MR Perfusion Techniques in Pediatric Neuroimaging

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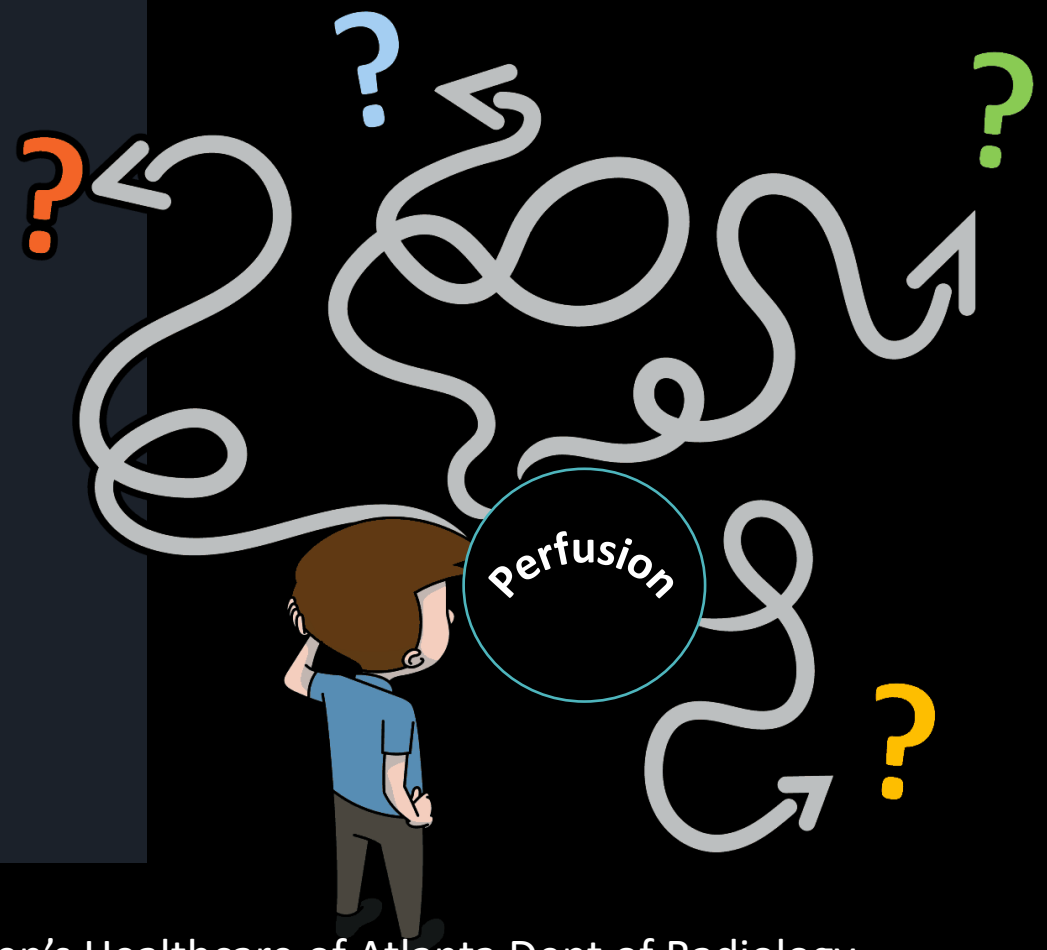

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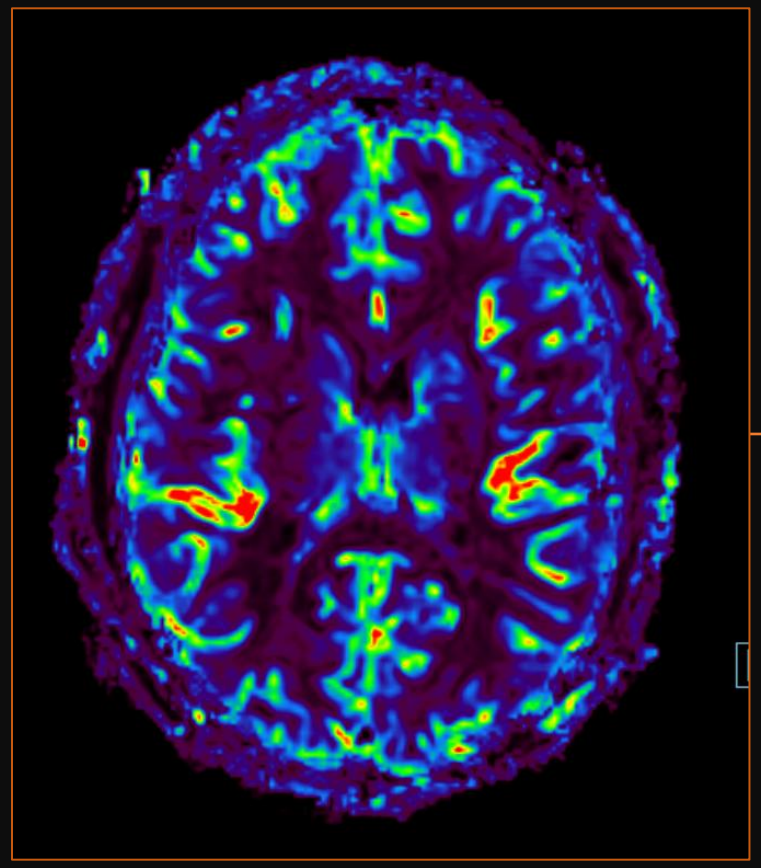
Advantages of perfusion imaging in children over adults

- Robust CBF
- Underpneumatized skull base

Disadvantages of perfusion imaging in children over adults

- Small size
- Motion sensitivity

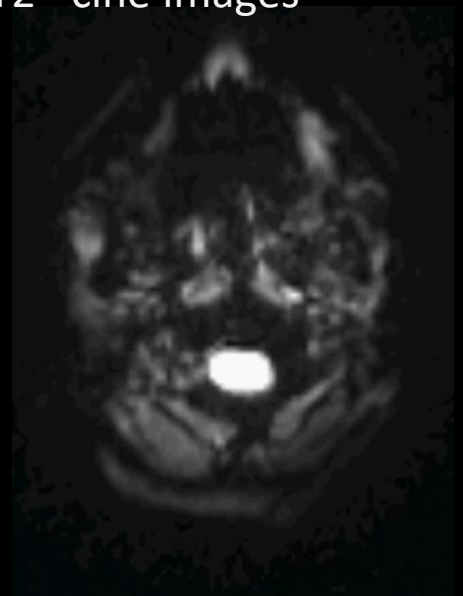


Dynamic Susceptibility Contrast (DSC) Perfusion Imaging

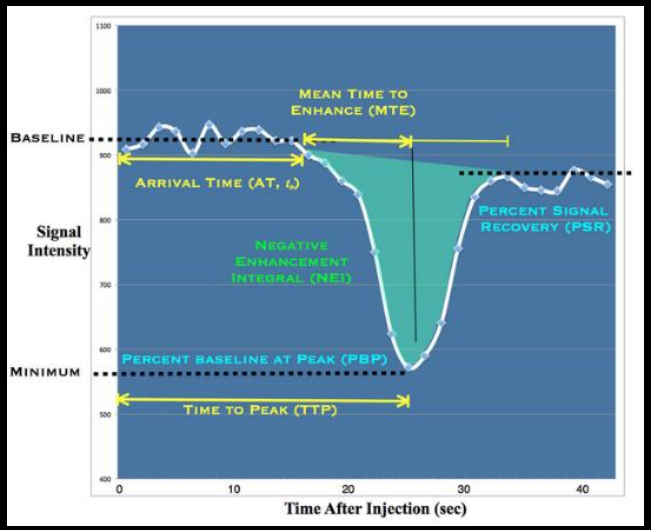
DSC Perfusion Imaging Technique

- A contrast enhanced MR perfusion technique
- A rapid, tight bolus of IV Gad is rapidly delivered
- T2* images obtained over 1-2 minutes (A)
- Intravascular Gad passing through the brain causes susceptibility effects that induce a change in relaxation rate proportional to the fraction of blood volume within each imaging voxel (B)

