Resuscitative Endovascular Balloon Occlusion of the Aorta Improves Cardiac Compression Fraction Versus Resuscitative Thoracotomy in Patients in Traumatic Arrest

William Teeter, MD, MS*; Anna Romagnoli, MD; Philip Wasicek, MD; Peter Hu, PhD; Shiming Yang, PhD; Deborah Stein, MD, MPH; Thomas Scalea, MD; Megan Brenner, MD, MS

*Corresponding Author. E-mail: williamteeter@umm.edu.

Study objective: Resuscitative endovascular balloon occlusion of the aorta (REBOA) is emerging as an alternative to resuscitative thoracotomy for proximal aortic control in select patients with exsanguinating hemorrhage below the diaphragm. The purpose of this study is to compare interruptions in closed chest compression or open chest cardiac massage during REBOA versus resuscitative thoracotomy.

Methods: From May 2014 to December 2016, patients in arrest who received aortic occlusion with REBOA or resuscitative thoracotomy were included. Total cardiac compression time was defined as the total time that closed chest compression was performed for REBOA patients and the total time that closed chest compression (before resuscitative thoracotomy) and open chest cardiac massage (after thoracotomy) were performed for resuscitative thoracotomy patients. Cardiac compression fraction was defined as the time compressions occurred during the entire resuscitation phase. All resuscitations were captured by multiview, time-stamped videography.

Results: Fifty patients with aortic occlusion after arrest were enrolled: 22 REBOA and 28 resuscitative thoracotomy. Most were men (86%) (median age 30.2 years, interquartile range [IQR] 24.9 to 42.3; median Injury Severity Score 27, IQR 16 to 42; neither differed between groups). The median duration of total cardiac compression time was 945 seconds (IQR 697 to 1,357) for REBOA versus 496 seconds (IQR 375 to 933) for resuscitative thoracotomy. During initial resuscitation, compressions occurred 86.5% of the time (SD 9.7%) during resuscitation with REBOA versus 35.7% of the time (SD 16.4%) in patients receiving resuscitative thoracotomy. Cardiac compression fraction improved after open cross clamp in resuscitative thoracotomy patients to 73.2% of the time (SD 18.0%) but remained significantly less than the same period for REBOA (86.7%; SD 9.4%). Mean cardiac compression fraction for REBOA was significantly improved over that for resuscitative thoracotomy (86.2% [SD 9.1%] versus 55.3 [SD 17.1%]; mean difference 31.0%; 95% confidence interval for difference 22.7% to 39.23%; $P<.001$). Median pause in resuscitation related to procedural tasks was 0 seconds (IQR 0 to 13) for REBOA and 148 seconds (IQR 118 to 223) in resuscitative thoracotomy.

Conclusion: Total duration of interruptions of cardiac compressions is shorter for patients receiving REBOA versus resuscitative thoracotomy before and during resuscitation with aortic occlusion. Markers for perfusion during resuscitation must be examined to understand the effects of cardiac compressions and aortic occlusion on patients in arrest because of hemorrhagic shock. [Ann Emerg Med. 2018;■:1-7.]

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INTRODUCTION

Background and Importance

There is increasing evidence that resuscitative endovascular balloon occlusion of the aorta (REBOA) is a feasible alternative to resuscitative thoracotomy with aortic cross clamping for patients without severe intrathoracic hemorrhage.[1] Resuscitative aortic occlusion has been shown to improve cerebral and coronary blood flow during cardiopulmonary resuscitation (CPR).[2-4] In the setting of medical arrest, the quality of CPR, as measured by the cardiac compression fraction, may improve outcomes after CPR,[5] but recently several studies have showed that the timing of initial compressions may affect these outcomes.[6] Recent evidence demonstrates that REBOA is associated with performance times similar to those of resuscitative thoracotomy with respect to time to aortic occlusion.[7]

Editor's Capsule Summary

What is already known on this topic

During traumatic cardiac arrest, aortic occlusion can stop exsanguination and divert blood flow to the heart and brain. Open thoracotomy and resuscitative endovascular balloon occlusion of the aorta (REBOA) are alternative methods to achieve aortic occlusion that have had little direct comparison.

