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Assessing the need for resuscitative endovascular balloon occlusion of the aorta (REBOA) for management of noncompressible hemorrhage at a Canadian urban trauma centre

The deployment of REBOA could be lifesaving or could reduce transfusion requirements in the most severely injured patients, but more prospective research is needed to determine if it improves patient outcomes.

ABSTRACT: Expert consensus suggests that resuscitative endovascular balloon occlusion of the aorta (REBOA) should be considered in the management of select trauma patients; however, there is a paucity of studies that evaluate the potential utility of REBOA in the Canadian setting.

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Our study objective was to evaluate the percentage of trauma patients presenting to a Canadian trauma centre that would have met REBOA criteria. We conducted a retrospective chart review of patients recorded in the BC Trauma Registry who warranted a trauma team activation at our institution. We identified REBOA candidates using criteria based on published guidelines. Fourteen patients were classified as likely candidates (2.2% of trauma team activations). Their median injury severity score was 31.5. While REBOA would be performed infrequently, it could be a potentially lifesaving procedure in a small group of severely injured trauma patients; however, the impact on the Canadian trauma system needs further evaluation.

Massive exsanguination resulting in circulatory collapse is one of the leading causes of preventable death in trauma.^{1,2} The cornerstone of the emergency management of massive hemorrhage is obtaining control of the bleeding. However, source control becomes a challenge when the source of major hemorrhage involves noncompressible regions such as the trunk and ilio-junctional regions.³ Consequently, noncompressible

hemorrhage represents most traumatic exsanguination fatalities, accounting for 45% to 60% of deaths.^{4,5} Historically, the only means of attempting to control this type of bleeding was to perform a resuscitative thoracotomy as a bridge to definitive surgical management in the operating room.^{3,6} This highly invasive procedure is associated with high levels of mortality and complications.⁶

Within the last 10 years, innovation has led to the development and popularization of a second option for the management of life-threatening noncompressible hemorrhage. Resuscitative endovascular balloon occlusion of the aorta (REBOA) involves inflation of a balloon in the aorta as a means of reducing blood flow to the distal hemorrhage site and preferentially directing blood flow to critical organs, including the heart and brain.^{2,3,7-10} Although REBOA is less invasive than resuscitative thoracotomy, evidence of the efficacy of REBOA is conflicting, and REBOA has been associated with complications, including organ ischemia, vascular injury, and limb amputations;¹¹⁻¹⁷ nevertheless, expert consensus suggests that REBOA should be considered in select severely injured patients.^{18,19}

The method for REBOA deployment first requires femoral access. The device is inserted through the femoral artery and threaded into the aorta until the deflated balloon is positioned in either zone 1 (between the left subclavian artery and the celiac trunk) for intra-abdominal or retroperitoneal hemorrhage, or in zone 3 (between the most caudal renal artery and the aortic bifurcation) for pelvic, inguinal, or lower extremity hemorrhage. The balloon is then inflated until physiologic improvement is achieved, indicating distal blood flow is occluded.

REBOA is deployed primarily by trauma surgeons in Canada; however, it is within the scope of practice of vascular surgeons, interventional radiologists, intensivists, and emergency physicians in some countries.^{13,18,19} The procedure time ranges from approximately 4 to 12 minutes in the conventional models,^{7,20} but newer models have recently entered the market and have a mean procedure time of 70.1 seconds.²¹ The existing literature does not include the use of these newer devices, which are not yet in widespread use; therefore, it is not known if the shorter procedure time will result in improved outcomes in patients who are managed with endovascular resuscitation.

