ISSN 1220-8841 (Print)
ISSN 2344-4959 (Online)

ROMANIAN
NEUROSURGERY

Vol. XXXVI | No. 2 June 2022

Diagnostic and prognostic role of magnetic resonance imaging in cases of moderate to severe traumatic brain injury

Sanjeev Pattankar,
Nishanth Sadashiva,
Priyadarshi Dikshit,
Ved Prakash Maurya,
Dhaval P. Shukla,
Umamaheswara Reddy V.,
Rakesh Mishra,
Amit Agrawal

DOI: 10.33962/roneuro-2022-037

Romanian Neurosurgery (2022) XXXVI (2): pp. 209-215
DOI: 10.33962/roneuro-2022-037
www.journals.lapub.co.uk/index.php/roneurosurgery

Diagnostic and prognostic role of magnetic resonance imaging in cases of moderate to severe traumatic brain injury

Sanjeev Pattankar[1], Nishanth Sadashiva[2], Priyadarshi Dikshit[1], Ved Prakash Maurya[1], Dhaval P. Shukla[2], Umamaheswara Reddy V.[3], Rakesh Mishra[4], Amit Agrawal[5]

[1] Department of Neurosurgery. Sanjay Gandhi Post Graduate Institute of Medical Sciences, INDIA
[2] National Institute of Mental Health and Neurosciences [NIMHANS], Bangalore, INDIA
[3] Department of Radiology, Narayana Medical College Hospital, Chinthareddypalem, Nellore, Andhra Pradesh, INDIA
[4] Department of Neurosurgery. Institute of Medical Sciences, Banaras Hindu University, Varanasi, INDIA
[5] Department of Neurosurgery. All India Institute of Medical Sciences, Saket Nagar, Bhopal, Madhya Pradesh, INDIA

Keywords
diffusion axonal injury, haemorrhagic, magnetic resonance imaging, non-haemorrhagic, prognostication, traumatic brain injury

Corresponding author:
Ved Prakash Maurya

Department of Neurosurgery. Sanjay Gandhi Post Graduate Institute of Medical Sciences, Lucknow, India

vpmsurgery@gmail.com

ABSTRACT

Moderate to severe traumatic brain injury (TBI) remains a leading cause of death and disability worldwide. Timely diagnosis and accurate prognostication play a key role in informed clinical decision-making. Though magnetic resonance imaging (MRI) is a superior anatomical scan compared to computerized tomography (CT), the latter remains the current investigation of choice in the clinical setting of TBI due to some of the former's inherent deficiencies in imaging bone/blood, limited access, cost, etc. Nevertheless, the fact that MRI is a valuable adjunct in evaluating the TBI patients with clinical findings disproportionate to the CT scan substantiates its possible complementary/supplementary diagnostic and prognostic role in TBI. MRI scan is ideally placed on demonstrating the shear/diffuse axonal injury (DAI), non-haemorrhagic intraparenchymal lesions, and brain stem lesions poorly delineated by a CT scan. The currently available literature demonstrates that DAI and caudal brainstem lesions are indicators of poorer outcomes. However, the prognostic value of MRI, in addition to that of CT, remains an area of active investigation. We have tried to present the evidence-based use of MRI in moderate to severe TBI. Advances in newer MRI sequences like susceptibility-weighted imaging (SWI), diffusion tensor imaging (DTI), functional MRI (fMRI), and magnetic encephalography (MEG) have the potential to revolutionize the current role of MRI in TBI.

INTRODUCTION

Though computerized tomography (CT) scan of the head remains the investigation of choice for evaluation of a victim of acute traumatic

Copyright and usage. This is an Open Access article, distributed under the terms of the Creative Commons Attribution Non-Commercial No Derivatives License (https://creativecommons.org/licenses/by-nc-nd/4.0/) which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is unaltered and is properly cited.
The written permission of the Romanian Society of Neurosurgery must be obtained for commercial re-use or in order to create a derivative work.