A. T2* cine images

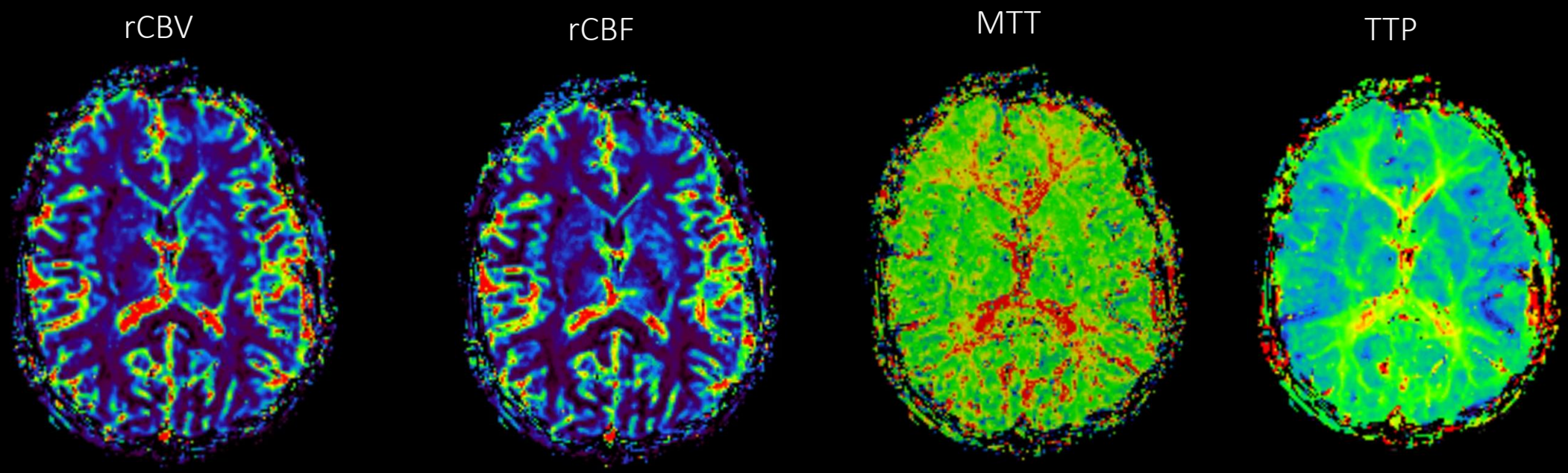


B. Time intensity curve



https://mriquestions.com/dsc-curve-analysis.html

DSC Hemodynamic Parametric Maps

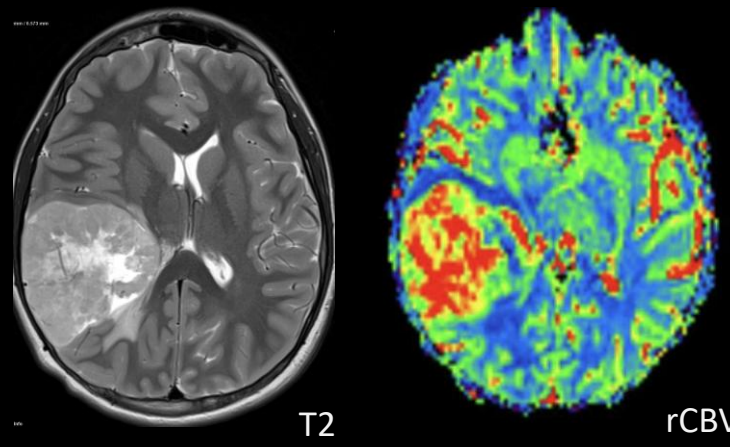


Hemodynamic parametric maps of relative cerebral blood volume (rCBV), relative cerebral blood flow (rCBF), mean transit time (MTT), and time to peak (TPP) provide relative perfusion metrics derived from subsequent analysis of the relaxation time curves.

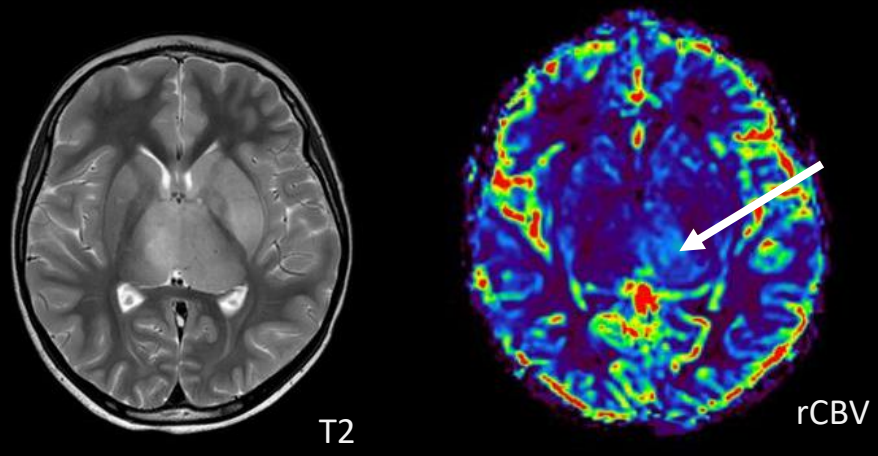
DSC Perfusion Imaging in Children

Tumor grading

A. High grade glioma (HGG) with increased rCBV



B. Diffuse midline glioma (DMG) with increased rCBV in left thalamus

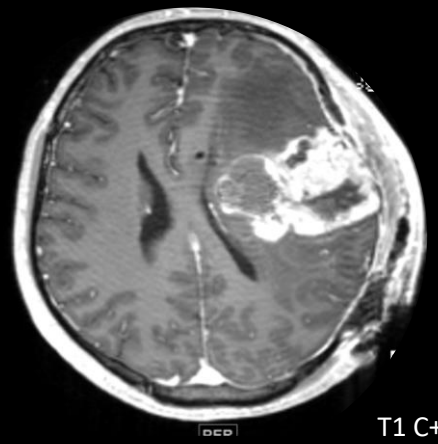


DSC perfusion can be performed simultaneously with contrast enhanced MR brain tumor imaging. High grade tumors like high grade glioma (HGG) in image (A) can demonstrate increased perfusion related to increased tumoral neovascularity. In other tumors such as the diffuse midline glioma in (B) higher grade areas within the tumor (arrow) can be identified and can guide biopsy.

DSC Perfusion Imaging in Children

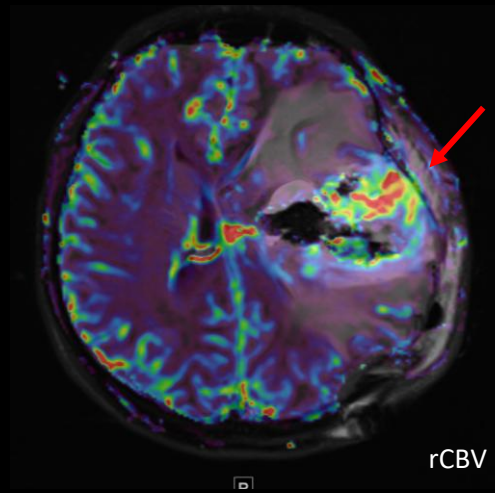
Differentiating recurrent tumor from pseudoprogression

Concern for tumor progression vs RTX necrosis



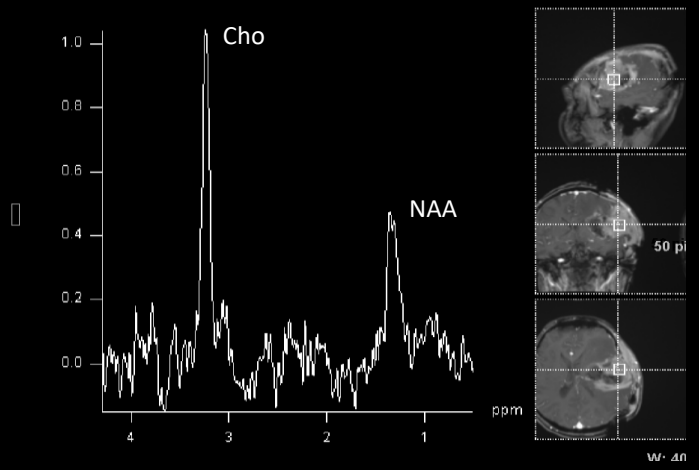
T1 C+

Increased rCBV supports tumor progression



rCBV

Increased Cho:NAA ratio lends further multi-modal support for tumor progression



MRS

Areas of increasing enhancement in treated brain tumors can be difficult to differentiate between progressive tumor and radiation (RTX) necrosis. Tumoral neoangiogenesis from abnormal neoplastic capillaries typically results in increased rCBV.