What question this study addressed

This observational study compared interruptions in chest or cardiac compressions during traumatic cardiac arrest from 22 REBOA and 28 thoracotomy cases.

What this study adds to our knowledge

Aortic occlusion is completed approximately 2 minutes earlier with thoracotomy, but interruptions in chest compressions were substantially reduced by REBOA.

How this is relevant to clinical practice

Although slightly slower for achieving aortic occlusion in this cohort, REBOA produces fewer interruptions in other ongoing procedures compared with open thoracotomy.

However, to our knowledge the time required for each procedure and its effect on resuscitation, specifically the cardiac compression fraction, have yet to be examined.

Goals of This Investigation

The purpose of this study was to use real-time videography linked with a high-fidelity, continuous-vital-sign-measurement system during resuscitation of all trauma patients arriving in arrest to a high-volume urban tertiary care trauma center. We hypothesized that REBOA patients would have higher cardiac compression fraction compared with patients receiving resuscitative thoracotomy. The outcomes of this study were chosen to represent resuscitation timing and mechanics only because comparison of patient-oriented outcomes in these 2 biased and heterogenous cohorts is not meaningful.

MATERIALS AND METHODS

Study Design and Setting

The University of Maryland School of Medicine Institutional Review Board approved this prospective, observational study for data collection on May 1, 2014, through December 31, 2016. The R Adams Cowley Shock Trauma Center is a primary adult resource center in Baltimore, MD.

Selection of Participants

We included patients if they arrived to the trauma resuscitation unit in cardiac arrest or developed cardiac arrest shortly after arrival, and underwent either REBOA or resuscitative thoracotomy with aortic cross clamping. Indications for REBOA followed our institutional protocol whereby patients in arrest from hemorrhage below the diaphragm received REBOA,[8] whereas those in arrest from intrathoracic hemorrhage received resuscitative thoracotomy as a standard of diagnosing and potentially treating intrathoracic hemorrhage. This protocol follows Advanced Trauma Life Support (ATLS) guidelines: chest radiograph and extended focused assessment with sonography for trauma to determine source of suspected exsanguination. If clinicians suspected a supradiaphragmatic source according to those results, then the patient received resuscitative thoracotomy; otherwise, a source below the diaphragm was likely and the patient received REBOA. We excluded patients if they were younger than 18 years, received both procedures, or did not receive videographic recording of adequate quality or continuous vital signs measurements.

Interventions

All patients arriving to the University of Maryland Shock Trauma Center are recorded by 24-hour, multiview, real-time videography. We synchronized these recordings with simultaneous time stamping. We identified patients by procedure type and resuscitation videos downloaded for review. Two physician reviewers who were not blinded to the study outcomes, but were blinded to each other's results, reviewed the videos independently. A senior physician evaluated all results and discrepancies. Each reviewer recorded events according to a predetermined list of significant resuscitation events.

Methods of Measurement and Outcome Measures

We assigned timing points based on patient arrival, time of aortic occlusion by balloon or open cross clamp, return of spontaneous circulation as determined by return of measurable blood pressure, and cessation of efforts. We began at admission and ended at official time of death or a period of return of spontaneous circulation that resulted in the clinician's decision to transfer the patient out of the video-study area to further diagnostic or treatment modalities. We calculated cardiac compression fraction as the total number of seconds identified on video review that the patient received either closed chest compression or open chest cardiac massage divided by the total resuscitation time. We also calculated cardiac compression fraction values before or after aortic occlusion. We correlated periods of return of spontaneous circulation with bedside Advanced Cardiac Life Support (ACLS) documentation. Pauses in resuscitation that met ACLS or ATLS guidelines, including use of bedside ultrasonography, pulse checks, or change of personnel providing compressions, were classified as nonprocedural pauses. Any pauses in resuscitation because of REBOA or resuscitative thoracotomy were classified as procedure-related pauses. We defined total cardiac compression time as the total duration in seconds that either CPR or open chest cardiac massage was performed during resuscitation.