Many US centres that receive high volumes of trauma and perform regular resuscitative thoracotomies have already adopted REBOA. Globally, REBOA is available in many major centres in Europe and Japan.^{13,14,17,22} However, the pattern and volume of trauma are different in Canada.^{23,24} A 2021 survey found that only 21.9% of Canadian level 1 or 2 trauma centres currently have a REBOA program.²⁵ These centres are mainly in Ontario and Quebec, and there is one centre in British Columbia. However, there has been a paucity of studies on the impact of this tool on trauma care or its potential utility in the Canadian context,^{26,27} and it has yet to be adopted as standard of care in Canada. The reason for this is multifactorial but is likely related to the implications to the overall trauma system in various health authorities that would result from implementation of this device. A recent editorial has highlighted the need for further research in the Canadian setting prior to widespread adoption of REBOA.²⁸ Our study is a Canadian-based

trauma population-driven assessment of the need for acquisition of REBOA at a tertiary care level 1 trauma centre in British Columbia. The objective of this study was to evaluate the percentage of trauma patients at our Canadian institution who sustained injury that resulted in life-threatening hemorrhage below the diaphragm, in which case REBOA would have been indicated as a component of the emergency department resuscitation.

Methods

Study design

This retrospective descriptive study was conducted at Royal Columbian Hospital in New Westminster, BC. It is the only Canadian level 1 trauma centre in a health authority with a catchment area of 1.9 million people or more. Royal Columbian Hospital sees approximately 400 trauma consults annually. We used medical record data for trauma patients recorded in the BC Trauma Registry who presented to our emergency department between 1 January 2016 and 31 December 2018. The BC Trauma Registry is a comprehensive and organized provincial trauma surveillance and data collection system that is regularly quality checked.

Population

All BC Trauma Registry cases that were trauma team activations were screened for inclusion in this study. Trauma team activations are called for patients when there is concern about severe injury based on a set of physiologic, anatomic, and mechanistic criteria established by the health authority.

Inclusion and exclusion criteria

The inclusion and exclusion criteria for REBOA candidacy were chosen based on suggested REBOA protocols published in the literature^{29,30} and the indications published in the 2018 and 2019 American College of Surgeons and American College of Emergency Physicians guidelines.^{18,19}

Outcome measures

The primary outcome was identification of REBOA candidacy according to inclusion and exclusion criteria. Additionally, information on patient characteristics, clinical variables, and the traumatic event was collected for each case.

Data collection

Records for each trauma team activation were accessed through the health authority's patient care information system. Each case was screened

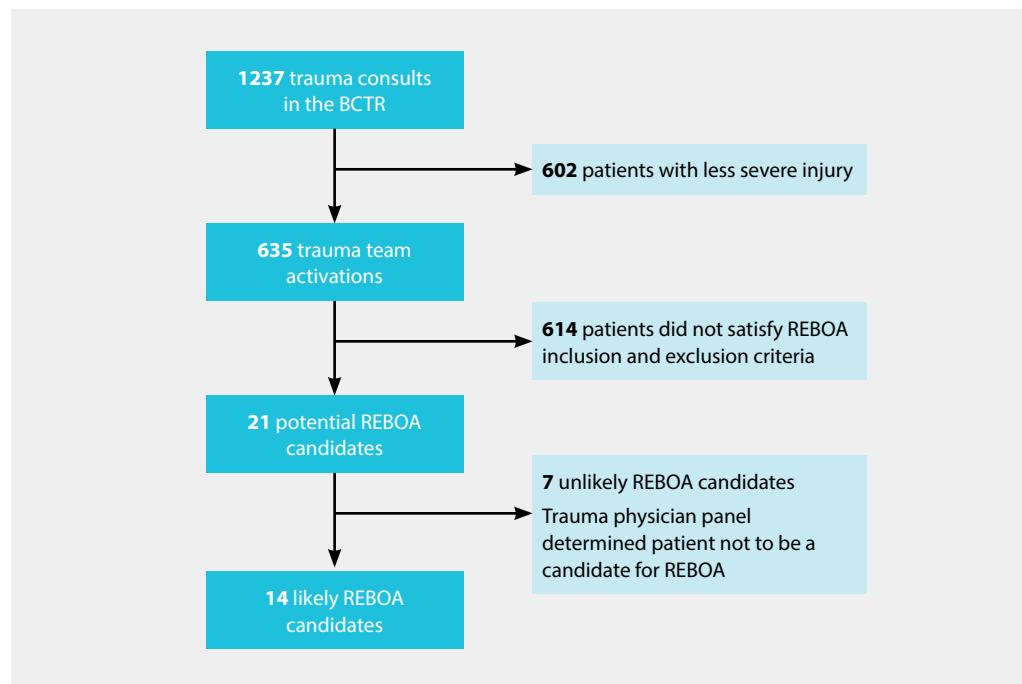


FIGURE. Flow diagram of assessment for potential and likely REBOA candidacy.

