


## ORIGINAL RESEARCH

## Trauma

# Resuscitative endovascular balloon occlusion of the aorta and traumatic out-of-hospital cardiac arrest: A nationwide study

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**Abstract**

**Objective:** Resuscitative endovascular balloon occlusion of the aorta (REBOA) is a less-invasive method for temporary hemostasis compared with cross-clamping the aorta through resuscitative thoracotomy (RT). Although the survival benefits of REBOA remained unclear, pathophysiological benefits were identified in patients with traumatic out-of-hospital cardiac arrest (t-OHCA). We examined the clinical outcomes of t-OHCA with the hypothesis that REBOA would be associated with higher survival to discharge compared with RT.

**Methods:** A retrospective cohort study was conducted using the Japan Trauma Data Bank (2004–2019). Adult patients with t-OHCA who had arrived without a palpable pulse and undergone aortic occlusion were included. Patients were divided into REBOA or RT groups, and propensity scores were developed using age, mechanism of injury, presence of signs of life, presence of severe head and/or chest injury, Injury Severity Score, and transportation time. Inverse probability weighting by propensity scores was performed to compare survival to discharge between the 2 groups.

**Results:** Among 13,247 patients with t-OHCA, 1483 were included in this study. A total of 144 (9.7%) patients were treated with REBOA, and 5 of 144 (3.5%) in the REBOA group and 10 of 1339 (0.7%) in the RT group survived to discharge. The use of REBOA was significantly associated with increased survival to discharge (odds ratio, 4.78; 95% confidence interval, 1.61–14.19), which was confirmed by inverse probability weighting (adjusted odds ratio, 3.73; 95% confidence interval, 1.90–7.32).

**Conclusions:** REBOA for t-OHCA was associated with higher survival to discharge. These results should be validated by further research.

**KEYWORDS**

aortic occlusion, balloon occlusion, cardiac arrest, mortality, OHCA, REBOA, resuscitative thoracotomy, traumatic cardiac arrest

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## 1 | INTRODUCTION

### 1.1 | Background

Trauma victims with out-of-hospital cardiac arrest (OHCA) have a dismal prognosis, with extremely low survival rates reported globally.<sup>1-5</sup> Although some studies have reported that nearly half of patients with traumatic OHCA (t-OHCA) had severe traumatic brain injuries, severe hemorrhage has also been recognized as a main cause of unfavorable clinical outcomes after t-OHCA.<sup>5,6</sup> Although aortic occlusion via cross-clamping has been performed as a resuscitative procedure to temporarily control bleeding below the diaphragm, it has not been demonstrated to be effective in patients with t-OHCA, particularly when patients present with no signs of life after blunt trauma.<sup>1,7-10</sup>

### 1.2 | Importance

Resuscitative endovascular balloon occlusion of the aorta (REBOA) is an emerging technique that is a relatively less-invasive alternative to externally cross-clamping the aorta during resuscitative thoracotomy (RT),<sup>11-14</sup> and the beneficial effects and feasibility of REBOA have been tested on trauma patients, including those with t-OHCA.<sup>15-17</sup> A retrospective study analyzed the pathophysiological benefits of REBOA during cardiopulmonary resuscitation (CPR) for traumatic cardiac arrest, which identified augmented blood pressure and increased rate of return of spontaneous circulation.<sup>15</sup> Another prospective study of traumatic cardiac arrest found a shorter duration of interruption of cardiac compression in patients treated with REBOA compared with those receiving RT.<sup>16</sup> In addition, an analysis using the American Association for the Surgery of Trauma Aortic Occlusion in Resuscitation for Trauma and Acute Care Surgery database, in which more than half of patients required out-of-hospital CPR, reported higher post-occlusion systolic blood pressure in patients treated with REBOA compared with those treated with RT.<sup>17</sup>

### 1.3 | Goals of this investigation

Despite the promising results and increasing popularity of REBOA, obvious favorable clinical outcomes in t-OHCA remain uncertain.<sup>18</sup> To eventually ascertain whether REBOA might be a therapeutic option during the resuscitation of t-OHCA in a prospective study, we used a Japanese nationwide trauma database to examine the clinical outcomes of trauma victims with OHCA who had received aortic occlusion by RT or REBOA. We hypothesized that REBOA would be associated with higher survival to discharge compared with RT.

