Original Article

DOI: https://doi.org/10.26676/jevtm.23392

Prevalence and Contraindications of Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA): A Comparative Study of Severe and Nonsevere Traumatic Brain Injury Patients

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Background: Traumatic brain injury (TBI) is the leading cause of poor neurological outcomes and multiple organ failure worldwide. The use of resuscitative endovascular balloon occlusion of the aorta (REBOA) has been proposed to increase proximal pressure above the balloon to proximal organs, particularly improving cerebral and cardiac perfusion. This study assessed the prevalence of REBOA candidates and absolute contraindications in major trauma patients with varying TBI severities.

Methods: A retrospective analysis was conducted on 1158 major trauma patients who were transported to a Level I trauma center in Bangkok, Thailand, between 2020 and 2021. After exclusions, we analyzed two groups: 258 patients with severe TBI and 293 with nonsevere TBI.

Results: REBOA candidacy was significantly greater in the nonsevere TBI group (65.5% vs. 37.2%, $p < 0.001$). This group also exhibited more severe bleeding in regions below the occlusion where bleeding control is critical: abdomen-to-groin (58.7% vs. 29.1%, $p < 0.001$), intra-abdominal sources (47.1% vs. 23.3%, $p < 0.001$), and unstable pelvic injuries (19.1% vs. 9.3%, $p = 0.002$). In addition, the nonsevere TBI group had a greater prevalence of REBOA contraindications: overall (44.0% vs. 1.9%, $p < 0.001$), aortic (30.4% vs. 1.2%, $p < 0.001$), and cardiac (18.1% vs. 1.2%, $p < 0.001$) injuries. Concomitant conditions were more frequent in the nonsevere TBI group (5.5% vs. 1.2%, $p = 0.012$).

Conclusions: The nonsevere TBI group demonstrated significantly more potential REBOA candidates, absolute contraindications, and concomitant conditions than the severe TBI group. These findings underscore the need for a comprehensive evaluation of the advantages of REBOA in unstable patients comparing severe and nonsevere TBI patients.

Keywords: *REBOA; Resuscitation; Resuscitative Endovascular Balloon Occlusion of the Aorta; Trauma; Traumatic Brain Injury*

Received: 24 April 2024; Accepted: 26 June 2024

INTRODUCTION

Traumatic brain injury (TBI) and exsanguination, especially with noncompressible torso hemorrhage, are leading causes of death in trauma patients [1,2]. Recent advances in trauma resuscitation have enhanced the early detection and management of these conditions, improving survival rates significantly. This progress includes the broad application of endovascular resuscitation in trauma management (EVTM) techniques, including resuscitative endovascular balloon occlusion of the aorta (REBOA). This procedure has proven particularly effective in controlling severe hemorrhage in patients with noncompressible torso hemorrhage and

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ensuring essential perfusion to critical organs such as the heart and brain. The use of REBOA has been integrated into numerous clinical guidelines for prehospital and inpatient settings [3–7]. Moreover, injury mechanisms such as hanging, major burns with shock, intoxication, and electric shock causing cardiac arrest, while less likely to cause severe bleeding, may still necessitate advanced resuscitative efforts. In such cases, the deployment of REBOA can be pivotal. By increasing proximal pressure to critical organs, REBOA enhances support during cardiopulmonary resuscitation and can act as a bridge to extracorporeal cardiopulmonary resuscitation, potentially improving survival outcomes.

TBI is closely associated with poor prognosis, primarily due to initial brain damage and subsequent clinical deterioration, which often precipitates multiorgan dysfunction. Numerous guidelines recommend multidisciplinary discussions to evaluate the prognosis of severe and catastrophic brain injuries, ensuring that care decisions, including the timing of care withdrawal, are well-informed and prevent premature cessation of support [8–14]. However, accurately assessing neurological status during initial trauma resuscitation is complex due to various confounding factors. Computed tomography (CT) is important for assessing TBI severity but is frequently impractical for unstable patients during initial management. Typically, these patients first receive essential resuscitative procedures or surgery, with a CT scan deferred until hemodynamic stability is assured. Recent studies have highlighted the benefits of REBOA in enhancing proximal arterial pressure to critical organs, particularly the brain. In addition, REBOA serves as a bridging intervention, allowing unstable patients to stabilize for necessary diagnostics and strategic planning, potentially including preparations for organ donation [15,16].

