Original Article

Combined, converted, and prophylactic use of resuscitative endovascular balloon occlusion of the aorta for severe torso trauma: a retrospective study

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Introduction: Resuscitative endovascular balloon occlusion of the aorta (REBOA) is used as an intra-aortic balloon occlusion in Japan; however, protocols for its effective use in different conditions have not been established. This study aimed to summarize the strategies of REBOA use in severe torso trauma.

Methods: Twenty-nine cases of REBOA for torso trauma treated at our hospital over 5 years were divided into hemodynamically unstable (HU) (n = 12), cardiac arrest (CA) (n = 13), and hemodynamically stable (HS) (n = 4) groups. We retrospectively examined patient characteristics, trauma mechanism, injury site, severity score, intervention type, and survival rates at 24 h in each group.

Results: In the HU group, 9 and 3 patients survived and died within 24 h, respectively; time to intervention (56.6 versus 130.7 min, P = 0.346) tended to be shorter and total occlusion time (40.2 versus 337.7 min, P = 0.009) was significantly shorter in survivors than in nonsurvivors. In the CA group, 10 patients were converted from resuscitative thoracotomy with aortic cross-clamp (RTACC); one patient survived. All four patients in the HS group survived, having received prophylactic REBOA.

Conclusion: The efficacy of REBOA for severe torso trauma depends on the patient's condition. If the patients are hemodynamically unstable, time to intervention and total occlusion time could correlate with survival. The combined use of REBOA with definitive hemostasis could improve outcomes. Conversion from RTACC in the cardiac arrest patients and prophylactic use in the hemodynamically stable patients can be one of the potentially effective options, although further studies are needed.

Key words: Hemorrhagic shock, multiple trauma, resuscitation, resuscitative endovascular balloon occlusion of the aorta, resuscitative thoracotomy with aortic cross-clamp

INTRODUCTION

RESUSCITATIVE ENDOVASCULAR BALLOON occlusion of the aorta (REBOA) was developed in 1953 by Edwards *et al.*[1] for use in abdominal aortic aneurysm surgery. In 1989, Gupta *et al.*[2] launched its clinical application to intra-abdominal bleeding due to trauma. In Japan, the first clinical application of the aortic occlusion catheter for bleeding control in blunt abdominal trauma was reported in 1998; since then, it has been used in scenarios involving intra-aortic balloon occlusion (IABO) among others; however, there is little evidence regarding the efficacy of this practice.

In the United States, REBOA was reintroduced by Stannard *et al.* in 2011,[3] followed by several reports on its clinical efficacy. Recently, several studies, including systematic reviews,[4–7] have shown the superiority of REBOA over resuscitative thoracotomy with aortic cross-clamp (RTACC), performed for the same purpose.

However, there are data from Japan showing that mortality was higher in cases in which REBOA was used,[8] and there are reports indicating the usefulness of prophylactic use in hemodynamically stable patients.[18,19] Therefore, there are many unknown facts and novel findings to be clarified regarding its appropriate use and timing.

The present study aimed to categorize REBOA use in severe torso trauma and evaluate the trauma care strategies using REBOA.

METHODS

WE INCLUDED 29 patients with torso trauma treated with REBOA between 2016 and 2021 at our facility.
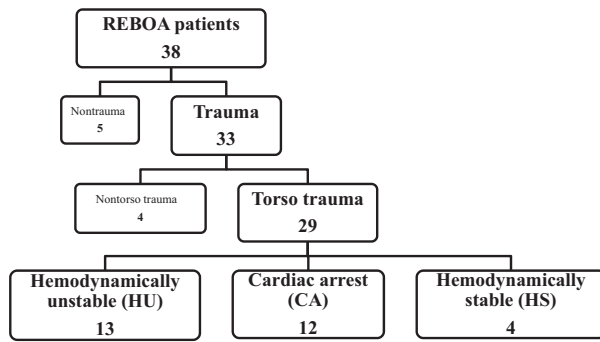
Fig. 1. Patients who underwent resuscitative endovascular balloon occlusion of the aorta (REBOA) for severe torso trauma who were included in this study. A total of 29 patients with torso trauma were divided into cardiac arrest (CA) (*n* = 13), hemodynamically unstable (HU) (*n* = 12), and hemodynamically stable (HS) (*n* = 4) groups.

