Published in final edited form as:
Crit Care Med. 2014 January ; 42(1): . doi:10.1097/CCM.0b013e318298a890.

Preliminary Report on Cardiac Dysfunction after Isolated Traumatic Brain Injury

Sumidtra Prathep, MD[1], **Deepak Sharma, MD, DM**[1,2], **Matthew Hallman, MD**[1], **Aaron Joffe, DO**[1], **Vijay Krishnamoorthy, MD**[1], **G. Burkhard Mackensen, MD PhD**[1], and **Monica S. Vavilala, MD**[1,7]

[1]Departments of Anesthesiology & Pain Medicine, University of Washington, Seattle, WA

[2]Department of Neurological Surgery, University of Washington, Seattle, WA

[7]Department of Radiology, University of Washington, Seattle, WA

Abstract

Objective—The aim of this study was to examine cardiac dysfunction during the first two weeks after isolated traumatic brain injury (TBI) and its association with in-hospital mortality.

Methods—After Institutional Review Board approval, data from adult patients, with isolated TBI who underwent echocardiography during the first 2 weeks after TBI between 2003-2010 were examined. Patients with preexisting cardiac disease were excluded. Clinical characteristics and echocardiogram reports were abstracted. Cardiac dysfunction was defined as left ventricular ejection fraction (LVEF) < 50% or presence of regional wall motion abnormality (RWMA).

Interventions—None

Measurement and Main Results—We examined data from 139 patients with isolated TBI who underwent echocardiographic evaluation. Patients were aged 58 ± 20 years, 66% were males and 62.6% had subdural hematoma; admission Glasgow Coma Scale score (GCS) was 3 ± 1 (3-15) and head abbreviated injury scale (AIS) was 4 ± 1 (2-5). Of this cohort, 22.3% had abnormal echocardiogram: reduced LVEF was documented in 12% (LVEF 43 ± 8%), and 17.5% of patients had a RWMA. Hospital day 1 was the most common day of echocardiographic exam. Abnormal echocardiogram was independently associated with all cause in-hospital mortality (9.6 [2.3-40.2]; p= 0.002).

Conclusions—Cardiac dysfunction in the setting of isolated TBI occurs and is associated with increased in hospital mortality. This finding raises the question as to whether there are uncharted opportunities for a more timely recognition of cardiac dysfunction and subsequent optimization of the hemodynamic management of these patients.

Keywords

Traumatic Brain Injury; Cardiac Function; Echocardiography

Please direct all correspondence to: Monica S. Vavilala, MD, Professor, Department of Anesthesiology, Harborview Medical Center, 325 Ninth Avenue. Box 359724, Seattle, WA 98104, vavilala@uw.edu, Fax: 206-744-8090, Phone: 206-744-3210.

Conflicts of interest
There are no conflicts of interest.

The remaining authors have disclosed that they do not have any potential conflicts of interest.

INTRODUCTION

Traumatic brain injury (TBI) affects over 1.8 million people annually carrying with it significant morbidity, mortality and economic cost.(1) Despite the frequency with which TBI affects the general population and the high incidence of secondary end-organ dysfunction after TBI, its potential impact on cardiac function has received little attention outside of case reports and small case series.(2, 3) Nonetheless, significant brain-heart interactions and paroxysmal sympathetic hyperactivity are observed in other neurological conditions.(4, 5) In similar ways, TBI may negatively influence cardiac function and may have its own downstream impact on physiological endpoints and patient outcomes.

Abnormal intracranial pressure resulting from intracranial lesions has been reported to cause cardiac dysfunction in experimental models, (6-8) and myocardial damage has been reported to be independently associated with increased mortality (9-11) in a variety of other neurological conditions (12-16). However, it is unknown what, if any, effects these brain-heart interactions may have on morbidity and/or mortality associated with TBI. This gap in knowledge is important to bridge as part of broad efforts to limit secondary insults after TBI, which may, if left untreated, result in secondary injury and avoidable poor outcomes. The main aim of this study was to examine cardiac dysfunction during the first two weeks after TBI and its association with in-hospital mortality. We hypothesized that isolated TBI is associated with cardiac dysfunction and that cardiac dysfunction is independently associated with in-hospital mortality following TBI.