This study aimed to examine differences in the prevalence of potential candidates for REBOA in patients with severe versus nonsevere TBI. In addition, the study sought to identify the absolute contraindications to REBOA in these groups. This analysis will enable more precise and effective deployment of REBOA, optimizing the use of local resources in the management of these critical conditions.

METHODS

In this retrospective study, we evaluated adult patients older than 18 years who sustained major trauma and were transported to a Level I trauma center in Bangkok, Thailand, between 2020 and 2021. We modified the definition of major trauma from the 2011 Field Triage Decision Scheme [17] to suit our trauma unit's medical resources and capabilities. The Abbreviated Injury Scale (AIS) demonstrates the level of injury based on anatomical location and severity: AIS-head was characterized by CT scans or autopsy reports as an AIS of the head region of 3 or higher being defined as "severe TBI," which is associated with clinical progression and outcome. We excluded patients with lethal brain injuries (including pontomedullary or brainstem lacerations, exposed brain matter, and decapitation) and those with incomplete medical records.

The characteristics and parameters of patients were reviewed including the age, gender, and mechanism of injury. Data were collected from two groups which included patients with severe trauma who presented with unstable conditions such as systolic blood pressure below 90 mmHg and/or traumatic cardiac arrest with signs of life on arrival, individuals who were declared dead at the scene of major trauma and transported to the Department of Forensic Medicine, and those who were pronounced dead upon hospital arrival. Given the challenges in assessing patient status at major trauma scenes within Thailand's trauma system, our research is also interested in focusing on the group of patients that died at the scene. Emergency responses at the scene of major trauma typically involve volunteers and private ambulance services with widely varying levels of clinical expertise. This variability complicates the detection of subtle signs of life and accurate neurological assessment, especially in patients in profound shock or traumatic cardiac arrest with limited performance in our system. Our study thus sought to identify potential missed opportunities for resuscitation in these critical patients.

Referring to various clinical practice guidelines [4–6, 18,19], we selected the patients eligible for REBOA including those who experienced traumatic cardiac arrest and/or significant intra-abdominal bleeding. The eligibility criteria for significant intra-abdominal bleeding were as follows:

- AIS scores of 3 or higher for liver and spleen injuries, and scores of 4 or higher for kidney injuries; active hemorrhaging from the abdominal vasculature, the presence of unstable pelvic fractures, or injuries at groin junctions.

Due to the risk of exacerbating conditions following balloon inflation, the absolute contraindications for the use of REBOA were aortic injury and cardiac injuries, with or without cardiac tamponade.

Statistical Analysis

We summarized the demographic and clinical characteristics of the participants using descriptive statistics. Statistical analyses were performed with PASW Statistics, version 18 (SPSS Inc., Chicago, IL, USA). Categorical variables are presented as numbers and percentages, and continuous variables are presented as means ± standard deviations or medians and interquartile ranges. The distribution of all continuous data in

this study was normal. Categorical comparisons utilized the chi-square test or Fisher's exact test, as appropriate. Student's *t* test was applied to analyze normally distributed continuous data. A *p*-value of less than 0.05 was considered to indicate statistical significance for all tests.

Ethical Approval and Informed Consent

The Siriraj Institutional Review Board of the Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand, approved the study protocol (reference number Si-874/2023). Due to the retrospective and anonymity-preserving design of this study, written informed consent was not required from the participants.

RESULTS

This study evaluated 1158 major trauma patients who were transported to our center between 2020 and 2021. After applying the exclusion criteria, we analyzed two groups: 258 patients with severe TBI and 293 patients with nonsevere TBI (**Table 1**).

Both groups were predominantly male and the average age was approximately 40 years. Blunt injuries were significantly more common in the severe TBI group than in the nonsevere TBI group (93.0% vs. 81.9%, $p < 0.001$). Motorcycle accidents were the predominant cause of blunt injuries in both groups (60.9% in severe TBI and 56.3% in nonsevere TBI). In contrast, the incidence of penetrating injuries, stabbing, and other injuries was significantly greater in the nonsevere TBI group than in the severe TBI group (14.0% vs. 7.0%, $p = 0.012$; 9.6% vs. 0.4%, $p < 0.001$; and 4.1% vs. 0.4%, $p = 0.010$, respectively).