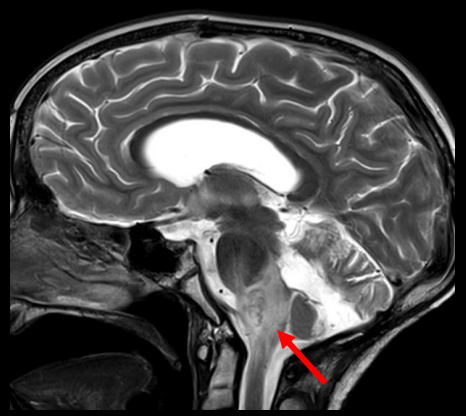
DSC Perfusion Imaging in Children

Differentiating recurrent tumor from pseudoprogression

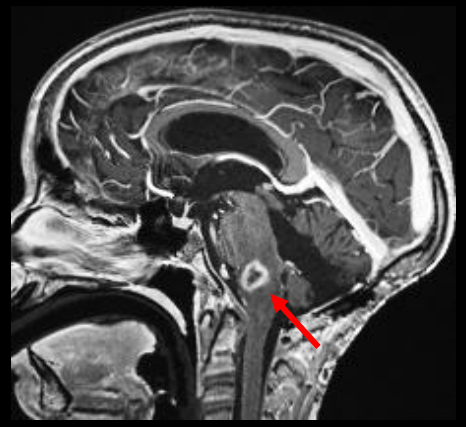
Concern for tumor progression vs RTX necrosis

Decreased rCBV supports RTX necrosis

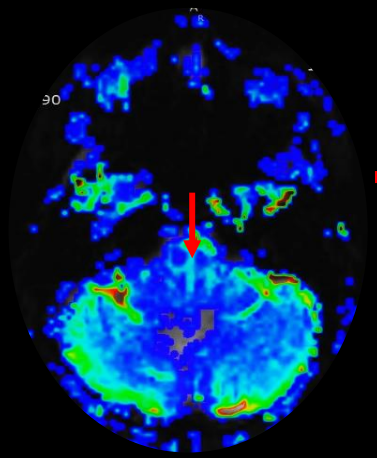
Interval improvement



T2

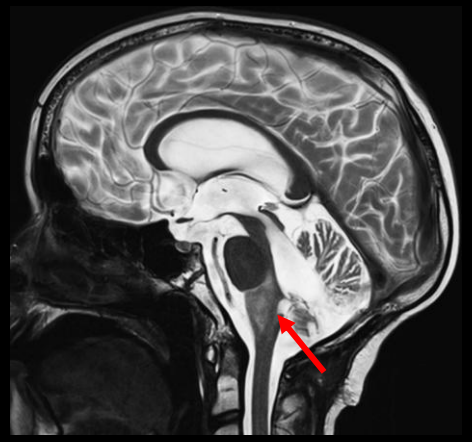


T1 C+

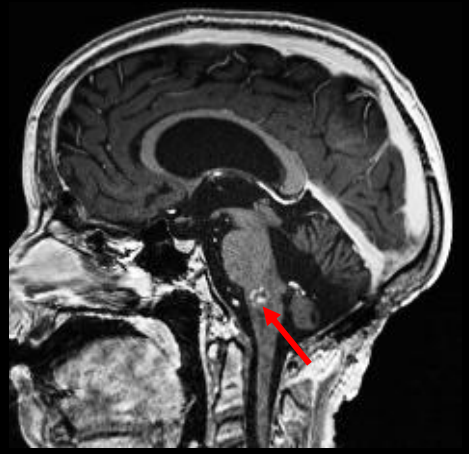


rCBV

steroids



T2



T1 C+

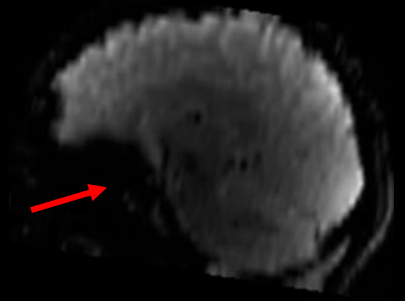
Radiation (RTX) causes fibrinoid necrosis, endothelial thickening and damage, and hyalinization. These can appear on imaging as florid focal enhancement and vasogenic edema, mimicking high grade tumor progression. DSC perfusion can demonstrate decreased rCBV typically seen with RTX necrosis, helping differentiation.

Limitations of DSC Perfusion Imaging in Children

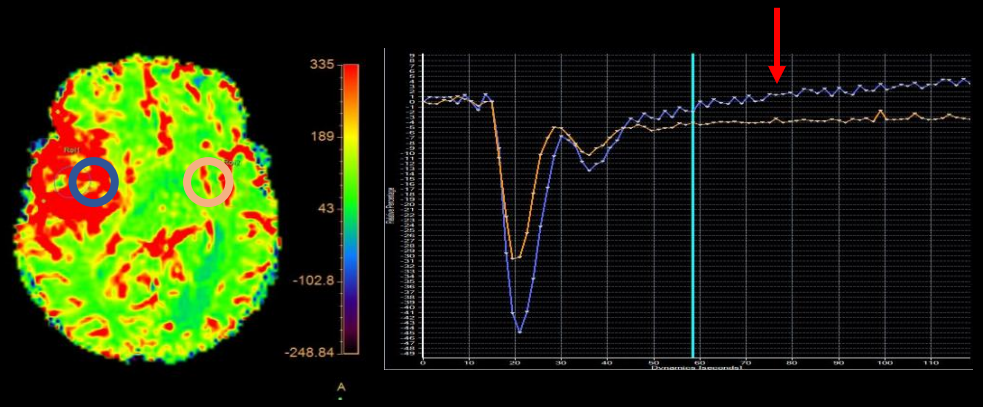
- Need for IV contrast, placement of large bore IV, and power injection with associated technical challenges and gadolinium safety concerns

https://kids.kiddle.co/Intravenous_therapy

- Susceptibility artifacts
  - Metal (orthodontic hardware)



- Contrast leakage and blood brain barrier disruption
  - Failure of the time intensity curve to return to baseline following contrast injection from tumor leakage results in inaccurate rCBV estimates

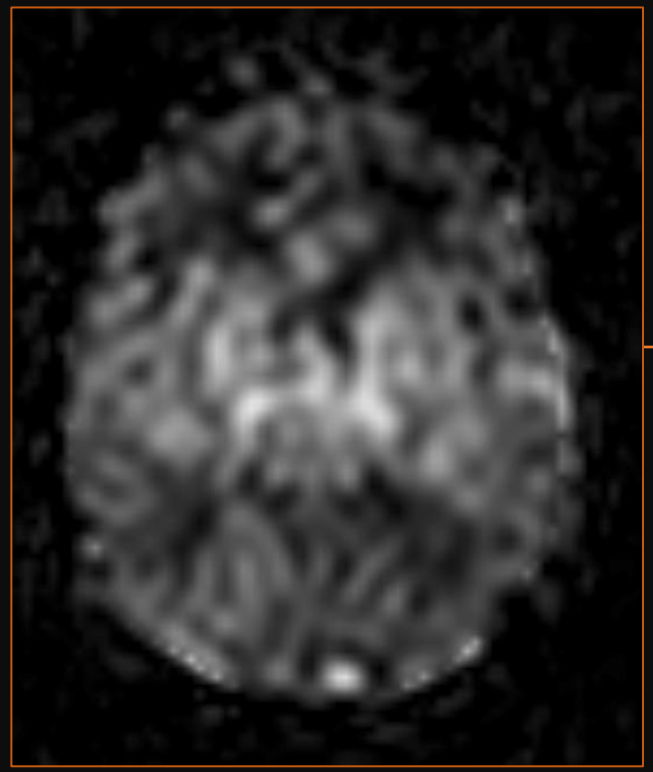


DSC in Pediatric Neuroimaging

Summary

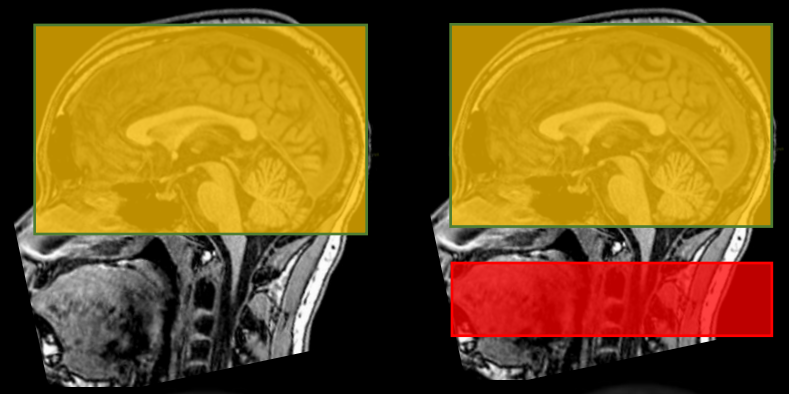
DSC perfusion MRI is the most commonly used perfusion technique in pediatric neuroimaging. It is well-validated for distinguishing high-grade from low-grade gliomas and differentiating tumor progression from pseudoprogression.

