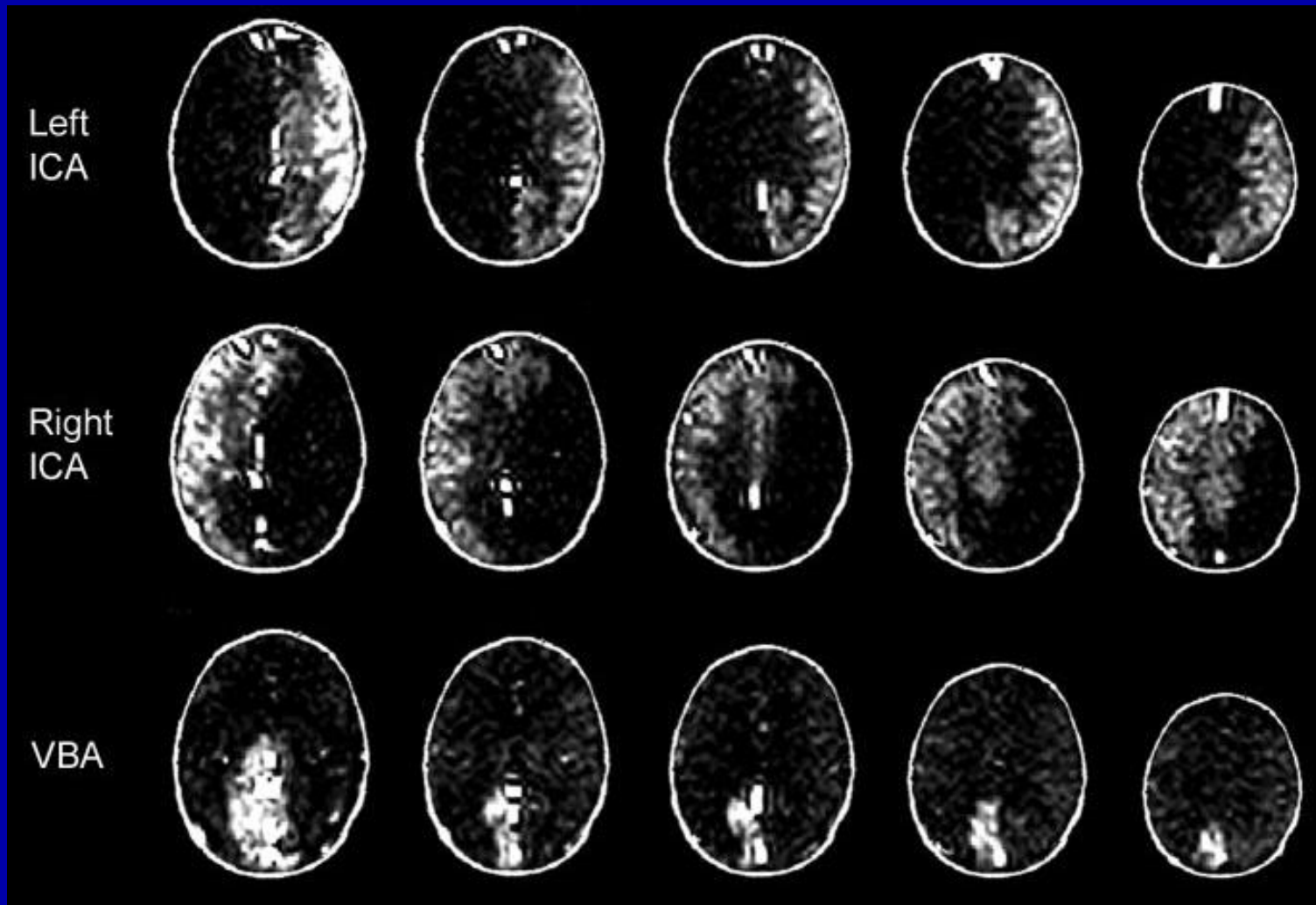
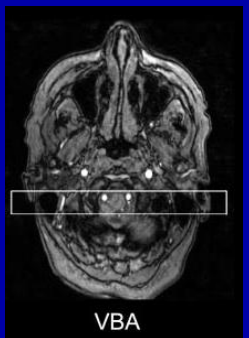
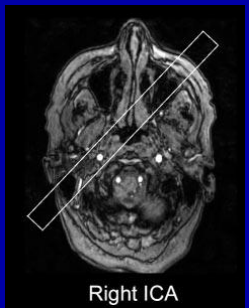
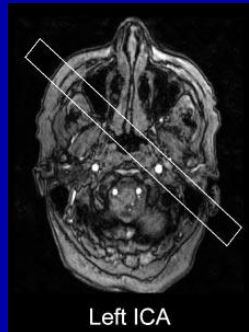


Reperfusion after acute stroke



QUIPSII

Selective Arterial Spin Labeling



Conclusion

Perfusion can be examined in MR-examinations

by DSC-MRI using the first pass of contrast agents

Parameter maps of CBF and CBV can be obtained
and MSR and time-to-peak maps

by ASL techniques, which are non invasive, but less sensitive