METHODS

Setting

This retrospective study was performed at Harborview Medical Center, a 413-bed county medical center in Seattle, WA, affiliated with the University of Washington and the only Level 1 trauma center in a five state area (Washington, Wyoming, Alaska, Montana and Idaho). Harborview Medical Center has 88 intensive care unit (ICU) beds with separate ICUs for medical, cardiac, trauma/surgical, burn, and neurology/neurosurgery patients not including pediatrics. All ICUs have 24-hour in-house physician coverage and are staffed by intensivist-led teams consisting of an attending physician, critical care fellow, senior level and junior level resident. The departments of surgery, anesthesiology, and internal medicine provide physician coverage, attendings and trainees. This study was approved by the University of Washington Institutional Review Board (Seattle, WA, USA).

Study Population

Eligibility criteria included: (1) Age ≥18 years; (2) Discharge diagnosis of traumatic brain injury (ICD 9 codes 800-801.9, 803-804.9 or 850-854.1), and (3) Presence of transthoracic or transesophageal echocardiography report documented by cardiologists within 14 days after TBI. Exclusion criteria were presence of extracranial injuries (such as but not limited to orthopedic/chest/cardiac/abdominal/pelvis), pre-existing cardiac disease (defined as documented preadmission myocardial ischemia/infarction, arrhythmia, heart failure, untreated hypertension and cardiac pacemaker) and brain death.

Data Sources

Figure 1 describes the data sources and data linkages performed to obtain the final sample of isolated TBI patients who underwent echocardiography. Briefly, data sources were the Harborview Medical Center (HMC) Trauma Registry, HMC billing data, and HMC electronic medical records. A list of eligible patients were identified from the HMC Trauma

registry and linked to HMC billing data to yield a final list of isolated TBI patients who underwent echocardiography.

Clinical Care of Patients with Severe TBI

TBI was categorized as mild (GCS 13-15), moderate (GCS 9-12) and severe (GCS 3-8) (17) and categorized by Head Abbreviated Injury Scale (AIS); 1 = minor, 2 = moderate, 3 = serious, 4 = severe, 5 = critical and 6 = unsurvivable, (18) as previously described. During the study period, patients were resuscitated according to institutional practice, consistent with the Brain Trauma Foundation Guidelines (19, 20) during that period. Relevant to this study, practice includes invasive intracranial pressure monitoring, maintaining intracranial pressure < 20 mmHg, minimum CPP of 50 mmHg, $PaCO_2$ 35-40 mmHg, SaO_2 > 90% and maintaining core body temperature between 35-37.5° C with antipyretics, cooling/warming blankets, or intravascular cooling devices if needed. Practices involving requests for echocardiography were not standardized during the time of this study and echocardiography was requested at the discretion of the primary attending intensivist.

Outcome Measures

Main outcomes were presence or absence of abnormal echocardiography findings (left ventricular ejection fraction [LVEF] < 50% *OR* regional wall motion abnormality [RWMA] grades 0 = none, 1+ = hypokinesis, 2+ = severe hypokinesis, 3+ = akinesis, 4+ = dyskinesis (21), and in-hospital mortality. We also recorded frequency of echocardiography and when available, cardiac enzyme data (elevated enzyme levels being defined as creatine phosphokinase MB isoenzyme [CK-MB] > 9 ng/mL, troponin-I > 0·4 ng/mL or B-type natriuretic peptide [BNP] > 101 pg/mL as per institutional norms) during the first 14 days after injury. We documented the presence of any ICU hypotension, defined as systolic blood pressure (SBP) < 90mmHg.

Statistical Analyses

Statistical analyses were performed using SPSS19.0 (Chicago, Illinois). *Descriptive statistics* were used to describe clinical characteristics, echocardiography utilization, echocardiographic findings, computed tomography scan lesions, and mortality of TBI patients who underwent echocardiography. Data are presented as mean and standard deviation (SD) for parametric data or median and standard error of the mean (SEM) for non-parametric data, or as percentages for categorical variables.

Univariate analysis was used to examine the relationship between the outcome (abnormal echocardiography) and a priori selected demographic factors (age and gender), injury severity factors (head AIS and GCS), cardiac factors (hypotension [ED and ICU] and cardiac enzymes). Factors which had $p < 0.2$ level in univariate analysis were included in multivariate logistic regression analysis and only the significant ($p<0.05$) factors were captured in the final model for this analysis (outcome abnormal echocardiography).