- Tumor grading and biopsy site selection
- Assessing malignant transformation and pseudoprogression
- Differentiating radiation necrosis from recurrent tumor
- Evaluating perfusion in other pediatric brain disorders

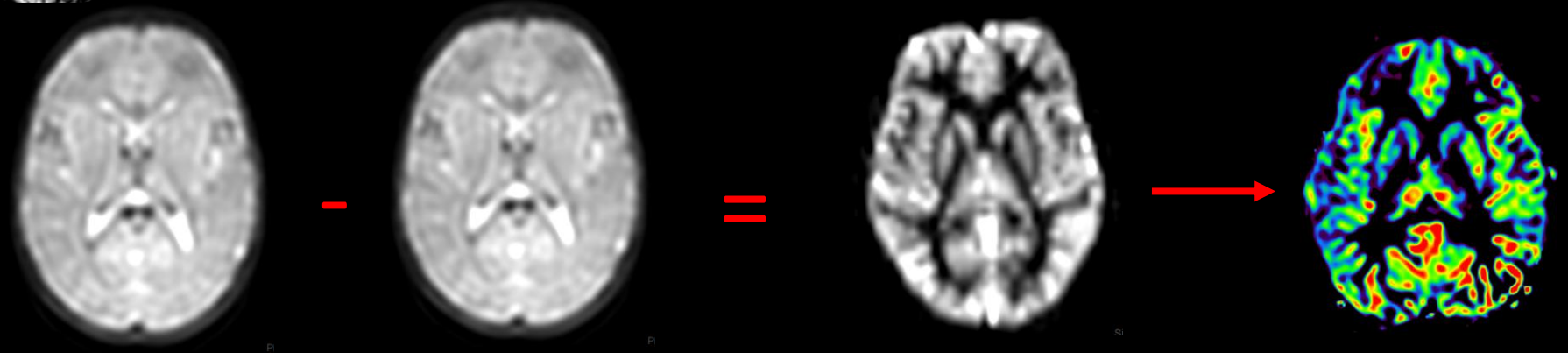


Arterial Spin Labeling (ASL) Perfusion Imaging

ASL Perfusion Imaging Technique



3-5 minutes



Control image

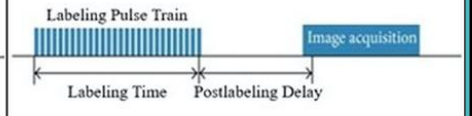
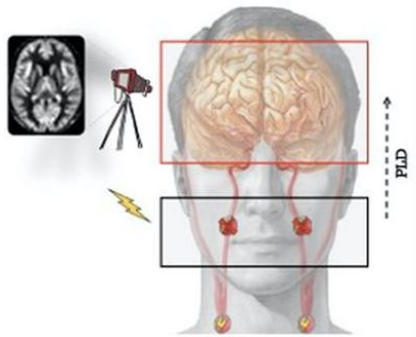
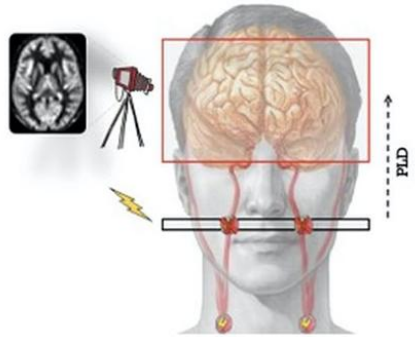
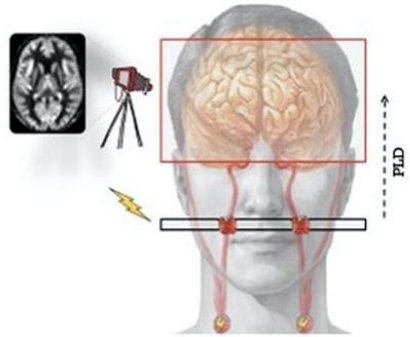
Labeled image

Perfusion-weighted image

Cerebral blood flow map

Noninvasive perfusion technique that does not require IV contrast administration, is quantifiable and repeatable, making it well suited for use in neonates and young children.

Single-delay ASL Techniques

Sequence type	PASL	CASL	PCASL
Pulse scheme			
Labeling / readout scheme			
Advantages	• Short RF pulse = lower energy deposition • Shorter labeling/scan time	• High signal-to-noise ratio (SNR)	• Higher SNR than PASL and less energy deposition than CASL
Drawbacks	• Low SNR - Low temporal duration due to small labeling bolus	• High energy deposition = Tissue heating	**Recommended labeling scheme**
Typical sequence parameters	**TR** ~ 3-4 s **LD** ~ 700-900 ms **PLD** ~ 1600-2000 ms **Labeling distance:** 2-4 cm from the most inferior slice	**TR** ~ 4-5 s **LD** ~1800-2000 ms **PLD** ~ 1800-2000 ms **Labeling distance:** 5-10 cm from the most inferior slice	

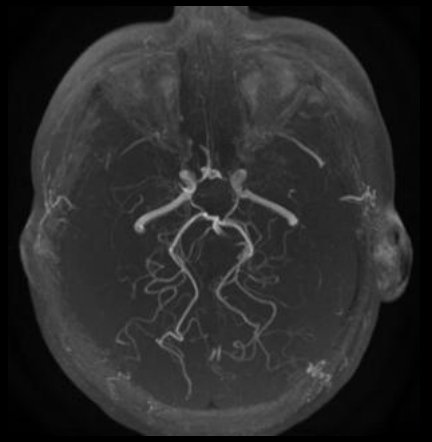
PCASL is the current clinical standard ASL technique due to its balance of SNR, efficiency, and practicality.

Diagnostic and interventional imaging. 2013 Dec 1;94(12):1211-23.

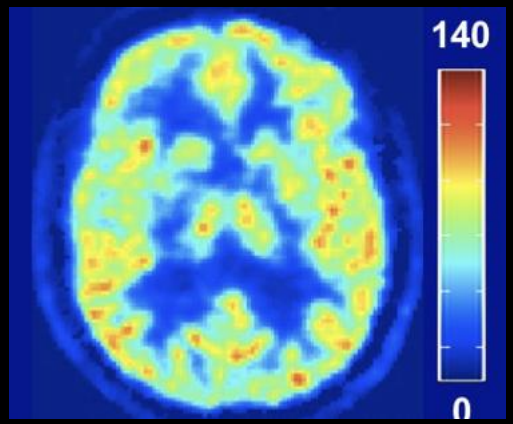
Multi-delay ASL Technique

- Acquires perfusion images at several different post-labeling delays (PLDs)
- Allows simultaneous estimation of both cerebral blood flow (CBF) and arterial transit time (ATT), which improves accuracy compared to single-delay ASL
  - Helps in distinguishing areas of actual reduced blood flow from overestimations by standard ASL and more closely correlates to PET imaging
- Preferred technique in cases with variable or prolonged ATT, such as non-invasive monitoring of moyamoya disease

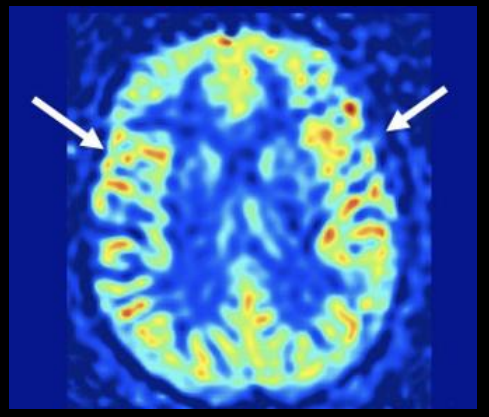
Angiogram showing moyamoya



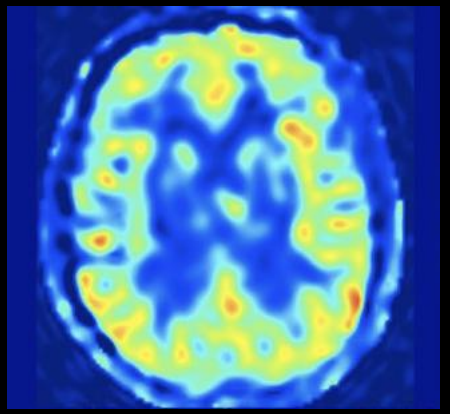
[^{15}O]-water PET
Mean CBF 64.1 (ml/100g/min)



Single-delay ASL
Mean CBF 47.8 (ml/100g/min)



Multi-delay ASL
Mean CBF 58.6 (ml/100g/min)

