Neuroimaging following Mild Traumatic Brain Injury in the Non-Deployed Setting

Introduction and Background

More than 273,000 service members have sustained a traumatic brain injury (TBI) between 2000 and the first quarter of 2013.[1] The majority of these (approximately 85%) occurred in the non-deployed environment and 82.4% were classified as mild TBI (mTBI), also known as concussion.[1,2] Neuroimaging following mTBI has been addressed in the deployed setting by the Joint Theater Trauma Systems (JTTS) Clinical Practice Guideline, "Use of Magnetic Resonance Imaging in the Management of Mild Traumatic Brain Injury (mTBI) Concussion in the Deployed Setting", the "Department of Defense Guidance for Management of Mild traumatic Brain Injury/ Concussion in the Deployed Setting" (Department of Defense Instruction DoDI 6490.11) as well as the

"Concussion Management Algorithms" (CMA).[3,4,5] The Veterans Affairs and Department of Defense clinical practice guideline, "Management of Concussion/ mTBI" provides guidance for imaging after seven days, (the acute stage).[6] This clinical recommendation (CR),

"Neuroimaging following mTBI in the Non-Deployed Setting" and companion clinical support tool (CST) offer guidance for Military Health System (MHS) providers as a standard approach for imaging from the acute through chronic stages following mTBI. Additionally, an appendix (Appendix A) containing expert recommended minimum technical parameters and sequencing is provided to promote standardization amongst the radiology community.

Summary

The guidance contained in this CR represents a review of currently published literature and expert contributions obtained by the Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury (DCoE) in collaboration with clinical subject matter experts representing the Services, Department of Veterans Affairs (VA), academic, research and civilian sectors. The TBI Quad Service group, an inter-agency, multi Service collaborative effort organized by TBI subject matter experts, which includes representatives from the Army, Navy, Marine Corps, Air Force, Defense and Veterans

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Coast Guard and the Department of Veterans Affairs (VA) have reviewed this recommendation. Current clinical imaging modalities included in this recommendation are: computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET) and single photon emission computed tomography (SPECT). The individual's history of concussion, clinical expertise, provider judgment and operational requirements may supersede any recommendation for each individual case, as service member safety is always paramount.

Neuroimaging is not recommended as part of a routine evaluation for all service members following mTBI. A physical exam, individual history and provider judgment should be combined to develop the best evaluation and treatment plan for each individual. Neuroimaging is recommended for the evaluation of service members with clinical red flags (Table 1.0, page 2), new onset or persistent or worsening symptoms, and individuals whose recovery is not progressing as anticipated. The specific recommendations described here for those individuals with acute, sub-acute and chronic mTBI. The clinical diagnosis of mTBI is based on a history of a traumatic injury in the context of a change in alteration in consciousness. Neuroimaging findings are not typically included in the diagnosis of mTBI. Current literature reports that 10-15% of individuals who sustain trauma, are alert and have grossly normal neurological function including a Glasgow Coma Scale score of 15 will have an acute brain lesion on CT, while fewer than 1% will have a lesion that requires neurosurgical intervention.[7] The lack of positive imaging findings does not invalidate a diagnosis of mTBI; nor do symptoms reported. In addition, the lack of neuroimaging findings should not deter the need for specialty referral should this be clinically indicated. Standardized

recommendations of testing parameters can aid care across the MHS by creating the capability to compare similar studies regardless of their origin as well as decrease repeated neuroimaging when not indicated.

Clinical Recommendation General Considerations

Red Flags

Current guidance of DODI 6490.11 and the CMA for management of concussion in deployed setting includes careful examination for red flags (clinical symptoms or signs that may indicate more severe injury).[4,5] Neuroimaging is important in the evaluation of service members with clinical red flags and can be completed with CT or MRI (see Table 4.0) if available and not contraindicated. Clinical Red Flags are reflected in Table 1.0 and combine the provider red flags indicated in the CMA and the recommended CT indications from the New Orleans Criteria.[5, 8]

Table 1.0 RED FLAGS (CMA and New Orleans Criteria for CT Scan[5, 8])			
Progressive declining level of consciousness (LOC)	Progressive declining, neurological exam	Focal neurological deficit: motor or sensory, slurred speech	Cannot recognize people or disoriented to place
Pupillary asymmetry	GCS < 15	Double vision	LOC > 5 minutes
Seizures	Worsening headache	Visible physical injury above clavicle	Repeated vomiting
Drug or Alcohol intoxication	Coagulopathy	Unusual behavior	Age > 60

Common mTBI Pathophysiology

The purpose or goal of neuroimaging determines the modality and techniques employed. There is increasing evidence that specific MRI imaging techniques correspond, at least in a general way, with specific posttraumatic histopathology. For example, diffusion tensor imaging (DTI) abnormalities are thought to correspond to axonal injury and susceptibility weighted imaging (SWI) abnormalities to microhemorrhages.[9] Table 2.0 provides information on the specific mTBI pathophysiology that may be identified for each imaging technique.

