Original Article

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Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) After Traumatic Brain Injury

Kristen D Nordham[1], Scott Ninokawa[1,2], Ayman Ali[1,3], Jacob M Broome[1], Scott McCraney[1], John T Simpson[1], Danielle Tatum[1], Olan Jackson-Weaver[1], Sharven Taghavi[1], Patrick McGrew[1] and Juan Duchesne[1]

[1]Department of Surgery, Tulane University School of Medicine, New Orleans, LA, USA
[2]Department of Emergency Medicine, University of California San Diego, San Diego, CA, USA
[3]Department of Surgery, Duke University School of Medicine, Durham, NC, USA

Background: The effects of resuscitative endovascular balloon occlusion of the aorta (REBOA) on progression of traumatic brain injury (TBI) are unclear. Two hypotheses prevail: increased mean arterial pressure may improve cerebral perfusion, or cause cerebral edema due to elevated intracranial pressure. This study compares outcomes in hypotensive, blunt trauma patients with TBI treated with and without REBOA.
Methods: A retrospective analysis compared hypotensive (systolic blood pressure [SBP] >90) blunt trauma patients with TBI treated with REBOA to those treated without. Patients with spontaneous circulation at admission and at initiation of aortic occlusion were included. Patients requiring cardiopulmonary resuscitation in the emergency department (ED) were excluded. Radius matching used age, injury severity score (ISS), abbreviated injury score (AIS)-head, and Glasgow coma score (GCS) and SBP at ED arrival.
Results: Of 232 patients, 135 were treated with REBOA and 97 without. REBOA patients were older and had higher ISS, AIS-head, AIS-chest and AIS-extremity. There was no difference in TBI severity, and mortality. In the matched analysis (n = 76 REBOA, n = 54 non-REBOA), there was no difference in ISS, AIS-head, pre-hospital, ED, or discharge GCS, ED SBP, or mortality. Despite longer hospital stays for REBOA patients, there was no difference in intensive care unit length of stay, rate of discharge home, or discharge GCS.
Conclusions: REBOA was used in more severely injured patients, but was not associated with higher mortality rate. REBOA should be considered for use in patients with non-compressible torso hemorrhage and concomitant TBI, as it did not increase mortality, and outcomes were similar to non-REBOA patients.

Keywords: *Traumatic Brain Injury; REBOA; Non-Compressible Torso Hemorrhage, Trauma Surgery*

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INTRODUCTION

Resuscitative endovascular balloon occlusion of the aorta (REBOA) can be a valuable tool to minimize blood loss in the acute setting of non-compressible torso hemorrhage (NCTH) before definitive control can be achieved. The effect of REBOA on the progression of traumatic brain injury (TBI) in the setting of NCTH is still unclear. Animal models have shown conflicting results; with one showing REBOA use leading to exacerbation of shock and TBI [1], another found REBOA increased carotid flow with no detrimental impact on the injured brain [2], and another reported mixed results for short and long-term outcomes [3]. Human data on the subject are lacking. In one study using human data, Elkbuli et al. compared outcomes of REBOA-treated patients who had concurrent TBI to those without TBI and found no difference in mortality rate between groups [4]. Norii et al. found that in Japan (which notably differs from the United States in terms of trauma volume and type, pre-hospital care, and wide acceptance

Corresponding author:
Kristen Nordham, 1430 Tulane Ave, New Orleans, LA 70112, USA.
Email: knordham@tulane.edu

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of REBOA use in Japan), blunt trauma patients with TBI treated with REBOA had a higher mortality rate compared to those treated without it [5].

Two hypotheses largely prevail regarding the impact of REBOA in the setting of TBI: the increased mean arterial pressure caused by REBOA improves cerebral perfusion, crucial for the injured brain, or conversely, causes cerebral edema due to elevated blood pressure and intracranial pressure (ICP). Increased ICP has been associated with detrimental outcomes, including increased mortality rate [6]. In a swine model of TBI and hemorrhagic shock, rapid blood resuscitation, not REBOA, resulted in large ICP increases [2]. While hypertension has detrimental effects on TBI, hypotension is also associated with poor outcomes, including increased mortality [7].

