Neuroimaging of TBI: Current Clinical Guidelines and Future Direction

Brain Injury Alliance of Colorado 2017

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OBJECTIVES

1. Understand when CT is appropriate for imaging patients with traumatic brain injury (TBI)
2. Understand how and when conventional MR imaging is used to evaluate TBI patients
3. Understand how some of the newer imaging techniques are being applied to the evaluation of the TBI patient, particularly in the setting of mild TBI (MTBI)

IMAGING MODALITIES

- Diagnostic X-ray
- Computed tomography (CT)
  - Including CT angiography
- Magnetic resonance (MR) imaging
  - Including MR angiography
- Positron Emission Tomography (PET)
- Single photon emission computed tomography (SPECT)
- In-111 DTPA cisternography – suspected CSF leak
- Ultrasound (transcranial doppler)
- Magnetoencephalography

THE MAIN ISSUE? CT OR MR

A NOTE ABOUT UTILIZATION

- Knowing when ‘not’ to image is as important as knowing when to image and with what test
- ACR Appropriateness Criteria: guidelines designed to help providers select the best imaging test for a specific clinical condition
  - grades imaging studies from 1 > 9 (not > usually appropriate)
  - based on a thorough literature review which is updated periodically
- Literature cited in 2015 head trauma review included 61 level 1-4 studies published in the literature from 1999-2014

Shetty VS, et al. ACR Appropriateness Criteria® Head Trauma. Available at https://acsearch.acr.org/docs/69481/Narrative/. American College of Radiology. Accessed Apr 28, 2017.

Date of origin: 1996
Last review date: 2015

American College of Radiology
ACR Appropriateness Criteria®

Clinical Condition: **Head Trauma**

Variant 1: **Minor or mild acute closed head injury (GCS ≥13), imaging not indicated by NOC or CCHR or NEXUS-II clinical criteria (see Appendix 1). Initial study.**

Radiologic Procedure	Rating	Comments	RRL*
CT head without IV contrast	2		☢☢☢
MRI head without IV contrast	1		O
MRA head and neck without IV contrast	1		O
MRA head and neck without and with IV contrast	1		O
CT head without and with IV contrast	1		☢☢☢
CTA head and neck with IV contrast	1		☢☢☢
MRI head without and with IV contrast	1		O
MRI head without IV contrast with DTI	1		O
CT head with IV contrast	1		☢☢☢
X-ray skull	1		☢
FDG-PET/CT head	1		☢☢☢☢
Arteriography cervicocerebral	1		☢☢☢
Tc-99m HMPAO SPECT head	1		☢☢☢☢
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

UTILIZATION

- NOC, CCHR, NEXUS – II: clinical guidelines used to identify patients with mild acute CHI who can safely avoid imaging
- CCHR - CT is not required if ALL of the following are met:
  - GCS ≥15 at 2 hours post-injury
  - No suspected open or depressed skull fracture
  - No sign of basilar skull fracture (hemotympanum, raccoon eye, CSF otorrhea or rhinorrhea, Battle sign)
  - Less than two episodes of vomiting
  - Age ≤65 years
  - No amnesia before impact ≥30 minutes,
  - No dangerous mechanism (pedestrian struck by MV, ejection from MV, fall from elevation <3 feet or <5 steps)

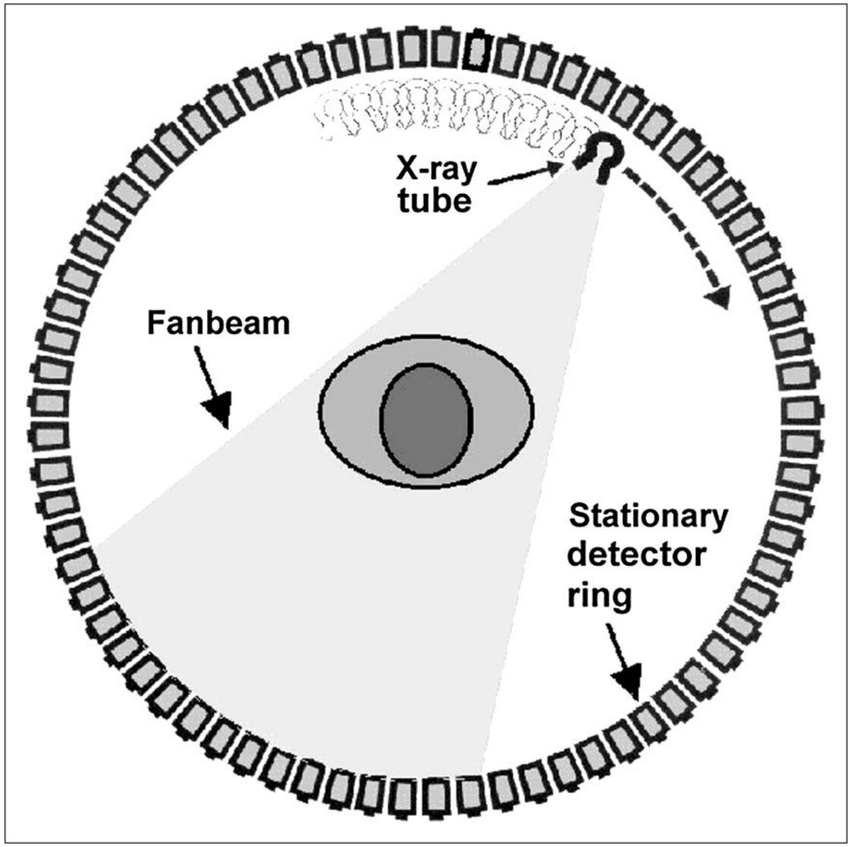
UTILIZATION

- Prospective multicenter study comparing the Canadian CT Head Rule (CCHR) and the New Orleans Criteria (NOC)
- 1,822 patients with GCS of 15; 8 (0.4%) required neurosurgical intervention and 97 (5.3%) had a clinically important brain injury.
  - Both the NOC and the CCHR were 100% sensitive
  - CCHR was more specific for predicting both the need for neurosurgical intervention (76.3% vs 12.1%) and the presence of clinically important brain injury (50.6% vs 12.7%)
  - CCHR would have resulted in lower CT rates (52% vs 88%)

Stiell IG, et al. *JAMA* 2005; 294(12):1511-1518.

CT


SIEMENS
300.0
-2000.0
SOMATOM Force


X-ray tube
Fanbeam
Stationary detector ring

ADVANTAGES OF CT

- Readily available at virtually all acute care facilities.
- Extremely fast (< 5s for 16/32/64/128/256 slice scanners).
- Highly sensitive and specific for identifying actionable lesions:
  - Intracranial hemorrhage (epidural, subdural, subarachnoid, parenchymal, and intraventicular)
  - Intracranial mass effect & herniation
  - Depressed skull fractures
- And, a negative head CT effectively excludes the likelihood of significant injury that would require early intervention

IMAGING OF ACUTE TBI

- CT is appropriate for acute TBI evaluation in the following situations:
  - Mild closed head injury in which imaging is indicated by NOC or CCHR or NEXUS-II criteria
  - Any moderate or severe acute closed head injury (GCS <13)
  - Any penetrating injury, but stable and neurologically intact
  - A known or suspected skull fracture
- For suspected vascular injury: CTA and MRA (in combo with CT or MR) are equally efficacious
  - we typically use CTA due to 24/7 availability, speed, cost

Shetty VS, et al. ACR Appropriateness Criteria® Head Trauma. Available at https://acsearch.acr.org/docs/69481/Narrative/. American College of Radiology. Accessed Apr 28, 2017.