Primary Data Analysis

We used Pearson's χ^2 or Fischer's exact test to compare proportions, unpaired *t* test to compare percentages, and the Mann-Whitney test for all nonparametric comparisons. We tested normality of distribution for continuous variables with the Agostino-Pearson's normality test. We report normally distributed values as mean (SD), whereas non-normally distributed values are reported as median (interquartile range [IQR]). We considered $P<.05$ to be statistically significant. We used GraphPad Prism (version 7.03; GraphPad, La Jolla, CA) for all summary statistics and statistical testing.

RESULTS

During the study, there were 22 REBOA procedures and 28 resuscitative thoracotomy procedures. Most patients were men, 43 of 50 (86%), with similar proportions in the 2 groups (REBOA 17/22 [77.3%] and resuscitative thoracotomy 26/28 [92.9%]). Median age for all patients was 30.2 years (IQR 24.9 to 42.3; REBOA 27.1 years [IQR 24.4 to 50.7] and resuscitative thoracotomy 34.1 years [IQR 25.3 to 40.8]). Blunt injuries accounted for 10.7% of the resuscitative thoracotomy group and 72.7% of the REBOA group. Median Injury Severity Score was 27 (IQR 16 to 42) for all patients, with a score of 34 (IQR 18 to 41) for the REBOA group and 22.5 (IQR 12 to 42) for the resuscitative thoracotomy group (Table 1). Two patients in the REBOA group survived to discharge, with no other survivors. There was an additional trend toward survival past the emergency department (ED) for REBOA (9/22; 40.9%) compared with resuscitative thoracotomy (3/28 [10.7%]; difference 30.2%; 95% confidence interval [CI] 3.3% to 54.0%).

The total cardiac compression time, cardiac compression fraction, and timing data for both groups are summarized in Table 2. Each patient's resuscitation is represented visually in the Figure. The median total cardiac compression time for each group was 945 seconds (IQR 697 to 1,357) for REBOA versus 496 seconds (IQR 375 to 933) for resuscitative thoracotomy, whereas the median total time for resuscitation was 1,051 seconds (IQR 816 to 1,532) and 913 seconds (IQR 758 to 1,631), respectively. Cardiac compression fraction for total length of resuscitation for REBOA was significantly improved over that for resuscitative thoracotomy (86.2% [SD 9.1%] versus 55.3% [SD 17.1%]). The cardiac compression fraction before aortic occlusion in the resuscitative thoracotomy group was 35.7% (SD 16.4%), whereas that for the REBOA group was 86.5% (SD 9.7%). Cardiac compression fraction improved for resuscitative thoracotomy after aortic occlusion to 73.2% (SD 18.0%), but remained significantly less than that for the same period for REBOA (86.7%; SD 9.4%). Comparisons for paired differences between cardiac compression fraction before and after aortic occlusion for REBOA showed no difference (–0.23; 95% CI –4.6 to 4.4), whereas cardiac compression fraction increased significantly for resuscitative thoracotomy (37.5; 95% CI 26.0 to 46.1) after aortic occlusion. Pauses in resuscitation related to the procedure itself were significantly higher in the resuscitative thoracotomy group as opposed to the REBOA group (Table 2). Pauses not related to each procedure were not significantly different but trended higher in the resuscitative thoracotomy group (218 seconds; IQR 122 to 287]) than the REBOA group (131 seconds; IQR 60 to 255).

Median time to aortic occlusion was 577 seconds (IQR 377 to 815) in the REBOA group and 451 seconds (IQR 275 to 648) in the resuscitative thoracotomy group (difference 126; 95% CI –34 to 291 seconds). The cardiac compression fraction was greater than 60% in 21 of 22 REBOA patients (95.5%) compared with only 2 of 28 resuscitative thoracotomy patients (7.1%), with only an additional 3 patients' cardiac compression fraction falling short of 80% in the REBOA group versus all in the resuscitative thoracotomy group (18/22 versus 0/28; difference 88%; 95% CI 61.3% to 95.6%).

Table 1. Baseline characteristics of study populations.