In this study, 65.5% of patients in the nonsevere TBI group were identified as potential candidates for REBOA. This proportion was significantly greater than the 37.2% observed in the severe TBI group ($p < 0.001$). Notably, the incidence of severe bleeding in the abdomen-to-groin region was higher in the nonsevere TBI group (58.7%) than in the severe TBI group (29.1%, $p < 0.001$). Similarly, 47.1% of the nonsevere TBI patients experienced intra-abdominal bleeding, which was significantly more than the 23.3% observed in the severe group ($p < 0.001$). In addition, unstable pelvic injuries were present in 19.1% of nonsevere TBI patients versus 9.3% of their severe counterparts ($p = 0.002$; **Table 2**).

Regarding REBOA contraindications, the nonsevere TBI group had a significantly higher overall incidence of contraindications (44.0% vs. 1.9%, $p < 0.001$), including aortic injuries (30.4% vs. 1.2%, $p < 0.001$), and significant cardiac injuries (18.1% vs. 1.2%, $p < 0.001$). In addition, concomitant conditions were more common in the nonsevere TBI group (5.5%) than in the severe TBI group (1.2%, $p = 0.012$; **Table 2**).

DISCUSSION

Advanced trauma resuscitation techniques are continually improving survival rates for the two leading causes of death in major trauma patients: TBI and exsanguination. The application of REBOA in TBI has two primary objectives. First, it enhances arterial pressure proximal to the balloon to boost cerebral and cardiac blood flow. Second, it controls hemorrhage to preserve hemoglobin and oxygen transport. These factors are critical for preventing secondary brain injury [20]. Translational research involving rodent polytrauma models has shown promising results, indicating that REBOA may

Table 1 Demographic and mechanism of injury profiles in major trauma patients in the severe TBI and nonsevere TBI groups.

Characteristics	*Severe TBI Group (n = 258)*	*Nonsevere TBI Group (n = 293)*	*p-value*
Age (years), mean±SD	40.2±18.2	40.4±16.9	0.894
Male sex, ***n*** (%)	214 (82.9%)	252 (86.0%)	0.383
Mechanism of injury, ***n*** (%)			
• Blunt	240 (93.0%)	240 (81.9%)	<0.001
– Motorcycle accident	157 (60.9%)	165 (56.3%)	0.322
– Motor vehicle collision	15 (5.8%)	21 (7.2%)	0.639
– Pedestrian struck	33 (12.8%)	22 (7.5%)	0.055
– Fall from height	22 (8.5%)	17 (5.8%)	0.282
– Fall from the same level	7 (2.7%)	13 (4.4%)	0.396
– Other blunt injury	6 (2.3%)	2 (0.7%)	0.210
• Penetrating	18 (7.0%)	41 (14.0%)	0.012
– Gunshot wound	17 (6.6%)	12 (4.1%)	0.264
– Stab wound	1 (0.4%)	28 (9.6%)	<0.001
– Other penetrating injury	0 (0.0%)	1 (0.3%)	>0.999
• Others[a]	1 (0.4%)	12 (4.1%)	0.010

TBI, traumatic brain injury.

[a]*Includes cases resulting from hanging, major burns with shock, intoxication, and electric shock causing cardiac arrest.*

Table 2 Suitability of REBOA in severe versus nonsevere traumatic brain injury groups.

	Severe TBI (n = 258)	*Nonsevere TBI (n = 293)*	*p-value*
Potential indications for REBOA, *n* (%)			
• Overall potential indication for REBOA (including the purpose of bleeding control and restoring circulation)	96 (37.2%)	192 (65.5%)	<0.001
• **Significant bleeding source(s) at the abdomen–groin**	75 (29.1%)	172 (58.7%)	<0.001
○ Major intra-abdominal bleeding	60 (23.3%)	138 (47.1%)	<0.001
○ Unstable pelvic injury	24 (9.3%)	56 (19.1%)	0.002
○ Junctional hemorrhage injury at the groin	1 (0.4%)	2 (0.7%)	0.920
Absolute contraindications for REBOA, *n* (%)			
• Overall	5 (1.9%)	129 (44.0%)	<0.001
• Aortic injury	3 (1.2%)	89 (30.4%)	<0.001
• Cardiac injury with or without cardiac tamponade	3 (1.2%)	53 (18.1%)	<0.001
Potential indications and contraindications for REBOA in the same case, *n* (%)	3 (1.2%)	16 (5.5%)	0.012