American College of Radiology
ACR Appropriateness Criteria®

Clinical Condition: **Head Trauma**

Variant 1: **Minor or mild acute closed head injury (GCS $\geq$13), imaging not indicated by NOC or CCHR or NEXUS-II clinical criteria (see Appendix 1). Initial study.**

Radiologic Procedure	Rating	Comments	RRL*
CT head without IV contrast	2		☢☢☢
MRI head without IV contrast	1		O
MRA head and neck without IV contrast	1		O
MRA head and neck without and with IV contrast	1		O

Clinical Condition: **Head Trauma**

Variant 2: **Minor or mild acute closed head injury (GCS $\geq$13), imaging indicated by NOC or CCHR or NEXUS-II clinical criteria (see Appendix 1). Initial study.**

Radiologic Procedure	Rating	Comments	RRL*
CT head without IV contrast	9		☢☢☢
MRI head without IV contrast	5	This procedure may be appropriate in the outpatient setting, but there was disagreement among panel members on the appropriateness rating as defined by the panel's median rating.	O
MRA head and neck without IV contrast	2		O
MRA head and neck without and with IV contrast	2		O
CTA head and neck with IV contrast	1		☢☢☢

EFFICACY OF SCREENING CT

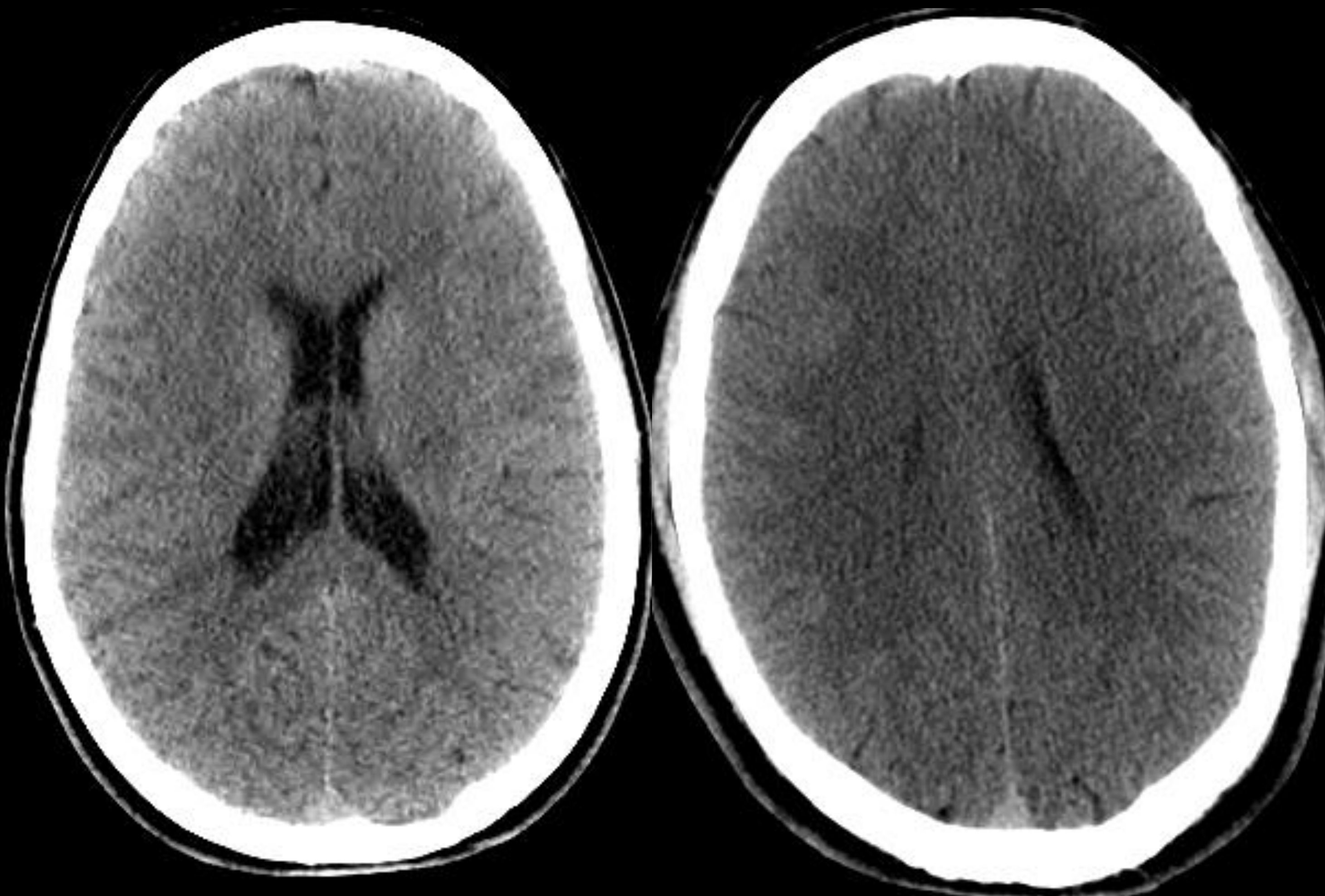
- 2766 pts with isolated mild head injury
  - 1170 pts had normal CT; none required craniotomy
  - 2112 pts had normal neuro exam; 59 (~3%) required surgery
  - CT sensitivity was 100%; NPV 100%
  - CT alone would have saved 3924 hospital days, 814 ICU days, and $1.5M in hospital charges

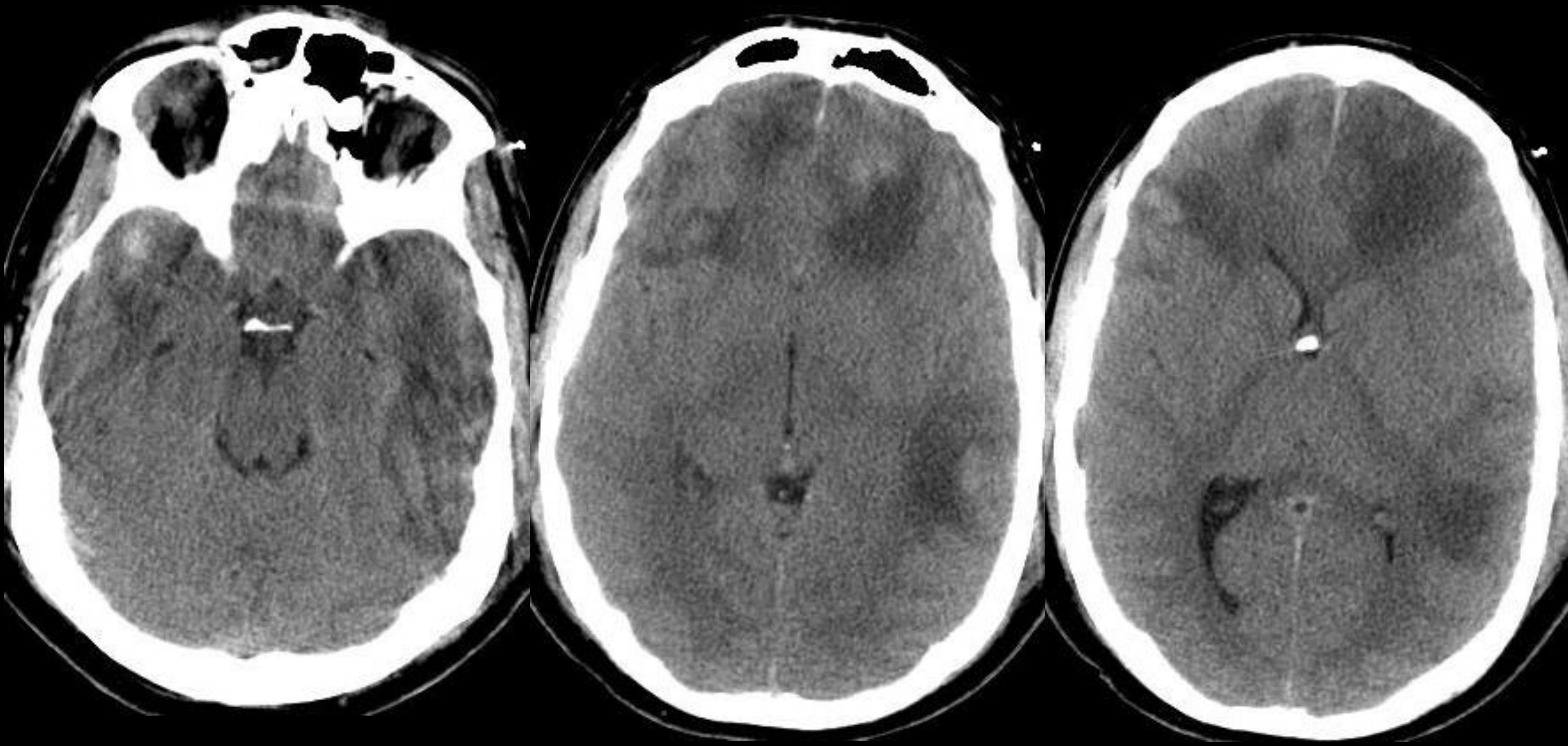
Shackford SR, et al. J Trauma 1992 Sep;33(3):385-94