## 2 | METHODS

### 2.1 | Study design and setting

We conducted a retrospective cohort study using data from the Japan Trauma Data Bank (JTDB). The JTDB was established as a Japanese

#### The Bottom Line

Extremely low survival rates are reported for patients with traumatic out-of-hospital cardiac arrest attributed to uncontrolled hemorrhage. Resuscitative endovascular balloon occlusion of the aorta has been proposed as a means for temporizing hemorrhage to help improve outcomes. This retrospective study of 144 adults who received resuscitative endovascular balloon occlusion of the aorta found significantly higher rates of survival compared with patients who underwent resuscitative thoracotomy (n = 1339), 3.5% versus 0.7%, respectively.

nationwide trauma registry in 2003 and has been maintained by the Japanese Association for the Surgery of Trauma and the Japanese Association for Acute Medicine, representing >200 participating hospitals and tertiary care centers. JTDB data are collected prospectively and entered into an online data collection portal by treating physicians or volunteer registrars designated by each hospital.<sup>12</sup> Before initiating the study, all collaborating hospitals obtained individual local institutional review board approval for conducting research with human subjects.

In Japan, emergency medical service (EMS) personnel perform CPR according to the Japanese CPR guidelines, which were developed and revised based on the American Heart Association and International Liaison Committee on Resuscitation guidelines.<sup>19</sup> Although most EMS crews have an emergency life-saving technician who is certified to obtain intravenous access, no EMS personnel are authorized to perform advanced trauma life support interventions, such as intrasosseous access or needle/tube thoracostomy.<sup>20</sup>

Current practice in Japan recommends RT for patients with t-OHCA who arrive at an emergency department without a palpable pulse. However, as trauma surgeons are not always present in the hospital, REBOA is sometimes performed by emergency physicians, which involves placing a REBOA catheter in zone 1 (between the left subclavian artery and celiac artery) through the femoral artery with fluoroscopy and/or ultrasound. REBOA is also sometimes used after aortic occlusion by external cross-clamping during RT to help trauma surgeons focus on the surgical repair of the thoracic injury. Ten-French (Fr) REBOA catheters were used until 2013 when 7-Fr options became clinically available.<sup>12</sup>

### 2.2 | Study population

We retrospectively reviewed data from the JTDB between January 2004 and March 2019. Trauma patients with t-OHCA (1) who were aged 15 years or older, (2) who had arrived without a palpable pulse and with a Glasgow Coma Scale (GCS) score of 3, and (3) who had received aortic occlusion by either cross-clamping through RT or REBOA were

included. Patients who had arrived with >30 minutes of transportation time from the scene were excluded because it has been reported that most patients with t-OHCA were transported from the scene within 30 minutes in Japan.<sup>20</sup> Patients with missing or invalid data on in-hospital survival or transportation time were also excluded.

### 2.3 | Data collection and definitions

Out-of-hospital information was prospectively collected by EMS personnel; in-hospital information was collected by treating physicians in each institution. Available data in the database included age, sex, mechanism of injury, out-of-hospital vital signs, presence of signs of life at the scene, time of emergency call, time of ambulance arrival, time of departure from the scene, time of hospital arrival, vital signs on arrival, presence of signs of life on arrival, any surgical procedures or angiography, Abbreviated Injury Scale score, Injury Severity Score, hospital length of stay, and survival status at discharge. Data on time of recognition of cardiac arrest, witness status, presence of bystander CPR, and time of aortic occlusion were not available in the database. REBOA catheter size, position of REBOA placement, duration of REBOA inflation, and complications related to REBOA were not available in the database.

Transportation time was defined as the interval between departure from the scene and hospital arrival. Signs of life were defined as the presence of any of the following: spontaneous respiration, palpable pulse, measurable blood pressure, electrical activity of the heart, pupillary reactivity, or GCS  $\geq 4$ . Conflicting and/or ambiguous data on time elements were considered invalid. Severe head/chest injury was defined as an injury with Abbreviated Injury Scale > 3 in the head/chest.