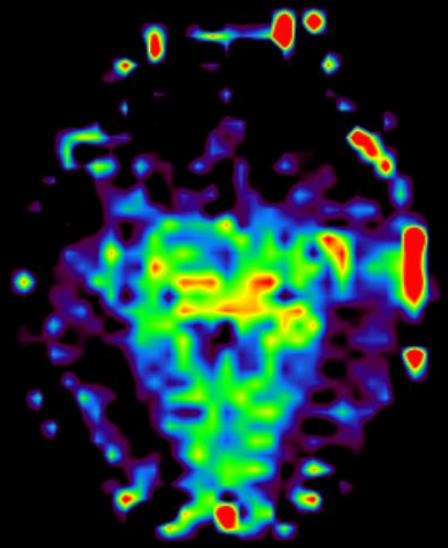


Images from Fan AP et al. Proc. Intl. Soc. Mag. Reson. Med. 26 (2018

ASL in Pediatric Neuroimaging

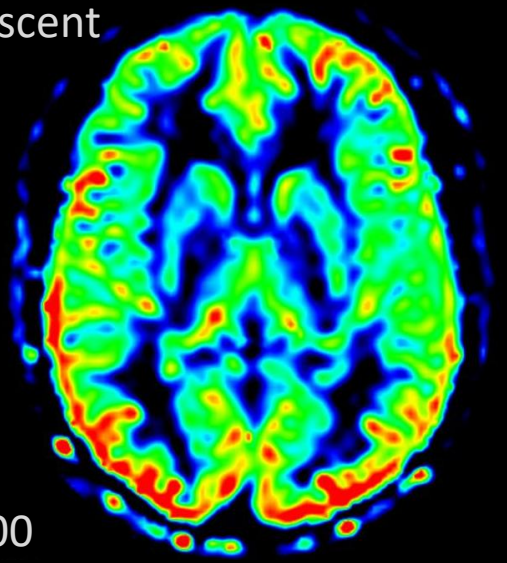
Monitoring developmental changes

Neonate



PLD: 1600

Adolescent

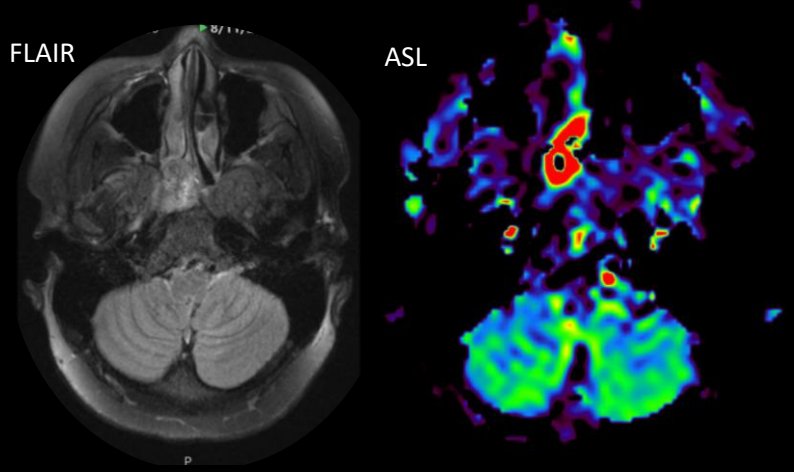


PLD: 1800

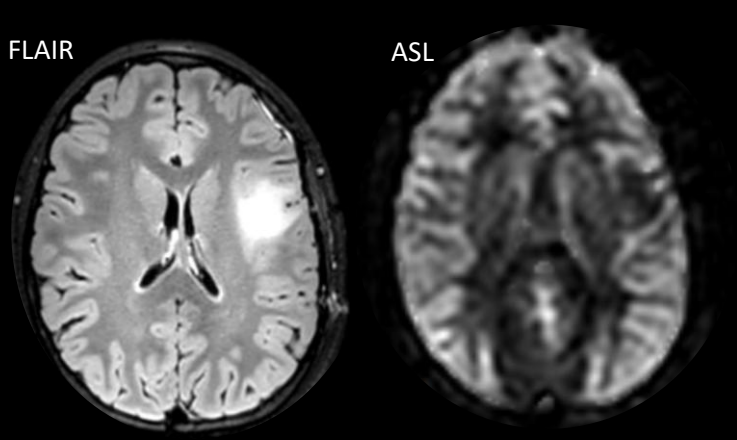
Neonates have lower global CBF, higher occipital and thalamic perfusion and rapid age-related changes. As the child ages, CBF becomes higher and more uniform, ASL technique in neonates and infants also differs with shorter PLDs beings more optimal due to the infants short neck.

ASL in Pediatric Neuroimaging

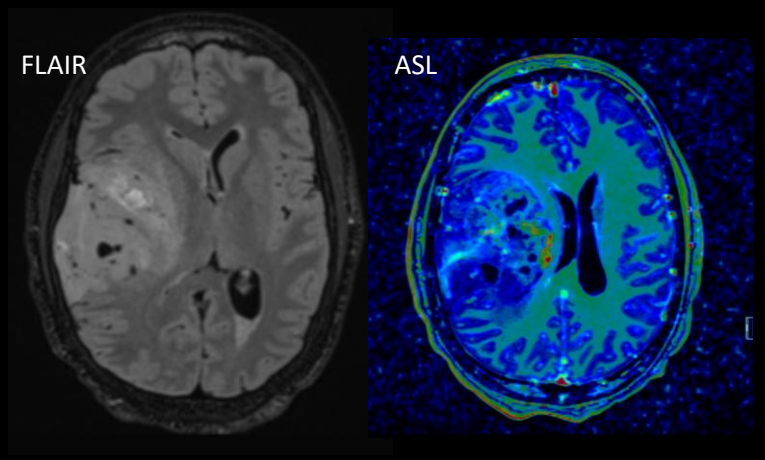
Tumor evaluation



A. Juvenile Nasopharyngeal Angiofibroma (JNA)



B. Low Grade Glioma

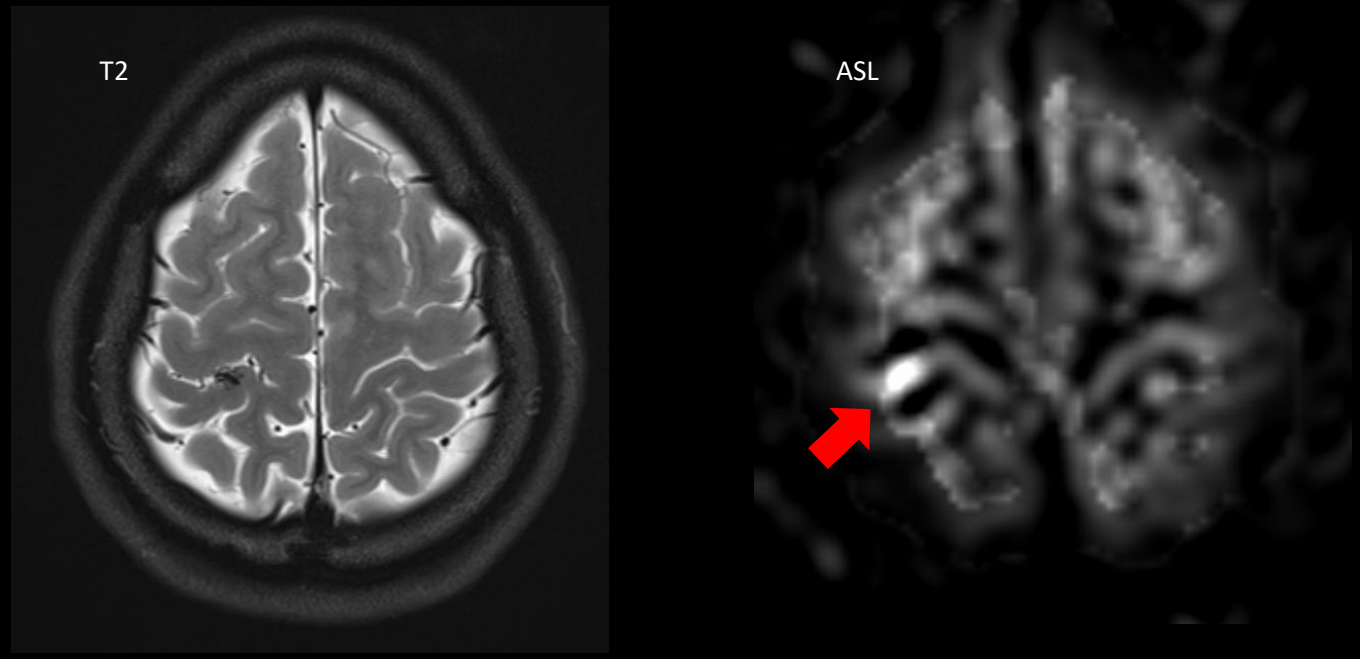


C. Glioblastoma Multiforme (GBM)

ASL is used for tumor characterization by noninvasively measuring cerebral blood flow (CBF), which helps differentiate tumor grade. ASL is comparable in diagnostic accuracy to DSC perfusion for grading gliomas and detecting tumor progression and is less affected by susceptibility artifacts. Visual assessment of ASL maps is often sufficient for clinical decision-making. In case (A) the JNA is easily identified on ASL. Decreased and increased perfusion is demonstrated in cases (B) and (C) respectively, reflecting tumor grade.