WHAT DO WE LOOK FOR

- 4 key things: blood, contusions, mass effect, fractures
- Findings that correlate with poor outcome:
  - Traumatic subarachnoid hemorrhage
  - Large and/or multiple hematomas
  - Diffuse hemispheric swelling
  - Effacement of the basilar cisterns
  - Midline shift
  - Brainstem injury

d'Avella D, et al. Neurosurgery 2002 Jan;50(1):16-25
Firsching R, et al. Acta Neurochir (Wien) 2001;143(3):263-71
Eisenberg HM, et al. J Neurosurg 1990 Nov;73(5):688-98



SHORT TERM FOLLOW-UP

Clinical Condition: **Head Trauma**

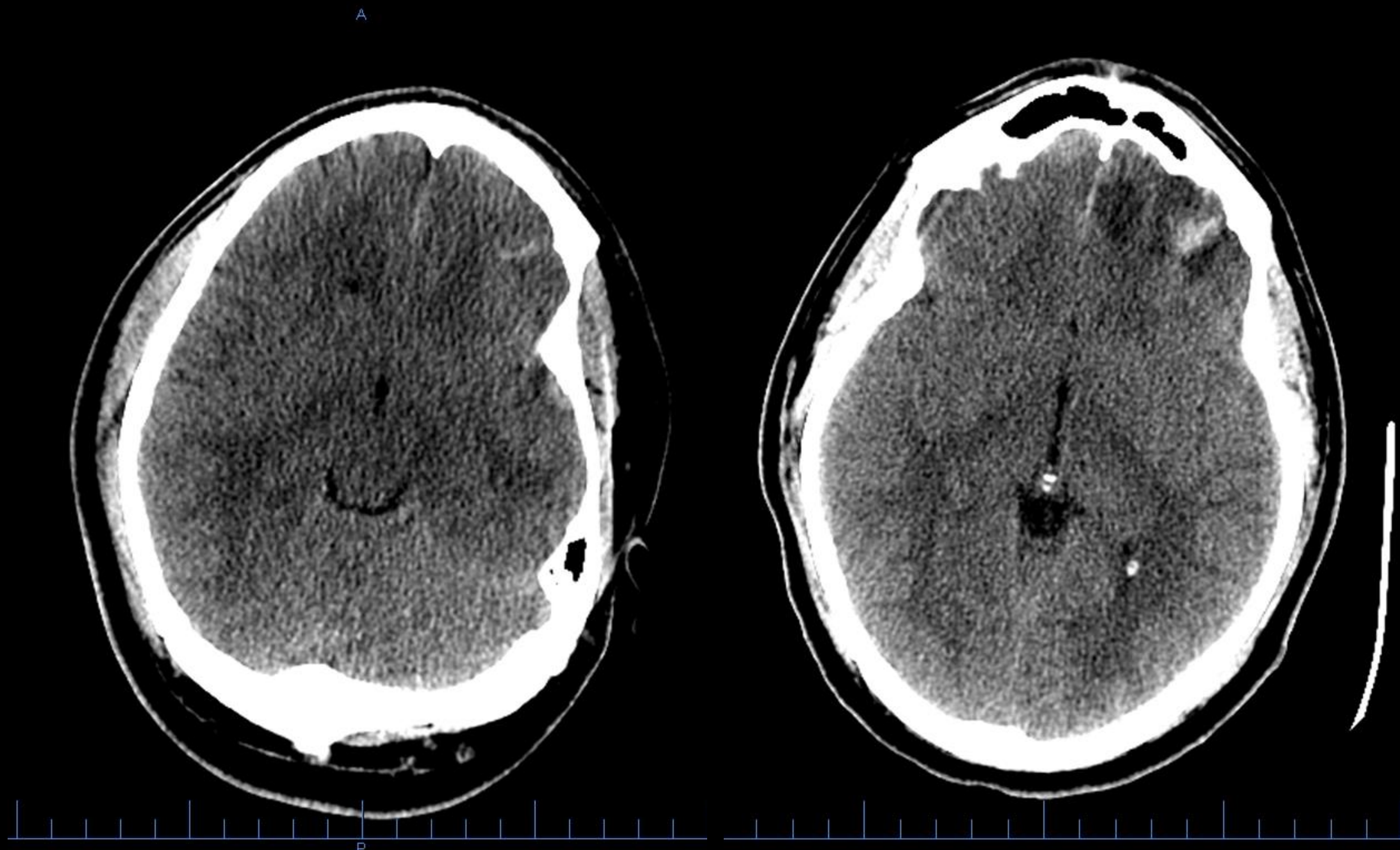
Variant 4: **Short-term follow-up imaging of acute traumatic brain injury. No neurologic deterioration.**

Radiologic Procedure	Rating	Comments	RRL*
CT head without IV contrast	5	This procedure can be used in patients with risk factors (see narrative).	☢☢☢
CTA head and neck with IV contrast	2		☢☢☢
MRI head without IV contrast	2		O
MRA head and neck without IV contrast	2		O

Clinical Condition: **Head Trauma**

Variant 5: **Short-term follow-up imaging of acute traumatic brain injury. Neurologic deterioration, delayed recovery, or persistent unexplained deficits.**

Radiologic Procedure	Rating	Comments	RRL*
CT head without IV contrast	9		☢☢☢
MRI head without IV contrast	8	This procedure is complementary if CT does not explain clinical symptoms.	O
CT head without and with IV contrast	5	This procedure can be used in patients with suspected post-traumatic infection.	☢☢☢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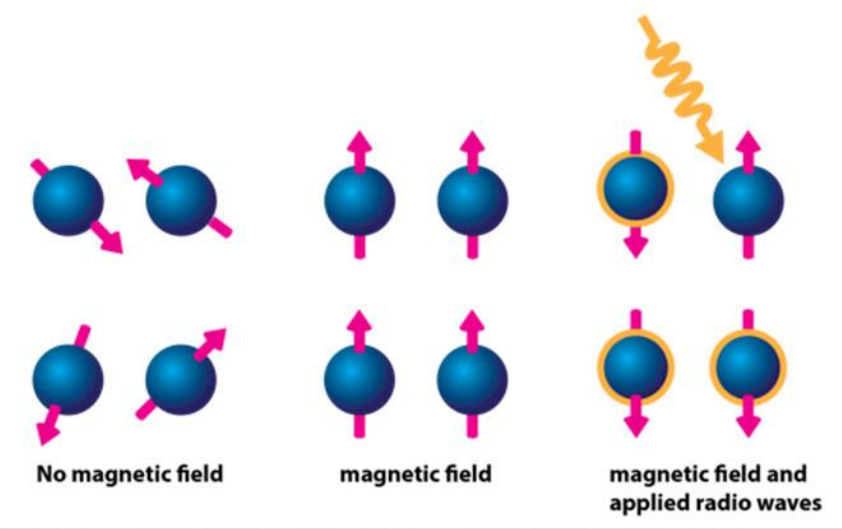
TAKE HOME POINTS – 1

1. CCHR and NOC can be used to reduce inappropriate use of head CT's in the setting of acute trauma.
2. CT remains the preferred imaging test for the initial evaluation of acute TBI because its fast & it readily identifies abnormalities that require urgent medical attention or surgical intervention.
3. A negative head CT effectively rules out an injury that needs surgical intervention