ISSN online 2344-4959
© Romanian Society of Neurosurgery

First published
June 2022 by
London Academic Publishing
www.lapub.co.uk

brain injury (TBI), magnetic resonance imaging (MRI) can play a valuable complementary diagnostic/prognostic role in the same [1]. MRI is a superior anatomical scan to CT in all clinical settings, except in the acute moderate to severe TBI, due to its inherent deficiencies in imaging bone/blood. With ever-increasing accessibility seen to MRI scanners worldwide, there is an accompanying increase in the interest, among clinicians and radiologists alike, regarding the utility of MRI in diagnosing and prognosticating a variety of traumatic pathological conditions [2].

The role of MRI scanning in identifying and characterizing specific sequelae of TBI is well documented [3]. Particularly in evaluating patients whose clinical findings are disproportionate to the CT findings, MRI represents a valuable adjunct even in the acute phase. In such cases, MRI demonstrates the shear/diffuse axonal injury (DAI), non-hemorrhagic intraparenchymal lesions, and brain stem lesions poorly delineated by a CT scan. In subacute or chronic head injury, MRI is superior to CT and should be the primary imaging technique whenever possible [3]. Despite its unparalleled sensitiveness to deep intraparenchymal TBI lesions and shear injuries, the broad clinical adaptation of MRI in the trauma setting is limited, partly due to its higher costs, finite access, and more prolonged time consumption.

Early prognostication of moderate to severe TBI facilitates appropriate counseling of patients/families, aiding in sound clinical decisions. These informed clinical decisions are essential, as >50% of such patients end up with a permanent disability. Widely used CT prognostication scoring systems like Rotterdam/Marshall/Stockholm predict mortality better than TBIs' morbidity/permanent disability [1,4]. The 'centripetal model' of TBI, based on animal and postmortem studies, was proposed to better understand the role of shearing injury in clinical outcomes, and add to the existing CT prognostication [5]. It stated that the severity of grading of TBI should be directly proportional to the most caudal cerebral structure affected by the shearing injury. MRI is an ideal imaging modality to achieve the same. Nevertheless, the prognostic value of MRI, in addition to that of CT, remains an area of active investigation. We have tried to present the evidence-based use of MRI in moderate to severe TBI.

Protocol of MRI for TBI

The National Institute of Neurological Disorders and Stroke (NINDS) and several co-sponsoring Federal agencies have proposed common data elements (CDE) for developing data standards for clinical research. The following table shows the CDE for tier 1 evaluation of TBI using 1.5T MRI. Other advanced protocols are available at the NINDS website (**Table 1**).

Diagnostic Role of MRI in TBI

MRI appearance of traumatic lesions

Though CT is highly sensitive for detecting large intracranial hematomas, Gradient echo (GRE) and T2-weighted MRI are equally sensitive. T2 FLAIR (Fluid Attenuated Inversion Recovery) is more sensitive than CT to detect minor cerebral contusions. T2 FLAIR and GRE are as sensitive as CT for traumatic subarachnoid haemorrhage (SAH). T2 FLAIR and DWI (Diffusion-weighted Imaging) are more sensitive for non-hemorrhagic DAI, and GRE and SWI (Susceptibility weighted Imaging) for hemorrhagic DAI. Susceptibility weighted imaging (SWI) is a high-resolution three-dimensional imaging sequence. It is roughly six times more sensitive than the T2-weighted sequence for detecting traumatic microhemorrhages [6]. DWI is the sequence of choice for ischemia. It is essential to differentiate between hemorrhagic and non-hemorrhagic lesions as the hemorrhagic lesions are associated with a worse prognosis. The GRE and T2-weighted MRI sequences also detect signal dropout caused by iron-containing heme groups in slow-moving blood. Distributions of the microhemorrhages in areas associated with axonal injury such as the corpus callosum, brainstem, and other white matter tracts strongly suggest an imaging diagnosis of DAI. DAI microhemorrhages typically appear as punctate signal-free lesions in the white matter that 'bloom'.

