PERFUSION – MRI
CONTRAST BASED TECHNIQUES

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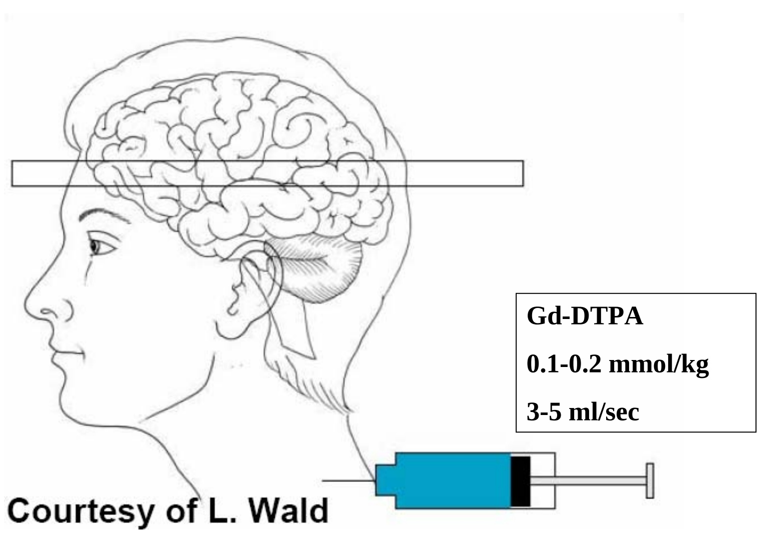
PERFUSION - MRI

- **BOLUS TRACKING TECHNIQUES**
  - *Dynamic Susceptibility contrast*
  - *Dynamic Relaxivity contrast*
- **STEADY-STATE TECHNIQUES**
  - *Steady-state Susceptibility contrast*
  - *Steady-state Relaxivity contrast*
- **USING DIFFUSIBLE TRACERS**

