www.clinicalimagingscience.org

ScientificScholar® Knowledge is power
Publisher of Scientific Journals

Journal of Clinical Imaging Science

Neuroradiology/Head and Neck Imaging *Original Research*

Use of Magnetic Resonance Imaging in Acute Traumatic Brain Injury Patients is Associated with Lower Inpatient Mortality

Hwan Lee[1], Yifeng Yang[2], Jiehui Xu[3], Jeffrey B. Ware[1], Baogiong Liu[2]

[1]Department of Radiology, University of Pennsylvania Perelman School of Medicine, Philadelphia, Pennsylvania, [2]Department of Internal Medicine, University of Iowa Hospitals and Clinics, Iowa City, Iowa, [3]Division of Biostatistics, New York University Grossman School of Medicine, New York, United States.

***Corresponding author:**
Hwan Lee,
Department of Radiology,
University of Pennsylvania
Perelman School of Medicine,
Philadelphia, Pennsylvania,
United States.

hwan.lee@pennmedicine.upenn.edu

Received : 25 July 2021
Accepted : 13 September 2021
Published : 04 October 2021

DOI
10.25259/JCIS_148_2021

Quick Response Code:

ABSTRACT

Objectives: While magnetic resonance imaging (MRI) has higher sensitivity than computed tomography for certain types of traumatic brain injury (TBI), it remains unknown whether the increased detection of intracranial injuries leads to improved clinical outcomes in acute TBI patients, especially given the resource requirements involved in performing MRI. We leveraged a large national patient database to examine associations between brain MRI utilization and inpatient clinical outcomes in hospitalized TBI patients.

Material and Methods: The National Inpatient Sample database was queried to find 3,075 and 340,090 hospitalized TBI patients with and without brain MRI, respectively, between 2012 and 2014 in the United States. Multivariate regression analysis was performed to independently evaluate the association between brain MRI utilization and inpatient mortality rate, complications, and resource requirements.

Results: The MRI group had a lower unadjusted mortality rate of 0.75% compared to 2.54% in the non-MRI group. On multivariate regression analysis, inpatient brain MRI was independently associated with lower mortality (adjusted OR 0.32, 95% CI 0.12–0.86), as well as higher rates of intracranial hemorrhage (adjusted OR 2.20, 95% CI 1.27–3.81) and non-home discharge (adjusted OR 1.33, 95% CI 1.07–1.67). Brain MRI was independently associated with 3.4 days ($P < 0.001$) and \$8,934 ($P < 0.001$) increase in the total length and cost of hospital stay, respectively.

Conclusion: We present the first evidence that inpatient brain MRI in TBI patients is associated with lower inpatient mortality, but with increased hospital resource utilization and likelihood of non-home discharge.

Keywords: Traumatic brain injury, Magnetic resonance imaging, Mortality, Outcome, Resource requirement

INTRODUCTION

Traumatic brain injury (TBI) is a leading cause of death in the US, resulting in over 50,000 deaths annually among patients of all ages.[1] TBI also incurs high economic burden in the US, estimated at over \$10 billion for direct medical care and over \$60 billion for indirect expenditures annually.[2] While neuroimaging can be selectively utilized for patients with minor head injury,[3] it plays an essential role in acute moderate to severe TBI, providing assessment of the type, location, and severity of injury to guide medical and surgical treatment.