### 2.4 | Outcome measures

The primary outcome was survival to discharge, recorded as discharge to home or other health care facilities in the database. A secondary outcome was hospital-free days until day 90, a composite of in-hospital mortality and hospital length of stay, defined as the number of days alive and out of the hospital between day of hospital arrival and 90 days later.

### 2.5 | Statistical analysis

Patient data were divided between REBOA and RT groups. The REBOA group consisted of patients who had undergone REBOA, whereas the RT group consisted of those who had received aortic occlusion by cross-clamping through RT. Patients who had undergone REBOA and subsequently received RT without cross-clamping the aorta for the repair of thoracic injuries were included in the REBOA group, whereas those who had undergone aortic occlusion by cross-clamping through RT along with REBOA were included in the RT group. Unadjusted anal-

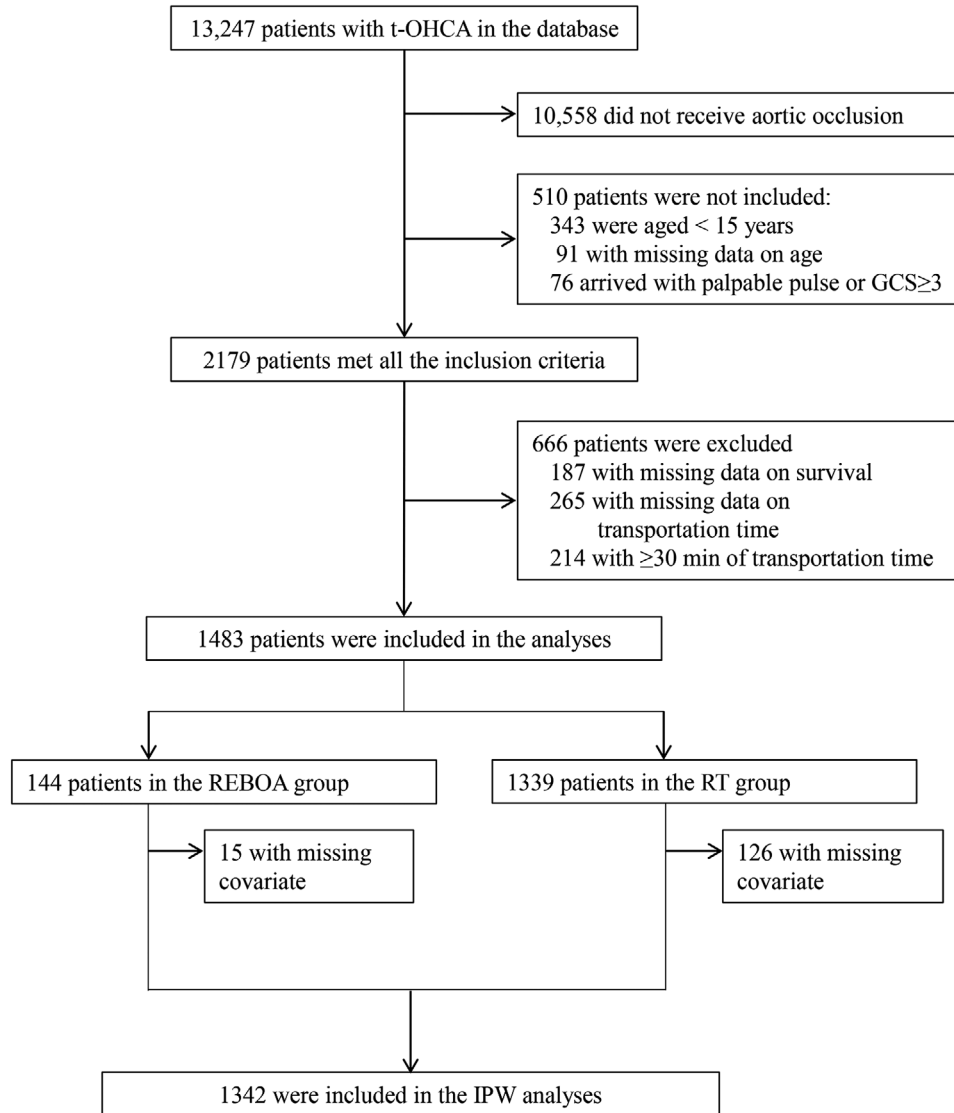
yses were performed on the primary and secondary outcomes with the  $\chi^2$  test and ordinal logistic regression analysis, respectively.