ASL in Pediatric Neuroimaging

Arteriovenous shunting



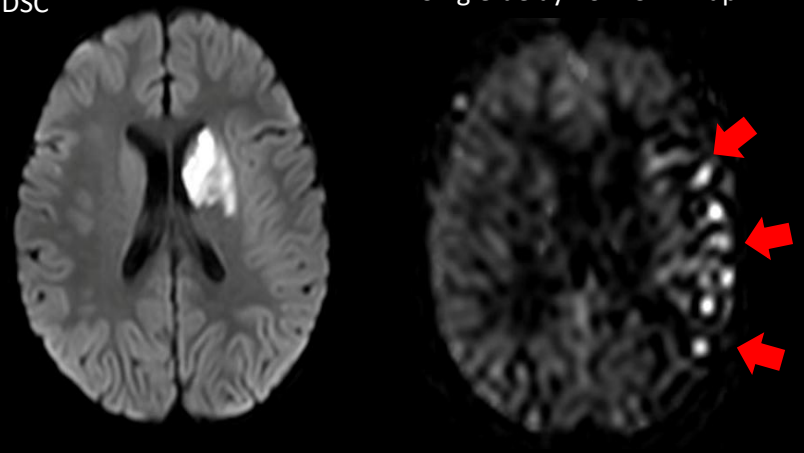
Arterial transit artifact (ATA) in the context of an arteriovenous shunt refers to abnormal high signal on arterial spin labeling (ASL) (arrow) that appears in venous structures due to rapid transit of labeled arterial blood directly into veins through the shunt, bypassing the capillary bed. ATA is diagnostically useful for identifying and evaluating AVMs and fistulas.

ASL in Pediatric Neuroimaging

Estimation of tissue perfusion

DSC

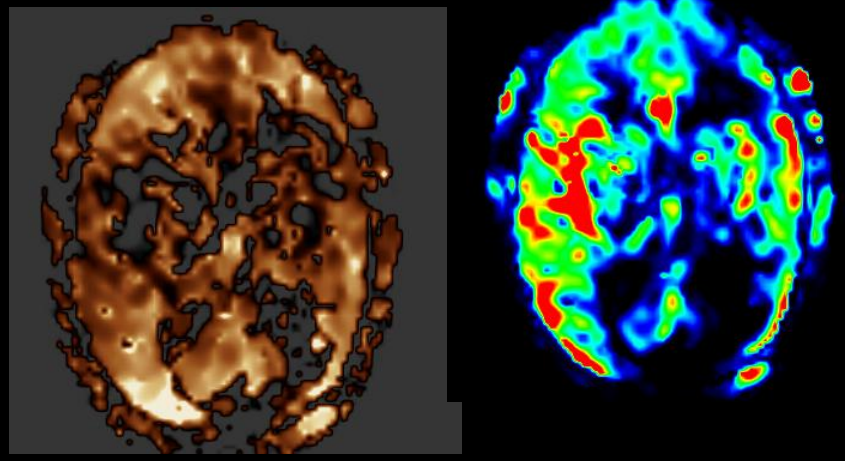
Single-delay ASL rCBF Map



A. Acute stroke: Ischemic penumbra and collateral flow

Multi-delay ASL ATT Map

Multi-delay ASL CBF Map



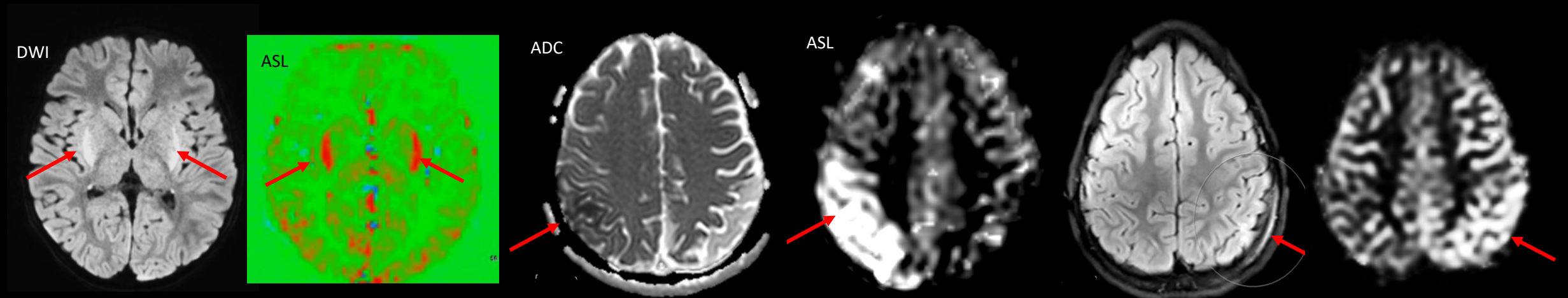
B. Hypoxic-ischemic injury: Estimation of cerebral perfusion

(A) In acute ischemic stroke, arterial transit artifact (ATA) (arrows) occurs when the labeled blood has not yet reached the tissue capillary bed at the time of image acquisition, resulting in increased intravascular signal. The presence of ATA in this setting is important to recognize because it's associated with better collateral status and a higher likelihood of tissue salvage.

(B) Multi-delay ASL produces two complementary maps, the arterial transit time (ATT) map which shows regional differences in arterial arrival times (early arrival, low signal) and the CBF map (high perfusion, high signal) providing quantitative perfusion metrics and more reliable values across variable hemodynamics. This dual mapping is especially valuable in clinical scenarios with altered or heterogeneous cerebral blood flow.

ASL in Pediatric Neuroimaging

Hyperperfusion states



A. Post hypoxic ischemic injury from near-drowning

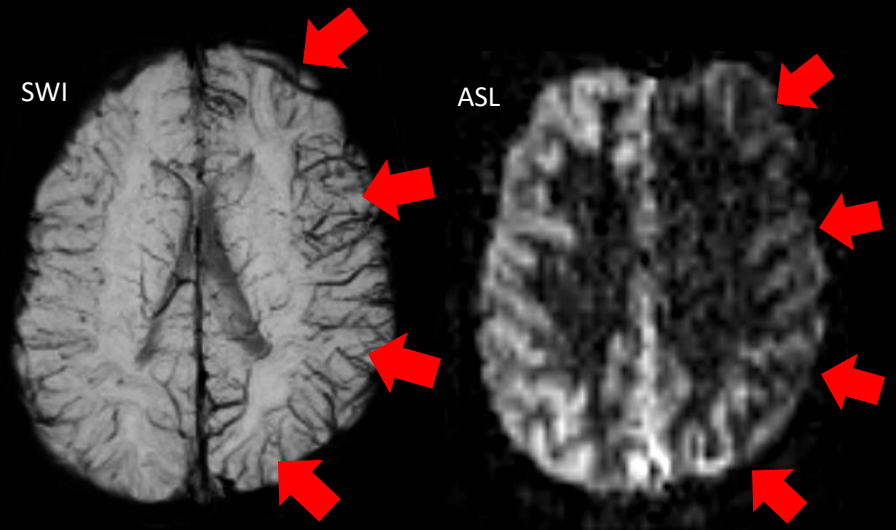
B. MELAS

C. Contusion

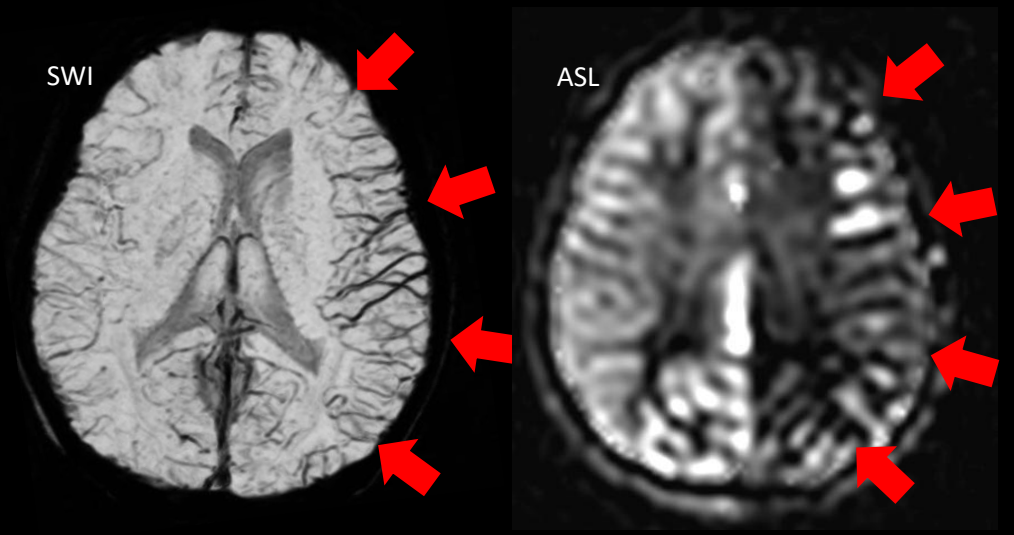
Rebound hyperperfusion is identified as focal or regional increased CBF on perfusion imaging post ischemic stroke or HIE. In case (A) increased CBF secondary to rebound hyperperfusion can be seen in the ischemic basal ganglia (arrows). It can be a marker of successful reperfusion and favorable outcome, though it can also signal risk for secondary injury in severely damaged tissue. In metabolic strokes (B), loss of autoregulation due to metabolic derangement can present as hyperperfusion (arrows) in the acute phase and help differentiate from acute ischemic arterial stroke. Focal traumatic brain injury (C), can also result in loss of autoregulation and manifest as regional hyperperfusion (arrows).