Computed tomography (CT) is the primary imaging modality for evaluation of acute TBI, given its ability to detect clinically significant TBI with rapid scan time, wide availability, low cost, and few contraindications.[4] CT can show acute primary findings including hemorrhages, fractures, and foreign bodies, as well as secondary injuries such as cerebral edema, ischemia, and herniation.[5,6] In addition, CT-based scoring systems such as the Marshall Classification and Rotterdam Score can be used to predict mortality in acute TBI patients.[7] As a result, CT is widely implemented as the first-line screening study, obtained in over 80% of emergency department visits for head injury and in virtually all TBI patients requiring hospitalization.[8]

When magnetic resonance imaging (MRI) is used for evaluation of TBI, a recommended imaging protocol includes standard T1-weighted, T2-weighted, fluid-attenuated inversion recovery, and diffusion-weighted sequences, as well as a susceptibility-weighted or T2*-weighted gradient echo sequence for detection of blood products.[9] The overall image acquisition takes approximately 20–25 min, and three-dimensional acquisitions are preferred for improved detection, localization, and characterization of small lesions.[10] Advanced MRI techniques such as perfusion imaging, diffusion tensor imaging, functional imaging, spectroscopy, and elastography are under active investigation but not in routine clinical use.[11]

The use of MRI is limited in acute TBI due to complex logistics, potential contraindications, and resource requirements.[4] A persistent neurological deficit not explained by CT is the main indication for MRI, as 30% of hospitalized TBI patients with normal CT can have abnormalities on MRI.[12] Specifically, MRI has higher sensitivity for certain types of traumatic injuries such as contusions, small hemorrhages, and axonal injuries.[4,6,7] MRI-based scoring methods such as the Firsching Score and Adams-Gentry Classification can also provide prognostic information in acute TBI patients.[13] Whether the additional information gained from MRI in acute TBI patients may lead to improved clinical outcomes, however, remains an important unanswered question given the cost and practical difficulties associated with performing MRI in hospitalized TBI patients.

To address this question, outcomes research is needed to determine the clinical benefits conferred by MRI and its resource requirements in acute TBI patients. Given the heterogeneity in patient management following TBI in hospitalized TBI patients across various practice settings,[14] a multi-institutional study design is preferred to gain generalizable insights into the clinical value of MRI. In this study, we leveraged a large national patient database to examine associations between brain MRI utilization and inpatient clinical outcomes in hospitalized TBI patients.

MATERIAL AND METHODS

Study population

The study was exempt from local Institutional Review Board approval due to the use of an anonymized public database. We conducted a retrospective cohort study using the National Inpatient Sample (NIS), a large database representing 20% of all inpatient admissions at non-federal hospitals in the United States.[15] Organized by the Agency for Healthcare Research and Quality, the NIS is based on International Classification of Diseases codes for both diagnoses and procedures. We used 3 years of data from 2012 to 2014, including over 21 million discharges from over 4,000 hospitals in 45 states.

We searched the NIS database to find a cohort of patients 18 years or older who were hospitalized with the principal diagnosis of TBI between 2012 and 2014. The patients were then stratified into those who underwent brain MRI during hospitalization and those without inpatient brain MRI. The baseline characteristics of the patients were obtained from the database with respect to gender, age, race, income, and insurance type, as well as hospital characteristics including hospital location, size, and teaching status. The presence of 15 different baseline comorbidities that may affect inpatient outcomes was also recorded.

Study outcomes

The primary outcome of the study was in-hospital mortality. The secondary outcomes were chosen to reflect two categories: inpatient complications and resource requirements. Inpatient complications included intracranial hemorrhage, tracheostomy, gastrostomy, and non-home discharge. Resource requirements were assessed based on the length of stay and total cost of hospitalization.

Statistical analysis

Stratification, clustering, and weighting were applied during analysis to accommodate the NIS design as described previously.[16] The baseline characteristics of the MRI and no MRI groups were compared using Chi-squared test for categorical variables and *t*-test for continuous variables. For each outcome, multivariable regression analysis was performed to isolate its association with brain MRI, using logistic regression for clinical outcomes and ordinary least squares linear regression for resource requirements. All statistical tests were performed using the weighted sample survey data analysis tool on Stata version 14 (StataCorp, College Station, TX).[17] Two-sided statistical tests with the alpha value of 0.05 were used throughout the study.