Consequently, signal loss caused by punctate haemorrhages from DAI can be visualized years after injury though lesions fade over time. The density of T2-weighted lesions is associated with the severity of TBI in terms of admission Glasgow Coma Scale (GCS) and maximum intracranial pressure (ICP) during admission 3-month Glasgow Outcome Score. Another factor that needs consideration is the magnetic field strength used, as a 3 Tesla MRI demonstrates practically twice the sensitivity of a 1.5 Tesla device for microhemorrhages.

Table 1. Common data element (CDE) protocol for imaging parameters for MRI in TBI[1].

Sequence	3D T1W (MPRAGE, 3D IRFSPGR, 3D FFE)	T1W SE (opt if no 3D T1W)	T2W FSE	T2W FLAIR	DWI EPI	3D SWI†	2D GRE (FFE) (opt if no 3D SWI)
Orient	Sagittal	Sagittal	Axial*	Axial*	Axial*	Axial*	Axial*
TR (ms)	9-30	500-600	>3500	>9500	>5000	50	>500
TE(ms)	3-5	15-20	>90	>110	>100	40	>20
TI (ms)	1000			>2000			
FA (degrees)	8-10	90	90	150	90	15	15-20
Freq FOV mm (Phase FOV)	256(100%)	230(87.5%)	230(87.5%)	230(87.5%)	256(100%)	230(87.5%)	230(87.5%)
Matrix size	256x256	256x192	256x192	256x192	128x128	512x192	256x192
# Slices/ Thickness (mm)	120/2	32/4	32/4	32/4	32/4	94/2	32/4
Gap	0	0-20%	0-20%	0-20%	0-20%	0	0-20%
Voxel size(mm)	1x1x2	1x1x4	1x1x4	1x1x4	2x2x4	0.5x1x2	1x1x4
NEX	1	2	1-2	2	1-3	1	1-2
Phase Enc. Dir	A to P	A to P	R to L	R to L	A to P	R to L	R to L
Fat suppress	no	no	no	yes	yes	no	no
≅BW(Hz/Px)	160	120	130	200	≥1200	80	80-100
Flow Comp	no	slice	no	no	no	slice	slice
≅ETL			15-20	30	128		
b-values (sec/mm^2) (Directions)					0/1000** (3)		
≅Time* **	8:00	3:00	3:00	3:00	2:00	8:00	3:00

[1] Source-https://www.commondataelements.ninds.nih.gov/Traumatic%20Brain%20Injury#pane-162

*Recommend angle to AC-PC line; ** Use 800 sec/mm2 for infants <1 year old; ***To reduce acquisition time, use parallel imaging, if possible, AF/CL of 2/24-32; † Can use SWAN on GE systems.

Abbreviations: IR-FSPGR - Inversion recovery, fast spoiled gradient recalled echo; MPRAGE - Magnetization prepared-rapid gradient echo; FFE - Fast field echo; FSE – Fast spin echo; SE- Spin echo; FLAIR – Fluid attenuated inversion recovery; EPI - echo-planar imaging; SWI- Susceptibility-weighted imaging; GRE- Gradient echo; TE - echo delay time; TR - repetition time; TI- Inversion time; FA - fractional anisotropy; FOV - field of view; NEX - number of acquisitions; BW – bandwidth; ETL- Echo train length; A to P – Anterior to posterior; R to L – Right to left.

Classification of Severity of DAI

Grading of DAI has been described histologically according to the anatomic distribution of injury, which correlated with the clinical outcome. The classification was proposed first by Adams in 1989 and divided DAI into three grades [5]. This is the commonly applied grading system for classifying DAI lesions seen on MRI.

- Grade I: Involves grey-white matter interfaces (Figure 1).