ASL in Pediatric Neuroimaging

Stroke mimics



A. Hemiplegic migraine. Child with right sided weakness.



B. Post-ictal paralysis. Child with right sided weakness.

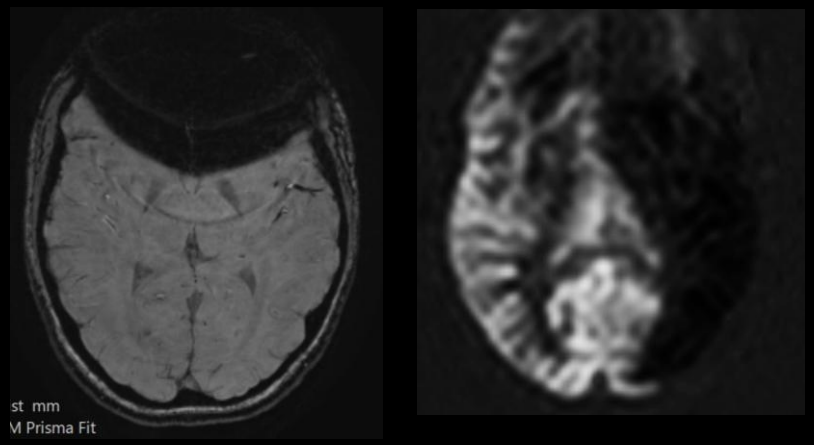
During the acute (aura) phase of hemiplegic migraine (A), ASL often shows regional hypoperfusion in the symptomatic hemisphere. SWI performed during the same phase frequently demonstrates prominent hypointense draining veins in the same regions, thought to result from increased oxygen extraction and deoxyhemoglobin concentration secondary to reduced perfusion (arrows). ASL and SWI findings in post-ictal paralysis (B) are correlated, with ASL showing hypoperfusion and SWI showing prominent veins due to increased oxygen extraction, both localizing to the clinically affected region (arrows).

Limitations of ASL in Pediatric Neuroimaging

- Low SNR
- Appropriate post label delay (PLD) in neonates and young children with small anatomy
- Sensitivity to arterial transit time
  - Shorter and more variable ATT in neonates and young children can lead to under- or overestimation of perfusion unless multi-delay ASL is used
- Longer acquisition times as compared to DSC and sensitivity to motion
  - Impractical for young or uncooperative children
- Technical complexity and artifacts

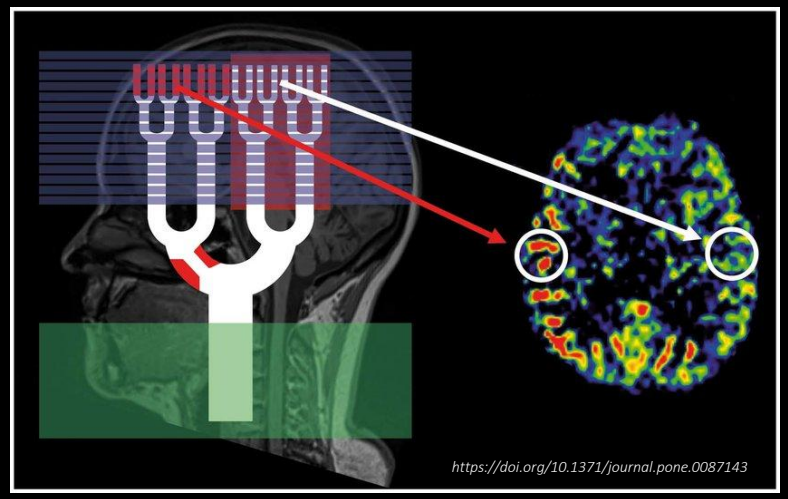
Common ASL artifacts

Arising during labeling



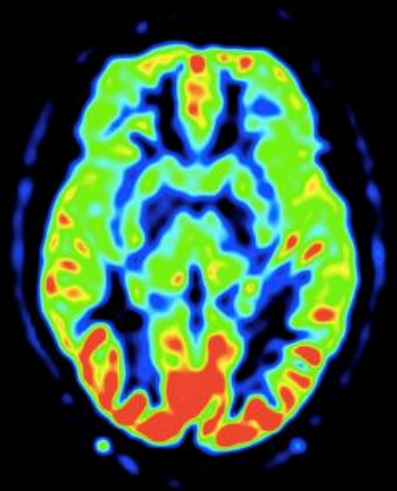
Dental hardware susceptibility leading to false appearance of hemispheric hypoperfusion

Arising during transit



Arterial transit artifact from a proximal stenosis

Arising during read-out



Physiologic bi-occipital hyperperfusion

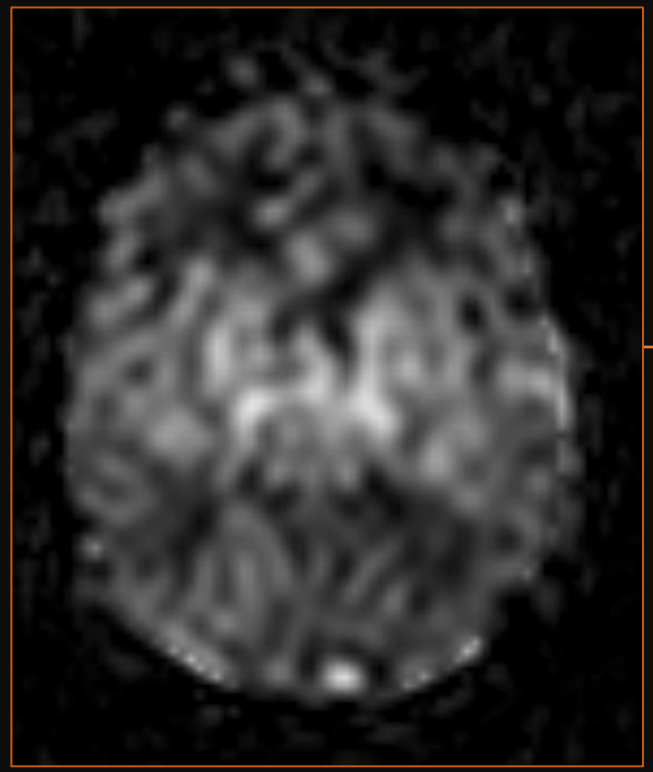
Neuroradiology 57, 1181–1202 (2015)
Neuroradiol J. 2021 Jun;34(3):154-168.
JMagn Reson Imaging JMRI 2016; 43: 11–27

ASL in Pediatric Neuroimaging

Summary

ASL is a robust, safe, and versatile tool for pediatric brain perfusion imaging, with broad clinical utility and growing adoption in routine practice.

- ASL is a noninvasive, contrast-free MRI technique for quantifying cerebral blood flow (CBF), making it especially valuable for pediatric neuroimaging
- It can evaluate a range of neurologic conditions, including stroke, vascular malformations, epilepsy, brain tumors, hypoxic-ischemic injury, and migraine
- Interpretation requires awareness of normal developmental perfusion patterns and potential pitfalls