RESULTS

Baseline characteristics

A total of 3,075 patients in the MRI group and 340,090 patients in the no MRI group were included in the study [Table 1]. The patients in the MRI group were more likely to be women (P = 0.043), non-white (P = 0.005), earning higher income (P < 0.001), medically insured (P = 0.020), and admitted to a teaching hospital (P = 0.020) in the Northeast (P < 0.001). There was no significant difference in age between the two groups (P = 0.161). The baseline comorbidity profiles were overall similar between the two groups, except for higher rate of hypertension (P = 0.002) and lower rate of congestive heart failure (P = 0.004) in the MRI group.

Clinical outcomes

The MRI group had a lower unadjusted mortality rate of 0.75% compared to 2.54% in the non-MRI group [Table 2]. On multivariate regression analysis, inpatient brain MRI was independently associated with significantly lower mortality rate (adjusted OR 0.53, 95% CI 0.12–0.86, P = 0.024).

Regarding in-hospital complications, the unadjusted rate of intracranial hemorrhage was nearly twice in the MRI group (2.11%) compared to the no MRI group (1.14%). Slightly increased rate of non-home discharge was also observed in the MRI group (50.75% vs. 44.69%). On multivariate regression analysis, inpatient brain MRI was significantly associated with intracranial hemorrhage (adjusted OR 2.20, 95% CI 1.27–3.81, P = 0.005) and non-home discharge (adjusted OR 1.33, 95% CI 1.07–1.67, P = 0.012). There was no significant difference in the rates of gastrostomy (P = 0.093) or tracheostomy (P = 0.806) between the two groups.

Resource utilization

Unadjusted average length of stay was longer in the MRI group at 5.9 days compared to 3.9 days in the no MRI group [Table 3]. The average total cost of hospitalization was also higher at $15,559 in the MRI group compared to $10,633 in the non-MRI group. On multivariate regression analysis, brain MRI was independently associated with additional 3.4 days (95% CI 2.1 days-4.5 days, P < 0.001) and $8,934 (95% CI $5,031–$12,848, P < 0.001) in the total length and cost of hospital stay, respectively.

DISCUSSION

In the present study, we used a large national dataset to show that brain MRI in hospitalized TBI patients is associated with lower in-hospital mortality. Since differences in baseline characteristics were found between the MRI and no MRI

Table 1: Baseline characteristics of the study cohorts.

Variable	MRI *n*=3,075 (%)	No MRI *n*=340,090 (%)	*P*-value
Women	47.6	43.6	0.043
Race			
White	65.8	72.8	0.005
Black	11.2	9.3	
Hispanic	12.4	9.3	
Asian or Pacific Islander	6.4	3.3	
Native American	0.0	3.3	
Other	4.2	3.1	
Median age, y	63.7	62.5	0.161
Median annual income in patient's zip code, US$			
$1–$38,999	20.5	26.3	<0.001
$39,000–$47,999	19.2	24.6	
$48,000–$62,999	23.3	24.7	
$63,000 or more	37.0	24.5	
Insurance type			
Medicaid	56.6	54.6	0.020
Medicare	10.6	9.1	
Private	27.0	26.5	
Uninsured	5.8	9.8	
Hospital characteristics			
Hospital region			
Northeast	49.1	20.6	<0.001
Midwest	13.0	21.5	
South	19.4	34.8	
West	18.5	23.1	
Hospital bed size			
Small	7.0	8.0	0.341
Medium	20.5	23.4	
Large	72.5	68.6	
Location of hospital			
Rural hospital	4.2	4.1	0.907
Urban hospital	95.8	95.9	
Teaching status of hospital			
Non-teaching hospital	23.9	30.2	0.020
Teaching hospital	76.1	69.8	
Comorbidities			
Dementia	14.5	16.0	0.291
History of myocardial infarction	4.4	4.4	0.971
Malignancy	2.9	2.0	0.092
Thrombocytopenia	4.1	4.2	0.852
Chronic liver disease	6.3	4.9	0.125
Human immunodeficiency virus	0.5	0.2	0.050
Hypertension	58.1	51.4	0.002
Diabetes mellitus	22.0	18.8	0.052
Chronic obstructive lung disease	8.1	6.9	0.268
Chronic kidney disease	10.9	9.1	0.133
Atrial fibrillation/flutter	11.9	13.8	0.190
Coronary artery disease	16.9	17.9	0.560
Peripheral artery disease	3.6	4.2	0.477
Obesity	4.1	3.5	0.417
Congestive heart failure	5.4	8.8	0.004