MR IMAGING

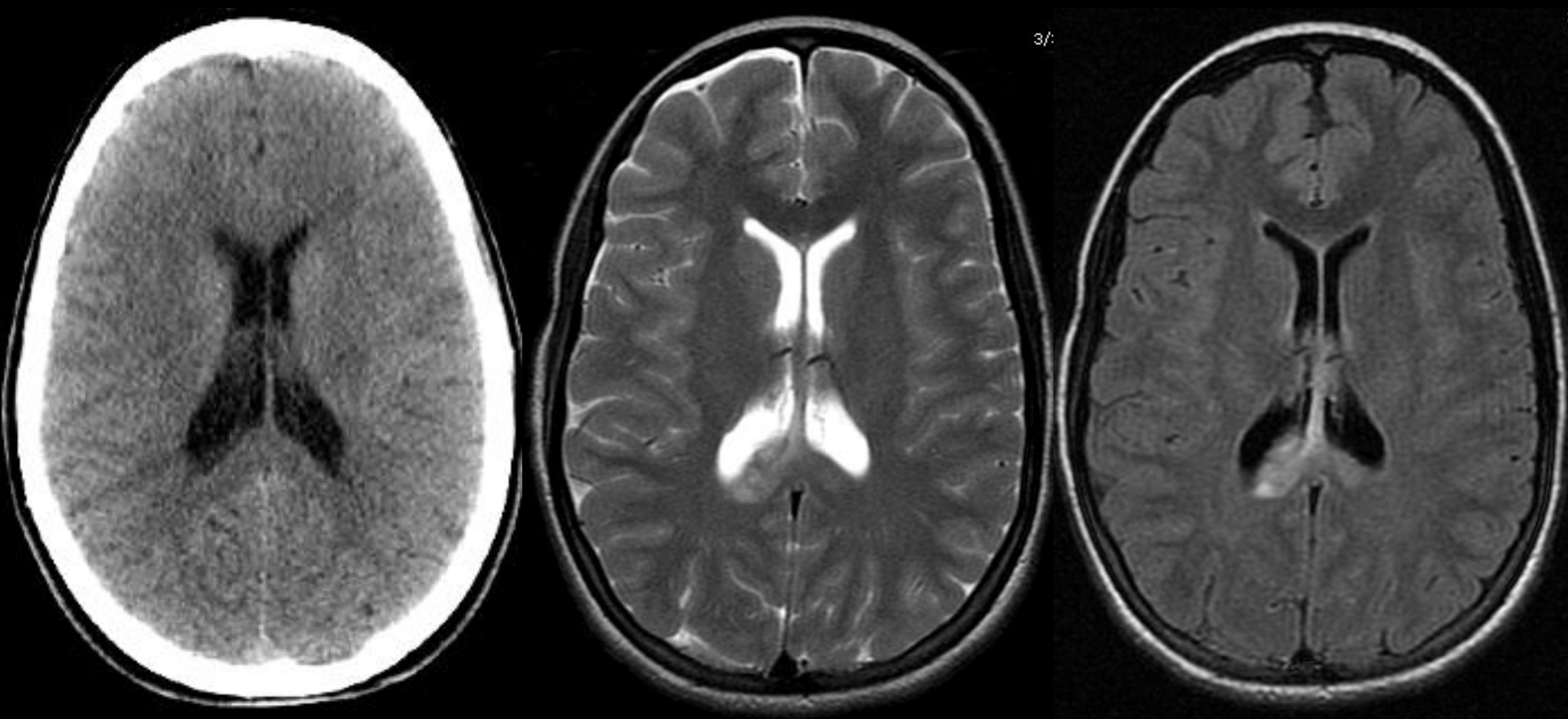

No magnetic field
magnetic field
magnetic field and applied radio waves

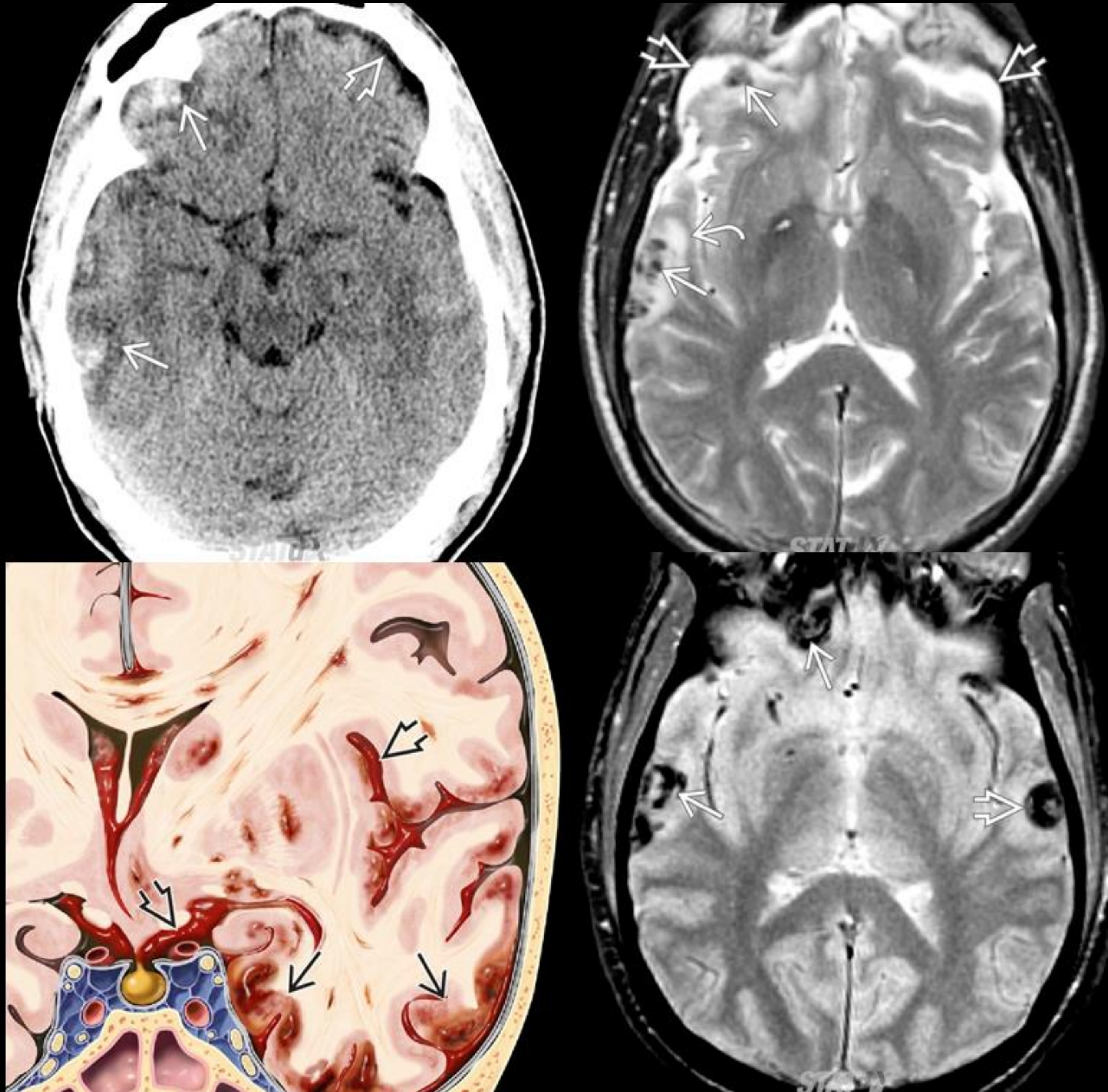

Vantage Elan
TOSHIBA

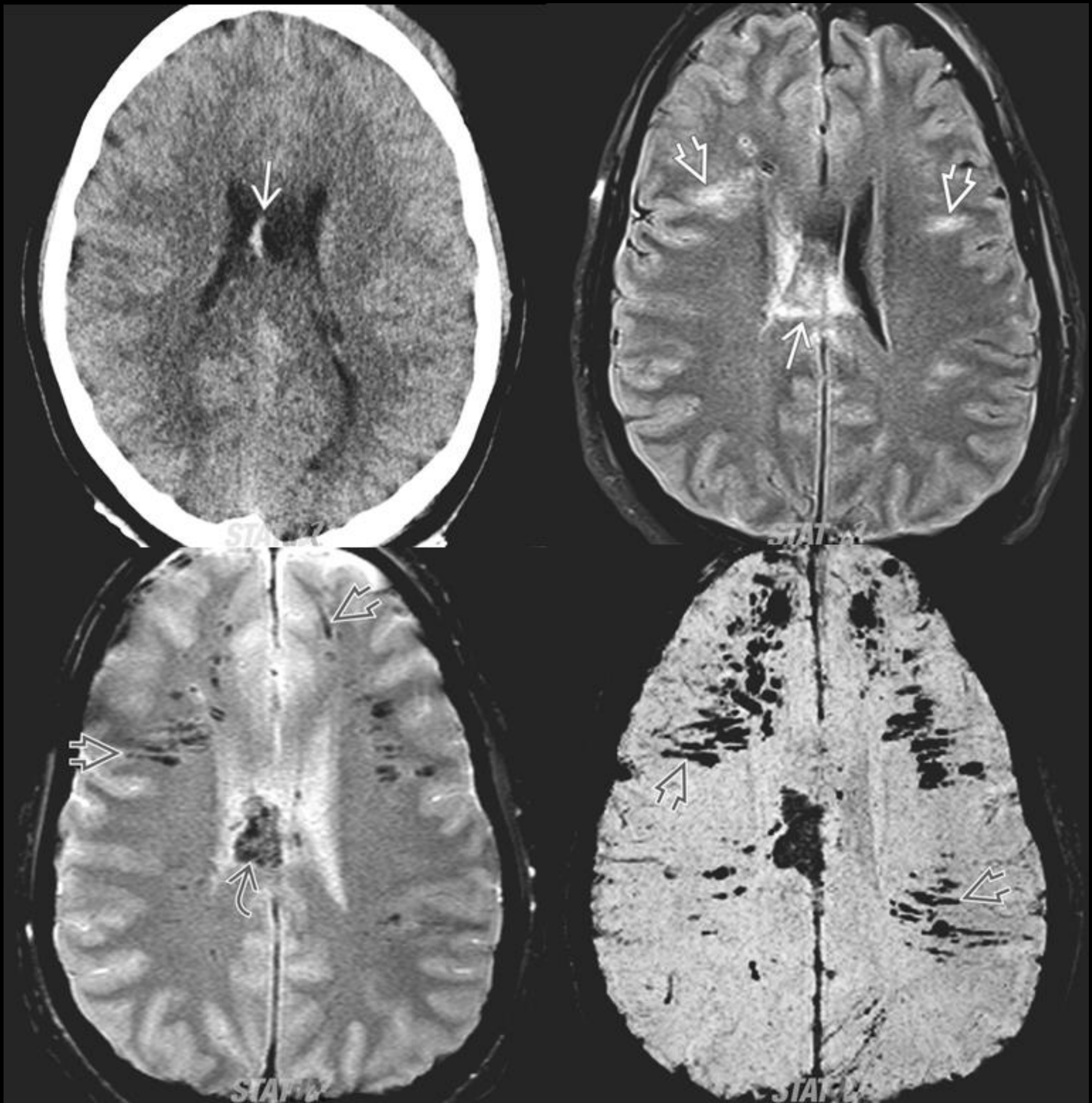
MR IMAGING

- MR's superior soft-tissue contrast makes it better for detecting:
  - non-hemorrhagic lesions (contusions)
  - hemorrhagic lesions (including DAI)
  - any secondary effects of trauma (such as edema and HIE)
- Also better for frontal lobe, temporal lobe & brainstem injuries
- 2015 ACR Appropriateness Criteria
  - MR is the study of choice in the subacute or chronic phase of closed head injury with new or persistent cognitive and/or neurologic deficit(s) not explained by CT

Shetty VS, et al. ACR Appropriateness Criteria® Head Trauma. Available at https://acsearch.acr.org/docs/69481/Narrative/. American College of Radiology. Accessed Apr 28, 2017.







ria
RADIOLOGY
IMAGING ASSOCIATES P.C.

T2* GE

T2W

MR CORRELATION WITH SEVERITY

- T2* GE findings correlate with GCS and PTA; T2 SE findings better predicts TFC
- Lesion depth on MR correlates with degree/duration of impaired consciousness and initial GCS
- Lesions on T2* gradient-echo images correlate with duration of impaired consciousness
- Significant differences have been found on neuropsych testing in mild TBI between pts with traumatic MR lesions and those without