Most commonly: Parasagittal regions of frontal lobes, periventricular temporal lobes, Parietal and occipital lobes, internal and external capsules, and cerebellum.

- Grade II: Involves corpus callosum in addition to grade I locations (Figure 2).

Most commonly: Posterior body and splenium but advance anteriorly with increasing injury severity. Most frequently seen unilateral. It may be seen on the SWI sequence.

- Grade III: Involves brainstem in addition to grade I and II locations (Figure 3).

Most commonly: Rostral midbrain, superior cerebellar peduncles, medial lemnisci, and corticospinal tracts.

Grading of brainstem lesions was proposed by Firsching et al. and has been validated by others [7–10]

- Grade I: No brainstem involvement; lesions of only hemispheres.
- Grade II: Unilateral brainstem lesions at any level with or without supratentorial lesions.
- Grade III: Bilateral lesions of the mesencephalon with or without supratentorial lesions.
- Grade IV: Bilateral lesions of the pons with or without lesions of lesser grades.

Brainstem injury can be categorized as anterior or posterior, hemorrhagic or non-hemorrhagic, and unilateral or bilateral [11]. Other alternative classification of brainstem injury is primary or secondary due to herniation. The primary injury can be due to a direct impact against the tentorial free edge or as a part of DAI [12,13]. The brainstem lesions are also classified as superficial or deep [13]. The grading assigned by both the systems is determined by the most caudal brain lesion present, though their definitions vary.

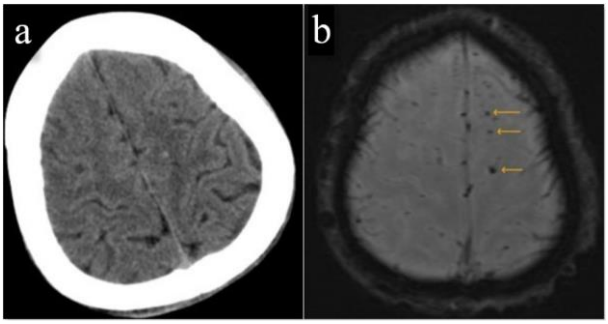

Figure 1. Computerized tomography (CT) scan (a) and magnetic resonance imaging (MRI) – susceptibility-weighted imaging (SWI) sequence (b) showing multiple haemorrhages in left parasagittal grey-white junction (yellow arrows). The presence of such lesions in absence of corpus callosal or brainstem involvement indicates grade 1 diffuse axonal injury (DAI).

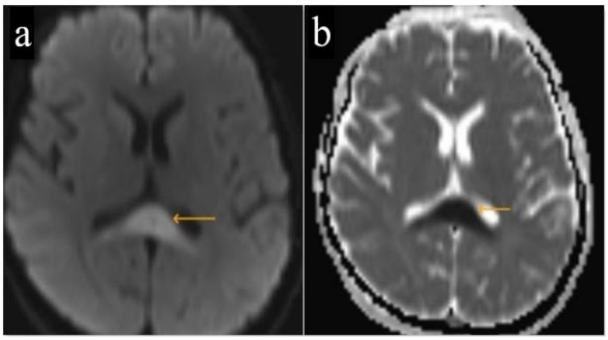

Figure 2. Magnetic resonance imaging (MRI) – diffusion-weighted imaging (DWI) sequence (a) and apparent diffusion coefficient (ADC) sequence (b) showing restricted diffusion (yellow arrows) in the splenium of corpus callosum indicating grade 2 diffuse axonal injury (DAI).