REBOA, resuscitative endovascular balloon occlusion of the aorta; TBI, traumatic brain injury.

improve cerebral perfusion by temporarily improving intracranial pressure and brain tissue oxygenation [21]. In addition, REBOA has been shown to maintain circulation effectively in potential organ donors, even in patients with severe TBI and a poor prognosis [16]. Our findings highlight a high prevalence of REBOA candidates, including those with severe or nonsurvivable TBI, with numbers exceeding those reported in some prior studies [22–27]. By distinguishing between these groups, our research sought to refine the approaches and effectiveness of resuscitation strategies, contributing to enhanced patient care protocols, especially the necessity for REBOA implementation in controlling significant bleeding sources.

Recent research on the use of REBOA in TBI patients has produced mixed results. Studies indicate that it either improves neurological outcomes or shows no difference. These outcomes are influenced by the physiological effects of aortic occlusion [20,28,29]. However, the application of REBOA warrants careful consideration. There are concerns that supraphysiological pressures generated above the balloon could increase intracranial pressure. This elevation may lead to brain edema and aggravate intracranial bleeding, risks that are highlighted as contraindications in several clinical guidelines [18,30].

Debate persists over the benefits of maintaining increased proximal pressure above the balloon for critical organs, particularly the brain and heart, even when there is no active bleeding beneath the REBOA placement. For example, one study compared hypotensive blunt trauma patients with TBI who were treated both with and without REBOA. It reported no significant differences in mortality rates or discharge Glasgow Coma Scale (GCS) scores [28]. Similarly, data from the American College of Surgeons Trauma Quality Improvement Program (ACS TQIP) database from 2015 to 2017 were collected from adult civilian blunt trauma patients, both with and without TBI, who underwent REBOA. Analysis revealed no notable differences in inpatient mortality or complications. Notably, TBI patients treated with REBOA presented with lower GCS scores, lower systolic blood pressure values, and greater injury severity scores [29]. Importantly, both studies excluded patients who died upon arrival at the hospital or who required immediate cardiopulmonary resuscitation.

A study by the Multi-Institutional Trials Committee of the American Association for the Surgery of Trauma examined extremely unstable TBI patients. The mortality odds were 3.1 times greater for resuscitative thoracotomy than for REBOA, suggesting a potential benefit of REBOA in reducing mortality. However, the study encompassed a broad range of TBI severities, from mild (27% of the study population) to severe. This diversity is critical because different severities of TBI naturally progress in varying ways [20]. Therefore, this variability highlights the need for cautious application of REBOA, considering that its perceived effectiveness might also be influenced by these inherent differences in the progression of TBI.

Future studies are expected to refine approaches for various scenarios and systems, thus enhancing our understanding of the risk–benefit balance associated with REBOA. A key factor in clinical decision-making is the feasibility of conducting thorough investigations, including necessary CT scans, which are vital for guiding treatment strategies in TBI patients. The complexity of clinical presentations, influenced by multiple factors, often complicates the accuracy of initial evaluations. The initial GCS score is generally insufficient for formulating early definitive plans because it can be affected by external factors not directly related to primary brain injury.

One major obstacle to finalizing a diagnosis of TBI is the patient's unstable hemodynamic status. This instability can delay definitive diagnostic procedures in favor of more immediate life-saving interventions, such as damage control surgery or radiological measures. In these situations, REBOA can be strategically deployed as a bridging maneuver to maintain hemodynamic stability, thereby allowing for the timely completion of essential diagnostic assessments and the development of definitive treatment plans. Conversely, the inappropriate application of REBOA might occur if its use is not carefully tailored to the patient's injury severity. It may be overused in patients with predictably poor outcomes or underused in situations where it could benefit nonbleeding patients by enhancing cerebral blood supply. Accurate resolution of these complex issues is crucial for optimizing resource management and improving the standard of care for polytrauma patients. The necessity for treatment strategies that are precise and tailored to individual needs underscores the importance of continuously updating clinical protocols to align with emerging data and outcome analyses.

A noteworthy finding in our study was the reduced number of severe TBI patients identified as potential candidates for REBOA compared with those with nonsevere TBI (**Table 2**). This observation aligns with other research that reported fewer potential REBOA candidates among severe TBI patients [31]. Understanding this disparity is essential for integrating REBOA effectively into clinical practice, particularly within our healthcare system.