Levin HS, et al. Neurosurgery 1997 Mar;40(3):432-40
Grados MA, et al. J Neurol Neurosurg Psychiatry 2001 Mar;70(3):350-8
Yanagawa Y, et al. J Trauma 2000 Aug;49(2):272-7
Kurca E, et al. Neuroradiology 2006, 48: 661–669

MR CORRELATION WITH OUTCOME

- Lesion depth correlates with disability at discharge from rehab and with outcome at 1y and 3y.
- Lesions on T2* gradient-echo images correlate w/ GOS at 3 mo.
- Traumatic callosal and dorsolateral brainstem lesions predict poor recovery.

Kampfl A, et al. Lancet 1998 Jun 13; 351(9118):1763-7
MacKenzie JD, et al. AJNR 2002 Oct; 23:1509-1515

TAKE HOME POINTS – 2

- Superior contrast resolution makes MR the preferred imaging tool for identifying the extent of TBI and its complications (shear injury, ischemia, etc).
- MR imaging of TBI must include GRE or SWI to optimally detect shear injury

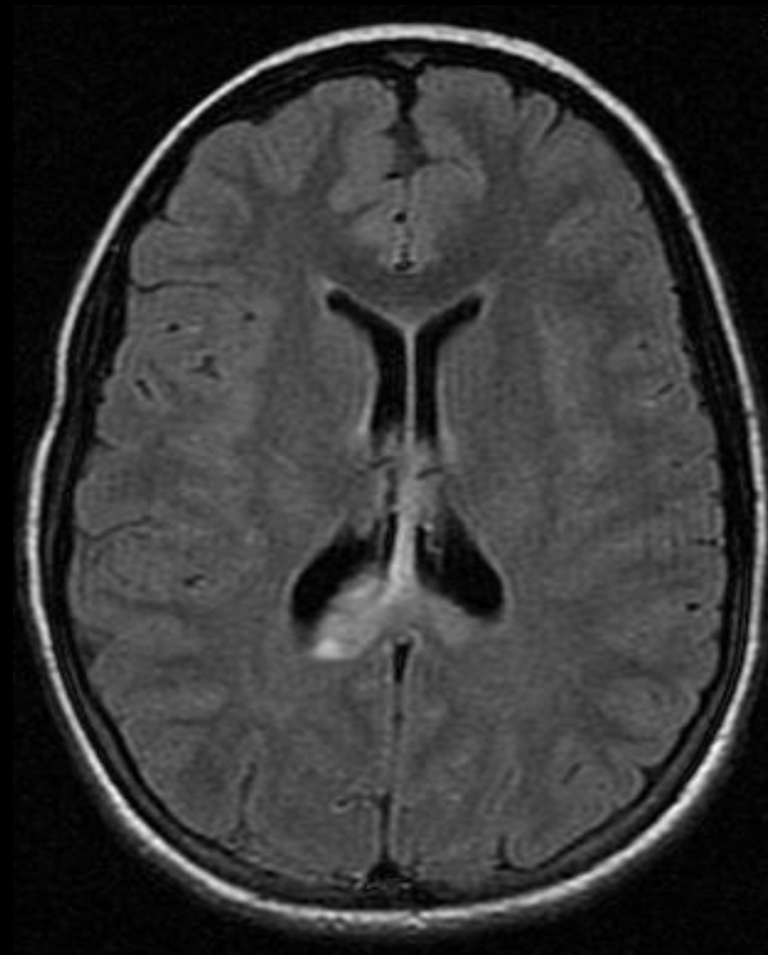
ANATOMIC IMAGING PROBLEM

- Based on animal studies, we know that pathologic/metabolic changes occur even in mild TBI, and those with persistent metabolic changes are at risk for second impact syndrome[1]
- Despite that, *43% to 68% of MTBI patients have normal conventional MR scans* despite neuropsychological or clinical impairment (the 'post-concussive syndrome')[2,3]
- Annually, mild TBI represents 75-90% of all head injuries, and accounts for ~ 44% of the $56B cost of TBI in the US[4,5]