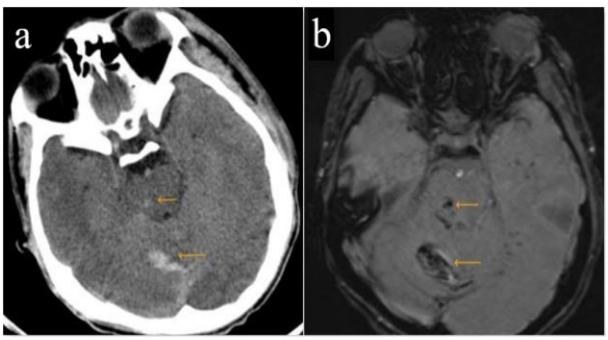

Figure 3. Computerized tomography (CT) scan (a) and magnetic resonance imaging (MRI) - susceptibility-weighted imaging (SWI) sequence (b) showing hemorrhages (yellow arrows) in right paramedian brainstem and cerebellum indicating grade 3 diffuse axonal injury (DAI).

Newer MRI sequences for TBI

Diffusion tensor imaging (DTI) is a newer MRI sequence increasingly used to diagnose DAI [14,15]. DTI is based on the principle of calculating the directional asymmetry of water diffusion, called anisotropy, in mapping white matter tracts. The injured axons in white matter tracts have lower anisotropy than normal ones. Some studies had found it extremely sensitive to axonal injuries following TBI of any severity, even when the CT and conventional MRI sequences showed no abnormalities [15,16]. DTI comes with its fair share of limitations, like its relative insensitivity to axonal injuries in complex white matter regions, due to the absence of one predominant direction of the axons and lack of spatial resolution to detect injuries in small white matter tracts. Other described unique MRI sequences for TBI include magnetic resonance spectroscopy (MRS), functional MRI (fMRI) and magnetic encephalography (MEG). MRS can map changes in the brain metabolic processes and resulting metabolite concentration changes after TBI [17]. fMRI can also reveal areas of either reduced or increased activation and altered connectivity via its BOLD (Blood Oxygenation Level-Dependent) imaging technique [18]. Some authors have reported the usefulness of MEG in detecting TBI induced abnormalities that were not identified with DTI or conventional MRI and correlated with clinical outcome [19].

Prognostic Role of MRI in TBI

There is no consensus about the optimal timing for MRI after TBI for predicting outcome. However, it should preferably be performed within the first-week post-injury for reliable prognostication [20]. The presence of brainstem involvement is correlated with outcome. Mortality increases gradually from 14% with grade I brainstem lesions to 100% with grade IV lesions [10]. Bilateral brainstem involvement is strongly associated with poor outcomes. Posterior location is associated with disability. The non-haemorrhagic, anterior lesions or unilateral injuries are associated with better outcome [11]. Superficial lesions are associated with better outcomes than deeper lesions [13]. SWI lesions in the midbrain corresponding to substantia nigra and tegmentum are independently related to poor outcomes [20].

The grading is also used as a prognostic indicator for recovery of consciousness. Park et al. reported that 14.3% of patients with cerebral white matter lesions (grade 1) did not recover their consciousness, and 50% of patients with corpus callosum lesions (grade 2), 51.6% of patients with brain stem lesion (grade 3) did not recover their consciousness [21]. The grading of DAI is well correlated with time to regain consciousness after TBI. Patients with grade 1 injury become conscious within a week after injury, while grade 2 take two weeks to recover, and patients with grade 3 take two months to regain consciousness [21]. Besides grading, the lesion volume also bears the outcome. The volume of visible DAI lesions in the corpus callosum, brainstem, and thalamus, in DWI and T2 FLAIR sequences, are independent prognostic factors in patients with severe TBI. An essential predictive MRI variable is DWI lesion volume in the corpus callosum. However, in moderate TBI cases, the number of cortical contusions is more critical for prognosis [22].

A systematic review published by Haghbayan et al. (2017), reviewing the prognostic value of MRI in moderate to severe TBI, concluded that the brainstem lesions were associated with higher mortality and unfavourable functional outcome (Glasgow Outcome Scale 1-3) at ≥ 6 months [23]. And that DAI patterns were associated with an increased risk of unfavourable functional outcomes, with depth-based MRI scores demonstrating an increased risk of unfavourable outcomes as more caudal structures were affected. Along the same lines, a recent meta-analysis by M. M. Van eijck et al. (2018), studying the prognostic value of DAI in TBI, reported that the presence of DAI resulted in three times higher risk of an unfavourable outcome, and this risk further increased three times with each increasing grade of DAI [24]. This meta-analysis reviewed data from 32 selected articles, deducing an overall unfavourable (Glasgow outcome score 1-3) functional outcome of 38% in patients with DAI in TBI.