The technique was indicated for patients requiring hemorrhage control below diaphragm. The mean age was 56.6 years, and 19 patients were male. The patients were divided into hemodynamically unstable (HU) (*n* = 12), cardiac arrest (CA) (*n* = 13), and hemodynamically stable (HS) (*n* = 4) groups (Fig. 1).

Hemodynamically unstable was defined as systolic blood pressure levels of <90 mmHg or shock index of >1 point at the time of arrival or at the scene and requiring intervention other than blood transfusion alone. Cardiac arrest was defined as CA at the time of arrival or within a short time after arrival. Hemodynamically stable was defined as achieving stability after transfusion between the time of arrival and start of the intervention and where the patient did not progress to shock.

The design and protocol of this study adhered to the Declaration of Helsinki and were approved by an Institutional Review Board of Aichi Medical University (approval number: 2019–097), and informed consent was obtained from all participants.

Data acquisition and statistical analysis

The following variables were compared between each group: demographic and clinical characteristics, trauma mechanism, trauma score (abbreviated injury score [AIS] calculation was based on AIS98 until 2018 and AIS2008 after 2019) and mortality (Table 1). In addition, patients in each group were divided into mortality and survival groups at 24 h and intervention type and context (time to insertion, time to intervention, total occlusion time in HU group, percentage of conversion to REBOA from RTACC in CA group, and percentage of inflation needed in HS group) were compared.

Table 1. Characteristics of 29 patients who underwent resuscitative endovascular balloon occlusion of the aorta for severe torso trauma

	Hemodynamically unstable (*n* = 12)	Cardiac arrest (*n* = 13)	Hemodynamically stable (*n* = 4)	*P*-value
Age (years)	57.5 (22.8–80)	52 (36–75.5)	71 (60.5–81.5)	0.474
Male, *n* (%)	6 (50)	10 (77)	3 (75)	
Mechanism of injury, *n*				
MVA	8	10	2	
Fall	2	2	2	
Compression	1	1	0	
Stab	1	0	0	
Injury site (duplication included), *n*				
Thorax	2	9	0	
Abdomen	8	7	0	
Pelvis	5	4	4	
Extremity	1	1	1	
ISS	24 (16–41)	35 (29–48.5)	23.5 (13–42.3)	0.225
RTS	4.71 (3.3–6.78)	0.87 (0–4.23)	7.33 (6.89–7.77)	0.001*
Ps	0.72 (0.2–0.86)	0.09 (0.01–0.4)	0.77 (0.56–0.95)	0.007*
Mortality, *n* (%)	3 (25)	12 (92.3)	0 (0)	

Note: Values are presented as median (interquartile range), unless otherwise indicated.
Abbreviations: ISS, injury severity score; MVA, motor vehicle accident; Ps, probability of survival; RTS, revised trauma score.
*$P < 0.05$.

Values are presented as the median (interquartile range). Data were analyzed using the Kruskal–Wallis test with Dunn's multiple comparison test between three groups and the Mann–Whitney *U*-test between two groups. Statistical analyses were undertaken using GraphPad Prism 7 software (GraphPad Inc., San Diego, CA, USA), and statistical significance was set at *P*-values of <0.05.

RESULTS

THE CHARACTERISTICS OF the patients in each group are presented in Table 1. There were no significant differences regarding age, gender, or mechanism of injury. The main injury site is different in each group: abdominal organ in the HU group, thoracic organ in the CA group, and pelvic fracture in the HS group. Not listed in the table, AIS of chest trauma in the CA group is significantly higher than in HU and HS groups (4 ± 0.39 versus 2 ± 0.49, *P* = 0.048). The injury severity score was not significantly different between the three groups (29.3 ± 4.8 versus 38.5 ± 3.3 versus 26.3 ± 8.0, *P* = 0.225), however, the revised trauma score and probability of survival were significantly different depending on the hemodynamic status (4.96 ± 0.52 versus 2.39 ± 0.71 versus 7.33 ± 0.23, *P* = 0.001 and 0.56 ± 0.10 versus 0.20 ± 0.01 versus 0.76 ± 0.11, *P* = 0.007 respectively). This is the same for mortality. REBOA-related complications did not occur in all groups.