Maintaining normotension in TBI patients is critical. Animal models of TBI with hemorrhagic hypotension have demonstrated neuronal death [8] and enlarged contusion area due to hypotension [9]. Analysis of human data from the Traumatic Coma Databank found hypotension and hypoxemia in the setting of TBI to be associated with increased morbidity and mortality [10, 11]. Even single episodes of hypotension early in TBI management have been associated with increased mortality. In the pre-hospital setting, the Excellence in Pre-hospital Injury Care (EPIC) study increased survival to hospital discharge in TBI patients after implementing guidelines for TBI management focusing on prevention and treatment of hypotension and hypoxia before arrival at a hospital [12].

Here, we focused on REBOA, an in-hospital method to address hypotension (defined as systolic blood pressure (SBP) < 90 mmHg) in the acute setting until definitive control can be obtained. The current study investigated outcomes of hypotensive patients who suffered both blunt trauma and a TBI and were treated with REBOA to those treated without, using data from multiple trauma centers in the United States. The primary outcome of interest was survival to hospital discharge, and secondary outcomes included non-mortality, functional outcomes: hospital and intensive care unit (ICU) length of stay (LOS), ventilator days, discharge Glasgow coma score (GCS), and discharge location. Based on prior studies which reported association between hypotension and poor outcomes in TBI patients, we hypothesized that REBOA use would be associated with improved outcomes for hypotensive blunt trauma and TBI patients compared to patients treated without REBOA.

METHODS

Study Design and Subjects

Patients included were hypotensive (SBP <90 mmHg) adults (≥18 years old) with spontaneous circulation who suffered blunt trauma and a computed tomography-verified TBI with an abbreviated injury score (AIS)-head of 2 or greater between 1 January 2016 and 31 December 2021. Patients treated with REBOA were selected from the Aortic Occlusion for Resuscitation in Trauma and Acute Care Surgery (AORTA) registry [13]. Non-REBOA patients were selected from the institutional trauma registry of University Medical Center New Orleans, a large, urban level I trauma center. REBOA patients all had SBP of less than 90 mmHg and greater than 0 mmHg at the initiation of aortic occlusion. Patients who were pregnant, minors, prisoners, and/or required cardiopulmonary resuscitation (CPR) in the emergency department (ED) were excluded. A population-based registry study by Fröhlich et al. found the mortality rate for patients with TBI and shock index (SI) of 1–1.4 (average prehospital SI = 0.1 in non-REBOA patients in this study) to be 36.6% [14], and Elbuki et al. found a mortality rate of 62.4% for hypotensive trauma patients with TBI treated with REBOA [4]. Using these mortality rates, power analysis found that for a power of 0.8 and an alpha of 0.05, the sample size required in each group would be 58 for a total population of 116.

Study Variables

Data collected included patient demographics, mechanism of injury, pre-hospital vital signs and interventions, transfer from an outside hospital, ED vital signs and injury severity measured by the GCS, injury severity score (ISS), and AIS. Data points used to analyze outcomes included mortality, mortality day and location, hospital and ICU LOS, ventilator (vent) days, discharge location, and discharge GCS. Information on transfusion requirements including blood products and crystalloids for the entire hospital stay was collected.

Statistical Analysis and Methods

Univariate analysis was performed using either chi-squared and Mann–Whitney U tests for categorical or continuous variables, respectively. A subset analysis of matched REBOA versus non-REBOA groups was performed. To account for differences in injury severity between groups, propensity score matching with common support and radius matching with a caliper of 0.1 was used to match groups based on clinical factors that may be considered when deciding to place a REBOA in the acute setting: age, injury severity measured here by IS and AIS-head, ED GCS, and ED SBP. In the propensity score-matched cohorts, McNemar's test was utilized to assess categorical variables, while paired Wilcoxon signed-rank tests were used for continuous variables. A P value less than 0.05 was considered statistically significant. Matching and statistical analysis was performed using Stata version 14.