Table 2: In-hospital outcomes of TBI patients based on brain MRI utilization.

Outcome	Unadjusted Incidence (%)	Adjusted Odds Ratio (95% CI)	*P*-value
Mortality	0.75 vs. 2.54	0.32 (0.12–0.86)	0.024
Intracranial hemorrhage	2.11 vs. 1.14	2.20 (1.27–3.81)	0.005
Gastrostomy	1.46 vs. 0.72	1.90 (0.90–4.01)	0.093
Tracheostomy	0.33 vs. 0.22	1.28 (0.17–9.47)	0.806
Non-home discharge	50.75 vs. 44.69	1.33 (1.07–1.67)	0.012

*Data are shown as MRI group versus No MRI group, MRI: Magnetic Resonance Imaging, TBI: Traumatic Brain Injury

Table 3: In-hospital resource requirements of TBI patients based on brain MRI utilization.

Resource	Unadjusted Mean	Regression Coefficient (95% CI)	*P*-value
Length of stay	5.9 days vs. 3.9 days	3.4 days (2.1 days–4.5 days)	<0.001
Total cost	$15,559 vs. $10,633	$8,934 ($5,031–$12,838)	<0.001

*Data are shown as MRI group versus No MRI group, MRI: Magnetic Resonance Imaging, TBI: Traumatic Brain Injury

groups, especially with respect to income and insurance status, multivariable regression was an integral element of the analysis to independently examine the effects of brain MRI. Our study is the first to report the relationship between brain MRI utilization and change in outcome in TBI patients, in contrast to the rich body of literature focused on lesion detection and prognostication.

In the literature, the prognostic value of early brain MRI in TBI patients could be attributed to specific diagnostic information. In the multicenter TRACK-TBI study, detection of hemorrhagic axonal injury, brain contusion, and diffusion tensor imaging abnormality on early brain MRI predicted poor functional outcomes.[18,19] In a meta-analysis of 27 studies, detection of traumatic brainstem lesions on MRI predicted higher mortality and unfavorable functional outcomes, especially with involvement of more caudal structures.[13] While most prognostic studies focused on post-discharge outcomes, several studies showed that diffuse axonal injury and brainstem lesions on inpatient MRI were associated with increased duration and intensity of inpatient care as well as poor functional status at discharge.[20-23]

In contrast, the mechanisms by which diagnostic information obtained from MRI may alter patient management and improve the mortality rate in TBI patients remain unclear. Previously, Fiser *et al.* evaluated 40 hospitalized acute TBI patients to find that addition of MRI did not led lead to change in patient management despite detection of more injuries.[24] Similarly, Manolakaki *et al.* showed that the diagnostic value added by MRI did not lead to subsequent change in treatment in 123 acute TBI patients.[25] In a study involving 377 hospitalized TBI patients, Kin *et al.* found that finding a mismatch between CT and diffusion-weighted MRI had the potential to guide surgical management by predicting enlargement of hemorrhagic lesions.[26] Since mortality occurs in only a minority of hospitalized TBI patients, the single-center studies, each involving only few cases of mortality, were unlikely to be adequately powered to reveal the potential change in management leading to difference in mortality. The role of MRI imaging is a component of the ongoing analyses in the multi-national CENTER-TBI study (NCT02210221) involving 4,559 acute TBI patients, which may explain the findings of our study.