Table 2.0 Relationship Between Neuroimaging Techniques and Common mTBI Pathophysiology	
mTBI Pathophysiology	MRI imaging Technique
Axonal Injury/White matter injury	Fluid Attenuated Inversion Recovery (FLAIR) Diffusion Weighted Imaging (DWI) 2D/3D T2
Traumatic Sub-Arachnoid Hemorrhage (tSAH)	FLAIR 3D T1 weighted imaging Susceptibility Weighted Imaging (SWI)/Gradient Echo (GRE)
Cortical contusions / microhemorrhages	FLAIR 3D T1-weighted imaging SWI/GRE
Vascular injury	SWI/GRE
Volume loss	3D T1-weighted imaging

Neuroimaging in the Service Member who sustains mTBI: Acute, Sub-acute and Chronic Stages Acute Stage

The acute stage is defined as time of injury to seven days.[6] Most patients who sustain an mTBI complain of common symptoms such as headache or dizziness. In the absence of red flags or CT criteria (Table 1.0, page 2), no imaging is recommended. The goal of imaging in the acute stage of mTBI is to identify surgical masses or lesions in a service member with signs or symptoms of significant injury, such as the previously listed clinical red flags.[10, 11, 12] CT scan is the recommended acute imaging modality for persons with head injury and suspected intracranial pathology. CT is readily available, highly sensitive and is the least expensive test for the rapid detection of intracranial injury requiring urgent neurosurgical intervention and a standard imaging study in acute trauma protocols. CT does not include the risk of MRI with ferromagnetic materials such as in fragments which can be common in improvised explosive devices. Imaging studies for the individual with acute mTBI should be obtained within 48 hours.[13] CT exam is the recommended standard to determine trauma and/or focal neurological changes in the acute time period.[14] If clinically indicated, a CT exam is the first line for imaging in the acute stage. If symptoms are improving no imaging is recommended.

If new onset, persistent or worsening symptoms are observed, providers may consider obtaining an MRI after 72 hours when available and not contraindicated. An MRI should be considered in the acute stage if the service member:[3]

1. Sustained a concussion with alteration of consciousness (AOC) to include any memory loss greater than 15 minutes and has persisting or worsening symptoms after 72 hours.
2. S ustained concussion with loss of consciousness (LOC) <30 minutes and has persisting or worsening symptoms after 72 hours despite a normal CT.
3. Sustained three or more concussions in past 12 months.
4. H as a documented diagnosis of concussion and has a Military Acute Concussion Evaluation (MACE) Cognitive Score <25 after 72 hours post-injury.

In cases of contraindications, the primary care provider (PCP) may consider consult with specialists in nuclear medicine, radiology or neurology. It is recommended that PCPs consult a specialist if the clinical presentation is unusual or if their level of clinical experience or confidence may require additional expertise. Cervical spine (c-spine) imaging is recommended if there is point tenderness, pain with flexion or extension, focal neurological findings or mechanism of injury that is likely to affect the cervical spine (e.g., fall greater than three feet, motor vehicle crash, etc.). MRI studies can reveal incidental findings unrelated to patient-reported symptoms that may require unnecessary follow-up on irrelevant artifacts.

Sub-acute Stage

The sub-acute stage of mTBI is defined as 8 days to 89 days post-injury.[6] In the absence of red flags, new, persistent or worsening symptoms or if symptoms are improving, no imaging is recommended. The goal of imaging in the subacute stage of mTBI is to evaluate the service member, enhance understanding of symptoms, provide education and identify the need for specialist referral. Treatment of mTBI in the sub-acute stage includes addressing symptoms obtained by history. An accurate history aids in standardization and results in providing recommendations in the subacute stage as well as reducing unnecessary imaging in the mTBI population. The key pieces of information for the PCP to collect to better understand the service member's injury are reflected in Table 3.0.

