International Journal of Healthcare Sciences ISSN 2348-5728 (Online)
Vol. 7, Issue 2, pp: (130-137), Month: October 2019 - March 2020, Available at: www.researchpublish.com

ROLE OF COMPUTED TOMOGRAPHY IN UNDERSTANDING THE SEVERITY, PATHOGENESIS AND MANAGEMENT OF TRAUMATIC BRAIN INJURY- LITERATURE REVIEW

[1*]Dr Xu HaiBo, [2]DR MOUSUMY ABBAS

[*]Corresponding Author: Dr Xu HaiBo

Abstract: **Traumatic Brain Injury (TBI) continues to affect millions of population around the globe on yearly basis. TBI is responsible for about 50,000 deaths per year in United States of America. As per information from CDC (Centres for Disease Control), the total number of TBI-related emergency out –patient visits, In-patient admissions and mortality rates have increased in the decade 2001–2010. In US, according to recent CDC report, there is an economic impact of about 80 billion$ due to TBI. TBI can be actively classified into mild, moderate and severe based on GCS scale, permanent disability rate of 10%, 60% and 100% respectively and overall mortality rate of 20% to 30%. However, per person, the number of deaths related to TBIs has reduced during this same period , most likely because of increased awareness, better hospital infrastructure and management guidelines and significant technological developments in current treatment modalities. Overall rates for TBIs are likely underreported , considering percentage of TBIs that out reach medical attention .The highest rates of TBI is observe to be in age-group:(0-4y) (15-24 y)and (>65 y). The leading two important causes of TBI are falls and motor vehicle accidents. With an increase in number of TBIs, there seen to have a lower mortality rate due to above mentioned strategies , but have an increasing morbidity rate with respect to their TBI.**

Keywords: **Traumatic Brain Injury (TBI), CDC (Centres for Disease Control), GCS scale.**

1. INTRODUCTION

Traumatic brain injury (TBI) is one of the most important cause for mortality and morbidity in patients. Clinically TBI is classified based on severity into mild, moderate and severe. Among these, mild TBI is most common and usually due to non-penetrating blunt head trauma which further leads to stretching and tearing of axons resulting in diffuse axonal injury. Majority of mild TBI patients recover quickly but minority of them have persistence of symptoms called post-concussive symptoms. With repeated concussive and sub-concussive impacts, it can end in a chronic neurodegenerative inflammatory condition called chronic traumatic encephalitis (CTE).The primary impact is caused by the mechanism of trauma like thrown out from a motor vehicle, pedestrian versus vehicle, fall from a height which cannot be reversed, so most of the intervention modalities is focussed on reducing secondary impact by maintaining adequate blood pressure, oxygen saturation thereby maintaining adequate cerebral perfusion pressure (CPP), which inturn responsible for appropriate cerebral blood flow (CBF). The main goal in such situations is rapid diagnostic modality like neuroimaging which inturn helps in rapid and accurate decision making regarding the management protocol like active neurosurgical intervention (decompressive craniotomy) or observation in hospital with strict vitals monitoring or observation at home with proper instructions should be given regarding what to observe , danger signs of worsening, signs of recovery and when to follow up.

2. METHODS

From systematic reviews of various relevant literatures in the Medline PubMed database by using keywords : traumatic brain injury;TBI; Computed tomography angiography;management.