Regarding in-hospital complications, we found that brain MRI was associated with a higher rate of intracranial hemorrhage, which can be attributed to the higher sensitivity of MRI for detecting small hemorrhages.[7,12] Even after accounting for baseline characteristics such as insurance status that affect discharge disposition for TBI patients,[27] MRI was independently associated with non-home discharge. We speculate that the additional intracranial abnormalities found on MRI likely resulted in increased perceived severity of the patients' injuries, qualifying them for discharge to rehabilitation facilities more easily from medical and insurance perspectives. The higher rate of non-home discharge suggests that MRI is associated with additional resource requirements even beyond the period of acute hospitalization for TBI.

We found that MRI independently accounted for over 50% of the length and cost of hospitalization for acute TBI. Although the cost effectiveness of CT in acute TBI has been examined in several previous studies,[28] a counterpart analysis for MRI is lacking, likely due to the poor characterization of the clinical value of MRI in acute TBI. Since the adjusted OR of 0.32 for mortality in our study translates to approximately 68% relative risk reduction with rare outcome assumption,[29] further validation of the mortality benefit will likely support the cost effectiveness of MRI, especially given that the cost of direct medical care represents only a fraction of the total economic burden of TBI.[2]

The major limitation of the study is its observational design, which makes it difficult to directly attribute the mortality benefit to MRI utilization. Although many baseline characteristics were accounted for in our multivariable analysis, the NIS database does not contain information on the patients' clinical status at the time of imaging, such as the Glasgow Coma Scale, pupillary exam, and blood pressure which affect outcomes in acute TBI patients.[30] The unknown mechanism and severity of injury in our patient population are potential additional confounders with influence on inpatient mortality rate and hospital resource requirements.[31] Controlling for the clinical confounders is essential to validate the results of our study, especially due to the introduction of selection bias when the decision to obtain MRI is made based on lack of abnormality on CT. Patient-level analysis with stratification based on CT findings would address this source of bias,[32] although it is beyond the capabilities of the NIS database. Furthermore, MRI studies are under-reported in the NIS database;[33] in a commercially insured US population, as high as 15% of patients obtain MRI within 2 days of diagnosis even for mild TBI.[34] Nevertheless, the large number of patients in our study offered sufficient statistical power for hypothesis testing. The MRI group exclusively contained patients who received brain MRI, and the statistical effect of contamination in the no MRI group was diluted by the low overall rate of MRI utilization in hospitalized TBI patients. Finally, we did not take into account the MRI techniques used for evaluation of TBI,[11] which may have different degrees of impact on inpatient outcomes.

Despite the limitations, the major significance of the study is the suggestion of a link between MRI utilization and lower inpatient mortality in acute TBI patients, which has not been examined previously. While it is neither judicious nor practical to recommend MRI in every patient admitted with TBI, the potential value of MRI in providing survival benefit beyond prognostication raises a possibility that merits further investigation. Identification of a subset of TBI patients who will likely derive survival benefit from MRI will justify integration of MRI into the clinical workflow for TBI evaluation, with the understanding that it may incur additional resource requirements and non-home discharge.

CONCLUSION

Inpatient brain MRI utilization in TBI patients is associated with lower inpatient mortality, as well as with increased hospital resource utilization and likelihood of non-home discharge. Further research is needed to clarify the nature of these associations and understand how MRI may be used to improve clinical outcomes in TBI patients. Since the initial hospitalization for acute TBI only marks the beginning of the medical care and rehabilitation process for TBI patients, the long-term benefits and costs associated with use of MRI in TBI patients remain to be investigated.

Declaration of patient consent

Not applicable given the use of an anonymized public database.