The characteristics of patients in the HU group are presented in Table 2. At 24 h, 9 and 3 patients were alive and dead, respectively. The injury severity score was not significantly different between the groups (26 ± 4.9 versus 39 ± 12.2, *P* = 0.259), however, the revised trauma score and probability of survival were significantly lower in the patients who died than in those who survived (5.74 ± 0.43 versus 2.62 ± 0.36, *P* = 0.009 and 0.70 ± 0.09 versus 0.14 ± 0.07, *P* = 0.03, respectively). The time to insertion (from arrival to REBOA insertion) was almost the same between survivors and nonsurvivors (16 versus 19 min, *P* = 0.573). The time to intervention (from REBOA inflation to intervention start) tended to be shorter in the patients who survived than in those who died (56.6 versus 130.7 min, *P* = 0.346; Fig. 2). Total occlusion time was significantly shorter in the patients who survived than in those who died (40.2 versus 337.7 min, *P* = 0.009; Fig. 3).

The characteristics of patients in the CA group are presented in Table 3. In each case, the injury severity was high, and the probability of survival was low. Resuscitative thoracotomy with aortic cross-clamp was carried out in 10 patients, including a patient who survived for 24 h, and REBOA was used as a conversion from RTACC. The surviving patient was a man aged in his early 30s who was injured by a fall. He underwent cardiac arrest during

Table 2. Characteristics of patients in the hemodynamically unstable (HU) group who underwent resuscitative endovascular balloon occlusion of the aorta

	Survivors (n = 9)	Non-survivors (n = 3)	P-value
Age (years)	61 (21.5–83)	54 (25–81)	>0.999
Male, *n* (%)	5 (56%)	1 (33%)	>0.999
Mechanism of injury, *n*			
MVA	7	1	
Fall	0	2	
Compression	1	0	
Stab	1	0	
Injury site (duplication included)			
Thorax	1	1	
Abdomen	6	2	
Pelvis	4	1	
Extremity	1	0	
ISS	19 (14.5–41)	41 (17–59)	0.259
RTS	5.68 (4.6–7.01)	2.93 (1.9–3.04)	0.009*
Ps	0.84 (0.6–0.87)	0.18 (0.004–0.24)	0.03*
Intervention	Operation 2 IR 7	Operation + IR 3	
Time to insertion (min)	16 (10–41)	19 (17–41)	0.573
Time to intervention (min)	63 (20.5–77)	107 (35–250)	0.346
Total occlusion time (min)	24 (7.5–87.5)	360 (145–508)	0.009*

Note: Values are presented as median (interquartile range) unless otherwise indicated.
Abbreviations: IR, interventional radiology; ISS, injury severity score; MVA, motor vehicle accident; Ps, probability of survival; RTS, revised trauma score.
**P* < 0.05.