3. PATHOGENESIS

Traumatic brain injuries(TBI) can occur from both blunt and penetrating trauma .The most important and common causes of TBI are Falls (35%) and motor vehicle collisions (17%) , in which motor vehicle accidents mainly contribute to increase in fatality rate. The most lethal TBI is Gunshot wounds to the head . TBI pathophysiology is a complex phenomenon as a result from primary and secondary injuries which can lead to temporary or permanent neurological damange. The primary injury is directly related to the primary external trauma of the brain. The secondary injury usually happens from minutes to days after the primary trauma and consists of a molecular, chemical and inflammatory complex cascade resulting in further cerebral damage. "Monro-Kellie hypothesis" states that total intracranial volume is comprised of brain parenchyma(83%), cerebro spinal fluid (CSF- 11%), venous and arterial blood(6%). Under normal situation cerebral blood flow (CBF) is maintained by cerebral autoregulatory mechanisms within a wide range of blood pressures but when pressure of one compartment is increased(e.g, may be by a hematoma), there will be a compensatory reduction in pressure in another compartment in order to balance intracranial tension thereby preventing increase in intracranial pressure (ICP). Primary impact to the brain cannot be reverted and results in brain parenchyma destruction followed by dysregulated cerebral blood flow (CBF) ,disturbances in metabolism with increase recruitment of inflammatory mediators and free radicals results in breach in blood brain barrier(BBB) leading to oxidative stress and cerebral vasospasm which ultimately lead to ischemia, hypoxia and worsening of the initial condition resulting in necrosis and diffuse cerebral edema.

Department of Defense and the U.S. Department of Veterans Affairs in 2008 developed classification of TBI, but this classification schema remains limited inspite of its great efforts because this symptom-based classification failed to recognize the complex mechanisms of trauma, that comprises of contusion, neuronal, glial, axonal and vascular injury and hemorrhage. Even proper history, mechanism of injury and complete physical and neurological examination still remain very important for the diagnosis of TBI. Now a days, medical imaging also plays a key role for the assessment of severity of TBI in both the clinical and research studies.

Mild	Moderate	Severe
Normal structural imaging	Normal or abnormal structural imaging	Normal or abnormal structural imaging
LOC=0-30min	LOC>30min and <24h	LOC>24h
AOC=a moment up to 24h	AOC>24h; severity based on other criteria	AOC>24h; severity based on other criteria
PTA=0-1d	PTA>1d and<7d	PTA>7d
GCS score=13-15	GCS score=9-12	GCS score=3-8

TBI, traumatic brain injury; LOC, loss of consciousness; AOC, alteration of consciousness/metal state; PTA, post-traumatic amnesia; GCS, Glasgow Coma Scale.

4. RESULTS

''Comparative Effectiveness of Neuroimaging Modalities on the Detection of Traumatic Brain Injury'',this is a report that was prepared by government officials which included CT, MRI, TCD, PET ,electrophysiologic techniques (magnetoencephalography [MEG], electroencephalography [EEG]), single photon emission computed tomography (SPECT) and fNIRS, which is submitted to congress in 2011 aimed at finding best radiological biomarker of TBI by comparing the efficacies of these mentioned 7 imaging modalities. A team of experters assessed the quality of these seven modalities in clinic and research setting by reviewing more than 450 articles. As a result, experters concluded that these 7 neuroimaging techniques have high research utility and moderate to high clinical utility for the diagnosis and assessment of traumatic brain injury, making correct choices between optimal medical and surgical intervention, also plays an

important role in surgical surveillance and detection of late onset complications (MRI of moderate , CT and TCD of high clinical utility for moderate and severe TBIs). There are various limitations for this report , which enable to draw significant inferences such as

1) various definitions for mild, moderate, severe and very severe traumatic brain injury;

2) difference in hospital protocol;

3) Non-authorized research techniques .

The preliminary modality for diagnosing and treating traumatic brain injury in a sector is,firstly quick and efficient neurological examination, followed by plain radiograph, fluoroscopy, CT and then MRI.

The medical care is categorised into 5 levels across militarily environment .

LEVEL 1: Immediate care by a medic in Army and Air Force or by a corpsman in Marines and Navy.

Imaging modality available is portable ultrasound

LEVEL 2: Battalion Aid Station.

Surgical Team with x-ray, ultrasound, sometimes fluoroscopy.

LEVEL 3: Combat Support Hospital.

Service related to CT and MRI are available, but it is limited to

moderate to severe TBIs.

LEVEL 4: Regional Medical Hospital.

LEVEL 5: State Medical Hospital.