BOLUS TRACKING TECHNIQUES

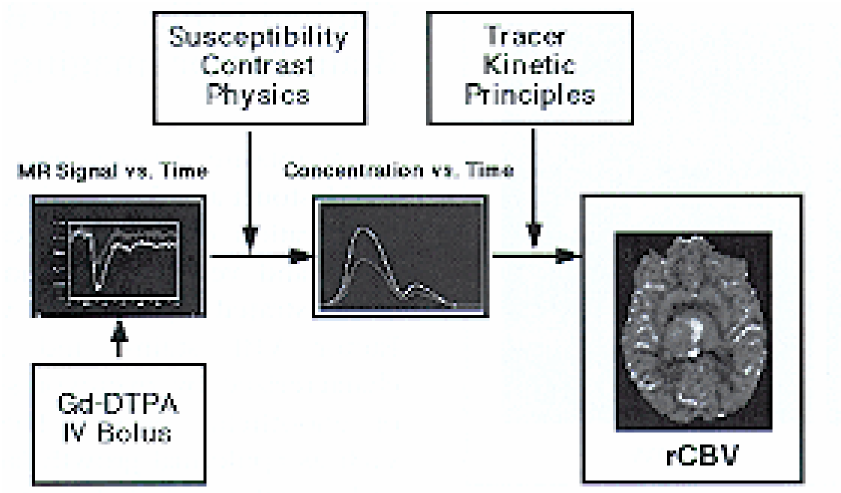
BOLUS TRACKING TECHNIQUES

- **PRINCIPLE**



BOLUS TRACKING TECHNIQUES

➢ PRINCIPLE



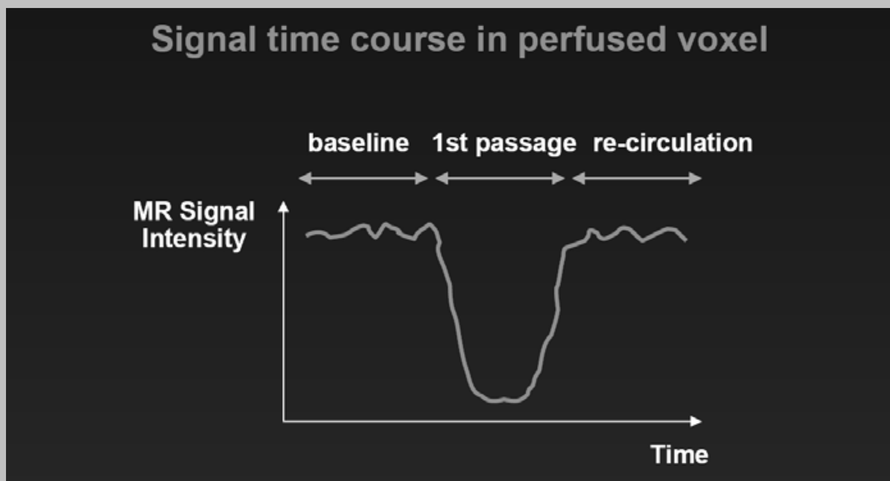
BOLUS TRACKING TECHNIQUES

➢ PRINCIPLE

- *Contrast agent* in brain vessels produce *changes in MR signal intensity*
- *Susceptibility effects → T_2* decreases → signal drop*
- *Relaxivity effects → changes in blood-water longitudinal relaxation rates (T1)*
- *Signal vs time curve → concentration vs time curve*
- *Integral of concentration time curve proportional to Cerebral Blood Volume (CBV)*

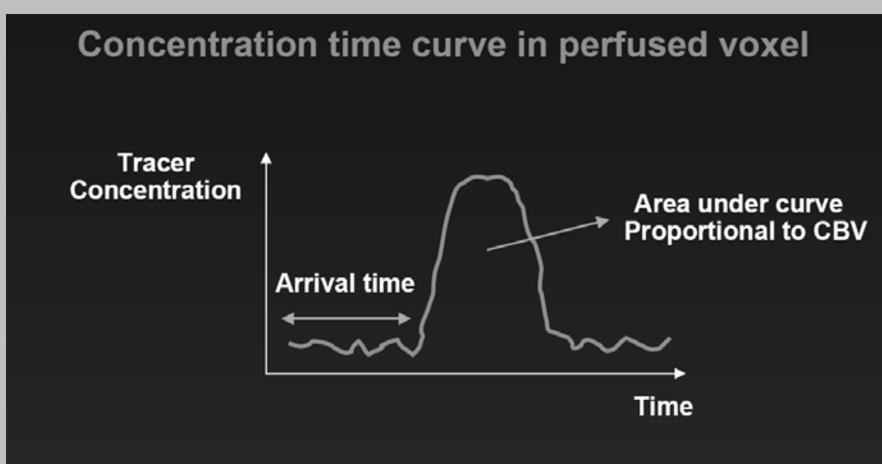
BOLUS TRACKING TECHNIQUES

- PRINCIPLE



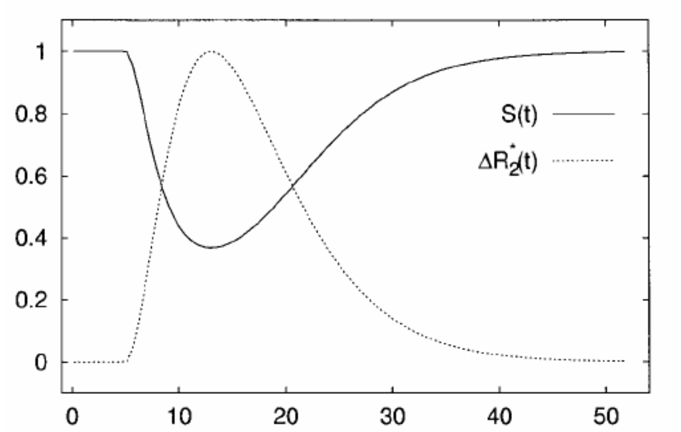
BOLUS TRACKING TECHNIQUES

- PRINCIPLE



BOLUS TRACKING TECHNIQUES

- **PRINCIPLE**



Time (s)

BOLUS TRACKING TECHNIQUES

- **TRACER KINETICS**

- ***Quantification of perfusion is done using Central volume theorem***

$$CBF = CBV / T_{mtt}$$

CBF – Cerebral Blood Flow

CBV – Cerebral Blood Volume

T_{mtt} – Mean Transit time

BOLUS TRACKING TECHNIQUES

➢ TRACER KINETICS

- *When a bolus of contrast agent is injected, the concentration $C_{voi}(t)$ of the tracer in a voxel (VOI) can be described as*

$$C_{voi}(t) = (\rho / k_h) \,.\, CBF_{voi} \,.\, (C_a(t) \,\Theta\, R(t))$$
$$= (\rho / k_h) \,.\, CBF_{voi} \,.\, \int C_a(\tau) \,.\, R(t-\tau)d\tau$$