BCTR = BC Trauma Registry

REBOA = resuscitative endovascular balloon occlusion of the aorta

by one of two reviewers for inclusion and exclusion criteria, and data from each identified case were extracted using a standardized data collection form. The data were subsequently copied into a secure electronic database.

Based on the defined indications for REBOA, the reviewers classified each case as to whether the patient would have been a potential or likely REBOA candidate. Potential candidates were defined as those who met inclusion criteria without any exclusion criteria. Likely candidates were those who met criteria for REBOA candidacy and received four or more units of packed red blood cells in the first hour of arrival in the emergency department. All cases that were identified as a likely REBOA candidate were then reviewed by a panel of trauma physicians for final determination of candidacy based on expert opinion. Additionally, the two reviewers assessed a sample of 60 cases (9.4% of charts) to ensure inter-rater reliability of case analysis.

Statistical analysis

Descriptive statistics were used. Parametric continuous data were expressed using means and standard deviations (SDs), nonparametric continuous data were expressed using medians and interquartile ranges (IQRs), and categorical data were expressed using n values (%). The kappa statistic was used to express inter-rater agreement between chart reviewers.

Results

The BC Trauma Registry recorded 1237 consults to the trauma service at our centre from 1 January 2016 to 31 December 2018. In total, 635 of these consults were trauma team activations. Following review, 21 patients were classified as potential REBOA candidates (3.3% of trauma team activations; 1.7% of total trauma consults) and 14 were classified as likely REBOA candidates (2.2% of trauma team activations; 1.1% of total trauma consults) [Figure].

The inclusion criteria met by the 14 likely candidates were as follows: 10 were blunt trauma with a pulse and systolic blood pressure < 90 mmHg (71.4%), 3 were penetrating trauma with a pulse and systolic blood pressure < 90 mmHg (21.4%), and 1 was blunt trauma and pulseless (7.1%) [Table 1]. No patients met

TABLE 1. Characteristics and injuries of potential and likely candidates for resuscitative endovascular balloon occlusion of the aorta.

	Potential candidates number (%)	Likely candidates number (%)
Candidates	21 (3.3)	14 (2.2)
Sex		
Male	12 (57.1)	5 (35.7)
Female	9 (42.9)	9 (64.3)
Mean age (years) (SD)	48.8 (17.8)	46.1 (18.9)
Inclusion criteria		
Blunt trauma with pulse; systolic blood pressure < 90 mmHg	17 (80.9)	10 (71.4)
Penetrating trauma with pulse; systolic blood pressure < 90 mmHg	3 (14.3)	3 (21.4)
Blunt trauma and pulseless	1 (4.8)	1 (7.1)
Penetrating trauma and pulseless	0 (0)	0 (0)
Mechanism of trauma		
Motor vehicle collision	3 (14.3)	3 (21.4)
Motorbike collision	1 (4.8)	1 (7.1)
Pedestrian struck	8 (38.0)	5 (35.8)
Fall	2 (9.5)	2 (14.3)
Crush	3 (14.3)	0 (0)
All-terrain vehicle/dirt bike	1 (4.8)	0 (0)
Gunshot wound	2 (9.5)	2 (14.3)
Stab	1 (4.8)	1 (7.1)
Main source of hemorrhage		
Pelvic fracture	9 (42.9)	6 (42.9)
Abdominal hemorrhage	13 (61.9)	10 (71.4)
Spleen injury	7 (33.3)	4 (28.6)
Liver injury	10 (47.6)	9 (64.3)
Kidney injury	3 (14.3)	2 (14.3)
Lower extremity amputation	0 (0)	0 (0)
Major vascular injury	3 (14.3)	3 (21.4)
Other	3 (14.3)	0 (0)

the penetrating trauma and pulseless criterion in our cohort.