5. IMPORTANCE OF COMPUTED TOMOGRAPHY IMAGING

Since 1970s, with the introduction of CT scanning, it has turned over and revolutionized the diagnosis and treatment of TBI and with no doubt, it has saved numerous lives. CT scan utilises the narrow beam of x-rays traversing the skull bone at particular controlled angles, hence it results in differential attenuation of these narrow x-rays by various structures of human brain of varying electron density which provides the information for digital image reconstruction of those structures under area of interest which further results in two-dimensional images called, ‘‘slices,’’ or it can even reconstruct to produce 3D volumetric images. The most common neuroimaging technique during the acute stage of traumatic head injury is CT scan of head for the detection of skull bone fracture, subcutaneous hemorrhage, subarachnoid hemorrhage(SAH), subdural hemorrhage(SDH) epidural hemorrhage(EDH), missile path , reminanats of missile, bone and other foreign bodies. The most recent advances as multi-detector CT ensured the use of CT technique for rapid and noninvasive scanning modality of cranial vasculature. Apart from its clinical utility, worries remain regarding its overuse particularly in children with TBI and those with mild TBI. A study conducted by Livingston and his colleagues in 2152 patients presented to emergency department with mildTBI and Glasgow Coma Scale (GCS) score of 14 to 15,calculated to have 99.7% negative predictive value for the basic intepretation of the CT head with the need for neurosurgical involvement.

CT scanning is very important life saving neuroimaging modality in patients with GCS score<13 on presentation to the emergency department with moderate to severe TBI, as it can rapidly identify whose require an emergent neurosurgical intervention such as extra-axial or parenchymal hemorrhage, incipient herniation and midline shift . CT scan also pays a primary role in detecting conditions that demand ICU monitoring such as small to medium-sized hematomas which has a potential to expand subsequently, diffuse cerebral edema, traumatic subarachnoid and intraventricular hemorrhages that can further result in hydrocephalus.According to the Brain Trauma Foundation guidelines (Guidelines for the management of acute traumatic brain injury), initial CTscan findings are very important in deciding the intervention;

1)Extra-axial hematomas more than 30mL with mid line shift of greater than 5mm of midline shift and parenchymal hematomas more than 20mL require active neurosurgical intervention in the form of craniotomy and aspiration.

2) Parenchymal hematomas with small to moderate-sized, traumatic subarachnoid hemorrhage and extra-axial haemorrhages with small to moderate-sized are usually kept under observation in hospital and plan for a rescanning within 24hrs, sometimes much earlier if there is a drop in GCS score of neurologic status, probably due to expansion of hematomas.

Contrast-enhanced CT(CECT) has a limited role in judging the severity ofTBI as it consumes more time and tiny haemorrhages may not be visible. CECT angiography with mutidetector is very helpful in detecting traumatic vascular injury, such as dissections,occlusions,aneurysms and pseudoaneurysms. Also who is at a higher risk for vascular injuries—gunshot injuries, overstabbing injuries, basal skull fractures, neck trauma—CECT angiography helps to prevent infarction by determining the best time for intervention. The calculation of images of cerebral blood flow (CBF), cerebral blood volume (CBV) and mean transit time (MTT) along with CT angiography is possible with new image reconstruction software provided by helical CT scanners. Especially in mild TBIs, CT head with out contrast is usually normal but CECT can identify regions with reduced CBF,CBV and prolonged MTT,which can be further confirmed with magnetic resonance imaging(MRI),however these have limited application in routine clinical setting,is more of research oriented. Following a TBI, after initial resuscitation patient usually subject to a plain CT with respect to their injuries according to triage. As per level II recommendations of Eastern Association for the Surgery of Trauma (EAST) suggests that , in acute setting (patients with TBI) if CTscan is available and then consider obtaining it whereas if CT scan is not available and then consider various criterias that determine the need for imaging obtained by the Canadian CT Head Rule and the New Orleans Criteria.

6. MODALITIES OF CT SCAN IN TBI

CT scan is not sensitive for detecting diffuse axonal injury (DAI -diffuse microstructural white matter damage), which forms the basis for almost all lethal mechanisms that occur in severe traumatic brain injury. It helps in identifying cases which require active neurosurgical intervention but it is led useful in predicting the prognosis after intervention. Intial CT scan can also miss patients with medium- or sometimes even large-sized intracranial haemorrhages which can be picked up on an CECT.

