


Intraoperative REBOA: an analysis of the American Association for the Surgery of Trauma AORTA registry

Michael A Vella,¹ Ryan Peter Dumas,^{1,2} Joseph DuBose,³ Jonathan Morrison ,³ Thomas Scalea,³ Laura Moore,⁴ Jeanette Podbielski,⁴ Kenji Inaba,⁵ Alice Piccinini,⁵ David S Kauvar,⁶ Valorie L Baggenstoss,⁶ Chance Spalding,⁷ Charles Fox,⁸ Ernest E Moore,⁸ Jeremy W Cannon,^{1,9} The AAST AORTA Study Group

► Additional material is published online only. To view please visit the journal online (<http://dx.doi.org/10.1136/tsaco-2019-000340>).

For numbered affiliations see end of article.

Correspondence to

Dr Michael A Vella, University of Rochester School of Medicine and Dentistry, 601 Elmwood Avenue, Box SURG, Rochester, NY 14642, USA; mavella2@gmail.com

These data were presented in poster format at the 77th Annual Meeting of the American Association for the Surgery of Trauma, September 26–29, 2018 in San Diego, California.

Received 3 June 2019
Revised 8 August 2019
Accepted 10 August 2019

ABSTRACT

Background Resuscitative endovascular balloon occlusion of the aorta (REBOA) is a less-invasive technique for aortic occlusion (AO). Commonly performed in the emergency department (ED), the role of intraoperative placement is less defined. We hypothesized that operating room (OR) placement is associated with increased in-hospital mortality.

Methods The American Association for the Surgery of Trauma AORTA registry was used to identify patients undergoing REBOA. Injury characteristics and outcomes data were compared between OR and ED groups. The primary outcome was in-hospital mortality; secondary outcomes included total AO time, transfusion requirements, and acute kidney injury.

Results Location and timing of catheter insertion were available for 305 of 321 (95%) subjects. 58 patients underwent REBOA in the OR (19%). There were no differences with respect to sex, admission lactate, and Injury Severity Score. The OR group was younger (33 years vs. 41 years, $p=0.01$) and with more penetrating injuries (36% vs. 15%, $p<0.001$). There were significant differences with respect to admission physiology. Time from admission to AO was longer in the OR group (75 minutes vs. 23 minutes, $p<0.001$) as was time to definitive hemostasis (116 minutes vs. 79 minutes, $p=0.01$). Unadjusted mortality was lower in the OR group (36.2% vs. 68.8%, $p<0.001$). There were no differences in secondary outcomes. After controlling for covariates, there was no association between insertion location and in-hospital mortality (OR 1.8, 95% CI 0.30 to 11.50).

Discussion OR REBOA placement is common and generally employed in patients with more stable admission physiology. OR placement was not associated with increased in-hospital mortality despite longer times to AO and definite hemostasis when compared with catheters placed in the ED.

Level of evidence IV; therapeutic/care management.

BACKGROUND

Hemorrhage remains the most common cause of preventable death in trauma patients and the second most common cause of all trauma-related deaths.^{1,2} In this population, non-compressible torso hemorrhage accounts for 60% to 70% of deaths^{3,4} due to severe hemorrhage from major vessels or solid organs in the chest, abdomen, or pelvis.⁴ Rapid hemorrhage control is essential in these situations,⁵

as delayed control is associated with increased mortality.^{6,7}

In select patients with non-compressible torso hemorrhage, resuscitative endovascular balloon occlusion of the aorta (REBOA) can be used as a bridge to definitive hemostasis.^{8–12} This approach affords temporary occlusion of the thoracic or infrarenal aorta with a balloon catheter inserted through the common femoral artery.^{13,14} As such, it represents a rapid, less-invasive alternative to open aortic occlusion (AO).