Ethical Approval and Informed Consent

Ethical approval to report these cases was given by our institutional review board and hospital research review committee. Written informed consent was not required as a waiver of consent was obtained for this study.

RESULTS

Analysis included 232 hypotensive, blunt trauma patients with TBI, 135 treated with REBOA and 97 treated without. Demographics, injury, pre-hospital and ED characteristics are found in Table 1. The REBOA group was significantly older compared to the non-REBOA group (P = 0.02). There was no difference in sex between groups with the majority of patients being male in both groups. Mechanism of injury (motor vehicle crash (MVC), motorcycle crash (MCC), auto vs. pedestrian, and fall) differed significantly between groups. Despite REBOA patients being more severely injured with higher ISS, AIS-head, AIS-chest, and AIS-extremity, there was no difference in TBI severity between groups.

Mortality did not differ between groups in the unmatched analysis (Table 2). There was also no significant difference in mortality day between groups, although location of death (ED, operating room (OR), interventional radiology (IR), ICU, or ward) was significantly different. The rate of craniectomy/craniotomy did not differ between groups. While REBOA patients had longer hospital LOS (P = 0.05), there was no difference in ICU LOS or vent days. The rates of discharge to home, to a rehab/nursing facility or other location (e.g. law enforcement or transfer) were significantly different between groups. The majority of both REBOA (87.0%) and non-REBOA (63.0%) patients were discharged to a rehab/nursing facility; however, a higher percentage of REBOA patients were discharged to these facilities. While discharge GCS differed significantly between groups (15 (15–15) for non-REBOA and 15 (11–15) for REBOA, P = 0.04), the median was 15 for both groups, and there was no difference in the proportions of patients with mild, moderate, and severe TBI noted by GCS at discharge.

Table 1 Cohort demographic, injury, pre-hospital and emergency department characteristics.

	Non-REBOA (n = 97)	*REBOA (n = 135)*	*P Value*
Age, years (median (IQR))	43 (24–58)	48 (31–61)	0.02
Male	73 (69.1%)	79 (74.5%)	0.34
Mechanism of injury			
MVC	26 (26.8%)	47 (34.8%)	<0.001
MCC	34 (35.1%)	54 (40.0%)	
Auto vs. pedestrian	12 (12.4%)	25 (18.5%)	
Fall	25 (25.8%)	9 (6.7%)	
Transfer from outside hospital	21 (21.6%)	19 (14.1%)	<0.001
Pre-hospital CPR	14 (14.4%)	6 (4.4%)	0.01
Pre-hospital intubation	33 (34.0%)	37 (27.0%)	0.48
Pre-hospital SBP	98 (78–118)	96 (79–121)	0.42
Pre-hospital HR	90 (79–117)	110 (88–130)	0.002
Pre-hospital GCS	3 (3–10)	3 (3–11)	0.54
ED SBP	75 (52–81)	80 (65–90)	<0.001
ED HR	96 (66–122)	115 (89–131)	<0.001
ED GCS	3 (3–15)	3 (3–9)	0.56
ED TBI severity			
Severe (GCS 3–8)	66 (70.1%)	98 (72.6%)	0.195
Moderate (GCS 9–12)	3 (3.2%)	11 (8.1%)	
Mild (GCS 13–15)	24 (25.8%)	26 (19.3%)	
ISS	27 (19–34)	43 (34–50)	<0.001
AIS-head	3 (2–3)	4 (3–5)	<0.001
AIS-chest	3 (2–3)	3 (3–4)	<0.001
AIS-abdomen	3 (2–4)	3 (2–4)	0.18
AIS-extremity	2 (2–3)	3 (2–4)	0.02

Values are reported as n (%) unless otherwise stated. Continuous variables are presented as median (interquartile range; IQR).