transport. Resuscitative thoracotomy with aortic cross-clamp was carried out immediately after admission to the emergency department and return of spontaneous circulation was achieved within 7 min. Focused assessment with sonography for trauma findings was positive, and emergent laparotomy was performed. After controlling the bleeding from the mesentery, REBOA was inserted from the right femoral artery and placed in Zone I with manual confirmation in the chest cavity. Subsequently, the chest wound was closed using thoracic drainage. Resuscitative endovascular balloon occlusion of the aorta was managed with partial occlusion and could be deflated with a total occlusion time of 68 min because of stable circulation.
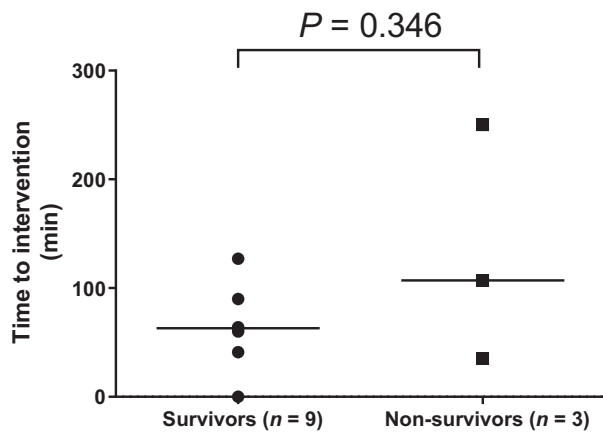
Fig. 2. Time to intervention in the hemodynamically unstable group of patients who underwent resuscitative endovascular balloon occlusion of the aorta (REBOA) for severe torso trauma. Time from REBOA inflation to start of intervention was shorter in survivors than in nonsurvivors (56.6 versus 130.7 min, $P = 0.346$).
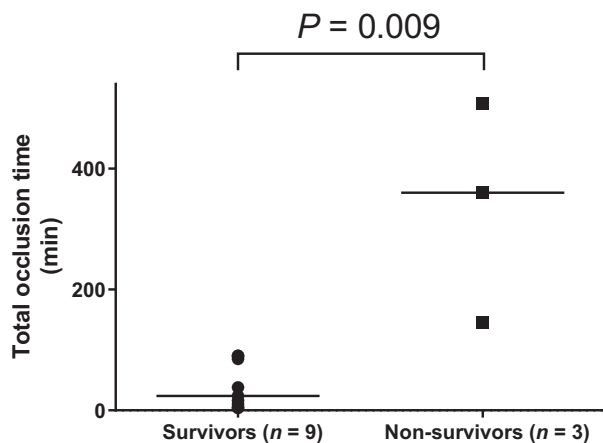

Fig. 3. Total occlusion time in the hemodynamically unstable group of patients who underwent resuscitative endovascular balloon occlusion of the aorta for severe torso trauma. Total occlusion time was significantly shorter in survivors than in non-survivors (40.2 versus 337.7 min, $P = 0.009$).

The characteristics of patients in the HS group are presented in Table 4. All four patients survived for 24 h with prophylactic care; one patient required inflation during treatment. This patient was a woman aged in her mid-80s; she was injured in a motor vehicle accident and was transported to our hospital by helicopter emergency medical service. At the emergency department, she was not in shock, presenting with a heart rate of 68 b.p.m. and blood pressure of 100/62 mmHg; however, radiography and computed tomography findings showed pelvic fracture and extravasation of

Table 3. Characteristics of patients in the cardiac arrest (CA) group who underwent resuscitative endovascular balloon occlusion of the aorta

	Survivors ($n = 1$)	Non-survivors ($n = 12$)
Age (years)	31	54.5 (43.3–76.3)
Male, *n* (%)	1 (100)	9 (75)
Mechanism of injury, *n*		
MVA	0	10
Fall	1	1
Compression	0	1
Stab	0	0
Injury site (duplication included), *n*		
Thorax	1	8
Abdomen	1	6
Pelvis	1	3
Extremity	0	1
ISS	41	34.5 (29–51.3)
RTS	0	2.48 (0–4.34)
Ps	0.02	0.12 (0.01–0.44)
Intervention	Operation 1	Operation 2
		IR 1
		Operation + IR 1
		Not achieved 8
Convert from RTACC	1 in 1 (100%)	9 in 12 (75%)

Note: Values are presented as median (interquartile range) unless otherwise indicated.
Abbreviations: IR, interventional radiology; ISS, injury severity score; Ps, probability of survival; MVA, motor vehicle accident; RTACC, resuscitative thoracotomy with aortic cross-clamp; RTS, revised trauma score.

contrast, and interventional radiology (transcatheter arterial embolization) was implemented. Preoperatively, a prophylactic REBOA was inserted through the left femoral artery, and interventional radiology was undertaken through the right femoral artery. Transcatheter arterial embolization was successfully completed with temporary inflation of the REBOA to maintain hemodynamic stability.