To adjust covariates between the 2 groups, inverse probability weighting (IPW) analyses with propensity scores were performed to compare the primary and secondary outcomes.<sup>21</sup> The propensity score was developed using the logistic regression model to estimate the probability of being assigned to the REBOA group compared with the RT group.<sup>22</sup> Relevant covariates were carefully selected from known or possible survival predictors in trauma patients based on previous studies, which included age, sex, mechanism of injury, severity of injuries (Injury Severity Score), presence of severe head and/or chest injury, presence of signs of life at scene and/or on hospital arrival, and transportation time. All of this information was subsequently entered into the propensity model.<sup>1–10,23–26</sup> Patients with missing covariates were excluded from the propensity score calculation, and missing data analyses on these variables were performed using the Little missing completely at random test. The precision of discrimination and propensity score calibration were analyzed using the c-statistic and the Hosmer-Lemeshow goodness-of-fit test.<sup>22</sup> The IPW analyses were then performed as adjusted analyses, in which the primary and secondary outcomes were compared with the  $\chi^2$  test and ordinal logistic regression analysis, respectively.<sup>21</sup>

Sensitivity analyses were performed to validate the primary results. To confirm that the results were not dependent on the propensity score, a generalized estimating equation model with an independence correlation structure to account for within-institution clustering was used in which the association between REBOA use and the primary outcome was analyzed. Potential confounders in the model were selected from the same covariates that had been used for the propensity score calculation. Furthermore, IPW with restriction was performed without using patient data with <0.1 or >0.9 of the propensity score to avoid extreme weights.

Subgroup analyses were performed to examine the relationships between REBOA use, clinical characteristics, and survival to discharge. IPW analyses on the primary outcome were repeated in the subgroup of patients who had been divided based on the presence of severe chest injury and the requirement of craniotomy and laparotomy. Another subgroup analysis was performed to evaluate the difference in the frequency of REBOA use between each institution, in which hospitals were categorized according to the proportion of patients who had undergone REBOA during the study period: low,  $\leq 25\%$ ; moderate, 25%–50%; high, 50%–75%; and very high, >75%. Furthermore, considering that some patients underwent both REBOA and RT, the IPW analysis was performed on the subgroup of patients who were treated only with REBOA or RT.

Descriptive statistics are presented as the mean, median (interquartile range), or number (percentage). Results are shown using standardized difference and 95% confidence interval (CI). Testing of the hypothesis was only performed on the primary outcome, in which a 2-sided  $\alpha$  threshold of 0.05 was considered statistically significant. All statistical analyses were conducted using SPSS, version 25.0 (IBM, Armonk, NY), and Microsoft Excel (Microsoft, Redmond, WA).



**FIGURE 1** Study flow diagram. Of 13,427 patients identified with t-OHCA during the study period, a total of 1483 patients were eligible for this study, among whom 144 (9.7%) underwent aortic occlusion with REBOA. IPW analyses were performed for 1342 patients after 15 patients in the REBOA group and 126 patients in the RT group were excluded as a result of missing covariates for the calculation of the propensity score. GCS, Glasgow Coma Scale; IPW, inverse probability weighting; REBOA, resuscitative endovascular balloon occlusion of the aorta; RT, resuscitative thoracotomy; t-OHCA, traumatic out-of-hospital cardiac arrest

### 3 | RESULTS

After the screening process, 13,247 trauma patients with a t-OHCA period were identified during the study. Among them, 343 were <15 years old, and 76 had arrived with a palpable pulse or GCS > 3. Although 2179 patients satisfied all inclusion criteria, 452 were excluded because of missing data on survival or transportation time, and 214 were excluded because of delayed hospital arrival with ≥30 minutes of transportation time. Figure 1 summarizes the patient flow diagram.