Conclusion

MRI following TBI provides valuable assistance, either complementary or supplementary to CT scan, in determining diagnosis and prognosis in individual cases. The presence of DAI and caudal brainstem lesions lead to a poorer outcome. Advances in newer MRI sequences like SWI, DTI, fMRI, MEG. have the

potential to revolutionize the current role of MRI in TBI.

Abbreviations:
ADC - Apparent diffusion coefficient
CT - Computed tomography
DAI - Diffuse axonal injury
DWI – Diffusion-weighted imaging
GCS - Glasgow Coma Scale
GRE - Gradient recalled echo
ICP - Intracranial pressure
MRI - Magnetic resonance imaging
NINDS - National Institute of Neurological Disorders and Stroke
SAH - Subarachnoid hemorrhage
SDH - Subdural hematoma
SWI – Susceptibility-weighted imaging
T2 FLAIR - T2-weighted Fluid Attenuated Inversion Recovery
TBI - Traumatic brain injury
fMRI – Functional magnetic resonance imaging
BOLD – Blood oxygen level-dependent
MRS – Magnetic resonance spectroscopy
DTI – Diffusion tensor imaging
MEG - Magnetic encephalography

References

1 Schweitzer AD, Niogi SN, Whitlow CT, et al. Traumatic brain injury: Imaging patterns and complications. Radiographics 2019;39:1571–95. doi:10.1148/rg.2019190076

2 Blennow K, Brody DL, Kochanek PM, et al. Traumatic brain injuries. Nat Rev Dis Prim 2016;2:1–19. doi:10.1038/nrdp.2016.84

3 Kelly AB, Zimmerman RD, Snow RB, et al. Head trauma: comparison of MR and CT--experience in 100 patients. AJNR Am J Neuroradiol;9:699–708.http://www.ncbi.nlm.nih.gov/pubmed/3135716

4 Mata-Mbemba D, Mugikura S, Nakagawa A, et al. Early CT findings to predict early death in patients with traumatic brain injury: Marshall and Rotterdam CT scoring systems compared in the major academic tertiary care hospital in Northeastern Japan. Acad Radiol 2014;21:605–11. doi:10.1016/j.acra.2014.01.017

5 Adams JH, Doyle D, Ford I, et al. Diffuse axonal injury in head injury: Definition, diagnosis and grading. Histopathology 1989;15:49–59. doi:10.1111/j.1365-2559.1989.tb03040.x

6 Su E, Bell M. Diffuse axonal injury. In: Laskowitz D, Gran G, eds. Translation Research in Traumatic Brain Injury. Boca Raton (FL): CRC Press/Taylor and Francis Group 2016.

7 Wedekind C, Hesselmann V, Lippert-Grüner M, et al. Trauma to the pontomesencephalic brainstem--a major clue to the prognosis of severe traumatic brain injury. Br J Neurosurg 2002;16:256–60. doi:10.1080/02688690220148842

8 Kampfl A, Schmutzhard E, Franz G, et al. Prediction of recovery from post-traumatic vegetative state with cerebral magnetic-resonance imaging. Lancet 1998;351:1763–7. doi:10.1016/S0140-6736(97)10301-4

9 Weiss N, Galanaud D, Carpentier A, et al. Clinical review: Prognostic value of magnetic resonance imaging in acute brain injury and coma. Crit Care 2007;11:230. doi:10.1186/cc6107