DISCUSSION

RESUSCITATIVE ENDOVASCULAR BALLOON occlusion of the aorta is an endovascular approach to aortic occlusion that aims to prevent CA in cases of severe hemorrhagic shock. It is less invasive than RTACC, which may be used for the same purpose, and it can be used in interventions that require precision, including partial or intermittent occlusion. However, REBOA could be more time-consuming than RTACC. These aspects of both

Table 4. Characteristics of patients in the hemodynamically stable (HS) group who underwent resuscitative endovascular balloon occlusion of the aorta (all patients survived beyond 24 h)

	Values
Age (years)	71 (60.5–81.5)
Male, *n* (%)	3 (75)
Mechanism of injury, *n*	
MVA	2
Fall	2
Compression	0
Stab	0
Injury site (duplication included), *n*	
Thorax	0
Abdomen	0
Pelvis	4
Extremity	1
ISS	23.5 (13–42.3)
RTS	7.33 (6.89–7.77)
Ps	0.77 (0.56–0.95)
Intervention	Operation 1
	IR 2
	Conservative 1
Inflation needed (%)	1 in 4 (25%)

Note: Values are presented as median (interquartile range) unless otherwise indicated.
Abbreviations: IR, interventional radiology; ISS, injury severity score; MVA, motor vehicle accident; Ps, probability of survival; RTS, revised trauma score.

procedures need to be considered to identify the approach that is most likely to yield desirable patient outcomes.

In the present study, we investigated 29 patients with torso trauma treated with REBOA in three groups divided by hemodynamic status: HU, CA, and HS. Aiming to categorize the REBOA use and evaluate the trauma care strategies using REBOA, the following data were compared in each group: time to insertion, time to intervention, and total occlusion time in the HU group, percentage of conversion to REBOA from RTACC in the CA group, and percentage of inflation needed in the HS group. Many suggestive findings were obtained from these results.

Previously, Inoue *et al.*[8] reported that the use of REBOA in situations where it is not indicated and the lack of systems that enable the rapid performance of definitive hemostasis could worsen the outcomes of patients undergoing REBOA. These patterns might reflect the specific Japanese context, which lacks standardized protocols for using REBOA across trauma centers.

It is also said in Japan that IABO/REBOA should not be implemented only to obtain a computed tomography scan but to shorten the time to controlled bleeding, and that the aim of using IABO/REBOA is to prevent CA.[9] Matsumoto *et al.*[10] reported that RTACC is more frequently undertaken in patients with thoracic trauma than in those without thoracic trauma in Japan. In this study, patients in the CA group had significantly more severe chest trauma. When REBOA is used, attention should be paid to the possibility of complications of head and chest injuries because the increase in blood pressure on the central side of the occlusion balloon could contribute to hemorrhage. Matsumura *et al.*[11] undertook a study based on a Japanese multicenter dataset, showing that partial occlusion, conversion from thoracotomy, and occlusion timing could increase the likelihood of hemodynamic stabilization and improve survival. Early recognition of patients who might require REBOA following early arterial access could help improve outcomes.[12]

This study showed that the time to insertion probably does not affect the outcome; however, the time to intervention and total occlusion time may correlate with the 24-h survival rates in the HU group, suggesting that prolonged shock and coagulopathy due to delayed hemostatic intervention and the progression of lower organ ischemia due to delay in REBOA deflation could worsen outcomes. Factors associated with survival may include shortening the time to the start of a hemostatic intervention and early REBOA deflation, that is, immediate definitive hemostasis.