REBOA: resuscitative endovascular balloon occlusion of the aorta; MVC: motor vehicle crash; MCC: motorcycle crash; CPR: cardiopulmonary resuscitation; SBP: systolic blood pressure; HR: heart rate; GCS: Glasgow coma score; ED: emergency department; TBI: traumatic brain injury; OR: operating room; IR: interventional radiology; LOS: length of stay; ISS: injury severity score; AIS: abbreviated injury score.

Table 2 Cohort outcomes.

	Non-REBOA (n = 97)	*REBOA (n = 135)*	*P Value*
Mortality	51 (52.6%)	81 (60.0%)	0.26
Mortality day (median (IQR))	1 (1–3)	1 (1–4)	0.43
Mortality location			
ED	17 (33.3%)	8 (9.9%)	0.002
OR	1 (2.0%)	15 (18.5%)	
IR	0 (0%)	1 (1.2%)	
ICU	33 (64.7%)	56 (69.1%)	
Ward	0 (0%)	1 (1.2%)	
Craniectomy/ craniotomy	0 (0%)	2 (1.5%)	0.09
Hospital LOS (median (IQR))	3 (1–19)	6 (1–31)	0.05
ICU LOS (median (IQR))	4 (2–11)	5 (1–16)	0.80
Vent days (median (IQR))	4 (2–10)	4 (1–14)	0.40
Discharge location			
Home	13 (28.3%)	7 (13.0%)	<0.01
Rehab/nursing facility	29 (63.0%)	47 (87.0%)	
Other (law enforcement, transfer)	4 (8.7%)	0 (0%)	
Discharge GCS	15 (15–15)	15 (11–15)	0.04
Discharge TBI severity			
Severe (GCS 3–8)	0	0	0.38
Moderate (GCS 9–12)	6 (17.8%)	9 (23.7%)	
Mild (GCS 13–15)	32 (84.2%)	29 (76.3%)	

Values are reported as n (%) unless otherwise stated. Continuous variables are presented as median (interquartile range; IQR).

ED: emergency department; OR: operating room; IR: interventional radiology; ICU: intensive care unit; LOS: length of stay; GCS: Glasgow coma score; TBI: traumatic brain injury; CPR: cardiopulmonary resuscitation; HR: heart rate.

Pre-hospital

The rate of transfer from outside hospital was significantly higher in non-REBOA patients ($P < 0.001$) and non-REBOA patients received pre-hospital CPR at a significantly higher rate than REBOA patients ($P = 0.01$) (Table 1). However, there was no difference in the rate of pre-hospital intubation between groups. Pre-hospital heart rate (HR) was significantly higher in REBOA patients ($P = 0.002$), but there were no differences in pre-hospital SBP or GCS between groups.

Emergency Department

Examination of initial vital signs on ED arrival showed SBP and HR to be significantly higher in REBOA patients ($P < 0.001$ for both) compared to non-REBOA patients (Table 1). There was no significant difference in average GCS or in rate of severe, moderate, or mild TBI between groups in the ED.

Transfusion

During the entire hospital course, REBOA patients received significantly more units of packed red blood cells ($P < 0.001$), fresh frozen plasma ($P < 0.001$) and platelets ($P < 0.01$) compared to non-REBOA patients (Table 3). There was no significant difference between groups in the volume of cryoprecipitate or crystalloids transfused during resuscitation.