1. Longhi L, et al. Neurosurgery 2005 Feb;56(2):364-74.
2. Hofman PA, et al: Am J Neuroradiol 2001; 22:441–449
3. Hughes DG, et al: Neuroradiology 2004; 46:550–558
4. Signoretti S, et al. Neurosurg Focus. 2010;29(5): 1-16
5. Thurman DJ. Head Trauma: Basic, Preclinical, and Clinical Directions. Edited by Miller L, Hayes R. New York, John Wiley & Sons, 2001, pp 327–347

ANATOMIC IMAGING PROBLEM

- TBI is not a single pathophysiological process. There are:
  - Subcellular events: calcium-mediated excitotoxicity, mitochondrial dysfunction, apoptotic cell death
  - Cellular level events: breakdown of the axonal cytoskeleton, cytotoxic edema
  - Macroscopic events: mass effect related to intra- or extra-axial hematomas, vascular compromise leading to ischemia
  - Psychological issues
- *Expecting a macroscopic anatomic imaging technique to sort all this out isn't realistic*



http://scientopia.org/blogs/scicurious/2011/05/04/science-101-the-neuron/

TOOLS

- MR Techniques
  - Diffusion-weighted imaging – evaluates cellular swelling
  - Diffusion tensor imaging – evaluates tissue microstructure
  - Spectroscopy – evaluates physiology (chemistry)
  - Functional MR – evaluates blood flow as a surrogate for neuronal function
- SPECT imaging – evaluates physiology (blood flow)
- PET imaging – evaluates physiology (metabolism), function
- US – Transcranial doppler – evaluates blood flow

ACR APPROPRIATENESS CRITERIA

- Advanced imaging techniques (perfusion CT, perfusion MRI, SPECT, and PET) "may be appropriate in selected cases"
  - Those techniques are not considered routine clinical practice at this time

DIFFUSION TENSOR IMAGING (DTI)

- DTI evaluates the directional diffusion of water molecules along the structural cytoskeleton (axolemma, microtubules, neurofilaments, and myelin sheaths).
- Diseases which disrupt axons or the cytoskeleton alter the pattern of diffusivity (water motion becomes less restricted)
- As a result, DTI allows us to assess changes in microstructural integrity (including injury related to diffuse axonal injury).

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RADIOLOGY

IMAGING ASSOCIATES P.C.

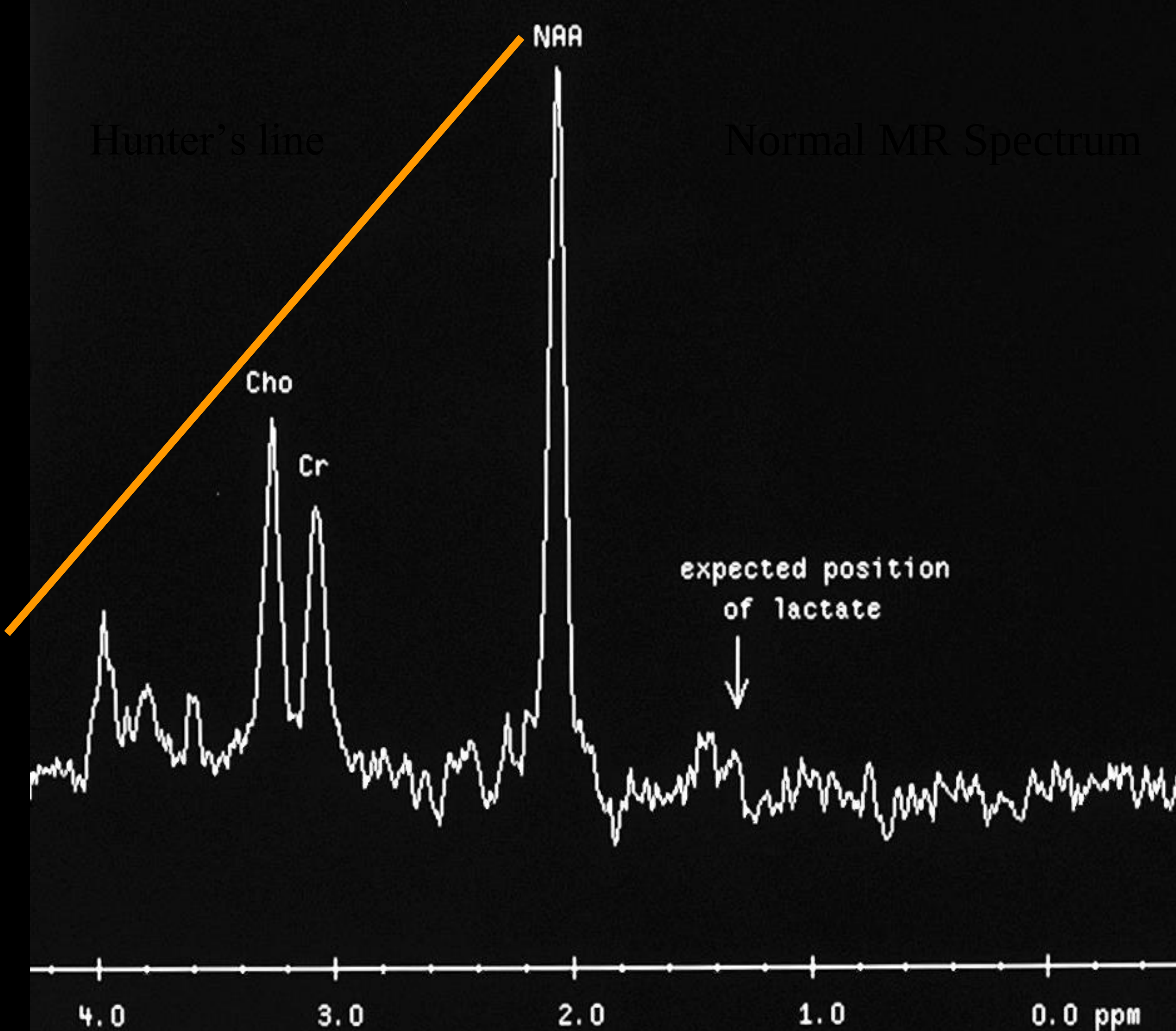
Predominant regions of DTI injury include: inferior longitudinal fasciculus (21%), uncinate fasciculus (29%), genu of the corpus callosum (21%), anterior corona radiata (41%), and cingulum bundle (18%).