Our previous study (*n* = 14) showed that blood pressure increased significantly with REBOA use without affecting patient outcomes. Meanwhile, reduced transfusion volume and total occlusion time (i.e., immediate definitive hemostasis) were factors associated with survival.[13] In addition, another study (*n* = 46) suggested that REBOA could be effective for treating shock, either combined with hemostatic intervention for hemodynamic stabilization or by achieving temporary hemostasis. It also suggested that prior insertion of REBOA (prophylactic use) might be effective if the patient is not in shock at the time of admission (T. Irahara, 2017, unpubl. data). In a case report from Japan, intraoperative bleeding was controlled, and a good surgical field was secured by the combined use of REBOA and hemostatic laparotomy, resulting in improved hemostasis completion and survival rates.[14] Reports from abroad, where proximal control with REBOA was useful before intraoperative retroperitoneal hematoma exploration, support these findings.[15,16]

In summary, for traumatic hemorrhagic shock, it is important to combine the use of REBOA with immediate

hemostatic intervention to achieve hemostasis first; alternatively, REBOA may be performed followed by hemostasis, provided delays can be avoided. Delays to obtain a computed tomography scan or because of REBOA-associated factors could be detrimental to patient outcomes.

In the CA group, the severity of injury and mortality rates were high; however, in some cases, the use of RTACC (conversion to REBOA) was effective. Conversion to REBOA helps reduce lower organ ischemia, prevent hypothermia, and reduce chest wall bleeding (associated with thoracotomy) by shifting from complete occlusion by RTACC to partial or intermittent occlusion by REBOA while ensuring the rapidity and certainty of RTACC. The REBOA handbook, the first official textbook in Japan, reports the usefulness of REBOA.[17] In addition, the position of the catheter tip can be confirmed visually and by palpation under thoracotomy. A combination of interventions may expand the range of protocols available and improve patient outcomes. Resuscitative thoracotomy with aortic cross-clamp should be carried out promptly for cases of impending cardiac arrest, and early conversion to REBOA could improve patient outcomes in some cases. The combined and conversion approaches are consistent with the original purpose of REBOA (resuscitative use by physiological indication).

In contrast, prophylactic REBOA use was helpful in some cases in the HS group. Prophylactic REBOA use could help to achieve rapid definitive hemostasis by stabilizing hemodynamic parameters and maintaining a good field of view by controlling bleeding. Previous case reports from Japan have shown the benefits of prophylactic use in patients at high risk of major bleeding due to intraoperative manipulation.[18,19] In addition, benefits of an intraoperative placement for patients with relatively stable presentation at admission have been observed.[20] Such a "nonresuscitative use" might seem paradoxical, given the name of REBOA, but it could improve outcomes.

Overall, REBOA may be used in different ways, some of which could help improve patient outcomes, provided great care is executed, and the intervention is delivered at the right time. Resuscitative endovascular balloon occlusion of the aorta can even be nicknamed the "countdown to death," referring to the risks associated with lower organ ischemia that increase while temporary hemodynamic stabilization is achieved; consequently, this approach should be used judiciously. Resuscitative thoracotomy with aortic cross-clamp for the same purpose can be used differently or in combination with REBOA, as required; however, the timing of intervention remains paramount to the outcomes.

This study has some limitations. First, the sample size was small. Second, this study was based at a single center.

Third, to evaluate the efficacy of REBOA to resuscitate HU or CA patients, we needed to define the outcome not as overall but short term (24-h) survival. Finally, the use of REBOA is generally limited to severe cases, including CA, which makes this study subject to selection bias. Prospective studies on REBOA are challenging; nevertheless, multicenter studies are required to provide evidence for the use of REBOA in clinical practice in Japan.

CONCLUSION

THE EFFECTIVE USE of REBOA for severe torso trauma depends on the patient's condition; a combined approach with immediate hemostasis could benefit HU patients, while conversion from RTACC for CA patients, and prophylactic use for HS patients can be one of the potentially effective options, although further studies are needed.

DISCLOSURE

APPROVAL OF THE research protocol: The design and protocol of this study adhered to the Declaration of Helsinki and were approved by an Institutional Review Board of Aichi Medical University (approval number: 2019–097).

Informed consent: In accordance with the privacy policy of the Aichi Medical University Hospital, a notice was posted stating that information that could identify the study participants would be de-identified and used in conference presentations and publications for research purposes. Informed consent was obtained from all participants.

Registry and registration no. of the study/trial: N/A.

Animal studies: N/A.

Conflict of interest: None.

DATA AVAILABILITY STATEMENT

THE DATASETS USED and/or analyzed during the current study are available from the corresponding author on reasonable request.

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