REBOA Group

Of the 135 patients treated with REBOA, the majority (77.8%) had REBOA placed in the ED, with fewer (17.0%) in the OR. Ultrasound guidance was used in approximately half (54.1%) of the cases, with percutaneous landmarks used in the rest. Most REBOAs were placed in Zone I between the left subclavian artery and celiac trunk, or the infrarenal Zone III. The vast majority of REBOAs (96.3%) achieved successful aortic occlusion, with improved hemodynamics in 86.7% of patients, and hemodynamic stability in 73.3% of the group. Nine (6.7%) cases were converted to open aortic occlusion. The average SBP was not hypotensive immediately after REBOA placement (median interquartile range (IQR) 108 (95–120) mmHg). On average, when REBOA was used, hemodynamic stability was achieved in 69 minutes from arrival at the ED. Definitive hemorrhage control was achieved, on average, within two hours of arrival, and an average time between successful aortic occlusion and definitive hemorrhage control was 74 minutes. Overall, duration of initial aortic occlusion was 50 minutes on average, with REBOAs in Zone I up for an average of 50 minutes, and those in Zone III up for 48 minutes. Twelve patients required a second aortic occlusion after the initial REBOA placement.

Radius Matching Analysis

As REBOA and non-REBOA patients differed in injury severity and blood pressure in the ED, the groups were

Table 3 Transfusion information (entire hospital course).

	Non-REBOA (n = 97)	*REBOA (n = 135)*	*P Value*
PRBCs (units)	3 (2–7)	14 (7–29)	<0.001
FFP (units)	2 (2–6)	10 (4–24)	<0.001
Platelets (packs)	1 (1–2)	3 (1–11)	<0.01
Cryoprecipitate (packs)	2 (0–3)	0 (0–1)	0.09
Crystalloids (1000 cc units)	5 (3–8)	4 (2–8)	0.09

Values are reported as median (interquartile range; IQR).

PRBCs: packed red blood cells; FFP: fresh frozen plasma.

Table 4 Radius matched analysis results.

	Non-REBOA (n = 76)	*REBOA (n = 54)*	*% Bias*	*P Value*
Age, years	45.3	44.4	–4.1%	0.83
ED SBP	72.7	74	10.6%	0.57
ED GCS	6.5	6.5	1.6%	0.93
ISS	32.8	34.1	10.7%	0.48
AIS-head	3.1	3.1	–2.2%	0.9
Pre-hospital GCS	6.5	6.8	6.2%	0.76
Discharge GCS	13.7	13.4	–10.70%	0.72
ICU LOS	10.3	11.3	8.2%	0.69
Hospital LOS (days)	13.6	20.1	34.4%	0.08

Values are reported as mean.

ISS: injury severity score; AIS: abbreviated injury score; GCS: Glasgow coma score; ED: emergency department; SBP: systolic blood pressure; ICU: intensive care unit; LOS: length of stay.

matched by age, ED SBP, ED CGS, ISS, and AIS-head. After radius matching, 54 REBOA patients and 76 non-REBOA patients remained for analysis. In comparing these groups, there was no significant difference in mortality (average treatment effect of the treated (ATT) = –0.028, standard error = 0.102). After matching, there was no significant difference in pre-hospital, ED, ED SBP, ICU LOS, hospital LOS, or in-hospital mortality rate between REBOA and non-REBOA groups (Table 4).

CONCLUSIONS

For patients who suffer non-compressible torso hemorrhage, occlusion of the aorta with REBOA can be a valuable tool to minimize blood loss in the acute setting before definitive hemorrhage control can be obtained. Investigation is ongoing to identify the optimal patient selection criteria for REBOA, as no universal guidelines exist. In a comparison of REBOA and resuscitative thoracotomy for NCTH patients with TBI, REBOA-treated patients were found to have improved survival and no difference in complications [15]. This supports the idea that REBOA should be considered for use in this patient population. Here, we investigated the effects of REBOA in hypotensive blunt trauma patients with concurrent TBI to compare mortality and functional outcomes in these patients treated with REBOA to those treated without.