Table 3.0	Comprehensive History
Key Consideration	Example

Trajectory of symptoms	Is the individual seeing improvement or worsening of symptoms?
Functional impact on patient. Consideration of the societal, occupational and familial function impacts on patient	Does the service member have the ability to rest or is there a requirement to return to normal activities immediately?
Service member's history of concussions	Has the service member experienced more than one concussion? If so, how many and over what period of time?
Service member's history of examinations and assessments	How many visits to medical care has the service member had since time of injury?
Symptom tracking and documentation	How are symptoms being documented and what is being used to track symptoms? (Example, Neurobehavioral Symptom Inventory).
Service member's history of imaging after injury	If indicated, has c-spine imaging been completed?

In the sub-acute stage of mTBI, there is a need to consider two possible presentations: those persons who have not received a previous imaging assessment and those who have received an imaging assessment and are currently receiving follow-up care. For both presentations, however, MRI is recommended as the imaging modality of choice in the sub-acute stage of mTBI.[10, 15, 16, 17] In a service member who has persistent or worsening symptoms, MRI may be 50% more sensitive than CT alone in detecting chronic lesions in white matter.[18] Additional considerations in sub-acute stage of mTBI as reflected in Table 4.0 in the sub-acute column include:

- In cases where the PCP refers to a specialist, it is recommended that a detailed individual history include history of injury and course of mTBI including past imaging studies and treatments.
- If MRI is unavailable or contraindications are present, CT is the modality of choice.• Preferred MRI sequences are listed in Table 4.0; Appendix A
- MRI should be completed prior to referral to a specialist.
- If there are no structural abnormalities identified on MRI or CT and/or abnormalities do not explain persistent symptoms, PET Hexamethylpropyleneamine Oxime (HMPAO) or Ethylcysteinate Dimer (ECD) SPECT may offer additional information in the understanding of sequelae following mTBI.[19, 20]
- If an individual has normal c-spine results during the acute stage, repetition of c-spine imaging is not recommended.

Chronic Stage

The chronic stage of mTBI is defined as 90 days or greater post-injury.[6] Imaging is not recommended unless the service member presents with, new, persistent or worsening symptoms. The goal of imaging in the chronic stage of mTBI is to further evaluate the individual's injury, enhance understanding of persistent symptoms, provide education and identify the need for specialist referral. Conventional MRI is the imaging modality of choice for the evaluation of new, persistent or worsening symptoms in individuals with chronic mTBI. If MRI is unavailable or contraindications are present, then non-contrast CT is the alternative modality. Additional considerations reflected in Table 4.0 in chronic stage mTBI include:

- A repeat of subsequent imaging is recommended if the previous exam was a CT.
- A repeat MRI is also suggested if a previous MRI indicates need for follow-up, or if it did not meet the minimum recommendations (see Table 4.0 and Appendix A).

- If there are no structural abnormalities identified on MRI or CT and/or abnormalities do not explain persistent symptoms, PET Hexamethylpropyleneamine Oxime (HMPAO) or Ethylcysteinate Dimer (ECD) SPECT may offer additional information in understanding sequelae following mTBI.[19, 20]

Table 4.0 Neuroimaging Recommendations following mTBI
No imaging is recommended if symptoms are improving

Modality	Clinical indications in mTBI	Acute (injury-7 days post injury) GOAL of IMAGING: Identify surgical mass or lesions via Clinical red Flags	Sub-Acute (8-89 Days post injury) GOAL of IMAGING: Evaluate, enhance counseling, identify need for referral	Chronic (90 days or greater post injury) GOAL of IMAGING: Evaluate, enhance counseling, identify need for referral
CT	Utility varies based upon length of time between injury and presentation	Modality of choice if clinical evaluation indicates	Use only if MRI is contraindicated	Use only if MRI is contraindicated
MRI	**Minimum** requirements of a mTBI exam includes: 1.5 tesla or above with 3D T1/T2, FLAIR, DWI/ DTI, SWI/GRE SWI/ GRE SWI may identify areas of prior DAI or prior microhemorrhage. GRE may be substituted if SWI not available or run as a complimentary exam DWI trace maps calculated from DTI data may be substituted for conventional DWI	If symptoms are worsening after 72 hours	Modality of choice	Modality of choice DWI has low yield for individuals with chronic mTBI and persistent symptoms
PET	18 FDG-PET	No clinical indication	If there are no structural abnormalities identified on MRI or CT and/or abnormalities do not explain persistent symptoms, PET may offer additional information in the understanding of sequelae following mTBI	If there are no structural abnormalities identified on MRI or CT and/or abnormalities do not explain persistent symptoms, PET may offer additional information in the understanding of sequelae following mTBI
SPECT	If PET not available, consider HMPAO or ECD SPECT	No clinical indication	If there are no structural abnormalities identified on MRI or CT and/or abnormalities do not explain persistent symptoms, SPECT may offer additional information in the understanding of sequelae following mTBI	If there are no structural abnormalities identified on MRI or CT and/or abnormalities do not explain persistent symptoms, SPECT may offer additional information in the understanding of sequelae following mTBI