Nine of the likely candidates were female (64.3%), and the mean age of the likely candidates was 46.1 years (SD 18.9) [Table 1].

The median injury severity score for the likely candidate group was 31.5 (IQR 26.8)

[Table 2]. The mean systolic blood pressure on arrival in the emergency department was 112.7 mmHg (SD 26.4 mmHg), and then dropped to less than 90 mmHg during the emergency department stay, as per the inclusion criteria. The mean number of units of blood products administered within the

first hour of arrival in the emergency department was 5.5 (SD 2.3), and the mean total within the first 24 hours was 39.2 (SD 40.3) [Table 2]. Two of the likely candidates received cardiopulmonary resuscitation (14.3%), one received resuscitative thoracotomy with aortic cross-clamping (7.1%), four underwent

angiography (28.6%), and four underwent laparotomy (28.6%) [Table 3]. Eight patients immediately went to either the operating room or interventional radiology suite from the emergency department (57.1%). In total, three of the likely candidates died from their injuries (21.4%) [Table 3].

The main sources of infradiaphragmatic hemorrhage in the likely candidates were secondary to an abdominal solid organ injury in 10 patients (71.4%), pelvic fracture in 6 patients (42.9%), and major vascular injury in 3 patients (21.4%) [Table 1]. Ten patients had multiple sources of hemorrhage (71.4%). Table 4 provides descriptions of each case that met the candidacy criteria.

Sixty of the cases were assessed independently by the two reviewers to determine inter-rater reliability. Good reliability was found between reviewers in identifying patient candidacy (kappa = 0.659).

TABLE 2. Clinical variables of potential and likely candidates for resuscitative endovascular balloon occlusion of the aorta.

	Potential candidates	Likely candidates
Median injury severity score (interquartile range)	34.0 (17.8)	31.5 (26.8)
Mean vitals (SD)		
Emergency Health Services systolic blood pressure (mmHg)	111.8 (25.4)	112.7 (26.4)
Emergency Health Services heart rate (beats per minute)	106.1 (22.3)	104.2 (21.5)
Emergency department systolic blood pressure (mmHg)	104.8 (40.2)	108 (41.7)
Emergency department heart rate (beats per minute)	102.7 (21.0)	102.4 (22.8)
Mean blood products received (SD)		
At 1 hour	7.0 (5.0)	5.5 (2.3)
At 2 hours	7.4 (8.2)	9.1 (9.2)
At 4 hours	3.5 (4.6)	3.9 (5.4)
At 24 hours	24.2 (40.8)	26.3 (47.6)
Total	34.6 (35.6)	39.2 (40.3)

TABLE 3. Interventions and outcomes of potential and likely candidates for resuscitative endovascular balloon occlusion of the aorta.

	Potential candidates number (%)	Likely candidates number (%)
Interventions		
Cardiopulmonary resuscitation	4 (19.0)	2 (14.3)
Resuscitative thoracotomy with aortic cross-clamping	1 (4.8)	1 (7.1)
Angiography	6 (28.6)	4 (28.6)
Laparotomy	4 (19.0)	4 (28.6)
Outcome		
Survival to emergency department discharge	18 (85.7)	12 (85.7)
Death in emergency department	3 (14.2)	2 (14.3)
Survival to hospital discharge	15 (71.4)	11 (78.6)
Death in hospital (post-emergency department)	3 (14.2)	1 (7.1)

Discussion

This study contributes to the evaluation of the population-driven need for acquisition of REBOA at Canadian trauma centres. We determined that over a 3-year period, 14 patients at our institution would have met the study criteria for use of REBOA during resuscitation. Those who met the criteria represented a group of severely injured patients and constituted 2.2% of the trauma team activations and 1.1% of all trauma consults. Our findings are consistent with those of two recent needs assessments on deployment of REBOA at major Canadian trauma centres in other provinces. Those studies found that 1.1% and 1.5% of major trauma patients at trauma centres in Edmonton²⁶ and Halifax,²⁷ respectively, met eligibility criteria for deployment of REBOA. Although a seemingly small number of patients met the eligibility criteria, this may be clinically significant given that trauma patients are often young, previously healthy individuals with the physiologic reserve to survive the REBOA procedure. Additionally, these patients stand to gain many potential high-quality years of life.