We developed a second logistic regression model which was used to examine whether abnormal echocardiography was associated with in hospital mortality after adjusting all confounders by change-in-estimate (CE) method. The potential confounders were age, gender, admission GCS, head AIS, ISS, cardiac enzymes, ED hypotension and ICU hypotension. We calculated two ORs of the effect of abnormal echo on mortality, one which is adjusted for potential confounders the other unadjusted. If two ORs differ by 10%, we concluded that the factor is a confounder. Age, gender and Head AIS met the CE criterion ≥ 10%. The final multivariate logistic regression model assessed the association of abnormal echo and mortality after adjusting for confounders. Data are described using crude and adjusted odds ratios with 95% CI.

RESULTS

Patient Characteristics and Final Sample

Data from 139 patients with isolated TBI whose medical record contained at least one echocardiography report (Table 1) were reviewed. Patients meeting eligibility criteria were 58 ± 20 years old and 66% were males. Most patients had severe (56.1 %) followed by mild TBI (36.7%). Median GCS was 3 ± 1 (range 3-15). One hundred and sixteen (83.5%) patients had head AIS 4-6. The majority of patients had subdural hematoma (62.6%) followed by subarachnoid hemorrhage (16.5%), contusion (8.6%), intraparenchymal hemorrhage (4.4%) and others (7.9%) on head computed tomography scan and overall all cause in-hospital mortality was 13.7%.

Echocardiography Utilization and Findings

One hundred and thirty three (95.7%) of the 139 patients with echocardiography data underwent one echocardiographic examination while 6 patients had two examinations. Overall, the median time to echocardiography was 3 (range 0-14) days after TBI. The most common day of echocardiography was hospital day 1 (30; 22%). The distribution of timing of echocardiographic evaluation was: hospital day 1 (admission)-3 days after TBI (76; 54.7%), 4-7 days after TBI (36; 25.9%) and 8-14 days after TBI (27; 19.4%). One hundred and thirty-three (96%) patients underwent transthoracic only and one patient underwent transesophageal echocardiography only. Five (4%) patients underwent both transthoracic and transesophageal echocardiography on the same day. Table 1 shows the findings of the first echocardiographic report.

Overall, 22.3% TBI patients with echocardiograms had cardiac dysfunction: reduced LVEF was documented in 12% (LVEF 43 ± 8%) of patients, and 17.5% patients had a RWMA. Eighteen (12.9%) of the 139 patients were receiving vasopressors/inotropes on the day of echocardiography for hypotension prior to echocardiography; five (27.8%) of these 18 patients had abnormal echocardiogram (3 reduced LVEF, 1 RWMA and 1 reduced LVEF and RWMA). Of these 5 patients, 1 patient received phenylephrine, 2 patients received dopamine and 2 patients received norepinephrine. Intravenous dobutamine was added to the vasopressor regimen for one patient previously receiving intravenous phenylephrine for treatment of hypotension after echocardiography findings revealed reduced LVEF (34%). None of the 18 patients had hypotension on day of echocardiogram.

Cardiac Enzymes

Some patients who underwent echocardiography had sampling for cardiac enzymes within the 2 weeks after admission. Of the 98/139 patients who had CK-MB drawn, 30 patients (30.6%) had elevated CK-MB levels. Thirteen (43.3%) of these 30 patients had abnormal echocardiography. Twenty four (22.4%) of the 107 patients sampled for troponin I had elevated troponin I levels. Twelve (50%) of these 24 patients had abnormal echocardiography. Nineteen (76%) of 25 patients who underwent BNP sampling had elevated BNP levels. Eleven (57.9%) of these 19 patients had abnormal echocardiography. There was no relationship between TBI severity (admission GCS or head AIS scores) and elevated cardiac enzymes.