Financial support and sponsorship

No funding support was received for the study.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Coronado VG, Xu L, Basavaraju SV, McGuire LC, Wald MM, Faul MD, *et al*. Surveillance for traumatic brain injury-related deaths-United States, 1997-2007. MMWR Surveill Summ 2011;60:1-32.
2. Centers for Disease Control and Prevention (CDC). CDC grand rounds: Reducing severe traumatic brain injury in the United States. MMWR Morb Mortal Wkly Rep 2013;62:549-52.
3. Stiell IG, Wells GA, Vandemheen K, Clement C, Lesiuk H, Laupacis A, *et al*. The Canadian CT head rule for patients with minor head injury. Lancet 2001;357:1391-16.
4. Wintermark M, Sanelli PC, Anzai Y, Tsiouris AJ, Whitlow CT. Imaging evidence and recommendations for traumatic brain injury: Conventional neuroimaging techniques. J Am Coll Radiol 2015;12:e1-14.
5. Bodanapally UK, Sours C, Zhuo J, Shanmuganathan K. Imaging of traumatic brain injury. Radiol Clin North Am 2015;53:695-715, 718.
6. Lee B, Newberg A. Neuroimaging in traumatic brain imaging. NeuroRx 2005;2:372-83.
7. Kim JJ, Gean AD. Imaging for the diagnosis and management of traumatic brain injury. Neurotherapeutics 2011;8:39-53.
8. Korley FK, Kelen GD, Jones CM, Diaz-Arrastia R. Emergency department evaluation of traumatic brain injury in the United States, 2009-2010. J Head Trauma Rehabil 2016;31:379-87.
9. Haacke EM, Duhaime AC, Gean AD, Riedy G, Wintermark M, Mukherjee P, *et al*. Common data elements in radiologic imaging of traumatic brain injury. J Magn Reson Imaging 2010;32:516-43.
10. Mutch CA, Talbott JF, Gean A. Imaging evaluation of acute traumatic brain injury. Neurosurg Clin N Am 2016;27:409-39.
11. Smith LG, Milliron E, Ho ML, Hu HH, Rusin J, Leonard J, *et al*. Advanced neuroimaging in traumatic brain injury: An overview. Neurosurg Focus 2019;47:E17.
12. Steyerberg EW, Wiegers E, Sewalt C, Buki A, Citerio G, de Keyser V, *et al*. Case-mix, care pathways, and outcomes in patients with traumatic brain injury in CENTER-TBI: A European prospective, multicentre, longitudinal, cohort study. Lancet Neurol 2019;18:923-34.
13. Haghbayan H, Boutin A, Laflamme M, Lauzier F, Shemilt M, Moore L, *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.
14. Huijben JA, Volovici V, Cnossen MC, Haitsma IK, Stocchetti N, Maas AI, *et al*. Variation in general supportive and preventive intensive care management of traumatic brain injury: A survey in 66 neurotrauma centers participating in the collaborative European NeuroTrauma effectiveness research in traumatic brain injury (CENTER-TBI) study. Crit Care 2018;22:90.
15. Healthcare Cost and Utilization Project Databases. Agency for Healthcare Research and Quality; 2020. Available from: https://www.hcup-us.ahrq.gov/nisoverview.jsp [Last accessed on 2020 Dec 01].