In the unmatched groups, REBOA patients were more severely injured compared to non-REBOA patients, as noted by higher ISS, AIS-head and AIS-chest. Despite being more severely injured, there was no difference in mortality, ICU LOS, or vent days between groups. REBOA patients did have longer hospital LOS compared to non-REBOA patients, but the similar length of ICU stay indicates that REBOA patients were stable to step down to the floor and did not require longer-term high acuity care compared to non-REBOA patients.

In the matched analysis results, there was no difference between REBOA and non-REBOA groups in terms of mortality, prehospital or discharge GCS, ICU LOS, or total hospital LOS.

Mortality was the primary outcome of interest for this study. When comparing patients treated with REBOA and without in both the unmatched and matched analysis, there was no significant difference in mortality, which suggests that the use of REBOA does not increase mortality of blunt trauma patients with concurrent TBI. Therefore, concurrent head trauma should not delay the deployment of REBOA in a hypotensive blunt trauma patient.

REBOA patients required significantly higher volumes of blood products transfused compared to non-REBOA patients. Interestingly, REBOA patients had both a higher ED HR, and a higher average ED SBP when compared to non-REBOA patients. The higher transfusion requirements in the REBOA group may reflect the procedure allowing time for additional stabilization or interventional radiology procedures before definitive control. Time to hemorrhage control was not available for analysis in the non-REBOA group. Notably, prior research has shown blood resuscitation, and not REBOA, to exacerbate TBI progression, with rapid blood transfusion increasing ICP more than REBOA [2].

As REBOA patients were more severely injured than non-REBOA patients, the radius matching analysis allows for a better understanding of the effect of REBOA in TBI patients, having accounted for other relevant clinical factors. While REBOA patients had longer hospital LOS compared to non-REBOA patients, discharge GCS, and discharge destination were not significantly different between the groups. These results suggest that REBOA use does not have a negative impact on functional outcomes in patients with head trauma.

Blunt trauma NCTH patients are often hypotensive by the time they arrive at the hospital and are in acute need of hemorrhage control. Pre-hospital TBI management protocols aimed at prevention and treatment of hypotension, hypoxia, and hyperventilation before arrival at definitive care have improved patient outcomes. The EPIC study showed increased survival to hospital discharge after implementing this protocol specific for TBIs [12]. Increased blood pressure up to 125 mmHg was associated with improved outcomes, including increased survival in TBI patients [16]. Notably, this threshold is higher than the commonly used 90 mmHg definition for hypotension. This emphasizes the importance of maintaining blood pressure and cerebral perfusion in TBI patients. Like these pre-hospital efforts to maintain blood pressure, REBOA is a tool to increase early cerebral perfusion until definitive control is achieved.

The size of the study population was a limitation of the study, and further subgroup statistical analysis based on AIS-head scores was prohibited by the number of patients. To identify any nuances in REBOA use in patients with mild, moderate, and severe TBI, future investigation with a larger patient population is needed. Detailed analysis of functional outcomes was limited by the data points collected in the AORTA registry and our institutional trauma registry. Glasgow outcome score (GOS) was not available. GOS would be an indicator of functional status after TBI, which was measured in this study by using discharge GCS and discharge location as proxies. ICP would have been valuable to this study to understand the effects of REBOA on ICP in the patient group, but was also not available. Not every subject included in this study had every data point present, and while we used all data points available to us, missing data present a limitation. Additionally, as we compared data from two separate databases, there is the chance for differences in the methods of data collection and recording between a multi-center database and a single institution trauma registry.

In conclusion, our findings show that functional outcomes are not detrimentally impacted by the use of REBOA to treat hypotensive blunt trauma in patients with concurrent TBI. Despite REBOA patients being more severely injured, this study found no difference in mortality rate between REBOA and non-REBOA patients. In the radius matched group analysis, the similar rates at which patients were discharged to home indicate that patients have a comparable functional status at the time of discharge, regardless of REBOA use. REBOA therefore should be considered for use in hypotensive NCTH patients with TBI.

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