Cardiac Dysfunction after TBI and In-Hospital Mortality

Univariate risk factors associated with abnormal echocardiography and in-hospital mortality are given in Table 2. Abnormal echocardiographic evaluation at all three time points examined (within 3, 7 and 14 days after TBI) was associated with in-hospital mortality ($p = 0.01$, 0.01 and <0.001, respectively). The distribution of cardiac dysfunction was 25%

(19/76 patients) 1-3 days after TBI, 19.4% (7/36 patients) 4-7 days after TBI and 18.5% (5/27 patients) 8-14 days after TBI. The distribution of abnormal echocardiograms by TBI severity when defined by GCS was equally high: severe (24.4%; 19/78 patients), moderate (20%; 2/10 patients) and mild (19.6%; 10/51 patients. When patients were categorized by head AIS, cardiac dysfunction by echocardiogram occurred in 25.9% (30/116 patients) who had head AIS 4-6 versus 4.3% (1/23 patients) of patients with head AIS 1-3. Thirty-six (25.9%) of 139 patients had documented hypotension (SBP < 90 mmHg) during their ICU stay, and one patient had both a documented myocardial infarction and an abnormal echocardiogram. Nineteen (52.8%) of 36 patients with hypotension had abnormal echocardiograms. Overall, two patients died with new cardiac diagnoses; one with myocardial infarction and one with severe aortic stenosis.

Multivariate risk factors for cardiac dysfunction during the first 2 weeks after TBI included age ≥ 65 years, elevated cardiac enzymes (CK-MB and troponin I), and head AIS 4-6 (Table 3).

Abnormal echocardiography during this period was associated with increased in-hospital mortality. Crude OR was 14.14 (95%CI; 3.53 -56.72). Age, head AIS and gender were considered confounders and after adjusting for these confounders, abnormal echocardiography was associated with increased in-hospital mortality (AOR 9.6; 95% CI 2.3-40.2).

DISCUSSION

The two main findings of this study are that patients with isolated TBI, including some who were receiving vasopressors, had cardiac dysfunction within 2 weeks after isolated TBI and that TBI-related cardiac dysfunction was associated with in-hospital mortality. Elevated cardiac enzymes occurred within 2 weeks after TBI and elevated CKMB and Troponin-I were associated with abnormal echocardiography. This is the first clinical study to document cardiac dysfunction and its association with in-hospital mortality after TBI.

Neurological injury has been linked to cardiac dysfunction in a variety of models of brain injury, including emotional stress, ischemic insults, and subarachnoid hemorrhage.(10, 16, 17) While the existence of echocardiographic abnormalities in patients with TBI is a novel finding, the idea of brain-heart interactions has been described for decades.(18) The proposed pathophysiologic mechanisms for this interaction have centered on a sudden catecholamine excess state and, more recently, the inflammatory cascade.(22, 23) Similar underlying mechanism may explain isolated neurogenic pulmonary edema (24) and stress cardiomyopathy, (25) likely due to heterogeneous vascular receptor interactions in the setting of a catecholamine excess state. In fact, left ventricular dysfunction as evidenced by a diminished LVEF and new regional wall motion abnormalities can be found even in a significant number of brain dead patients considered donors for solid organ transplantation. (26, 27) Myocardial biopsy specimens from patients diagnosed with brain death show pathologic features indicative of catecholamine-induced injury, similar to features observed in patients diagnosed with stress cardiomyopathy.(28) Although we do not have data to demonstrate sudden catecholamine excess, and did not include data from patients with brain death in this analysis, it is conceivable that the echocardiographic abnormalities observed in TBI are a variant of stress cardiomyopathy secondary to an acutely injured brain.

While we observed cardiac dysfunction up to 2 weeks after TBI, it is possible that the dysfunction had set-in earlier in the course of TBI but was overtly manifest and / or recognized only after echocardiographic documentation, the timing of which could be affected by numerous logistic factors. Our observation of cardiac dysfunction later in the

course of TBI beyond the first 72 hours may, in fact, reflect persistent rather than new onset dysfunction although we cannot confirm this for the lack of serial echocardiograms. Irrespective however, cardiac dysfunction was not uncommon in patients where it was clinically suspected leading to echocardiographic evaluation. Echocardiography timing and utilization was driven by clinical care needs and not by study design and may have been affected by provider preference. Our observations indicate a tendency for the intensivists to order echocardiograms for TBI patients who are older and have more severe TBI (lower GCS and higher head AIS) and hypotension. Therefore, true rates for cardiac dysfunction in TBI could be different than represented by our results. Due to selection bias, the incidence may be an overestimation of the true incidence. Conversely, it is conceivable that some patients who did not survive and who did not have echocardiograms also had cardiac dysfunction. While we may have residual confounding from other ICU events and cannot definitively determine whether echocardiography altered clinical practice and improved outcomes, this is a subject for future study. Future work can be framed based on these findings that document cardiac dysfunction in TBI. Our results also indicate that it may be possible for clinicians to predict cardiac dysfunction (and hence, the need for echocardiograms) based on select clinical characteristics namely, age ≥ 65 years, elevated cardiac enzymes (CK-MB and troponin I), and head AIS 4-6.