The primary injury mechanism in our region, motorcycle accidents, significantly contributes to life-threatening conditions in TBI patients. Unfortunately, detailed records on helmet usage were insufficient, but the correlation between motorcycle accidents and TBI was clear. In terms of hemorrhage control, our major trauma cohort had significantly more potential REBOA candidates in the nonsevere TBI group than in the severe TBI group. This finding suggests that there are different levels of physiological instability caused by life-threatening conditions between these groups.

Moreover, the findings underscore the need to develop strategies that expedite final diagnoses using CT imaging. Such strategies would enable timely and effective decision-making in our setting, where patients may lack substantial financial resources and some treatments are not covered by Thailand's Universal Coverage Scheme (a government health insurance program).

One guideline advocates for a whole-body CT scan before implementing REBOA when feasible [32]. However, given the significant number of patients at our hospital who are present with severe bleeding, prioritizing immediate surgical intervention or REBOA remains crucial to stabilize patients initially.

The application of REBOA in unstable patients demands a careful consideration of safety, particularly regarding contraindications. Although our study revealed a greater prevalence of potential REBOA candidates in the nonsevere TBI group, absolute contraindications and concurrent conditions must be assessed meticulously. This approach necessitates a detailed evaluation of both indications and contraindications during trauma resuscitation, tailored to the resources available at the medical facility.

How will our clinical practices evolve based on these findings? Recognizing the high frequency of bleeding sources in both severe and nonsevere TBI patients, where REBOA has shown potential benefits, we will consider implementing endovascular trauma management principles while simultaneously implementing early prevention of secondary brain injury, administration of tranexamic acid, and neurosurgical consultation which has been our practice following standard ATLS guidelines. In addition, our protocol will include securing early vascular access to expedite REBOA deployment, enhancing resuscitation monitoring, and ensuring swift preparation for immediate whole-body CT scans. Moreover, we will intensify our commitment to fulfilling surgical criteria and applying REBOA judiciously, with a balanced consideration of indications and contraindications.

This strategic enhancement aims to refine trauma resuscitation practices, ensuring that they are adaptable to the evolving needs and specific conditions of our patient population. We strive to optimize patient outcomes and use medical resources efficiently by integrating the study findings into our protocols.

Our study is limited by its retrospective design, single-center focus, and small sample size, which may affect the generalizability of the findings. Institutional policies on autopsies restricted detailed injury assessments: autopsies were limited to individuals with only severe injuries; minor wounds were not examined postmortem. These limit our ability to compute comprehensive injury severity scores for patients who died at the scene and were transferred to the Department of Forensic Medicine. These constraints highlight the variability in trauma care systems and available resources, which differ significantly from those in other studies. Future research should expand to multicenter and international settings to address these disparities and enhance the reliability of REBOA assessments. This expansion would allow for a more diverse range of clinical experiences and patient demographics, aiding in refining guidelines and improving their practical application in varied healthcare environments.

CONCLUSIONS

This study has revealed a greater prevalence of potential REBOA candidates in the nonsevere TBI group, particularly for controlling bleeding sources. However, a higher incidence of absolute contraindications in the

same group necessitates careful risk assessment when considering REBOA for resuscitation and as a bridging intervention to facilitate timely CT diagnostics. These findings suggest that employing REBOA could significantly enhance trauma care efficiency, especially when REBOA is integrated into protocols designed for rapid and comprehensive early evaluations. Such integration is crucial in settings constrained by limited resources and the necessity for cost-effective approaches for trauma patients with severe TBI, potentially leading to improved patient outcomes and more efficient use of healthcare resources.

Acknowledgments

The authors extend their sincere thanks to Miss Julaporn Pooliam of the Research Department, Faculty of Medicine Siriraj Hospital, Mahidol University, for her invaluable assistance with the statistical analyses. We also thank Mr. David Park for his expert linguistic editing.

Ethics Statement

(1) All the authors mentioned in the manuscript have agreed to authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.
(2) The authors declare that they have read and abided by the JEVTM statement of ethical standards including rules of informed consent and ethical committee approval as stated in the article.

Conflicts of Interest

The authors declare that there are no personal or professional conflicts of interest. There has been no financial support from companies that produce or distribute the drugs, devices, or materials discussed in this report.

Funding

This is an unfunded study.