Characteristics	REBOA (n=22)	RT (n=28)
Age, median (IQR), y	27.1 (24.4–50.7)	34.1 (25.3–40.8)
Men, %	77.3	92.9
Blunt injury, %	72.7	10.7
ISS, median (IQR)	34 (18–41)	22.5 (12–42)

RT, Resuscitative thoracotomy; *ISS*, Injury Severity Score.

Table 2. Comparison of total cardiac compression time, cardiac compression fraction, and other timing metrics for REBOA and thoracotomy.

	REBOA (n=22)				RT (n=28)					
	Median	IQR	Min	Max	Median	IQR	Min	Max	Median Difference	95% CI
Total cardiac compression time, s	945	697 to 1,357	343	1,822	496	375 to 933	52	1,952	449	127 to 613
Total resuscitation time, s	1,051	816 to 1,532	426	2,156	913	758 to 1,631	221	2,381	138	−226 to 329
CPR duration before AO, s	500	314 to 675	89	1,301	173	69 to 259	31	738	327	185 to 448
Time to AO, s	577	377 to 815	94	1,370	451	275 to 648	169	1,655	126	−34 to 291
Procedural pause in CC, s	0	0 to 13	0	99	148	118 to 223	63	410	148	119 to 192
Nonprocedural pause in CC, s	131	60 to 255	21	501	218	41 to 287	41	683	87	−136 to 12
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean difference	95% CI
Total CCF, %	86.2	9.1	69.3	97.7	55.3	17.1	23.5	83.5	31.0	27.7 to 39.2
CCF before AO, %	86.5	9.7	57.5	99.1	35.7	16.4	10.5	74.0	50.9	42.8 to 58.9
CCF after AO, %	86.7	9.4	63.8	100.0	73.2	18.0	39.9	95.4	13.6	4.4 to 22.8

Min, Minimum; *max*, maximum; *AO*, aortic occlusion; *CC*, chest compressions; *CCF*, cardiac compression fraction.

LIMITATIONS

This study was neither designed nor powered to comment on patient outcomes. Our institution has implemented a protocol to triage patients into either resuscitative thoracotomy or REBOA[8] according to ATLS guidelines including chest radiograph, extended focused assessment with sonography for trauma, and presentation physiology. This creates an inherent selection bias for penetrating injuries to the chest to be selected for resuscitative thoracotomy. The proportion of blunt injuries in each group suggests this expected selection bias, leading to heterogeneity between groups unfit for comparison of patient-oriented outcomes. Furthermore, the novelty of the research precluded any meaningful power calculations. Last, the lack of blinding of reviewers also allows observer bias.

DISCUSSION

The American Heart Association recommends a minimum cardiac compression fraction of 60% for the resuscitation of nontraumatic arrest, with an expert panel calling for a minimum of 80%.[9] Multiple studies have shown this to improve patient outcomes after ventricular fibrillation and ventricular tachycardia and medical arrest.[10,11] However, the literature remains unclear, containing several discrepant studies showing mixed results, indicating that cardiac compression fraction should not be considered in isolation when quality of CPR is evaluated, and remains only a part of predicting survival after cardiac arrest.[6] This is likely as true for patients in traumatic arrest, but remains poorly studied. However, recent evidence from 2 large retrospective cohort studies has suggested that, compared with open chest compression, closed chest compressions are associated with improved survival for patients experiencing blunt trauma.[12,13]

In this study, closed chest compressions were performed more often versus open cardiac massage. The cardiac compression fraction as a percentage of total resuscitation time of all patients taken together as one was 84.1% for REBOA and 56.8% for resuscitative thoracotomy. In addition, resuscitative thoracotomy had a wider range of cardiac compression fraction as opposed to REBOA, suggesting that although high cardiac compression fractions are possible in both resuscitative thoracotomy and REBOA, they are not as likely in resuscitative thoracotomy in our population. The cause of the variation in cardiac compression fraction for resuscitative thoracotomy before aortic occlusion is directly related to pauses in resuscitation related to the procedure itself. If these procedural pauses were included in the calculation of cardiac compression fraction as if CPR or open chest cardiac massage were being performed during these times, an additional 21 patients