Cardiac injury after other forms of acute brain injury such as subarachnoid hemorrhage is evidenced by elevated troponin levels and decreased LVEF. (32, 33) Patients with more severe forms of subarachnoid hemorrhage appear to be at greater risk for cardiac dysfunction (34), and LV dysfunction after subarachnoid hemorrhage increases the risk of cerebral infarction from vasospasm, hypotension, and pulmonary edema. (34) In patients without pre-existing heart disease suffering an aneurysmal subarachnoid hemorrhage, elevations in troponin I have been reported to be both sensitive and specific for myocardial dysfunction by echocardiography (29-31) whereas elevated CK-MB levels have been reported to be highly specific (29-31) but lack sensitivity. (31, 32) Examining the scope of the role of cardiac enzymes in predicting in hospital mortality was beyond the scope of this project but may warrant future investigation.

Pharmacologic elevation of blood pressure is frequently utilized in patients with TBI to prevent or treat cerebral ischemia by either treating hypotension or augmenting cerebral perfusion pressure. However, data on vasopressor effectiveness in this setting are limited and the results are conflicting despite the significant differences in pharmacodynamic profiles of vasopressor agents. While norepinephrine has mixed effects on α and β-adrenergic receptors it maybe more effective in augmenting cerebral perfusion pressure (CPP) than selective α1-adrenergic agonist (e.g. phenylephrine), suggesting that improved cardiac output may influence cerebral perfusion and that cardiac dysfunction may hinder CPP.(35) The findings of this study indicate that myocardial dysfunction may not be uncommon after TBI even in patients with no previously known cardiac disorders and may have to be accounted for in evaluating vasopressor effectiveness. Since the information about cardiac dysfunction may affect vasopressor choice, these findings also point towards the potential utility of echocardiography in evaluating cardiac function after TBI to make rationale and informed vasopressor choices. Moreover, since cardiac dysfunction was associated with mortality, there may be a role for myocardial protection in addition to neuroprotection after TBI.

CONCLUSIONS

In summary, this preliminary study suggests that cardiac dysfunction in the setting of TBI occurs and may be associated with increased in-hospital mortality. This finding raises the question as to whether there are uncharted opportunities for a more timely recognition of

cardiac dysfunction and subsequent optimization of the hemodynamic management of these patients.

Acknowledgments

Source of Funding:

Funding came from NINDS 3R01NS072308-03

Drs. Krishnamoorthy and Vavilala received funding support from the National Institutes of Health.