It is very important for the treating doctor in Emergency Department to decide whetherptients with mild TBIs require neuroimaging or not,in which noncontrast CT scan is the first choice of imaging. But very few patients (approximately < 10%) with mild TBIs have significant abnormalities detected on initial CT and rest of the patients have abnormalities of negligible neurosurgical intervention. CT scan has potential drawbacks which include cost, risks of transporting patients outside Emergency Department, improperly collocated imaging suit and exposure to ionizing radiation especially with children due to risk of cancer. With the help of CTA in young patients with TBI resulting in hemorrhage in subarachnoid cisterns and sylvian fissure attributed to aneurysmal rupture. Various studies have developed clinical criterias to help physicians to decide to do a CT head for patients with mild TBIs and the two most important and frequently used criterias are “New Orleans Criteria” and “Canadian CT Head Rule”.These criteria helps on understanding the sensitivity and specificity in identifying clinically relevant TBIs. In 2008, the American College of Emergency Physicians (ACEP) and the Centers for Disease Control and Prevention (CDC) published a clinical policy on various indications for head CT scans in adults with TBIs(in annexure 1).In patients with good GCS score or no signs of skull fracture, observation in hospital for 6 to 8 hours can be an alternative to CT Head. Some added risk factors may also interrupt in decision making like deteriorating patients condition, alcohol intake, age less than 1 year because of difficulty in neurological examination and may have an asymptomatic intracranial bleeding.Those patients with a normal GCS score, normal neurological examination and accompanied by a healthy bystander strict observation at home first 24hours can consider another option. About 20% to 30% of patients with significant abnormalities that is detected from initial CT Head has associated significant morbidity rate. Incomplete recovery is always associated with injury to parenchyma. When the CT is normal, then also there is minimal rate of incomplete recovery. Inadequate sensitivity of CT scanning is mentioned for DAI and diffuse vascular injury. When the patients with TBIs get discharged from ED, proper instructions should be given regarding what to observe(symptoms persisting more than 7days), danger signs of worsening, signs of recovery(usually recover within 1 to 4weeks) and when to follow up. Adequate counselling about emotional lability plas an important role in fastening the recovery and helps in reducing the psychosocial effects of TBIs.

7. DISCUSSION

In moderate to severe TBIs , many high quality evidences conclude that CT scanning is highly sensitive to detect intracranial haemorrhages that required neurosurgical intervention and can be life-saving but some high quality evidence from certain literatures conclude that CT scan has limited usefulness in predicting the functional recovery of such patients.

In mild TBI, few moderate quality evidences suggests that CT scanning is considered as less sensitive modality for the evaluation of those who presented to emergency department. Because of various inbuild limitations of CT scan, certain

blood neurobiomarkers has promised in successful detection of patients with mild TBIs who are at risk of developing post-concussive persistant symptoms, long term morbidities and those who can be safely discharged without a CTscan. Sadly , in day today clinical practice setting, CT scanning is misused and overused for patients with mild TBIs.

Annexure 1. Indications for CT Head in Adults with TBI

LEVEL A recommendation (generally has high degree of clinical certainty)

LOC or post traumatic amnesia with the presence of one or more of the following entities;

1.Headache

2.Vomiting

3.Age>60 years

4.Drug or alcohol intoxication

5.Deterioration of short-term memory

6.Evidence of trauma above the clavicle

7.Seizure

8.GCS score<15

9.Focal neurologic deficit

10.Coagulopathy

LEVEL B recommendation (generally has moderate degree of clinical certainty)

LOC or post traumatic amnesia with the presence of one or more of the following entities;

1.Focal neurologic deficit

2.Vomiting

3.Severe headache

4.Age >/= 65 years

5.Physical signs of a basilar skull fracture

6 GCS score<15

7.Coagulopathy

8.Mechanism of injury (thrown out from a motor vehicle, pedestrian versus vehicle, fall from a height of > 3 feet or >5 stairs)

CT: Computed Tomography; TBI:Traumatic Brain Injury; LOC: Loss Of Consciousness; GCS: Glasgow Coma Scale.