Our data indicate that the most common indication for the use of REBOA in our trauma population was for patients who had sustained blunt trauma, which is consistent with Canadian statistics. In comparison, the United States has a much higher rate of penetrating trauma.^{23,24} Of note, the percentage of cases that met candidacy criteria in our study was greater than that in a 2019 study at a US trauma centre that used similar inclusion criteria. In that study, 0.6% of the trauma patients (29 of 4818

TABLE 4. Case descriptions of likely candidates for resuscitative endovascular balloon occlusion of the aorta.

Candidate #	Likely candidate	Inclusion criteria met	Primary source of hemorrhage	Immediate surgical intervention	Death in hospital	Case description
1	Yes	Blunt, with pulse	Abdominal solid organ injury	Interventional radiology Operating room	No	Elderly patient with fall from standing. Presented 4 days after fall. Spleen and liver lacerations. Received 38 units of blood product in 24 hours. Femoral catheterization may not have been successful due to atherosclerosis noted.
2	No	Blunt, with pulse	Abdominal solid organ injury	None	No	Dirt bike crash. Required 3 units packed red blood cells. Stabilized after.
3	Yes	Penetrating, with pulse	Abdominal solid organ injury	Operating room	No	Gunshot wound to abdomen. Liver laceration. Received 50 units of blood product in 24 hours.
4	Yes	Blunt, with pulse	Pelvic fracture	Interventional radiology	No	Pedestrian struck by a vehicle. Received 17 units of blood product in 24 hours. Interventional radiology embolization successful.
5	Yes	Blunt, with pulse	Pelvic fracture	None	Yes	Pedestrian struck by a vehicle. Arrested in the CT scanner and died.
6	No	Blunt, with pulse	Other—crush injury	None	Yes	Trapped in a truck for 3 days prior to emergency department presentation. Died of acidosis secondary to crush injury to bilateral legs.
7	Yes	Blunt, with pulse	Pelvic fracture	None	No	Run over and trapped beneath a car. Sustained pelvic and femur fractures. Received 11 units of blood product in 24 hours. Did not require urgent operating room, but REBOA may have been deployed in the setting of a pelvic fracture prior to stabilization.
8	No	Blunt, with pulse	Abdominal solid organ injury	None	Yes	Struck by a train. No clear source of hemorrhage found that would have caused death.
9	Yes	Blunt, pulseless	Pelvic fracture	None	Yes	Run over by a dump truck. Arrested and died in the emergency department. Difficulty obtaining femoral access for arterial line during resuscitation likely secondary to crush injury to pelvis.
10	Yes	Penetrating, with pulse	Abdominal solid organ injury	Operating room	No	Stab to abdomen. Direct to operating room for trauma laparotomy. Received 14 units of blood product in 24 hours.
11	No	Blunt, with pulse	Pelvic fracture	None	Yes	Run over by heavy machinery. Likely died from respiratory arrest secondary to a high spinal cord injury.
12	Yes	Blunt, with pulse	Pelvic fracture Abdominal solid organ injury	Operating room	No	Pedestrian struck by a vehicle. Direct to operating room. Received 17 units of blood product in 24 hours.
13	Yes	Blunt, with pulse	Pelvic fracture Abdominal solid organ injury	Interventional radiology	No	Motor vehicle collision. Interventional radiology embolization of right ilio lumbar/lumbar arteries successful. Received 17 units of blood product in 24 hours.
14	Yes	Penetrating, with pulse	Abdominal solid organ injury Major vascular injury	Operating room	No	Gunshot wound to abdomen. Direct to operating room for trauma laparotomy. Received 33 units of blood product in 24 hours.
15	Yes	Blunt, with pulse	Abdominal solid organ injury	Interventional radiology	No	Fall from a second-story building. Underwent interventional radiology embolization for control of a liver laceration. Received 29 units of blood product in 24 hours.
16	No	Blunt, with pulse	Pelvic fracture Other—retroperitoneal hematoma	None	No	Pedestrian struck by a vehicle. Hypotension likely exacerbated by sedation. No intervention required for hemorrhage.
17	Yes	Blunt, with pulse	Abdominal solid organ injury Major vascular injury	Operating room	Yes	Motor vehicle collision. Arrested in the emergency department. Direct to operating room. Received an operating room resuscitative thoracotomy and cross-clamping of the aorta for attempted control of hemorrhage. Died in the operating room.
18	No	Blunt, with pulse	Pelvic fracture Abdominal solid organ injury	Interventional radiology	No	Pedestrian struck by a truck. Transferred from another institution. Responded to blood product resuscitation and stabilized prior to interventional radiology.