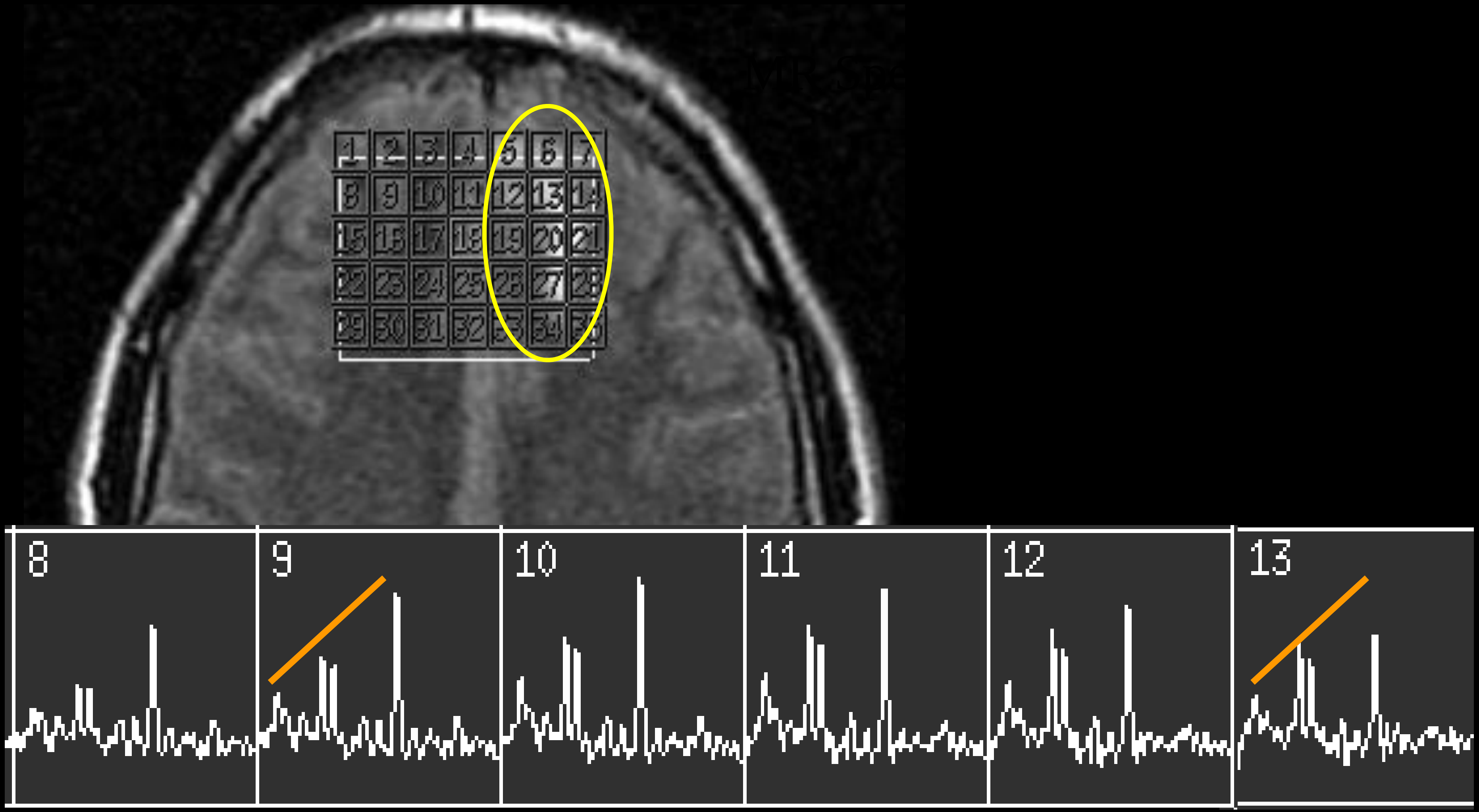
Niogi S et al. AJNR Am J Neuroradiol 2008; 29:967-973

MR SPECTROSCOPY

- MR imaging technique that produces a map of cerebral metabolites

Metabolite	Evaluates	Change in MTBI
NAA	Neuronal integrity	decr
Cr	Cellular energy metabolism	decr
Cho	Cellular turnover	incr
Lactate	Anaerobic glycolysis	present
Myo-Inositol	Astroglial proliferation	incr