Among 1483 patients eligible for this study, 144 (9.7%) had undergone aortic occlusion with REBOA, 55 of whom had subsequently received RT without cross-clamping the aorta for the repair of thoracic

injuries. A total of 1339 (90.3%) patients were included in the RT group, among whom 65 had undergone cross-clamping the aorta through RT along with REBOA. Table 1 listed a summary of the characteristics of patients with t-OHCA. Compared with the RT group, more patients in the REBOA group had signs of life at the scene and on hospital arrival (69 [47.9%] vs 292 [21.8%] and 9 [6.3%] vs 24 [1.8%], respectively), had severe head injuries (39 [27.1%] vs 267 [19.9%]), and had undergone laparotomy, angiography in the abdomen, and angiography in the pelvis (28 [19.7%] vs 138 [10.4%], 11 [8.2%] vs 15 [1.1%], and 10 [6.9%] vs 19 [1.4%], respectively). Fewer patients in the REBOA group had severe chest injuries compared with those in the RT group (80 [55.6%] vs 967 [72.2%]). The median transportation time was comparable between the 2 groups (10 [8] minutes vs 10 [10] minutes).

**TABLE 1** Characteristics of patients with traumatic out-of-hospital cardiac arrest

	Before IPW			After IPW <sup>a</sup>		
	REBOA	RT	Standardized difference	REBOA	RT	Standardized difference
Cases	144	1339				
Age, y, median (IQR)	53 (33)	55 (35)	0.005	53 (30)	53 (33)	0.080
Missing data, n (%)	0 (0.0)	0 (0.0)				
Sex, male, n (%)	98 (68.1)	921 (68.8)	0.016	903 (69.2)	928 (69.1)	0.002
Missing data, n (%)	0 (0.0)	0 (0.0)				
Mechanism of injury, blunt, n (%)	132 (91.7)	1228 (91.7)	0.002	122 (9.3)	112 (8.3)	0.036
Missing data, n (%)	0 (0.0)	0 (0.0)				
Signs of life at scene, n (%)	69 (47.9)	292 (21.8)	0.570	958 (73.4)	1001 (74.5)	0.026
Missing data, n (%)	6 (4.2)	47 (3.5)				
Signs of life on arrival, n (%)	9 (6.3)	24 (1.8)	0.228	1277 (97.9)	1314 (97.8)	0.001
Missing data, n (%)	0 (0.0)	0 (0.0)				
Severe head injury, n (%)	39 (27.1)	267 (19.9)	0.169	1017 (77.9)	1067 (79.4)	0.037
Missing data, n (%)	0 (0.0)	0 (0.0)				
Severe chest injury, n (%)	80 (55.6)	967 (72.2)	0.352	433 (33.2)	388 (28.9)	0.093
Missing data, n (%)	0 (0.0)	0 (0.0)				
ISS, median (IQR)	36 (25)	38 (50)	0.173	36 (29)	38 (45)	0.120
Missing data, n (%)	9 (6.3)	0 (0.0)				
Transportation time, min, median (IQR)	10 (8)	10 (10)	0.079	10 (8)	10 (8)	0.034
Missing data, n (%)	0 (0.0)	0 (0.0)				
Subsequent RT without cross-clamping, n (%)	55 (38.2)	-				
Simultaneous REBOA, n (%)	-	65 (4.9)				
<b>Surgery</b>						
Laparotomy, n (%)	28 (19.7)	138 (10.4)	0.264	250 (19.7)	145 (10.4)	0.236
Craniotomy, n (%)	2 (1.4)	7 (0.5)	0.089	11 (1.4)	8 (0.5)	0.029
<b>Angiography</b>						
Chest, n (%)	1 (0.8)	10 (0.8)	0.000	4 (0.8)	12 (0.8)	0.076
Abdomen, n (%)	11 (8.2)	15 (1.1)	0.340	82 (8.2)	17 (1.1)	0.266
Pelvis, n (%)	10 (6.9)	19 (1.4)	0.279	75 (6.9)	23 (1.4)	0.214

IPW, inverse probability weighting; IQR, interquartile range; ISS, Injury Severity Score; REBOA, resuscitative endovascular balloon occlusion of the aorta; RT, resuscitative thoracotomy.