8. CONCLUSION

In the situation of TBI, along with the traumatic causes, the nontraumatic causes like hypertension, cerebral amyloid angiopathy, aneurysms, vascular malformation, and hemorrhagic infarcts should also consider while dealing with intracerebral hemorrhage, but unfortunately the role of initial CT in evaluating these nontraumatic causes is still controversial. Another study which aimed at evaluating the cerebral arterial compliance (cAC) in TBI with or without intracranial hematomas (IHs) by using CT angiography. The results showed that cAC was reduced in both with or without IHs($p<0.001$) in which significant reduction was noticed in patients with IHs and one interesting fact concerned with this study is that even after removal of IHs, the cAC of perifocal region still lower as compared to the cAC of other zones of hemisphere. A study conducted by neurosurgery department of university of North Dokata found that whenever a patient present with intracranial hemorrhage particularly subarachnoid hemorrhage(SAH) or intraventricular hemorrhage whose GCS score is less than 9, the possibility of post traumatic vasospasm (PTV) should keep in mind and careful vitals monitoring with CNS metabolism regulation plays an important role in preventing PTV. Because prolonged PTV following TBI can result in delayed cerebral ischemia (DCI) which is very dangerous, can result in rapid

neurological deterioration beyond the time frame of initial brain injury. The diagnostic modalities for PTV include digital subtraction CT angiography- which is the gold standard along with certain PTV predictors like SAH, intraventricular hemorrhage, admission GCS score of less than 9 and young age of less than 30years. A retrospective case-control study revealed that use of CT angiography in addition to plain CT Head after blunt TBI doesnot alter the management and should be avoided in the absence of clear indications. On ICU circulatory considerations, the recommendation of Eastern Association for the Surgery of Trauma (EAST) suggests that all elderly patients on routine systemic anticoagulants suspected of TBI should obtain a rapid CT head and also within 2hours after reversal of anticoagulants with fresh frozen plasma(FFP) and vitamin K.

As a conclusion, TBI is one of the major cause of morbidity and mortality in both developed and developing countries, various recommendations suggested by different associations need to consider while treating TBI. One of the life saving neuroimaging modality is CT Head, inspite of its various limitations, still it is the gold standard in diagnosing TBI. Management of TBI should consider: time of onset, duration, severity and mechanism of impact regarding TBI. Along with the availability and necessity of CT Head plays a cornerstone in deciding the inpatient management with or without neurosurgical intervention or an outpatient observation.

REFERENCES

[1] Traumatic Brain Injury: Current Treatment Strategies and Future Endeavors:Michael Galgano, Gentian Toshkezi, Xuecheng Qiu, Thomas Russell, Lawrence Chin and Li-Ru Zhao,DOI:10,1177/0963689717714102. http://www.journals.sagepub.com/home/dl.

[2] A Review of the Effectiveness of Neuroimaging Modalities for the Detection of Traumatic Brain Injury:Franck Amyot, David B. Arciniegas, Michael P. Brazaitis, Kenneth C. Curley, Ramon Diaz-Arrastia, Amir Gandjbakhche, Peter Herscovitch, Sidney R. Hinds II, Geoffrey T. Manley, Anthony Pacifico, Alexander Razumovsky, Jason Riley, Wanda Salzer, Robert Shih, James G. Smirniotopoulos and Derek Stocker; JOURNAL OF NEUROTRAUMA 32:1693–1721 (November 15, 2015) ª Mary Ann Liebert, Inc. DOI: 10.1089/neu.2013.3306.

[3] Levin HS, Shum D, Chan RC. Understanding traumatic brain injury: current research and future directions. New York (NY): Oxford University Press; 2014.

[4] Narayan, R.K., Maas, A.I.R., Servadei, F., Skolnick, B.E., Tillinger, M.N., Marshall, L.F., and Traumatic Intracerebral Hemorrhage Study Group. (2008). Progression of traumatic intracerebral hemorrhage: a prospective observational study.