REFERENCES

1. Sosin DM, Sniezek JE, Waxweiler RJ. Trends in death associated with traumatic brain injury, 1979 through 1992. Success and failure. JAMA. 1995; 273(22):1778–1780. [PubMed: 7769773]
2. Riera M, Llompart-Pou JA, Carrillo A, Blanco C. Head injury and inverted Takotsubo cardiomyopathy. J Trauma. 2010; 68(1):E13–15. [PubMed: 19065115]
3. Bahloul M, Chaari AN, Kallel H, et al. Neurogenic pulmonary edema due to traumatic brain injury: evidence of cardiac dysfunction. Am J Crit Care. 2006; 15(5):462–470. [PubMed: 16926367]
4. Moussouttas M, Lai EW, Khoury J, et al. Determinants of central sympathetic activation in spontaneous primary subarachnoid hemorrhage. Neurocrit Care. 2012; 16(3):381–388. [PubMed: 22311230]
5. Hinson HE, Sheth KN. Manifestations of the hyperadrenergic state after acute brain injury. Current opinion in critical care. 2012; 18(2):139–145. [PubMed: 22322258]
6. Shanlin RJ, Sole MJ, Rahimifar M, et al. Increased intracranial pressure elicits hypertension, increased sympathetic activity, electrocardiographic abnormalities and myocardial damage in rats. J Am Coll Cardiol. 1988; 12(3):727–736. [PubMed: 3403832]
7. Shivalkar B, Van Loon J, Wieland W, et al. Variable effects of explosive or gradual increase of intracranial pressure on myocardial structure and function. Circulation. 1993; 87(1):230–239. [PubMed: 8419012]
8. Schrader H, Hall C, Zwetnow NN. Effects of prolonged supratentorial mass expansion on regional blood flow and cardiovascular parameters during the Cushing response. Acta Neurol Scand. 1985; 72(3):283–294. [PubMed: 4061050]
9. Di Angelantonio E, Fiorelli M, Toni D, et al. Prognostic significance of admission levels of troponin I in patients with acute ischaemic stroke. J Neurol Neurosurg Psychiatry. 2005; 76(1):76–81. [PubMed: 15607999]
10. James P, Ellis CJ, Whitlock RM, et al. Relation between troponin T concentration and mortality in patients presenting with an acute stroke: observational study. BMJ. 2000; 320(7248):1502–1504. [PubMed: 10834890]
11. Song HS, Back JH, Jin DK, et al. Cardiac troponin T elevation after stroke: relationships between elevated serum troponin T, stroke location, and prognosis. J Clin Neurol. 2008; 4(2):75–83. [PubMed: 19513307]
12. Kolin A, Norris JW. Myocardial Damage from Acute Cerebral-Lesions. Stroke. 1984; 15(6):990–993. [PubMed: 6506127]
13. Myers MG, Norris JW, Hachinski VC, et al. Cardiac sequelae of acute stroke. Stroke. 1982; 13(6): 838–842. [PubMed: 7147301]
14. Parr MJ, Finfer SR, Morgan MK. Reversible cardiogenic shock complicating subarachnoid haemorrhage. BMJ. 1996; 313(7058):681–683. [PubMed: 8811765]
15. Dupuis M, van Rijckevorsel K, Evrard F, et al. Takotsubo syndrome (TKS): a possible mechanism of sudden unexplained death in epilepsy (SUDEP). Seizure. 2012; 21(1):51–54. [PubMed: 21996459]
16. Wittstein IS, Thiemann DR, Lima JA, et al. Neurohumoral features of myocardial stunning due to sudden emotional stress. The New England journal of medicine. 2005; 352(6):539–548. [PubMed: 15703419]

17. Kono T, Morita H, Kuroiwa T, et al. Left ventricular wall motion abnormalities in patients with subarachnoid hemorrhage: neurogenic stunned myocardium. Journal of the American College of Cardiology. 1994; 24(3):636–640. [PubMed: 8077532]
18. Samuels MA. The brain-heart connection. Circulation. 2007; 116(1):77–84. [PubMed: 17606855]
19. Bullock R, Chestnut R, Chajar J, et al. Guideline for the management of severe traumatic brain injury. J Neurotrauma. 2000; 17:449–554.
20. Brain Trauma Foundation; American Association of Neurological Surgeons; Congress of Neurological Surgeons; Joint Section on Neurotrauma and Critical Care, AANS/CNS. Carney NA, Ghajar J. J Neurotrauma. 2007; 24(Suppl 1):S1–106. [PubMed: 17511535]
21. Flynn M, Curtin R, Nowicki ER, et al. Regional wall motion abnormalities and scarring in severe functional ischemic mitral regurgitation: A pilot cardiovascular magnetic resonance imaging study. J Thorac Cardiovasc Surg. 2009; 137:1063–1070. [PubMed: 19379967]
22. Mashaly HA, Provencio JJ. Inflammation as a link between brain injury and heart damage: the model of subarachnoid hemorrhage. Cleveland Clinic journal of medicine. 2008; 75(Suppl 2):S26–30. [PubMed: 18540142]
23. Ako J, Sudhir K, Farouque HM, et al. Transient left ventricular dysfunction under severe stress: brain-heart relationship revisited. The American journal of medicine. 2006; 119(1):10–17. [PubMed: 16431176]
24. Davison DL, Terek M, Chawla LS. Neurogenic pulmonary edema. Crit Care. 2012; 16(2):212. [PubMed: 22429697]
25. Richard C. Stress-related cardiomyopathies. Ann Intensive Care. 2011; 1(1):39. [PubMed: 21933374]
26. Gilbert EM, Krueger SK, Murray JL, et al. Echocardiographic evaluation of potential cardiac transplant donors. J Thorac Cardiovasc Surg. 1988; 95(6):1003–1007. [PubMed: 3287011]
27. Seiler C, Laske A, Gallino A, et al. Echocardiographic evaluation of left ventricular wall motion before and after heart transplantation. J Heart Lung Transplant. 1992; 11(5):867–874. [PubMed: 1420233]
28. Berman M, Ali A, Ashley E, et al. Is stress cardiomyopathy the underlying cause of ventricular dysfunction associated with brain death? The Journal of heart and lung transplantation: the official publication of the International Society for Heart Transplantation. 2010; 29(9):957–965. [PubMed: 20627624]
29. Mayer SA, Lin J, Homma S, et al. Myocardial injury and left ventricular performance after subarachnoid hemorrhage. Stroke; a journal of cerebral circulation. 1999; 30(4):780–786.
30. Parekh N, Venkatesh B, Cross D, et al. Cardiac troponin I predicts myocardial dysfunction in aneurysmal subarachnoid hemorrhage. Journal of the American College of Cardiology. 2000; 36(4):1328–1335. [PubMed: 11028491]
31. Bulsara KR, McGirt MJ, Liao L, et al. Use of the peak troponin value to differentiate myocardial infarction from reversible neurogenic left ventricular dysfunction associated with aneurysmal subarachnoid hemorrhage. Journal of neurosurgery. 2003; 98(3):524–528. [PubMed: 12650423]
32. Horowitz MB, Willet D, Keffer J. The use of cardiac troponin-I (cTnI) to determine the incidence of myocardial ischemia and injury in patients with aneurysmal and presumed aneurysmal subarachnoid hemorrhage. Acta Neurochir (Wien). 1998; 140(1):87–93. [PubMed: 9522914]
33. Tung P, Kopelnik A, Banki N, et al. Predictors of neurocardiogenic injury after subarachnoid hemorrhage. Stroke. 2004; 35(2):548–551. [PubMed: 14739408]
34. Temes RE, Tessitore E, Schmidt JM, et al. Left ventricular dysfunction and cerebral infarction from vasospasm after subarachnoid hemorrhage. Neurocrit Care. 2010; 13(3):359–365. [PubMed: 20945116]
35. Sookplung P, Siriussawakul A, Malakouti A, et al. Vasopressor use and effect on blood pressure after severe adult traumatic brain injury. Neurocrit care. 2011; 15(1):46–54. [PubMed: 20878264]