Special Considerations Service Member Education

In the mTBI population, delivering consistent and comprehensive education provides the individual who has sustained an mTBI with a better understanding of evidence-based outcomes with a focus on recovery. In instances where imaging tests are not indicated, service members should be educated on the potentially harmful effects from unnecessary testing. The service member's education may also include information about imaging modalities and expectations of imaging procedures if clinically indicated.

Pregnancy

Women of reproductive age should be screened for pregnancy prior to imaging, when CT or other x-rays are needed, as well as prior to accessing neuroimaging environments.[21] Potential harm to the fetus or embryo may be caused by exposure to ionizing radiation.[21] Only the head is directly irradiated when conducting a head CT; therefore the risk is estimated to be lower, due to indirect scattered radiation as compared to exposure due to background radiation during the entire gestation period.[22] There is no conclusive evidence of harmful effects of MRI exposure to the developing fetus. However, if pregnancy is established, a risk- benefit analysis of the MRI should be conducted.[22] Pregnant women undergoing an MRI should provide written informed consent as documentation of their understanding of the potential risks and benefits, and the desire to proceed with the study.[21, 22] It is further recommended that the radiologist consult with the referring physician and provide documentation of the following information:[22]

- The information requested from the MR study cannot be acquired via other nonionizing radiation means (e.g., ultrasonography).
- The referring physician does not feel it is sensible to wait for the end of pregnancy to obtain data.• The data are needed to potentially affect the care of the individual or fetus during the pregnancy.

Contrast agents, such as those that contain gadolinium, should not be administered during pregnancy. The decision to use contrast agents should be made on a case-by-case basis by the referring provider and should include a supervising radiologist. In addition, the information should be well documented and the referring provider should be able to defend the decision to administer contrast agent.[21, 22]

Recommended Standards for MRI

The quality of imaging may be affected by the consistency of approach and order of sequences. Poor quality or substandard testing may result in unnecessary repeated testing of the service member. The recommended standards per the American College of Radiology (ACR) for CT of the head or brain include the following:[13]

- Sequential single-slice technique, multislice helical (spiral) protocol, or multidetector multislice algorithm.
- Contiguous or overlapping axial slices should be acquired with a slice thickness of no greater than 5 mm.
- In the setting of trauma, images should be obtained and/or reviewed at window settings appropriate for demonstrating brain and bone abnormalities as well as small subdural hematomas and soft tissue lesions (subdural windows).
- For imaging of the cranial base, an axial slice thickness as thin as possible, but no greater than 3 mm with spiral techniques and 2 mm with multi-detector and non-spiral techniques, should be used for 2D reformatting or for 3D reconstruction.

MRI offers a higher contrast resolution image of the brain and is generally more sensitive for detecting subtle intracranial pathology. MRI at 1.5 T has been reported to detect different markers of cerebral injury in up to 30% of individuals that have a normal head CT.[23] The sensitivity of MRI may make it an informative imaging tool for concussion in certain circumstances (see Table 4.0). The recommended mTBI MRI protocols preferred and alternate protocols for 1.5T and 3.0T are outlined in Appendix A. The minimum recommended magnet strength is 1.5T. The recommended protocols in Appendix A are meant as a guideline for radiologists and technologists who are imaging individuals who sustain a TBI. The goal of the standard protocol is to maintain reproducibility and comparability across the Military Health System as well as individuals in the VA system. These standard protocols reflect the recommended minimum standard and are not meant to supersede the clinician or radiologists' clinical judgment. Several variables may contraindicate the recommended standards resulting in the necessity to use a lower strength machines (such as open MRI) or an alternative method of imaging such as CT. Such variables may include an individual's body size, claustrophobia or a service member with implanted hardware or with retained metal fragments.