[5] Greenberg MS, Arredondo N. Handbook of neurosurgery. 6th edition. New York (NY): Thieme Medical Publishers; 2006.

[6] Sternbach GL. The Glasgow coma scale. J Emerg Med. 2000.

[7] Cerebral Arterial Compliance in Traumatic Brain Injury. Dobrzeniecki M, Trofimov A, Bragin DE.

[8] Centers for Disease Control and Prevention. Injury prevention & control: traumatic brain. injury & concussion. http://www.cdc.gov/traumaticbraininjury/data/rates.

[9] Heltemes, K.J., Dougherty, A.L., MacGregor, A.J., and Galarneau, M.R. (2011). Inpatient hospitalizations of U.S. military personnel medically evacuated from Iraq and Afghanistan with combat-related traumatic brain injury.

[10] Faul, M., Xu, L., Wald, M.M., and Coronado, V.G. (2010). Traumatic Brain Injury in the United States: Emergency Department Visits, Hospitalizations and Deaths 2002–2006. Centers for Disease Control and Prevention: Atlanta, GA.

[11] Bigler, E.D. and Maxwell, W.L. (2012). Neuropathology of mild traumatic brain injury: relationship to neuroimaging findings.

[12] Xydakis, M.S., Ling, G.S.F., Mulligan, L.P., Olsen, C.H., and Dorlac, W.C. (2012). Epidemiologic aspects of traumatic brain injury in acute combat casualties at a major military medical center: a cohort study.

[13] Mac Donald, C.L., Johnson, A.M., Cooper, D., Nelson, E.C., Werner, N.J., Shimony, J.S., Snyder, A.Z., Raichle, M.E., Witherow, J.R., Fang, R., Flaherty, S.F., and Brody, D.L. (2011). Detection of blastrelated traumatic brain injury in U.S. military personnel. N. Engl. J. Med.

[14] Lee JJ, Segar DJ, Asaad WF. Comprehensive assessment of isolated traumatic subarachnoid hemorrhage. J Neurotrauma, 2014.

[15] Soustiel, J.F., Mahamid, E., Goldsher, D., and Zaaroor, M. (2008). Perfusion-CT for early assessment of traumatic cerebral contusions.

[16] Metting, Z, Cerliani, L, Rodiger, LA, and van der Naalt, J. (2013) Pathophysiological concepts in mild traumatic brain injury: diffusion tensor imaging related to acute perfusion CT imaging.

[17] Jacobs, B., Beems, T., van der Vliet, T.M., Diaz-Arrastia, R.R., Borm, G.F., and Vos, P.E. (2011). Computed tomography and outcome in moderate and severe traumatic brain injury: hematoma volume and midline shift revisited.

[18] Stiell, I.G., Wells, G.A., Vandemheen, K., Clement, C., Lesiuk, H., Laupacis, A., McKnight, R.D., Verbeek, R., Brison, R., Cass, D., Eisenhauer, M.E., Greenberg, G., and Worthington, J. (2001). The Canadian CT Head Rule for patients with minor head injury.

[19] Smits, M., Dippel, D.W.J., de Haan, G.G., Dekker, H.M., Vos, P.E., Kool, D.R., Nederkoorn, P.J., Hofman, P.A.M., Twijnstra, A., Tanghe, H.L.J., and Hunink, M.G.M. (2005). External validation of the Canadian CT Head Rule and the New Orleans Criteria for CT scanning in patients with minor head injury.

[20] Jagoda, A.S., Bazarian, J.J., Bruns, J.J., Cantrill, S.V., Gean, A.D., Howard, P.K., Ghajar, J., Riggio, S., Wright, D.W., Wears, R.L., Bakshy, A., Burgess, P., Wald, M.M., and Whitson, R.R. (2008). Clinical policy: neuroimaging and decisionmaking in adult mild traumatic brain injury in the acute setting.

[21] Ann. Emerg. Med. 52, 714–748. 59. Norlund, A., Marke ´, L.A., af Geijerstam, J.L., Oredsson, S., and Britton, M.; OCTOPUS Study. (2006). Immediate computed tomography or admission for observation after mild head injury: cost comparison in randomised controlled trial.