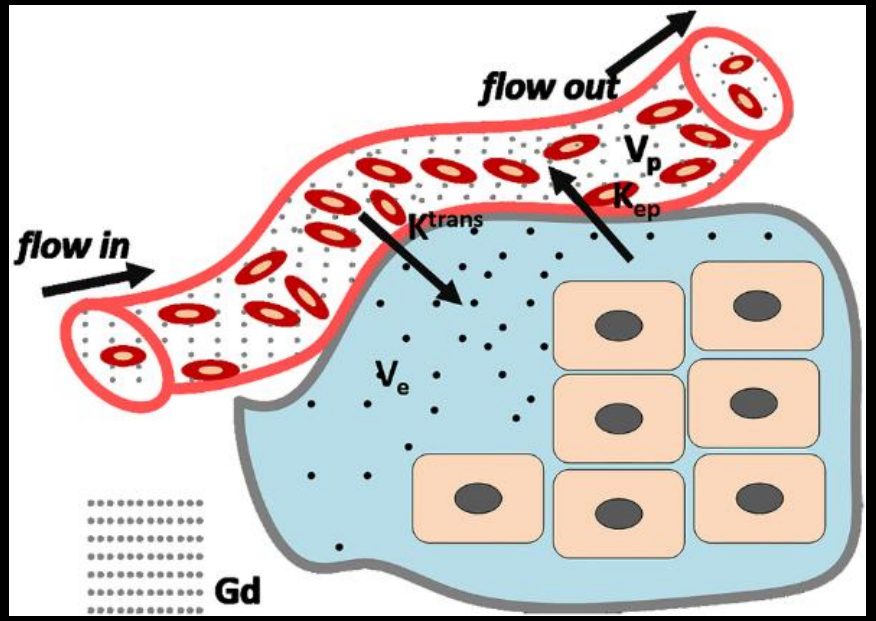


Dynamic Contrast Enhanced(DCE) Perfusion Imaging

DCE Perfusion Imaging Technique

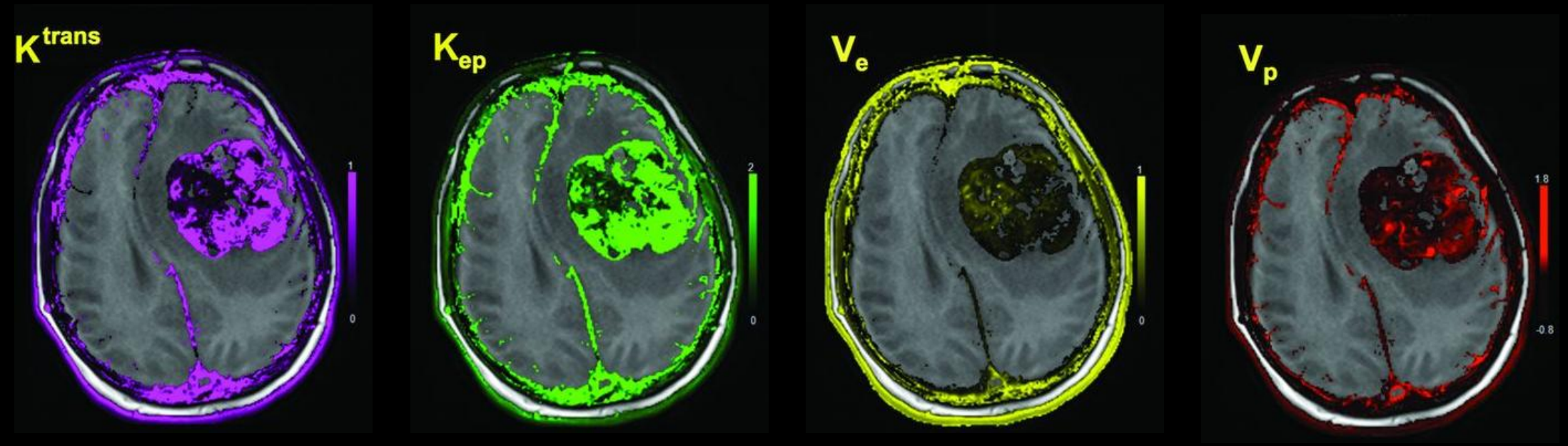
- Dynamic contrast-enhanced (DCE) perfusion imaging is an MRI technique that involves rapid, serial acquisition of T1-weighted images before, during, and after intravenous administration of a gadolinium-based contrast agent, allowing quantitative assessment of tissue perfusion and microvascular permeability

- It is most often used for tumor characterization and assessment of treatment-related changes



DOI:10.18632/oncotarget.16482

DCE Perfusion Pharmacokinetic Parametric Maps



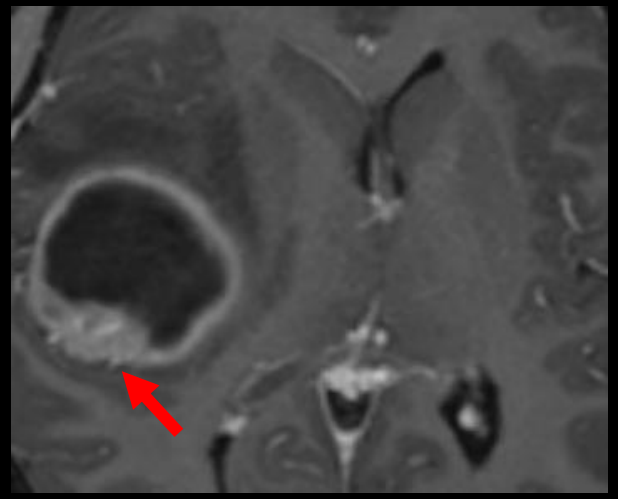
Vajapeyam et al. AJNR Am J Neuroradiol. 2017 Jan;38(1):170-175.

Advanced pharmacokinetic parametric maps are calculated such as the transfer constant from the blood plasma into the extracellular extravascular space (Ktrans), rate constant from extracellular extravascular space back into blood plasma (Kep), extracellular extravascular volume fraction (Ve), and fractional blood plasma volume (Vp). These are seful in blood-brain-barrier quantification and have fewer susceptibility induced artifacts.

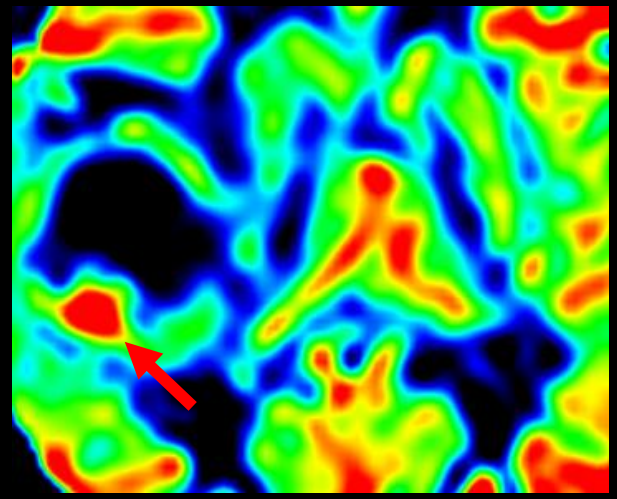
DCE Perfusion Imaging in Children

Tumor grading

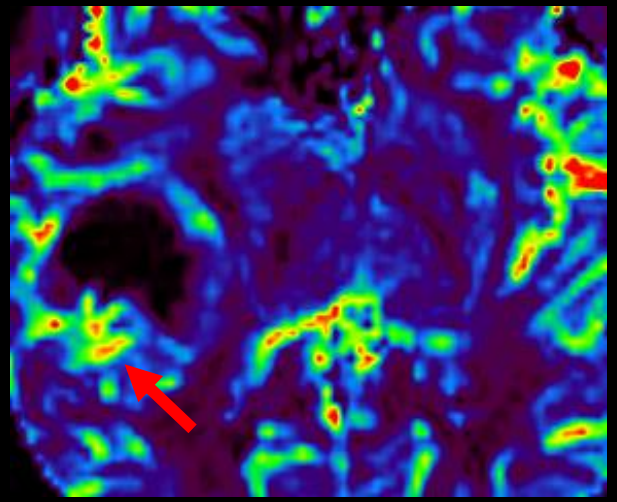
T1 C+



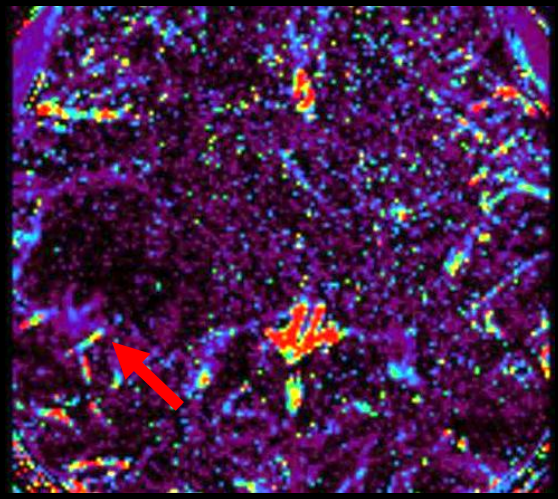
ASL



DSC



DCE K_{trans}



The K_{trans} parameter on dynamic contrast-enhanced (DCE) MRI is typically elevated in high-grade brain tumors, reflecting increased microvascular permeability and disrupted blood-brain barrier associated with aggressive neovascularization. JPAs typically show low K_{trans} (reflecting low microvascular permeability, arrows), while high-grade gliomas demonstrate markedly elevated K_{trans} due to increased angiogenesis and blood-brain barrier disruption.

Limitations of DCE in Pediatric Neuroimaging

- Need for intravenous contrast
- Longer acquisition times
- Complex post-processing
- While DCE is less commonly used than DSC in children, it is a valuable alternative or complement, especially when DSC is limited by technical factors or artifacts

DCE in Pediatric Neuroimaging

Summary

Dynamic contrast-enhanced (DCE) perfusion imaging plays an important role in pediatric neuroimaging, particularly for brain tumor evaluation, by providing quantitative assessment of microvascular permeability and blood-brain barrier integrity. It offers unique information about permeability that DSC and ASL do not provide.

- Tumor grading
- Treatment response assessment
- Differentiation of tumor recurrence from treatment effects
- Especially useful when combined with other advanced MR techniques.

Thank you!

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