ρ – density of the tissue

k_h – constant correcting for differences in hematocrit in capillaries and large vessels

BOLUS TRACKING TECHNIQUES

➢ TRACER KINETICS

$$C_{voi}(t) = (\rho / k_h) \,.\, CBF_{voi} \,.\, \int C_a(\tau) \,.\, R(t-\tau)d\tau$$

CBF_{voi} – perfusion in VOI

$C_a(t)$ – the arterial input function i.e. the concentration of contrast agent in the artery supplying blood to the VOI

$R(t)$ – the residue impulse response function i.e. the fraction of the bolus still present in the VOI at time t

BOLUS TRACKING TECHNIQUES

➢ TRACER KINETICS

- *The CBV is expressed as*

$$CBV = (k_h / \rho) \,.\, (\int C_{voi}(t)\, dt / \int C_a(t)\, dt)$$

- *Relative CBV can be estimated without knowledge of $C_a(t)$, assuming it the same for all parts of the tissue*

BOLUS TRACKING TECHNIQUES

➢ CONCENTRATION DEPENDENCY

- *C_{voi} used in the calculation of hemodynamics is related to the change in T2* relaxation*

$$C_{voi}(t) = k \,.\Delta R2^* = k \,.\Delta(1 / T2^*) = -(k / T_E) \,.\, \ln(S(t) / S_o(t))$$

k – proportionality constant

T_E – echo time

S(t) – signal intensity in VOI at time t

$S_o(t)$ – baseline signal intensity

$\Delta R2^*$ - relaxation rate

PERFUSION - MRI

- **BOLUS TRACKING TECHNIQUES**
  - ***Dynamic Susceptibility contrast***
  - ***Dynamic Relaxivity contrast***
- **STEADY-STATE TECHNIQUES**
  - ***Steady-state Susceptibility contrast***
  - ***Steady-state Relaxivity contrast***
- **USING DIFFUSIBLE TRACERS**

BOLUS TRACKING TECHNIQUES

- **DYNAMIC SUSCEPTIBILITY CONTRAST**
  - **PRINCIPLE**
    - ***T2*-weighted imaging sequence***
    - ***Signal vs time curve for each voxel***
    - ***Contrast agent concentration C_{voi}***
    - ***Concentration vs time curve for each voxel***
    - ***Arterial input function C_a is estimated from the signal of voxels containing or surrounding a large artery***
    - ***CBV and CBF are then calculated using tracer kinetics***

BOLUS TRACKING TECHNIQUES

➢ DYNAMIC SUSCEPTIBILITY CONTRAST

❖ PRACTICAL CONSIDERATIONS

- *Difficult to measure C_a*
- *In brain tissue, changes in R2* are due to extravascular spins*
- *In blood, changes in R2* are due to magnetic field gradients arising between RBC and plasma*
- *$C_{voi}(t)$ estimation is based on the assumption of absence of any T1 weighting → long TR → low temporal resolution*

BOLUS TRACKING TECHNIQUES

➢ DYNAMIC SUSCEPTIBILITY CONTRAST

❖ METHODS

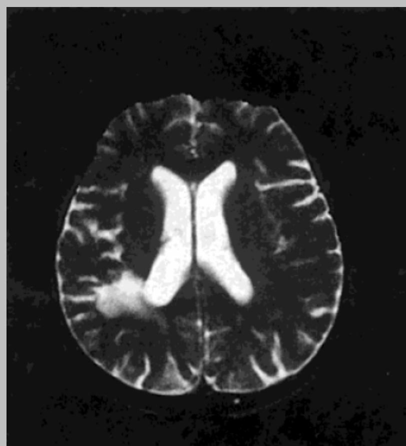
$$\mathrm{rCBV_{index}} = \int_0^t \Delta R_2^*(\tau)\,d\tau.$$

$$\mathrm{rMTT_{index}} = \frac{\int_0^t \tau \Delta R_2^*(\tau)\,d\tau}{\int_0^t \Delta R_2^*(\tau)\,d\tau}.$$