[22] Jacobs, B., Beems, T., Stulemeijer, M., van Vugt, A.B., van der Vliet, T.M., Borm, G.F., and Vos, P.E. (2010). Outcome prediction in mild traumatic brain injury: age and clinical variables are stronger predictors than CT abnormalities.

[23] Unde ´n, J., Ingebrigtsen, T., and Romner, B.; Scandinavian Neurotrauma Committee (SNC). (2013). Scandinavian guidelines for initial management of minimal, mild and moderate head injuries in adults: an evidence and consensus-based update.

[24] Kim, J.J. and Gean, A.D. (2011). Imaging for the diagnosis and management of traumatic brain injury.

[25] Livingston, D.H., Lavery, R.F., Passannante, M.R., Skurnick, J.H., Baker, S., Fabian, T.C., Fry, D.E., and Malangoni, M.A. (2000). Emergency department discharge of patients with a negative cranial computed tomography scan after minimal head injury.

[26] Amis, E.S. Jr. and Butler, P.F. (2010). ACR white paper on radiation dose in medicine: three years later.

[27] The Brain Trauma Foundation, Joint Section on Neurotrauma and Critical Care. (2007). Guidelines for the management of severe traumatic brain injury: J. Neurotrauma.

[28] (2012), Report to Congress: Comparative Effectiveness of Neuroimaging Modalities on the Detection of Traumatic Brain Injury.

[29] Acute Management of Traumatic Brain Injury:Michael A. Vella, MD, MBA, Marie Crandall, MD, MPH, FACS, and Mayur B. Patel, MD, MPH, FACS. Published in final edited form as: Surg Clin North Am . 2017 October ; 97(5): 1015–1030. doi:10.1016/j.suc.2017.06.003.

[30] Guillamondegui MBPOD. Traumatic brain injury, severe: medical and surgical management. Verlag Berline Heidelberg; Springer: 2015.

[31] Werner C, Engelhard K. Pathophysiology of traumatic brain injury. Br J Anaesth. 2007; [PubMed: 17573392]

[32] Chesnut RM, Marshall LF, Klauber MR, et al. The role of secondary brain injury in determining outcome from severe head injury. J Trauma. 1993; [PubMed: 8459458].

[33] Miller JD, Sweet RC, Narayan R, Becker DP. Early insults to the injured brain. JAMA. 1978; [PubMed: 660888].

[34] Cooper DJ, Myles PS, McDermott FT, et al. Prehospital hypertonic saline resuscitation of patients with hypotension and severe traumatic brain injury: a randomized controlled trial. JAMA. 2004.

[35] Bulger EM, May S, Brasel KJ, et al. Out-of-hospital hypertonic resuscitation following severe traumatic brain injury: a randomized controlled trial. JAMA. 2010.

[36] ATLS Book.

[37] Textbook of Farr's Physics for Medical Imaging, second edition,Penelope Allisy-Roberts and Jerry Williams.

[38] Book of Learning Radiology , Recognizing the basics-third edition , William Herring, MD.

[39] Stein SC, Smith DH. Coagulopathy in traumatic brain injury. Neurocrit Care. 2004; [PubMed: 16174954].

[40] Barbosa RR, Jawa R, Watters JM, et al. Evaluation and management of mild traumatic brain injury: an Eastern Association for the Surgery of Trauma practice management guideline. J Trauma Acute Care Surg. 2012.

[41] Smits M, Dippel DW, de Haan GG, et al. External validation of the Canadian CT Head Rule and the New Orleans Criteria for CT scanning in patients with minor head injury. JAMA. 2005.

[42] Carney N, Totten AM, O'Reilly C, et al. Guidelines for the Management of Severe Traumatic Brain Injury, Fourth Edition. Neurosurgery, 2016.

[43] J. Am. Coll. Radiol, Zasler, N.D., Katz, D.I., and Zafonte, R.D. (2007). Brain injury medicine: principles and practice.