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TABLE 4 (continued from 301). Case descriptions of likely candidates for resuscitative endovascular balloon occlusion of the aorta.

Candidate #	Likely candidate	Inclusion criteria met	Primary source of hemorrhage	Immediate surgical intervention	Death in hospital	Case description
19	No	Blunt, with pulse	Other—groin hematoma	None	No	Truck ran over legs of patient. Inguinal laceration was initially missed but was amenable to external compression.
20	Yes	Blunt, with pulse	Abdominal solid organ injury	Operating room	No	Motor vehicle collision. Sustained a grade 5 splenic injury that was taken to the operating room for definitive control. Received 57 units of blood products in 24 hours.
21	Yes	Blunt, with pulse	Abdominal solid organ injury Major vascular injury	Operating room	No	Motorcycle crash. Direct to operating room. Received 163 units of blood product in 24 hours.

total trauma patients) seen in the emergency department per year may have benefited from REBOA, and 72.4% (21 of 29 REBOA candidates) of them had sustained a penetrating traumatic injury.¹¹

The main limitation of our study is that in our retrospective chart review, the identification of cases that met REBOA candidacy did not necessarily indicate that the intervention would have changed patient outcomes. It is notable that of the 14 likely candidates, 3 died from their injuries (21.4%) and 11 survived without REBOA. Furthermore, only 8 of the 14 likely candidates (57.1%) went directly to the operating room or interventional radiology suite for attempted embolization. This reflects the reality that the physician's decision to deploy REBOA is made early during patient assessment and sometimes without definitive imaging. As with any intervention, REBOA can be deployed on a case-by-case basis according to the physician's clinical judgment that it will improve the patient's outcome.

It is also notable that the mean systolic blood pressure on emergency department arrival for both the potential and likely candidates was greater than 100 mmHg. However, a patient's clinical status cannot be determined by a single value because it is representative of only a moment in their postinjury course. All these patients became hypotensive and transient responders or nonresponders to resuscitation at some point during their emergency visit. In contrast, the mean number of units of blood product transfused in the likely candidates was 5.5 in the first hour and 39.2 total in the first 24 hours. This met the criteria for massive

transfusion at our institution and was indicative of the critical condition of these patients. This also suggests a potential benefit of REBOA in reducing transfusion requirements in hemorrhaging trauma patients.

While REBOA is a low-volume procedure, it could be lifesaving or could reduce transfusion requirements in the most severely injured patients; however, more prospective research is required to determine if the availability of REBOA improves patient outcomes.

Summary and future directions

Our study contributes to the evaluation of the potential value of REBOA in trauma management in the Canadian setting. We found that 1.1% of our annual trauma population would meet REBOA candidacy. While REBOA is a low-volume procedure, it could be lifesaving or could reduce transfusion requirements in the most severely injured patients; however, more prospective research is required to determine if the availability of REBOA improves patient outcomes. Furthermore, it is important to consider that using a tool such as REBOA requires

major systems changes, including an increase in multidisciplinary on-call coverage, training of providers, and quality assurance. Additional future directions include conducting a formal needs assessment for the implementation of REBOA that involves a cost-benefit analysis and evaluation of the implications to trauma systems at Canadian institutions. ■

Competing interests

None declared.

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