<sup>a</sup>The numbers in these columns indicate estimated numbers of patients, adjusted by weighting with propensity scores.

The propensity model predicting allocation to the REBOA group was validated to have sufficient discrimination and calibration ( $c$ -statistic = 0.708 and Hosmer-Lemeshow goodness-of-fit  $P$  = 0.162). A total of 15 patients in the REBOA group and 126 in the RT group were excluded from IPW analyses because of missing covariates for the calculation of propensity score, hence IPW analyses were performed for 1342 patients. Missing data analyses on these covariates revealed that missing data were completely random ( $P$  = 0.844 in the Little missing completely at random test). The characteristics of the patients after IPW are summarized with standardized differences in Table 1, in which most covariates were successfully adjusted (standardized difference < 0.1).

Survival to discharge was significantly higher among patients who had undergone aortic occlusion with REBOA compared with those who had received cross-clamping the aorta through RT in unadjusted analysis (5 [3.5%] vs 10 [0.7%]; odds ratio [OR], 4.78; 95% CI, 1.61–14.19;  $P$  = 0.01; Table 2); IPW analysis validated the results (3.0% vs 0.8%; OR, 3.73; 95% CI, 1.90–7.32;  $P$  < 0.001; Table 2). The use of REBOA was associated with longer hospital-free days until day 90 in unadjusted analysis (mean hospital-free days = 1.3 days vs 0.6 days; coefficient = 1.5 days; 95% CI, 0.4–2.6 days; Table 2) and in IPW analysis (1.1 days vs 0.7 days; coefficient = 1.3 days; 95% CI, 0.6–2.0 days; Table 2).

Sensitivity analyses were performed to assure that the primary results were not dependent on the propensity score. The generalized

**TABLE 2** In-hospital mortality and hospital-free days

	REBOA	RT	P value	OR/coefficients	95% CI
Unadjusted analyses					
Survival to discharge, n/total (%)	5/144 (3.5)	10/1339 (0.7)	0.01	4.78	1.61–14.19
Hospital-free days to 90 days, days, mean, median (IQR)	1.3, 0(0)	0.6, 0(0)		1.5 <sup>a</sup>	0.4–2.6
IPW					
Survival to discharge, % (95% CI)	3.0 (2.1–3.9)	0.8 (0.3–1.3)	<0.001	3.73	1.90–7.32
Hospital-free days to 90 days, days, mean, median (IQR)	1.1, 0(0)	0.7, 0(0)		1.3 <sup>a</sup>	0.6–2.0

CI, confidence interval; IPW, inverse probability weighting; IQR, interquartile range; OR, odds ratio; REBOA, resuscitative endovascular balloon occlusion of the aorta; RT, resuscitative thoracotomy.

<sup>a</sup>Ordinal regression analysis was performed.

**TABLE 3** Survival to discharge in sensitivity analyses

	Survival to discharge, % (95% CI)		OR	95% CI
	REBOA	RT		
IPW with restriction (0.1–0.9 of PS)	3.4 (1.7–5.1)	0.5 (0.0–1.2)	7.18	1.62–31.77
Generalized estimating equation			4.70	1.55–14.25

CI, confidence interval; IPW, inverse probability weighting; OR, odds ratio; PS, propensity score; REBOA, resuscitative endovascular balloon occlusion of the aorta; RT, resuscitative thoracotomy.

estimating equation model accounting for within-institution clustering revealed the relationship between REBOA and higher survival to discharge (OR, 4.70; 95% CI, 1.55–14.25; Table 3). Similarly, IPW excluding patient data with <0.1 or >0.9 of the propensity score showed that REBOA was significantly associated with higher survival to discharge (3.4% vs 0.5%; OR, 7.18; 95% CI, 1.62–31.77; Table 3).