Author Contributions

TS designed the study, collected and analyzed the data, and critically revised the manuscript. TW codesigned the study, conducted the literature search, collected and analyzed the data, and drafted and critically revised the manuscript. PP initiated the study concept, participated in data collection, and critically revised the manuscript. CS, PM, and NN also provided critical revisions to the manuscript. All authors have read and approved the final manuscript for submission.

REFERENCES

[1] Søreide K. Epidemiology of major trauma. Br J Surg. 2009;96(7):697–8.
[2] Zhang GX, Chen KJ, Zhu HT, et al. Preventable deaths in multiple trauma patients: the importance of auditing and continuous quality improvement. World J Surg. 2020;44(6):1835–43.
[3] Hörer TM, Pirouzram A, Khan M, et al. Endovascular resuscitation and trauma management (EVTM)—practical aspects and implementation. Shock. 2020; 56(1S):37–41.
[4] Bulger EM, Perina DG, Qasim Z, et al. Clinical use of resuscitative endovascular balloon occlusion of the aorta (REBOA) in civilian trauma systems in the USA, 2019: a joint statement from the American College of Surgeons Committee on Trauma, the American College of Emergency Physicians, the National Association of Emergency Medical Services Physicians and the National Association of Emergency Medical Technicians. Trauma Surg Acute Care Open. 2019;4(1):e000376.
[5] Brenner M, Bulger EM, Perina DG, et al. Joint statement from the American College of Surgeons Committee on Trauma (ACS COT) and the American College of Emergency Physicians (ACEP) regarding the clinical use of resuscitative endovascular balloon occlusion of the aorta (REBOA). Trauma Surg Acute Care Open. 2018;3(1):e000154.
[6] Inaba K, Hasan BA, Karen JB, et al. A western trauma association critical decisions algorithm: resuscitative endovascular balloon occlusion of the aorta. J Trauma Acute Care Surg. 2022;92(4):748–53.
[7] Castellini G, Gianola S, Biffi A, et al. Resuscitative endovascular balloon occlusion of the aorta (REBOA) in patients with major trauma and uncontrolled haemorrhagic shock: a systematic review with meta-analysis. World J Emerg Surg. 2021;16(1):41.
[8] Joint Trauma System Clinical Practice Guideline (JTS CPG) 2005. Traumatic Brain Injury Management and Basic Neurosurgery in the Deployed Environment [Internet]. Available from: https://jts.health.mil/assets/docs/cpgs/TBI_Neurosurgery_Deployed_Environment_15_Sep_2023_ID30.pdf [update: April 2024; cited 14 March 2024].
[9] Management of Perceived Devastating Brain Injury After Hospital Admission: A Consensus Statement [Internet]. 2018. Available from: https://ficm.ac.uk/sites/ficm/files/documents/2021-10/Management of Perceived Devastating Brain Injury After Hospital Admission.pdf. Accessed 11 April 2024.
[10] Souter MJ, Blissitt PA, Blosser S, et al. Recommendations for the critical care management of devastating brain injury: prognostication, psychosocial, and ethical management. Neurocrit Care. 2015;23(1):4–13.
[11] Moderate to Severe Traumatic Brain Injury is a Lifelong Condition [Internet] 2018. Available from: https://www.cdc.gov/traumaticbraininjury/pdf/moderate_to_severe_tbi_lifelong-a.pdf. Accessed 15 March 2024.
[12] Turgeon AF, Lauzier F, Zarychanski R, et al. Prognostication in critically ill patients with severe traumatic brain