10 Firsching R, Woischneck D, Klein S, et al. Classification of severe head injury based on magnetic resonance imaging. Acta Neurochir (Wien) 2001;143:263–71. doi:10.1007/s007010170106

11 Hilario A, Ramos A, Millan JM, et al. Severe Traumatic Head Injury: Prognostic Value of Brain Stem Injuries Detected at MRI. Am J Neuroradiol 2012;33:1925–31. doi:10.3174/ajnr.A3092

12 Shukla D, Mahadevan A, Sastry KVR, et al. Pathology of post traumatic brainstem and hypothalamic injuries. Clin Neuropathol 2007;26:197–209. doi:10.5414/NPP26197

13 Shibata Y, Matsumura A, Meguro K, et al. Differentiation of mechanism and prognosis of traumatic brain stem lesions detected by magnetic resonance imaging in the acute stage. Clin Neurol Neurosurg 2000;102:124–8. doi:10.1016/S0303-8467(00)00095-0

14 Niogi SN, Mukherjee P. Diffusion tensor imaging of mild traumatic brain injury. J Head Trauma Rehabil 2010;25:241–55. doi:10.1097/HTR.0b013e3181e52c2a

15 Hulkower MB, Poliak DB, Rosenbaum SB, et al. A decade of DTI in traumatic brain injury: 10 years and 100 articles later. Am J Neuroradiol 2013;34:2064–74. doi:10.3174/ajnr.A3395

16 Mac Donald CL, Johnson AM, Cooper D, et al. Detection of Blast-Related Traumatic Brain Injury in U.S. Military Personnel. N Engl J Med 2011;364:2091–100. doi:10.1056/nejmoa1008069

17 Maudsley AA, Govind V, Levin B, et al. Distributions of Magnetic Resonance Diffusion and Spectroscopy Measures with Traumatic Brain Injury. J Neurotrauma 2015;32:1056–63. doi:10.1089/neu.2014.3505

18 Irimia A, Van Horn JD. Functional neuroimaging of traumatic brain injury: Advances and clinical utility. Neuropsychiatr Dis Treat 2015;11:2355–65. doi:10.2147/NDT.S79174

19 Huang M-X, Theilmann RJ, Robb A, et al. Integrated Imaging Approach with MEG and DTI to Detect Mild Traumatic Brain Injury in Military and Civilian Patients. J Neurotrauma 2009;26:1213–26. doi:10.1089/neu.2008.0672

20 Abu Hamdeh S, Marklund N, Lannsjö M, et al. Extended Anatomical Grading in Diffuse Axonal Injury Using MRI: Hemorrhagic Lesions in the Substantia Nigra and Mesencephalic Tegmentum Indicate Poor Long-Term Outcome. J Neurotrauma 2017;34:341–52. doi:10.1089/neu.2016.4426

21 Park SJ, Hur JW, Kwon KY, et al. Time to Recover

Consciousness in Patients with Diffuse Axonal Injury : Assessment with Reference to Magnetic Resonance Grading. J Korean Neurosurg Soc 2009;46:205. doi:10.3340/jkns.2009.46.3.205

22 Moen KG, Brezova V, Skandsen T, et al. Traumatic Axonal Injury: The Prognostic Value of Lesion Load in Corpus Callosum, Brain Stem, and Thalamus in Different Magnetic Resonance Imaging Sequences. J Neurotrauma 2014;31:1486–96. doi:10.1089/neu.2013.3258

23 Haghbayan H, Boutin A, Laflamme M, et al. The prognostic value of MRI in moderate and severe traumatic brain injury: A systematic review and meta-analysis. Crit Care Med 2017;45:e1280–8. doi:10.1097/CCM.0000000000002731

24 van Eijck MM, Schoonman GG, van der Naalt J, et al. Diffuse axonal injury after traumatic brain injury is a prognostic factor for functional outcome: a systematic review and meta-analysis. Brain Inj 2018;32:395–402. doi:10.1080/02699052.2018.1429018