Subgroup analyses showed that patients who did not require craniotomy and those who had undergone laparotomy benefited from aortic occlusion with REBOA in terms of survival (3.0% [95% CI, 2.1%–3.9%] in the REBOA group vs 0.8% [95% CI, 0.3%–1.3%] in the RT group and 12.0% [95% CI, 8.0%–16.0%] in the REBOA group vs 0.9% [95% CI, 0.4%–1.4%] in the RT group, respectively; Table 4). However, these benefits disappeared in patients who needed craniotomy and those who had not undergone laparotomy. Higher survival to discharge was observed among patients in the REBOA group compared with those in the RT group, regardless of the presence of severe chest injury. Another subgroup analysis based on the proportion of patients who had undergone REBOA in each institution showed that REBOA was associated with higher survival to discharge only in hospitals where REBOA was performed with low frequency (4.3% [95% CI, 2.5%–6.1%] vs 0.8% [95% CI, 0.3%–1.3%]; Table 4). Furthermore, the subgroup analysis excluding patients who underwent both REBOA and RT similarly identified higher survival to discharge among patients in the REBOA group compared with those in the RT group (Table 4).

## 4 | LIMITATIONS

The results of this study must be interpreted within the context of the study design. We analyzed JTDB data, which, unfortunately, does not

record the indications of REBOA use. Thus, our results could have been different if the REBOA information had contained unrecorded strong survival predictors. However, REBOA use in this study might have been selected because of resource shortages,<sup>12</sup> as this study only included patients who had arrived without a palpable pulse, for whom RT is currently recommended in Japan and at international high-level trauma centers.<sup>7–10,23</sup>

Another limitation is that variables relating to REBOA placement, such as the size of REBOA catheter, position of placement, duration of inflation, procedural complications, and postprocedural response, were not available in the database. Data on time of recognition of cardiac arrest, witness status, presence of bystander CPR, and time of aortic occlusion were also not available in the database. Although the diversity of procedures and lack of well-established survival predictors of OHCA limit the interpretation of our results, we believe our results merit further studies on t-OHCA as a possible indication of REBOA use.

Furthermore, considering that some patients received subsequent RT after REBOA for the repair of thoracic injuries, and REBOA would sometimes follow external cross-clamping of the aorta following RT to help trauma surgeons focusing on the surgical repair of thoracic injury, we included patients who underwent both REBOA and RT, which resulted in dual interventions in this study. However, the subgroup analysis excluding patients treated with both REBOA and RT also identified higher survival to discharge among patients in the REBOA group compared with those in the RT group.

Finally, because this is a retrospective study, our results are not conclusive. Although the association between REBOA and higher survival to discharge was identified in IPW analysis adjusted with injury severity and other survival predictors, residual confounding and unmeasured survival predictors preclude confirming the efficacy of REBOA.

**TABLE 4** Survival to discharge in subgroup analyses

	Survival to discharge, % (95% CI)		OR	95% CI
	REBOA	RT		
Severe chest injury (+)	1.9 (1.0–2.8)	0.6 (0.1–1.1)	3.14	1.23–8.00
Severe chest injury (–)	5.3 (3.2–7.4)	1.0 (0.0–2.0)	5.39	1.85–15.71
Craniotomy (+)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	–	–
Craniotomy (–)	3.0 (2.1–3.9)	0.8 (0.3–1.3)	3.74	1.91–7.34
Laparotomy (+)	12.0 (8.0–16.0)	0.0 (0.0–0.0)	–	–
Laparotomy (–)	0.9 (0.3–1.5)	0.9 (0.4–1.4)	0.93	0.38–2.25
Within-institution REBOA use frequency				
Low (< = 25%)	4.3 (2.5–6.1)	0.8 (0.3–1.3)	5.41	2.53–11.57
Moderate (25%–50%)	3.8 (2.1–5.5)	0.9 (0.0–2.7)	4.26	0.56–32.27
High (50%–75%)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	–	–
Very high (> 75%)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	–	–
REBOA only vs RT only <sup>a</sup>	5.0 (3.5–6.5)	0.9 (0.4–1.4)	6.04	3.08–11.87

Inverse probability weighting analyses were performed in each subgroup. CI, confidence interval; OR, odds ratio; REBOA, resuscitative endovascular balloon occlusion of the aorta; RT, resuscitative thoracotomy.

<sup>a</sup>Patients treated only with REBOA or RT were analyzed.

Additional clinical investigations, such as well-designed prospective studies, are needed to validate our results.