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Appendix A

The following protocols (Minimum preferred 1.5T; Alternate 1.5 T; Preferred 3.0T; Alternate 3.0T) are meant as guidelines for radiologists and technologists who are imaging service members who sustain a TBI. The goal of the standard protocol is to maintain reproducibility and comparability across both the Military Health System as well as extending into the care of these individuals into the VA system. The standard protocols reflect the recommended minimum standard and are not meant to supersede the clinician or radiologists' individual clinical judgment. The following is recommended:

- Keep all fields of vision (FOVs) the same as noted in the table if at all possible.
- Higher resolution can be used if desired but it will be at the expense of time and signal-to-noise ratio (SNR).

- Do not change, flip angles or echo times significantly. There is some variability between manufacturers, but changing these parameters extensively will result in unintended artifact and signal characteristics.
- If SWI is not available, run the same parameters as shown in the tables and save the phase data. (It will then be possible to reconstruct SWI data prospectively using appropriate software).
- When limited to using a 2D GRE scan, the alternate protocol is recommended.

Preferred -TBI MRI 1.5T Protocol
Head (Center at the orbital ridge)

Note
Please follow the sequence order

- FLAIR, SWI, 3D T2, T2 GRE sequences are acquired with a rectangular FOV.
- Elliptical filter is ON in FLAIR, T1 MPRAGE, and T2 GRE sequences.
- All other filters are OFF

Sequence Order	#1	#2	#3	#4	#5	#6	#7
	3D FLAIR	3D SWI	DWI	T1 MPRAGE	3D T2	T2* GRE *optional	DTI* *optional
Sequence	tse_vfl	swiIPAT	ep2d_diff	tfl	tse_vfl	gre_r	ep2d_diff
Orientation	Sagittal	Axial	Axial	Sagittal	Sagittal	Axial	Axial
TR (ms)	6000	50	5400	2000	3500	1110	6500
TE (ms)	353	40	100	3.22	355	26	100
TI (ms)	2200	-	-	1000	-	-	-
FA (degree)	-	15		8	-	20	-
FOV (mm^2)	256x208	256x192	256x256	256x256	256x208	256x192	256x256
Matrix size	256x256	512x256	128x128	512x256	256x256	256x256	128x128
Nz/TH (mm)/slab	160/1	64/2	32/4	120/2	160/1	32/4	32/2
Voxel size (mm3)	1x1x1	0.5x1x2	2x2x4	0.5x1x2	1x1x1	1x1x4	2x2x2
Ave./Meas.	1/1	1/1	3/1	1/1	1/1	1/1	10/1
Concatenations	1	1	1	1	1	1	1
Phase oversmpl.	0%	0%	0%	0%	0%	0%	0%
Dist. factor	-	-	0%	-	-	0%	0%
Phase Enc. Dir	A>>P	R>>L	A>>P	A>>P	A>>P	R>>L	A>>P
iPAT	None	2/24	2/24	None	None	None	2/24
BW (Hz/pixel)	888	80	1502	160	751	78	1502
Flow Comp	-	Yes	-	-	-	Yes	-
Phase partial Fourier	Off	Off	6/8	Off	Off	Off	6/8
Slice partial Fourier	6/8	Off	Off	Off	6/8	Off	Off
Filter	Elliptical	-	-	Elliptical	-	Elliptical	-
Saturation Band	None	None	None	-	None	None	None
Gap/Thickness (mm)	-	-	-	-	-	-	-
Diffusion Mode	-	-	3-Scan Trace	-	-	-	MDDW
Diff. Weightings	-	-	3	-	-	-	2

Noise level/Diff Directions	-	-	40/3	-	-	-	40/6
b-values	-	-	0, 500, 1000	-	-	-	0, 1000
Echo spacing (ms)	3.3	-	0.75	10	3.38	-	0.75
Turbo factor	213	-	-	-	209	-	-
Echo trains per slice	-	-	-	-	-	-	-
Coils	8 Channel Head	8 Channel Head	8 Channel Head	8 Channel Head	8 Channel Head	8 Channel Head	8 Channel Head
Time	8:50	5:47	2:27	8:32	7:05	3:35*	8:16
Total Time							**41:02 (44:37*)**