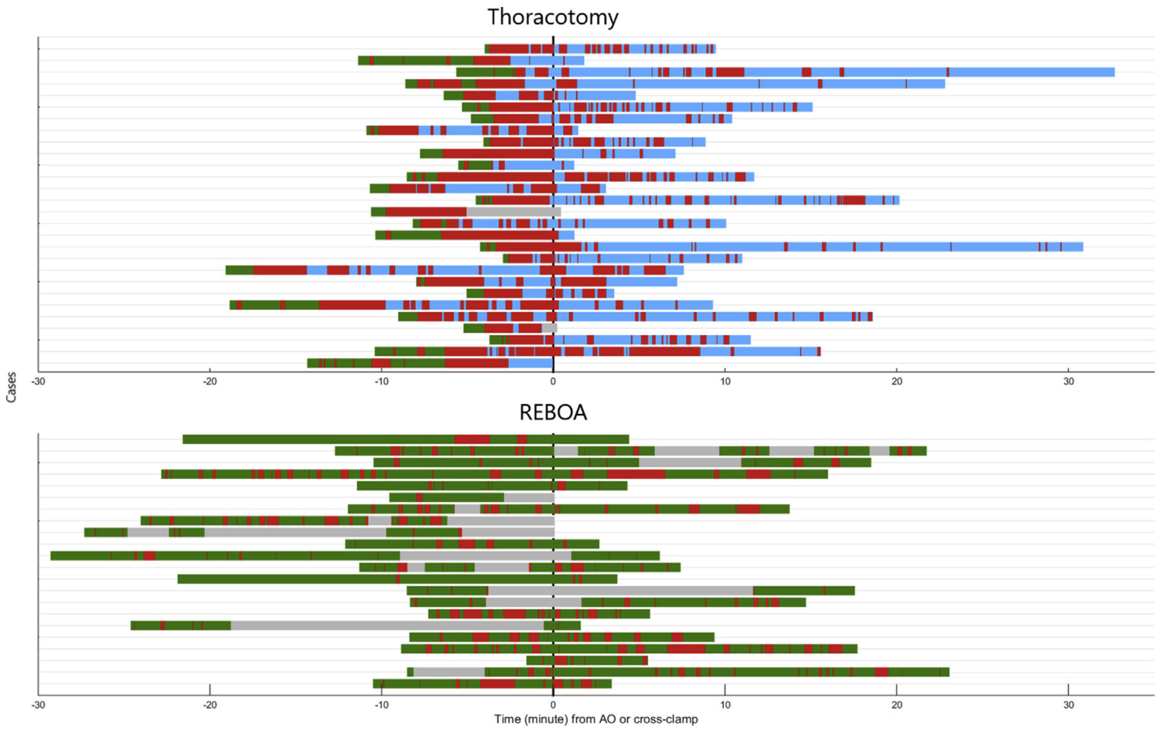

Figure. Periods of closed chest compression (green), open chest cardiac massage (blue), pauses (red), and return of spontaneous circulation (gray) for thoracotomy and REBOA.

receiving resuscitative thoracotomy would have cardiac compression fraction greater than 60% (23/28; 82.1%), which is not significantly different from that in the REBOA group, suggesting that the time spent in gaining access to the thoracic cavity is responsible for the lack of adequate compression fraction in the initial resuscitation before aortic occlusion.

The literature is unclear on the benefits of closed chest compression versus open chest cardiac massage in the setting of trauma. One study suggested that closed chest compression performed in the setting of cardiac arrest after truncal trauma was of no benefit,[14] yet all patients were found to have "major cardiovascular disruption" at resuscitative thoracotomy. Further work describing the hemodynamic effects in swine[15] and humans[16] suggested that open chest cardiac massage improved mean arterial pressure and cardiac output compared with closed chest compression. However, recent evidence suggested that closed chest compression was similar to open chest cardiac massage when end tidal carbon dioxide was used as a measure of resuscitation quality.[17] We performed sensitivity analysis of the data to account for variations in time between successful evisceration of the heart and start of aortic occlusion. Instead of using the aortic occlusion time as a point of justification, the time of first open chest cardiac massage was used for resuscitative thoracotomy to compare cardiac compression fraction for CPR against subsequent cardiac compression fraction, and the gap between the 2 methods of cardiac compression widened further (resuscitative thoracotomy 29.4 [SD 18.9%]), suggesting that even the possible benefits of open chest cardiac massage may be reduced by the pause related to resuscitative thoracotomy performance. Quality of resuscitation using these techniques must be examined to understand the effects of cardiac compressions and aortic occlusion on patients in traumatic cardiac arrest caused by hemorrhagic shock.