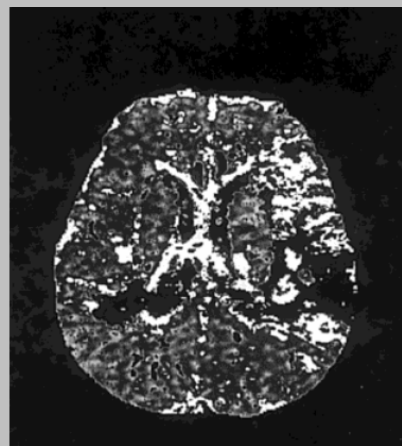
$$\mathrm{rCBF_{index}} = \frac{\mathrm{rCBV_{index}}}{\mathrm{rMTT_{index}}}.$$

BOLUS TRACKING TECHNIQUES

➢ **DYNAMIC SUSCEPTIBILITY CONTRAST**



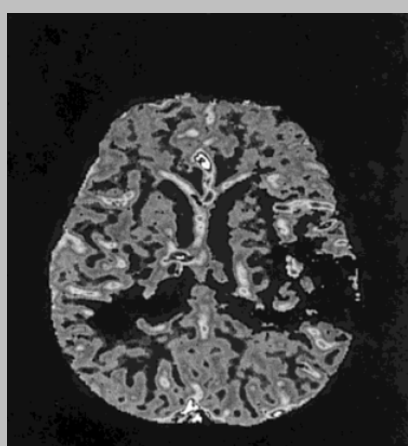
T2-weighted image of an ischemic edema-bearing patient