Alternate -TBI MRI 1.5T Protocol
Head (Center at the orbital ridge)

Note
Please follow the sequence order:

- **FLAIR, SWI, T2 TSE, T2 GRE sequences are acquired with a rectangular FOV.**
- **Elliptical filter is ON in FLAIR, T1 MPRAGE, T2 TSE and T2 GRE sequences.**
- **All other filters are OFF.**

Sequence Order	#1	#2	#3	#4	#5	#6	#7
	2D FLAIR	3D SWI	DWI	T1 MPRAGE	T2 TSE	T2* GRE *optional	DTI* *optional
Sequence	tse	swiIPAT	ep2d_diff	tfl	tse	gre_r	ep2d_diff
Orientation	Axial	Axial	Axial	Sagittal	Axial	Axial	Axial
TR (ms)	9540	50	5400	2000	7000	1110	6500
TE (ms)	114	40	100	3.22	106	26	100
TI (ms)	2500	-	-	1000	-	-	-
FA (degree)	150	15		8	160	20	-
FOV (mm^2)	256x192	256x192	256x256	256x256	256x192	256x192	256x256
Matrix size	256x256	512x256	128x128	512x256	256x256	256x256	128x128
Nz/TH (mm)/slab	32/4	64/2	32/4	120/2	32/4	32/4	32/2
Voxel size (mm3)	1x1x4	0.5x1x2	2x2x4	0.5x1x2	1x1x4	1x1x4	2x2x2
Ave./Meas.	2/1	1/1	3/1	1/1	1/1	1/1	10/1
Concatenations	2	1	1	1	1	1	1
Phase oversmpl.	0%	0%	0%	0%	0%	0%	0%
Dist. factor	0%	-	0%	-	0%	0%	0%
Phase Enc. Dir	R>>L	R>>L	A>>P	A>>P	R>>L	R>>L	A>>P
iPAT	2/30	2/24	2/24	None	None	None	2/24

BW (Hz/pixel)	201	80	1502	160	130	78	1502
Flow Comp	No	Yes	-	-	No	Yes	-
Phase partial Fourier	Off	Off	6/8	Off	Off	Off	6/8
Slice partial Fourier	Off	Off	Off	Off	Off	Off	Off
Filter	Elliptical	-	-	Elliptical	Elliptical	Elliptical	-
Saturation Band	None	None	None	-	None	None	None
Gap/Thickness (mm)	-	-	-	-	-	-	-
Diffusion Mode	-	-	3-Scan Trace	-	-	-	MDDW
Diff. Weightings	-	-	3	-	-	-	2
Noise level/Diff Directions	-	-	40/3	-	-	-	40/6
b-values	-	-	0, 500, 1000	-	-	-	0, 1000
Echo spacing (ms)	9.5	-	0.75	10	11.8	-	0.75
Turbo factor	29	-	-	-	17	-	-
Echo trains per slice	-	-	-	-	-	-	-
Coils	8 Channel Head	8 Channel Head	8 Channel Head	8 Channel Head	8 Channel Head	8 Channel Head	8 Channel Head
Time	2:53	5:47	2:27	8:32	2:55	3:35*	8:16
Total Time							**30:50 (34:25*)**

Preferred TBI MRI 3T Protocol
Head (Center at the orbital ridge)

Note
Please follow the sequence order:

- **3D SWI sequence is acquired with a rectangular FOV.**
- **Distortion Correction filters are OFF in all sequences.**

Sequence Order	#1	#2	#3	#4	#5	#6	#7
	3D FLAIR	3D SWI	DWI	T1 MPRAGE	3D T2	T2* GRE *optional	DTI* *optional
Sequence	tse_vfl	gre	ep2d_diff	tfl	tse_vfl	gre	ep2d_diff
Orientation	Sagittal	Axial	Axial	Axial	Sagittal	Axial	Axial
TR (ms)	6000	29	5000	1750	2500	818	818
TE (ms)	397	20	92	2.98	2.98	20	93
TI (ms)	2200	-	-	900	-	-	-
FA (degree)	-	15	90	9	-	20	-
FOV (mm^2)	256x256	256x192	256x256	256x256	256x256	256x192	256x256