Although our data demonstrates time to AO was longer with REBOA, we noted that time to AO decreased when we adopted the wire-free ER-REBOA catheter in 2016. A multi-institutional trial demonstrated similar time to AO between REBOA and RT groups.[18] More recent data from our institution shows time to AO using older technology is longer than time to AO with the newer device.[7] If we exclude patients in this cohort who received REBOA with the older devices ($n = 8$), median time to AO with REBOA was 427 seconds (IQR 275 to 776) versus 451 seconds with RT (IQR 275 to 648) (difference 24 seconds, CI 191 to 173).

The reasons for reduced cardiac compression fraction after aortic occlusion in the resuscitative thoracotomy patients compared with REBOA patients are not as clear. Although 75% (18/24) of the resuscitative thoracotomy resuscitations improved to cardiac compression fraction greater than 60% after aortic occlusion (REBOA 100%), the actual percentage of cardiac compression fraction remained significantly less than that observed for the REBOA patients (Table 2). One observation that may explain this difference was that the majority of closed chest compressions (for REBOA) were performed by nursing staff, whereas open cardiac massage was performed almost exclusively by physicians, including sometimes the physician identified as the team leader. This suggests that cardiac massage should also be performed by trained staff not directly associated with decisionmaking during resuscitation of these extremely ill patients, which was the case with REBOA. This is inherently fraught with training and exposure concerns if open chest cardiac massage is to be performed by staff.

Although the benefits of REBOA on CPR timing are clear, the potential risks of each procedure remain a point of discussion in the literature, and the difference in risk between the 2 procedures to both the patient and providers is decidedly not similar. Although to our knowledge no conclusive studies have been performed on the subject, it can be assumed that a minimally invasive procedure associated with percutaneous access of a peripheral artery would be less morbid than surgical exposure of the entire thorax involving multiple surgical planes and instruments. Our institutional REBOA experience has not yielded any occupational hazard with REBOA,[8] but the risks of thoracotomy are well documented in the literature.[19] Thoracotomy also imports significant risk on both medical and economic levels to the providers themselves in the form of blood-borne pathogen transmission.[20]

The rarity of the resuscitative thoracotomy procedure in most emergency medicine training programs prevents many providers from becoming facile and competent in either the resuscitative thoracotomy or initial treatment of intrathoracic injuries. Although REBOA may be even more rare, its component tasks (arterial puncture, wire manipulation, and advancement of endovascular device within a sheath) are not. In fact, recent evidence suggests that REBOA may be performed quickly, even in the setting of traumatic arrest, by ED providers in some populations.[21] Furthermore, there is increasing acceptance and competence among ED providers using ultrasonography for emergency vascular access.[22] With these skills, it is possible that endovascular damage control resuscitation procedures, such as REBOA, will become part of the armamentarium of ED providers, perhaps obviating the need for resuscitative thoracotomy in patients in arrest from hemorrhage below the diaphragm.

Total duration of interruptions of cardiac compressions is shorter for patients receiving REBOA versus resuscitative thoracotomy before and during resuscitation with aortic occlusion. Markers for perfusion during resuscitation must be examined to understand the effects of cardiac compressions and aortic occlusion on patients in arrest because of hemorrhagic shock.

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Author affiliations: From the Department of Trauma and Surgical Critical Care, University of Maryland Medical System/R Adams Cowley Shock Trauma, Baltimore, MD (Teeter, Romagnoli, Wasicek, Hu, Yang, Stein, Scalea, Brenner); and the Shock Trauma and Anesthesiology Research Center, University of Maryland, School of Medicine, Baltimore, MD (Hu, Yang).

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