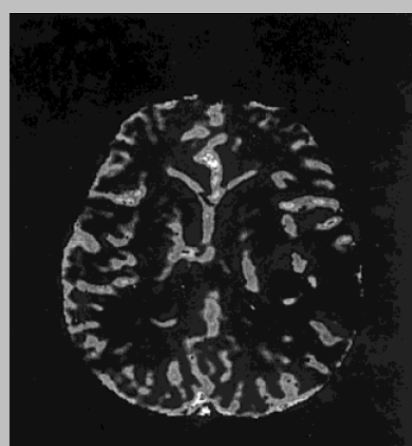
Mean Transit time (T_{mtt}) index

BOLUS TRACKING TECHNIQUES

➢ **DYNAMIC SUSCEPTIBILITY CONTRAST**



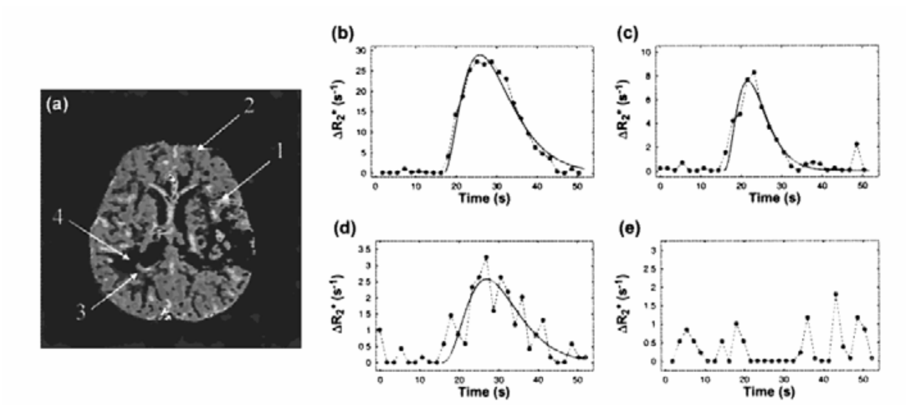
relative CBV index



relative CBF index

BOLUS TRACKING TECHNIQUES

➢ **DYNAMIC SUSCEPTIBILITY CONTRAST**

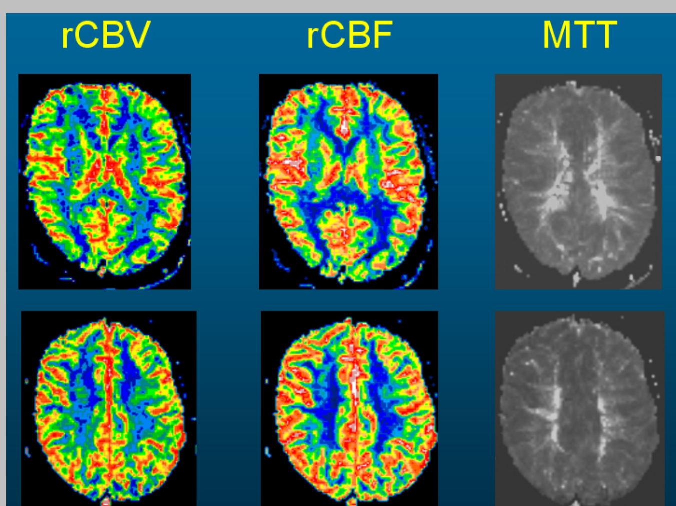


Susceptibility bolus tracking curves obtained from the regions (1-4) pointed by arrows in (a) (rCBV index)

*****Note the different vertical scales***

BOLUS TRACKING TECHNIQUES

➢ **DYNAMIC SUSCEPTIBILITY CONTRAST**



PERFUSION - MRI

- **BOLUS TRACKING TECHNIQUES**
  - ***Dynamic Susceptibility contrast***
  - ***Dynamic Relaxivity contrast***

- **STEADY-STATE TECHNIQUES**
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  - ***Steady-state Relaxivity contrast***

- **USING DIFFUSIBLE TRACERS**

BOLUS TRACKING TECHNIQUES

- **DYNAMIC RELAXIVITY CONTRAST**
  - **PRINCIPLE**
    - ***T1-weighted imaging sequence***
    - ***Assuming water exchange between the intra and extra-vascular compartments is negligible thus the MR signal can be written as***

      $\Delta S(t) = S_{intraV}(t) - S_{intraV}(0)$

      and originates from blood only
    - ***Like with Dynamic Susceptibility Contrast, this signal intensity is converted to a relative concentration of contrast agent***

BOLUS TRACKING TECHNIQUES

- **DYNAMIC RELAXIVITY CONTRAST**
  - **PRINCIPLE**
    - ***Change in relaxation rate ΔR1 is linearly related to the blood concentration in the contrast agent***
    - ***Using Inversion recovery or Saturation recovery fast imaging techniques, S(t) is linearly related to R1***
    - ***At low T1 values, signal vs concentration relationship decreases***

BOLUS TRACKING TECHNIQUES

- **DYNAMIC RELAXIVITY CONTRAST**

(A) Contrast-enhanced axial view T1-weighted image (B) Axial view T2-weighted image (C) Gradient-echo axial view perfusion MR image and rCBV color overlay map

BOLUS TRACKING TECHNIQUES

➢ **APPLICATIONS**

- ***Characterization of tumor vascularity***
- ***Follow-up of cancer treatments***
- ***Study of vasodilatory capacity of brain***
- ***Study of ischemia-reperfusion injuries and stroke***

BOLUS TRACKING TECHNIQUES

➢ **LIMITATIONS**

- ***High temporal resolution required to determine rCBV and rCBF is obtained at the expense of spatial resolution and SNR***

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STEADY-STATE TECHNIQUES

STEADY-STATE TECHNIQUES

PRINCIPLE

- *Uses contrast agents with a long half-life in the vascular pool (like SPIO, AMI-227)*
- *Standard gradient-echo or spin-echo imaging sequences are used*
- *Offers high spatial resolution but does not allow rCBF and T_{mtt} to be measured*

PERFUSION - MRI

BOLUS TRACKING TECHNIQUES

- *Dynamic Susceptibility contrast*
- *Dynamic Relaxivity contrast*

STEADY-STATE TECHNIQUES

- *Steady-state Susceptibility contrast*
- *Steady-state Relaxivity contrast*

USING DIFFUSIBLE TRACERS

STEADY-STATE TECHNIQUES

➢STEADY-STATE SUSCEPTIBILITY

❖ PRINCIPLE

- *Linear relationship between rCBV and R2* is exploited*
- *T2*-weighted imaging sequence*

STEADY-STATE TECHNIQUES

➢STEADY-STATE SUSCEPTIBILITY

❖ METHODS

▪ SINGLE GRADIENT ECHO

- *R2* changes due to contrast agent are obtained from the ratio of signal intensities before & after contrast injection*

$$\Delta R2^* = (1/T_E) \, . \, (S_{post} / S_{pre})$$

T_E – *echo time*
S_{post} – *signal intensity after contrast injection*
S_{pre} – *signal intensity before contrast injection*