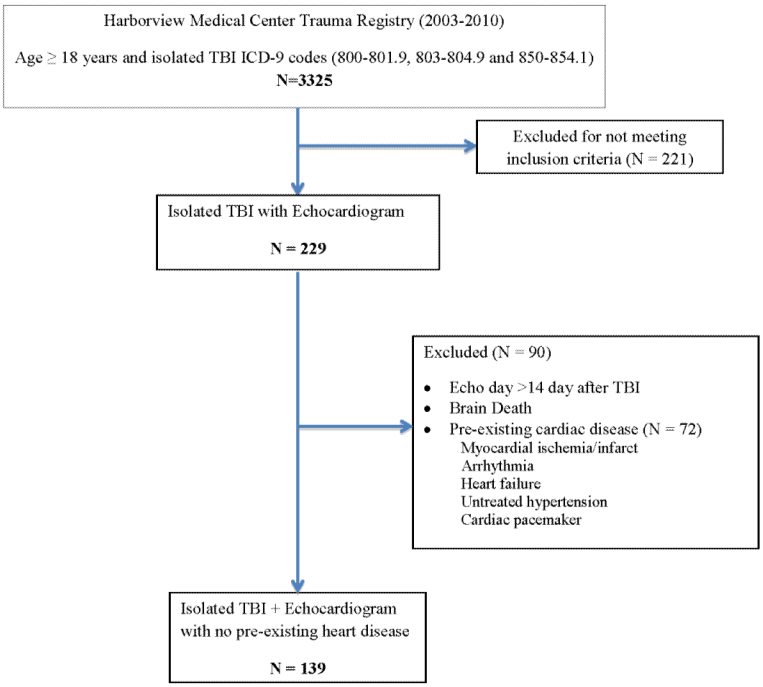

Figure 1.
Flowchart of Patient Sampling to Yield a Final Sample (N=139) of Patients with Isolated Traumatic Brain Injury (TBI) who Underwent Echocardiography.

Table 1

Clinical Characteristics and First Echocardiography Report Findings of 139 Patients with Isolated Traumatic Brain Injury (TBI) with Echocardiography Data. LVEF= Left Ventricular Ejection Fraction, RWMA = Regional Wall Motion Abnormalities. Data as n (%) mean ± SD (range) or median±SEM (*).