injury: the TBI-Prognosis multicentre feasibility study. BMJ Open. 2017;7(4):e013779.
[13] Graham M. Burying our mistakes: dealing with prognostic uncertainty after severe brain injury. Bioethics. 2020;34(6):612–9.
[14] Lazaridis C. Withdrawal of life-sustaining treatments in perceived devastating brain injury: the key role of uncertainty. Neurocrit Care. 2019;30(1):33–41.
[15] Bissoni L, Gamberini E, Viola L, et al. REBOA as a bridge to brain CT in a patient with concomitant brain herniation and haemorrhagic shock – a case report. Trauma Case Rep. 2022;38:100623.
[16] Sumislawski JJ, Foley DP, Moore EE, Moore HB. Resuscitative endovascular balloon occlusion of the aorta as a bridge to organ donation after blunt trauma. J Endovasc Resusc Trauma Manag. 2022;6(2):102–5.
[17] Centers for Disease Control and Prevention. 2011 Guidelines for Field Triage of Injured Patients: Recommendations of the National Expert Panel on Field Triage [Internet]. Available from: https://www.cdc.gov/mmwr/preview/mmwrhtml/rr6101a1.htm. Accessed 25 December 2023.
[18] Joint Trauma System Clinical Practice Guideline (JTS CPG). Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) for Hemorrhagic Shock (CPG ID:38) [Internet]. 2014 [cited 25 April 2024]. Available from: https://jts.health.mil/assets/docs/cpgs/Resuscitative_Endovascular_Balloon_Occlusion_of_the_Aorta_(REBOA)_for_Hemorrhagic_Shock_31_Mar_2020_ID38.pdf.
[19] McGreevy D, Abu-Zidan F, Sadeghi M, et al. Feasibility and clinical outcome of REBOA in patients with impending traumatic cardiac arrest. Eur J Vasc Endovasc Surg. 2019;58(6):e831–2.
[20] Brenner M, Zakhary B, Coimbra R, et al. Resuscitative endovascular balloon occlusion of the aorta (REBOA) may be superior to resuscitative thoracotomy (RT) in patients with traumatic brain injury (TBI). Trauma Surg Acute Care Open. 2022;7:e000715.
[21] Bailey ZS, Cardiff K, Yang X, et al. The effects of balloon occlusion of the aorta on cerebral blood flow, intracranial pressure, and brain tissue oxygen tension in a rodent model of penetrating ballistic-like brain injury. Front Neurol. 2019;10:1309.
[22] Thabouillot O, Bertho K, Rozenberg E, et al. How many patients could benefit from REBOA in prehospital care? A retrospective study of patients rescued by the doctors of the Paris fire brigade. J R Army Med Corps. 2018;164(4):267–70.
[23] Godø BN, Brede JR, Krüger AJ. Needs assessment of resuscitative endovascular balloon occlusion of the aorta (REBOA) in patients with major haemorrhage: a cross-sectional study. Emerg Med J. 2022;39(7):521–6.
[24] Mill V, Wellme E, Montán C. Trauma patients eligible for resuscitative endovascular balloon occlusion of the aorta (REBOA), a retrospective cohort study. Eur J Trauma Emerg Surg. 2021;47(6):1773–8.
[25] Karmy-Jones R, Friend A, Collins D, Martin MJ, Long W 3rd. Is there a role for REBOA? A system assessment. Am J Surg. 2021;221(6):1233–7.
[26] Fitzgerald M, Lendrum R, Bernard S, et al. Feasibility study for the implementation of resuscitative balloon occlusion of the aorta in peri-arrest, exsanguinating trauma at an adult level 1 Australian trauma center. Emerg Med Australas. 2020;32(1):127–34.
[27] Henry R, Matsushima K, Henry RN, et al. Who would have benefited from the prehospital use of resuscitative endovascular balloon occlusion of the aorta (REBOA)? An autopsy study. J Am Coll Surg. 2019;229(4):383–8.e1.
[28] D Nordham K, Ninokawa S, Ali A, et al. Resuscitative endovascular balloon occlusion of the aorta (REBOA) after traumatic brain injury. JEVTM. 2024;7(1):33–8.
[29] Elkbuli A, Kinslow K, Sen-Crowe B, Liu H, McKenney M, Ang D. Outcomes of resuscitative endovascular balloon occlusion of the aorta (REBOA) utilization in trauma patients with and without traumatic brain injuries: a national analysis of the American College of Surgeons trauma quality improvement program data set. Surgery. 2021;170:284–90.
[30] Williams AM, Bhatti UF, Dennahy IS, et al. Traumatic brain injury may worsen clinical outcomes after prolonged partial resuscitative endovascular balloon occlusion of the aorta in severe hemorrhagic shock model. J Trauma Acute Care Surg. 2019;86:415–23.
[31] Wannatoop T, Phuangphung P, Sornmanapong T. Resuscitative endovascular balloon occlusion of the aorta in trauma management: a comprehensive study of clinical indications and challenges. Trauma Surg Acute Care Open. 2024;9(1):e001264.
[32] Ordoñez CA, Rodríguez F, Parra M, et al. Resuscitative endovascular balloon of the aorta is feasible in penetrating chest trauma with major hemorrhage: proposal of a new institutional deployment algorithm. J Trauma Acute Care Surg. 2020;89(2):311–9.