STEADY-STATE TECHNIQUES

➢ STEADY-STATE SUSCEPTIBILITY

❖ METHODS

- **SINGLE GRADIENT ECHO**
  - ***T1-weighting of the signal may introduce T_E – dependent errors***
  - ***T1 effects cause underestimation of ΔR2****

STEADY-STATE TECHNIQUES

➢ STEADY-STATE SUSCEPTIBILITY

❖ METHODS

- **MULTIPLE GRADIENT ECHO**
  - ***Insensitive to T1-weighting***

$$\Delta R2^* = (1/T2^*_{post}) - (1/T2^*_{pre})$$

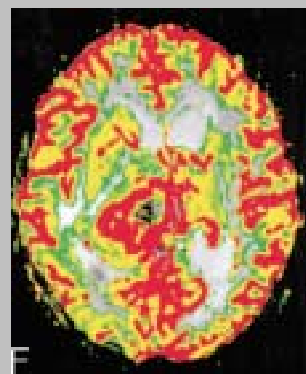
$T2^*_{post}$ ***- post injection relaxation time***

$T2^*_{pre}$ ***- pre injection relaxation time***

STEADY-STATE TECHNIQUES

➢ STEADY-STATE SUSCEPTIBILITY

Axial view T2-weighted image



Gradient-echo axial view perfusion MR image and rCBV color overlay map

STEADY-STATE TECHNIQUES

➢ STEADY-STATE SUSCEPTIBILITY

❖ **LIMITATIONS**

- ***Prior knowledge of the proportionality constant (k) between $\Delta R2^*$ and rCBV ($rCBV = k \cdot \Delta R2^*$)***
- ***Vessel-size dependent***
- ***Blood-Brain Barrier (BBB) should not be disrupted***

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  and originates from blood only

STEADY-STATE TECHNIQUES

➢ STEADY-STATE RELAXIVITY

❖ PRINCIPLE

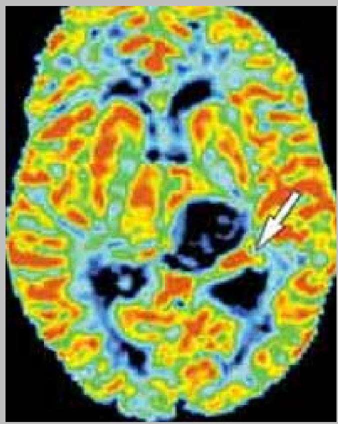
- *This increase in signal is related by*

$$rCBV(\%) = 100 \cdot (\Delta S(t)_{intraV} / \Delta S(t)_{ref})$$

$\Delta S(t)_{ref}$ - signal increase in a voxel that contains blood only

STEADY-STATE TECHNIQUES

➢ STEADY-STATE RELAXIVITY



This T1-weighted MRI scan shows a mass in the left thalamus of the brain. The rCBV map of the same brain shows regions of red signals (arrow) that indicate high CBV, revealing that the mass is probably a tumor

STEADY-STATE TECHNIQUES

➢ STEADY-STATE RELAXIVITY

❖ **LIMITATIONS**

- ***Partial volume effects***
- ***Hematocrit differences in capillaries and large draining veins***

A short echo time (T_E) is used

STEADY-STATE TECHNIQUES

➢ APPLICATIONS

- ***Understanding BOLD contrast in situations where changes in CBV and oxygenation occur simultaneously***
- ***measuring CBV in tumor studies***
- ***Study of vasodilatory capacity of brain***
- ***Study of ischemia-reperfusion injuries and stroke***

REFERENCES

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- Michael H. Lev and Fred Hochberg, ***Perfusion Magnetic Resonance Imaging to Assess Brain Tumor Responses to New Therapies***
- Meng Law, Khuram Kazmi, Stephan Wetzel, Edwin Wang, Codrin Iacob, David Zagzag, John G. Golfinos, and Glyn Johnson, ***Dynamic Susceptibility Contrast-Enhanced Perfusion and Conventional MR Imaging Findings for Adult Patients with Cerebral Primitive Neuroectodermal Tumors***
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