## 5 | DISCUSSION

In this retrospective study, aortic occlusion by REBOA instead of cross-clamping through RT was associated with higher survival to discharge. This relationship was validated with IPW, in which several survival predictors were adjusted. Notably, the observed association was consistent across several sensitivity analyses, suggesting that the results were not dependent on the method of propensity score or the weighting.

Although the reason behind the relationship between REBOA and higher in-hospital survival rate remains inconclusive, several pathophysiological mechanisms could be considered based on previous studies.<sup>15–17,27,28</sup> Some animal studies on cardiac arrest models have shown augmented coronary and cerebral perfusion during CPR by aortic occlusion.<sup>27,28</sup> A retrospective study on 11 patients with traumatic cardiac arrest who had received REBOA during CPR examined arterial blood pressure during closed-chest compressions and found that 8 patients had multiple episodes of return of spontaneous circulation, which may be attributed to increased perfusion pressures generated by REBOA.<sup>15</sup> Another prospective observational study on 22 REBOA cases and 28 RT cases analyzed interruptions of the chest and/or cardiac compressions and, compared with RT, identified fewer interruptions in patients who had received REBOA.<sup>16</sup> Considering these potential benefits of REBOA, we believe that increased coronary perfusion during closed-chest compressions with limited interruptions may have contributed to favorable clinical outcomes in our study.

Clinical characteristics of patients who benefited from REBOA were assessed in the subgroup analyses, which revealed that patients who

required laparotomy had higher survival to discharge after REBOA, whereas those without subsequent laparotomy did not. These findings suggest that REBOA provides only temporary hemostasis and that it always needs to be followed by definitive surgical treatment. It should also be noted that regardless of aortic occlusion method, no patients who underwent craniotomy survived, suggesting that those with severe head injuries may not qualify as candidates for occluding their aortas. Other subgroup analyses considering the frequency of REBOA use within each institution identified REBOA benefits only in hospitals where REBOA was less frequently performed. These findings suggest that patients with t-OHCA do not survive in institutions where resources are extremely limited or standard care is deviated.

Although some patients with t-OHCA would benefit from REBOA, some crucial differences between REBOA and cross-clamping the aorta through RT should be emphasized. Definitive hemostasis can be achieved with simultaneous procedures, such as cardiorrhaphy, aortorrhaphy, and pulmonary resection, in patients who receive RT but not REBOA.<sup>9,12,24,29</sup> In this study, about 40% of patients who had undergone REBOA subsequently received RT to repair their thoracic injuries, although the presence of severe chest injuries did not mitigate the beneficial effects of REBOA. The rapidity of aortic occlusion is another considerable difference between the 2 procedures. Although a longer time to aortic occlusion has been reported in patients treated with REBOA compared with RT,<sup>16,30</sup> the association between REBOA and higher survival to discharge in this study suggests that potential benefits such as fewer pauses in CPR during REBOA compared with cross-clamping the aorta may outweigh the longer time to aortic occlusion by REBOA.<sup>31</sup>

In summary, in patients with t-OHCA, REBOA was associated with improved survival to discharge instead of cross-clamping the aorta through RT. Patients with t-OHCA would therefore be considered potential candidates for REBOA when resources for immediate RT

are limited. Further research is necessary to validate the relationship between REBOA and increased survival to discharge.

## 5.1 | Data statement

The data of this study are available from the Japanese Association for Trauma Surgery and the Japanese Association for Acute Medicine, but restrictions apply to the availability of these data, which were used under license for the current study and so are not publicly available. However, data are available from the authors upon reasonable request and with permission of the Japanese Association for Trauma Surgery and the Japanese Association for Acute Medicine.

## CONFLICT OF INTEREST

The authors have no relevant conflicts of interest to disclose.

## AUTHOR CONTRIBUTIONS

Ryo Yamamoto and Masaru Suzuki designed the study. Yusho Nishida and Katsuya Maeshima performed data collection. Masaru Suzuki and Junichi Sasaki managed quality control. Ryo Yamamoto and Masaru Suzuki performed data analysis, data interpretation, writing, and critical revision. All authors revised the manuscript.

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