Matrix size	256x256	512x256	128x128	512x256	256x256	256x256	128x128
Nz/TH (mm)/slab	160/1	72/2	32/4	192/1	192/1	32/4	46/2
Voxel size (mm3)	1x1x1	0.5x1x2	2x2x4	0.5x1x1	1x1x1	1x1x4	2x2x2
Ave./Meas.	1	1/1	2	1	1/1	1/1	10/1
Concatenations	1	1		1	1	2	1
Slice oversmpl.	0%	22.2%	0%	0%	0%	0%	0%
Dist. factor	0%	0%	25%	0%	0%	0%	0%
Phase Enc. Dir	A>>P	R>>L	A>>P	R>>L	A>>P	R>>L	A>>P
iPAT	2/24	2/24	2/24	2/24	2/24	2/24	2/24
BW (Hz/pixel)	2/24	120	1346	180	751	180	1346
Flow Comp	No	Yes	-	No	No	Slice/Read	-
Phase partial Fourier	Allowed	Off	6/8	Off	Allowed	Off	6/8
Slice partial Fourier	7/8	Off		Off	Off	-	-
Saturation Band							
Gap/Thickness (mm)							
Diffusion Mode			3-Scan Trace				MDDW
Diff. Weightings							2
Noise level/Diff Directions			40				40/30
b-values			0, 500, 1000				0, 1000
Echo spacing (ms)	3.32			3.32	3.42		
Turbo factor	141		128		141		
Echo trains per slice	1				1		
Coils	Head+Neck	Head	Head	Head	Head	Head	Head
Time	05:20	04:35	1:27	04:03	04:02	2:58*	07:50
Total Time							**27:52 (30:50*)**

Alternate TBI MRI 3T Protocol
Head (Center at the orbital ridge)

Note
Please follow the sequence order:

- **2D FLAIR, 2D T2 sequences are acquired with a rectangular FOV.**
- **Distortion Correction filters are OFF in all sequences**

Sequence Order	#1	#2	#3	#4	#5	#6	#7
	2D FLAIR	3D SWI	DWI	T1 MPRAGE	2D T2	T2* GRE *optional	DTI* *optional
Sequence	tse	gre	ep2d_diff	tfl	tse	gre	ep2d_diff
Orientation	Axial	Axial	Axial	Axial	Axial	Axial	Axial
TR (ms)	8000	29	5000	1750	6000	818	7200
TE (ms)	129	20	92	2.98	94	20	93
TI (ms)	2500	-	-	900	-	-	-
FA (degree)	150	15	90	90	120	20	-
FOV (mm^2)	256x192	256x192	256x256	256x256	256x192	256x192	256x256
Matrix size	256x256	512x256	128x128	512x256	256x256	256x256	128x128
Nz/TH (mm)/slab	64/2	64/2	32/4	192/1	64/2	32/4	46/2
Voxel size (mm3)	1x1x2	0.5x1x2	2x2x4	0.5x1x2	1x1x2	1x1x4	2x2x2
Ave./Meas.	1/1	1/1	2	1	2/1	1/1	2
Concatenations	3	1		1	2	2	1
Slice oversmpl.	0%	22.2%	0%	0%	0%	0%	0%
Dist. factor	0%	0%	25%	0%	0%	0%	0%
Phase Enc. Dir	R>>L	R>>L	A>>P	R>>L	R>>L	R>>L	A>>P
iPAT	2/46	2/24	2/24	2/24	2/32	2/24	2/24
BW (Hz/pixel)	296	120	1346	180	222	180	1346
Flow Comp	Slice	Yes	-	No	Slice	Slice/Read	-
Phase partial Fourier	Off	Off	6/8	Off	Off	Off	6/8
Slice partial Fourier	Off	Off		Off	Off		
Saturation Band							
Gap/Thickness (mm)							
Diffusion Mode	-	-	3-Scan Trace	-	-	-	MDDW

Diff. Weightings	-	-		-	-	-	2
Noise level/Diff Directions	-	-	40	-	-	-	40/30
b-values	-	-	0, 500, 1000	-	-	-	0, 1000
Echo spacing (ms)	11.7	-		7.6	11.7	-	
Turbo factor	17		128		15		
Echo trains per slice	7				7		
Coils	Head+Neck	Head	Head	Head	Head	Head	Head
Time	03:14	04:35	1:27	04:03	03:02	2:58*	07:50
Total Time							**23:54 (26:52*)**