Hunter's line
Normal MR Spectrum
NAA
Cho
Cr
expected position
of lactate
4.0
3.0
2.0
1.0
0.0 ppm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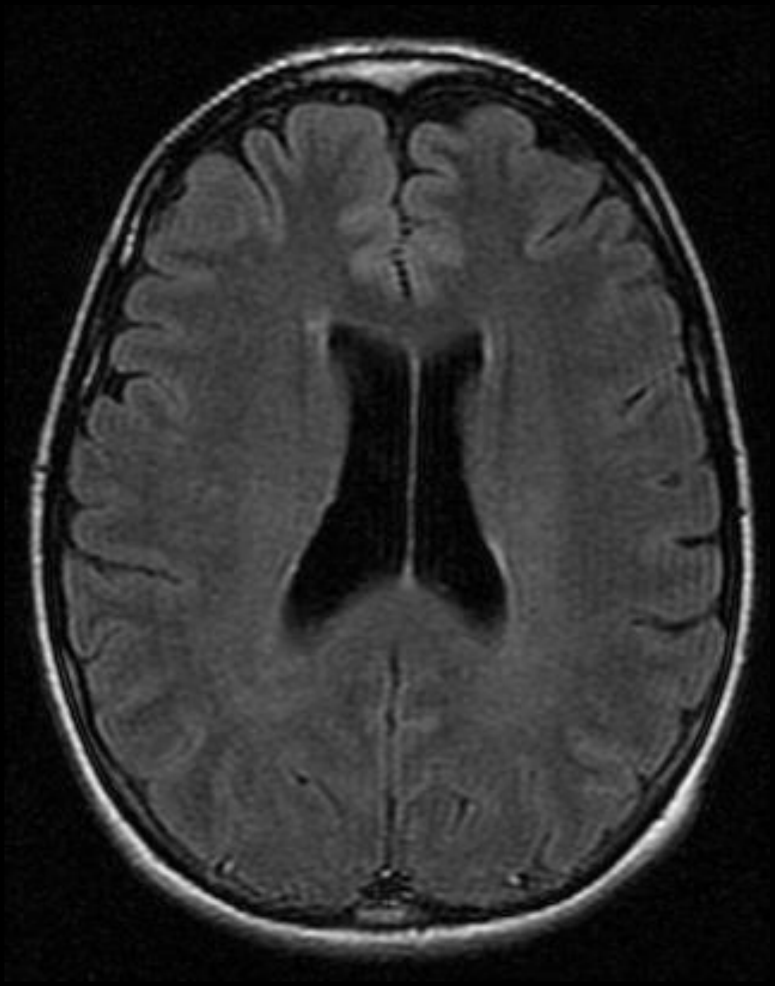
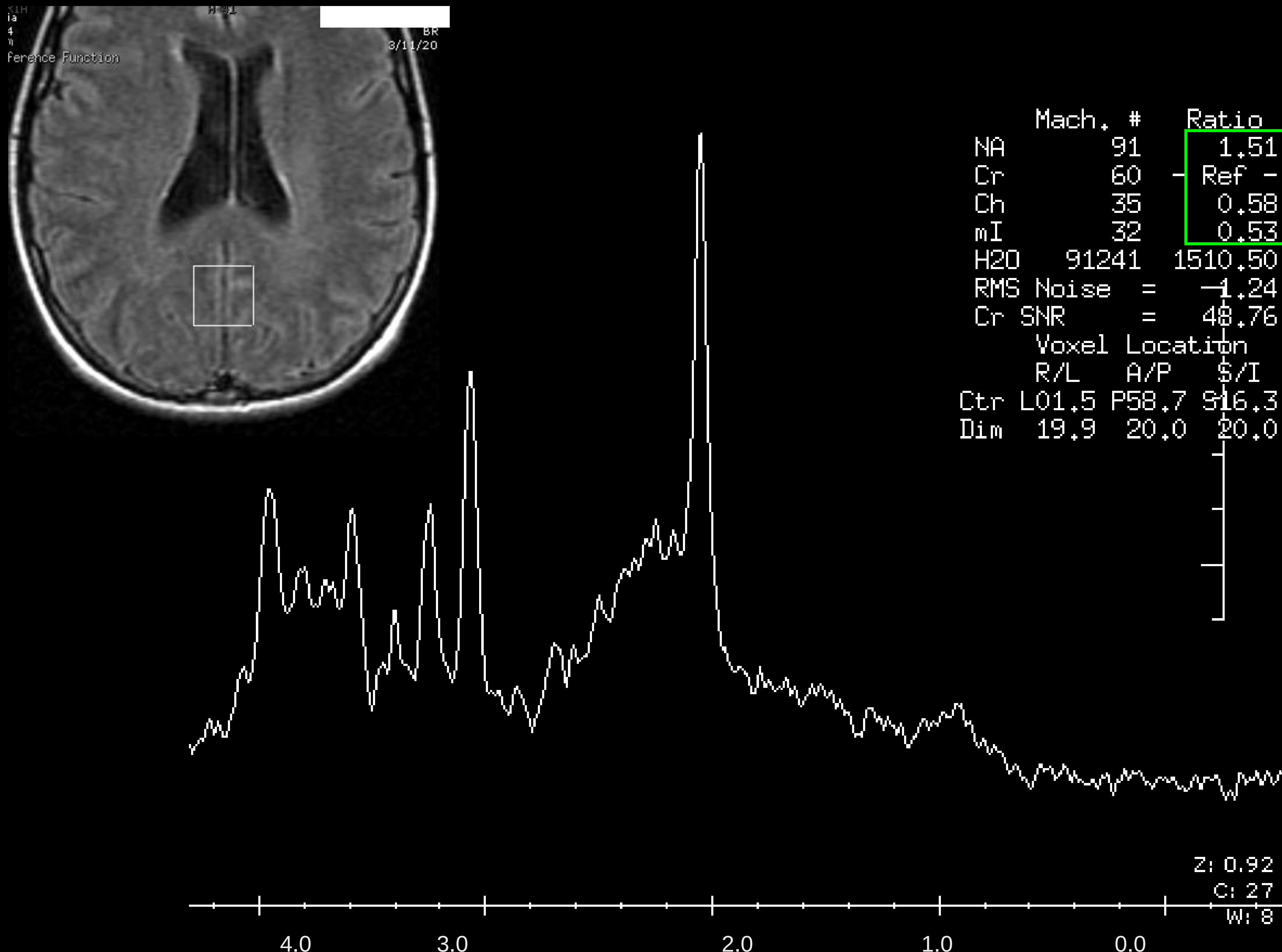
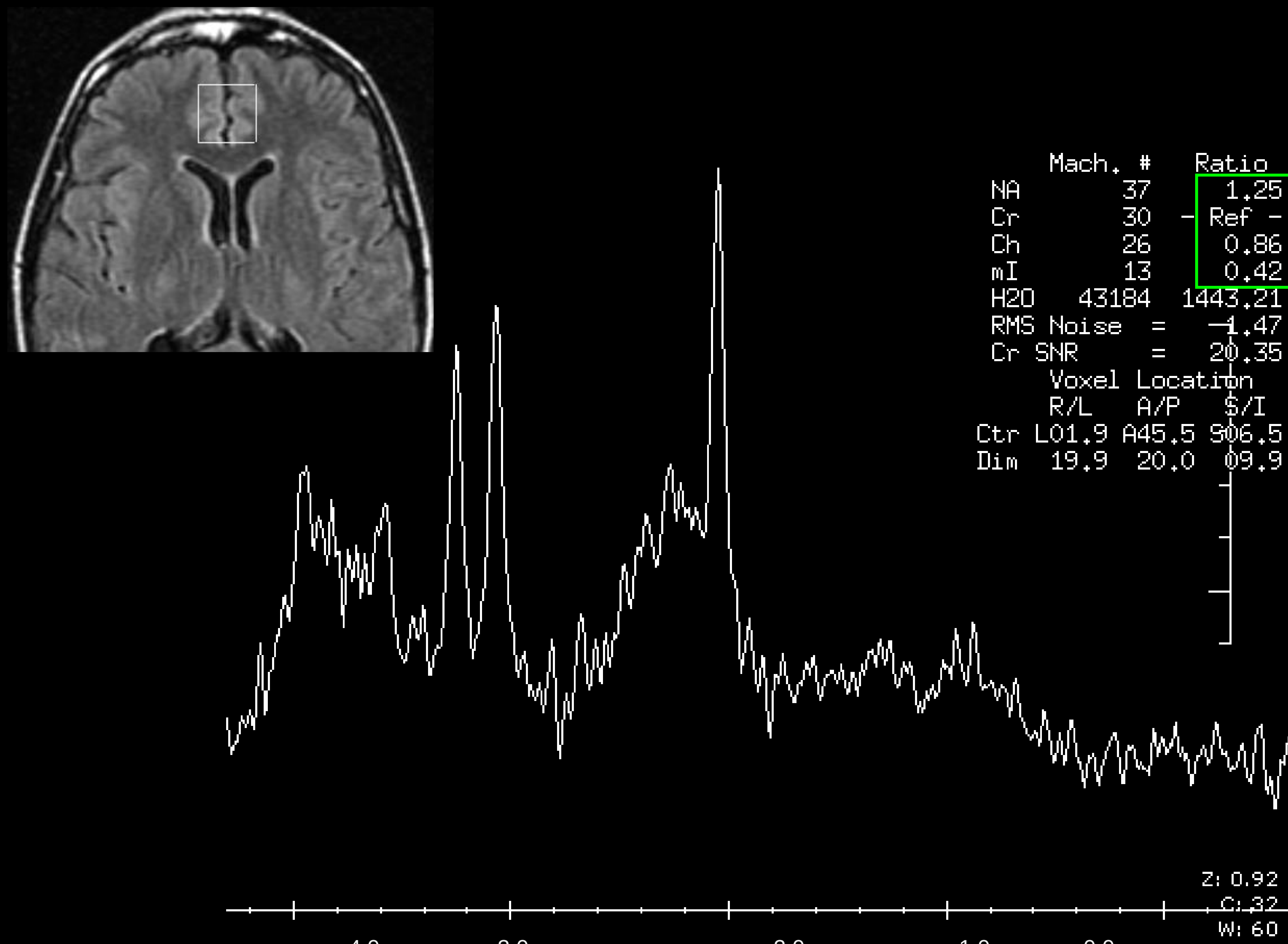



BR
3/11/20
Mach. # Ratio
NA 91 1.51
Cr 60 - Ref -
Ch 35 0.58
mI 32 0.53
H2O 91241 1510.50
RMS Noise = 1.24
Cr SNR = 48.76
Voxel Location
R/L A/P S/I
Ctr L01.5 P58.7 S16.3
Dim 19.9 20.0 20.0
Z: 0.92
C: 27
W: 8
4.0
3.0
2.0
1.0
0.0


Mach. # Ratio
NA 37 1.25
Cr 30 - Ref -
Ch 26 0.86
mI 13 0.42
H2O 43184 1443.21
RMS Noise = 1.47
Cr SNR = 20.35
Voxel Location
R/L A/P S/I
Ctr L01.9 A45.5 S06.5
Dim 19.9 20.0 09.9
Z: 0.92
C: 32
W: 60
4.0
3.0
2.0
1.0
0.0

Clinical Condition: **Head Trauma**

Variant 6: **Subacute or chronic traumatic brain injury with new cognitive and/or neurologic deficit(s).**

Radiologic Procedure	Rating	Comments	RRL*
MRI head without IV contrast	9		O
CT head without IV contrast	7	This procedure is an alternative; it is usually the first-line procedure in rapidly evolving new neurologic deficits or if MRI is contraindicated.	☢☢☢
MRA head and neck without IV contrast	3		O
MRA head and neck without and with IV contrast	3		O
FDG-PET/CT head	2		☢☢☢☢
CTA head and neck with IV contrast	2		☢☢☢
MRI functional (fMRI) head without IV contrast	2		O
MR spectroscopy head without IV contrast	2		O
MRI head without and with IV contrast	1		O
MRI head without IV contrast with DTI	1		O
CT head without and with IV contrast	1		☢☢☢
CT head with IV contrast	1		☢☢☢
X-ray skull	1		☢
Tc-99m HMPAO SPECT head	1		☢☢☢☢
Arteriography cervicocerebral	1		☢☢☢

TAKE HOME POINTS – 3

- Physiologic/functional techniques can provide insight into brain microstructure and function.
- They detect changes not demonstrated on conventional MR and CT and thus show promise as more sensitive tools for the detection of TBI.
- However, research data to date are insufficient to draw widespread conclusions, so more research is needed.

CONCLUSIONS

- CT: preferred imaging tool in the acute setting to triage TBI patients and identify lesions that require urgent surgery.
- MRI: preferred imaging tool to define the extent of TBI and identify shear injury, contusion, etc.
- Functional/physiologic techniques: provide insight into brain microstructure / function and may *ultimately* improve our ability to better characterize the extent of injury and predict outcome


LIPTON'S
TEA
ALT