16. Lee H, Yang Y, Liu B, Castro SA, Shi T. Patients with acute ischemic stroke who receive brain magnetic resonance imaging demonstrate favorable in-hospital outcomes. J Am Heart Assoc 2020;9:e016987.
17. StataCorp. Stata Survey Data Reference Manual, Release 14. United States: Stata Press Publication; 2015.
18. Yuh EL, Mukherjee P, Lingsma HF, Yue JK, Ferguson AR, Gordon WA, *et al*. Magnetic resonance imaging improves 3-month outcome prediction in mild traumatic brain injury. Ann Neurol 2013;73:224-35.
19. Yuh EL, Cooper SR, Mukherjee P, Yue JK, Lingsma HF, Gordon WA, *et al*. Diffusion tensor imaging for outcome prediction in mild traumatic brain injury: A TRACK-TBI study. J Neurotrauma 2014;31:1457-77.
20. Lv LQ, Hou LJ, Yu MK, Qi XQ, Chen HR, Chen JX, *et al*. Prognostic influence and magnetic resonance imaging findings in paroxysmal sympathetic hyperactivity after severe traumatic brain injury. J Neurotrauma 2010;27:1945-50.
21. Potapov AA, Danilov GV, Sychev AA, Zakharova NE, Pronin IN, Savin IA, *et al*. Clinical and MRI predictors of coma duration, intensive care and outcome of traumatic brain injury. Zh Vopr Neirokhir Im N N Burdenko 2020;84:5-16.
22. Lee HJ, Sun HW, Lee JS, Choi NJ, Jung YJ, Hong SK. Clinical outcomes of diffuse axonal injury according to radiological grade. J Trauma Inj 2018;31:51-7.
23. Sandhu S, Soule E, Fiester P, Natter P, Tavanaiepour D, Rahmathulla G, *et al*. Brainstem diffuse axonal injury and consciousness. J Clin Imaging Sci 2019;9:32.
24. Fiser SM, Johnson SB, Fortune JB. Resource utilization in traumatic brain injury: The role of magnetic resonance imaging. Am Surg 1998;64:1088-193.
25. Manolakaki D, Velmahos GC, Spaniolas K, de Moya M, Alam HB. Early magnetic resonance imaging is unnecessary in patients with traumatic brain injury. J Trauma 2009;66:1008-12.
26. Kin K, Ono Y, Fujimori T, Kuramoto S, Katsumata A, Goda Y, *et al*. The usefulness of CT-diffusion weighted image mismatch in patients with mild to moderate traumatic brain injury. Acta Med Okayama 2016;70:237-42.
27. McQuistion K, Zens T, Jung HS, Beems M, Leverson G, Liepert A, *et al*. Insurance status and race affect treatment and outcome of traumatic brain injury. J Surg Res 2016;205:261-71.
28. Alali AS, Burton K, Fowler RA, Naimark DM, Scales DC, Mainprize TG, *et al*. Economic evaluations in the diagnosis and management of traumatic brain injury: A systematic review and analysis of quality. Value Health 2015;18:721-34.
29. Cummings P. The relative merits of risk ratios and odds ratios. Arch Pediatr Adolesc Med 2009;163:438-45.
30. Steyerberg EW, Mushkudiani N, Perel P, Butcher I, Lu J, McHugh GS, *et al*. Predicting outcome after traumatic brain injury: Development and international validation of prognostic scores based on admission characteristics. PLoS Med 2008;5:e165.
31. McGarry LJ, Thompson D, Millham FH, Cowell L, Snyder PJ, Lenderking WR, *et al*. Outcomes and costs of acute treatment of traumatic brain injury. J Trauma 2002;53:1152-9.
32. Yue JK, Yuh EL, Korley FK, Winkler EA, Sun X, Puffer RC, *et al*. Association between plasma GFAP concentrations and MRI abnormalities in patients with CT-negative traumatic brain injury in the TRACK-TBI cohort: A prospective multicentre study. Lancet Neurol 2019;18:953-61.
33. Dismuke CE. Underreporting of computed tomography and magnetic resonance imaging procedures in inpatient claims data. Med Care 2005;43:713-7.
34. Pavlov V, Thompson-Leduc P, Zimmer L, Wen J, Shea J, Beyhaghi H, *et al*. Mild traumatic brain injury in the United States: Demographics, brain imaging procedures, health-care utilization and costs. Brain Inj 2019;33:1151-7.

How to cite this article: Lee H, Yang Y, Xu J, Ware JB, Liu B. Use of Magnetic Resonance Imaging in Acute Traumatic Brain Injury Patients is Associated with Lower Inpatient Mortality. J Clin Imaging Sci 2021;11:53.