Clinical Characteristics	
Age (years)	58 ± 20 (18-91)
Male gender (%)	66
Admission Glasgow Coma Scale* (GCS) score	3 ± 1 (3-15)
Mild TBI (GCS 13-15)	51 (36.7)
Moderate TBI (GCS 9-12)	10 (7.2)
Severe TBI (GCS ≤ 8)	78 (56.1)
Head Abbreviated Injury Score (AIS) 4-6	116 (83.5)
Injury Severity Score (ISS)*	21 ± 0.7(9-50)
CT diagnosis	
Subdural hematoma	87 (62.6)
Subarachnoid hemorrhage	23 (16.5)
Contusion	12 (8.6)
Intraparenchymal hemorrhage	6 (4.4)
Other	11 (7.9)
All cause In –hospital mortality	19 (13.7)
LVEF	
Low (LVEF < 50%)	16(12.1%)
	43±8
Normal (LVEF ≥ 50%)	107 (81.1%)
	60±3
Hyperdynamic state	9 (6.8%)
Thrombus present	1(0.8%)
RWMA grade	
Normal	109 (82.6%)
Mild hypokinesis	12(9.1%)
Severe hypokinesis	1 (0.8%)
Akinesis	8 (6.1%)
Dyskinesis	2(1.5%)
RWMA field abnormality (N=26)	
Left ventricle	21 (16.0%)
Right ventricle	0
Pericardial effusion/tamponade	3 (2.3%)

Table 2

Univariate Risk Factors Associated with Abnormal Echocardiography (Ejection Fraction < 50% OR Regional Wall Motion Abnormality) in 139 Patients with Isolated Traumatic Brain Injury (TBI). Hypotension = Systolic blood pressure < 90 mmHg; GCS = Glasgow Coma Scale Score, AIS = Abbreviated Injury Scale; ISS = Injury Severity Score; CK-MB = Creatine phosphokinase MB isoenzyme; ED = Emergency Department; ICU = Intensive Care Unit. Data as Crude Odds Ratio and 95% CI.

	Abnormal Echocardiogram OR (95% CI)	***In-Hospital Mortality OR (95% CI)***
Age ≥ 65 years (n= 62; 44%)	2.19 (0.94-5.11)	2.44 (0.70-8.56)
Male gender (n= 92; 66%)	1.47 (0.59-3.65)	2.79 (0.59-13.33)
Admission GCS ≤ 8 (n= 78; 56%)	0.96 (0.41-2.25)	1.14 (0.34-3.84)
Head AIS 4-6 (n= 109; 82%)	7.98 (1.03-61.86)	2.72 (0.34-22.05)
ISS >25 (n=65; 46%)	0.91 (0.40-2.10)	2.90 (0.83-10.16)
Elevated Cardiac Enzymes CK-MB (n = 30/98; 30%) Troponin I (n = 24/107; 22%) B-Type natriuretic peptide (n = 19/25; 76%)	 2.95(1.16-7.48) 4.73 (1.61-13.78) 7.86 (0.75-82.13)	 5.82 (1.60-21.23) 4.13 (1.57-10.87) 1.00 (0.08-11.93)
Abnormal echocardiogram (n=31; 22%)	N/A	14.14 (3.53-56.72)
ED hypotension (n=12; 9%)	1.21 (0.30-4.78)	4.11 (0.94-17.93)
Hypotension during ICU admission (n=36; 26%)	9.60 (3.79-24.30)	21.09 (4.32-102.87)

Table 3

Multivariate Risk Factors of Abnormal Echocardiography Findings (Ejection Fraction < 50% or Regional Wall Motion Abnormality) in 139 Patients with Isolated Traumatic Brain Injury. AIS = Abbreviated Injury Scale; CK-MB = Creatine phosphokinase MB isoenzyme. Data are adjusted for gender.

	Abnormal Echocardiogram ***AOR (95%CI)***
Age ≥ 65 years (n= 62; 45%)	1.05 (1.02-1.08)
Head AIS 4-6 (n= 109; 83%)	3.34 (1.19-9.34)
Elevated CK-MB (n = 30/98; 31%) Elevated Troponin I (n = 24/107; 22%)	3.63 (1.28-10.31) 6.21 (2.02-19.09)