Because the median time to death from severe hemorrhage is approximately 1 hour,¹⁵ there is now appropriate emphasis on shortening the time to hemostasis as much as possible.⁵ Currently, the majority of REBOA catheters are placed either in the emergency department (ED) or the operating room (OR).¹⁶ ED placement may afford more rapid time to temporary hemostasis or potentially delay definitive hemostasis if placed unnecessarily. Placement in the OR may delay temporary hemostasis, leading to increased mortality. As such, the benefits of ED REBOA insertion as compared with perioperative insertion in the OR have not been explored. We sought to characterize the use of intraoperative REBOA and hypothesized that insertion in the OR is associated with increased in-hospital mortality.

METHODS

The American Association for the Surgery of Trauma (AAST) AORTA registry prospectively identifies trauma patients undergoing open and endovascular AO at 29 centers. Using the AORTA registry, we performed a retrospective review of all patients who underwent endovascular occlusion of the aorta from January 2013 to December 2017. Collected variables included demographic information, mechanism of injury, blood transfusion requirements, admission physiology, time to successful AO, duration of occlusion, time to definitive hemorrhage control, and location of occlusion. Our primary endpoint was in-hospital mortality, and secondary outcomes included total AO time, transfusion requirements, and development of acute kidney injury.

A univariate analysis for non-parametric continuous variables was analyzed for skewness using the Shapiro-Wilk test of normality. Values <0.05 were considered skewed and were represented as medians and IQRs. Mann-Whitney U test was used

© Author(s) (or their employer(s)) 2019. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

To cite: Vella MA, Dumas RP, DuBose J, et al. *Trauma Surg Acute Care Open* 2019;4:e000340.

to compare medians between groups, and Student's t-test was used for normally distributed data. Categorical values were represented as n (%). A χ^2 analysis was performed to compare categorical values. Statistical significance was set at $p < 0.05$.

To investigate the relationships between REBOA occlusion location (OR vs. ED) and in-hospital mortality, we first performed univariate regression between candidate variables and inpatient mortality. Each candidate variable with $p < 0.2$ was then used in a multivariable regression model on the outcome of in-hospital mortality. To adhere to the principle of parsimony and avoid overfitting, we removed variables from the final multivariable model that did not contribute to model discrimination. To assess the adequacy of our sample size, we performed a post-hoc CI analysis with the minimal clinically important difference in mortality set at 10%.¹⁷ Stata V.14.2 was used for all statistical analyses.

RESULTS

Endovascular AO was performed on 321 patients during the study period. Data on the location and timing of insertion were available for 305 (95%) patients. Fifty-eight (19%) patients underwent REBOA in the OR compared with 247 (81%) in the ED. Thirty-six (64%) catheters were placed in aortic zone I in the OR versus 164 (69%) placed in zone I in the ED ($p = 0.60$). There were no differences between groups with respect to sex, admission lactate, and Injury Severity Score (ISS). However, patients who underwent REBOA in the OR were younger (33 years vs. 41 years, $p = 0.01$) and were more likely to have a penetrating mechanism (36% vs. 15%, $p < 0.001$). There were significant differences with respect to admission physiology; patients in the OR group were more likely to present with higher admission systolic blood pressure (SBP) (110 mm Hg vs. 80 mm Hg, $p < 0.001$), Glasgow Coma Scale (GCS) score (7 vs. 3, $p < 0.001$), and heart rate (HR) (114 vs. 101 beats per minute, $p = 0.04$). Patients in the OR group were less likely to have cardiopulmonary resuscitation (CPR) in progress at admission (3.4% vs. 32.5%, $p < 0.001$). Time from admission to AO was longer in the OR group (75 minutes vs. 23 minutes, $p < 0.001$) as was time to definitive hemorrhage control (116 minutes vs. 79 minutes, $p = 0.01$) (table 1).

Unadjusted in-hospital mortality was lower in the OR group (36.2% vs. 68.8%, $p < 0.001$), but there were no differences in transfusion requirements or acute kidney injury. Total AO time was also similar between the OR and ED groups (33 minutes vs. 30 minutes, $p = 0.61$). On univariate analysis, time to AO, admission SBP, GCS score, HR, ISS, age, lactate, CPR at admission, and location of REBOA insertion were all associated with the outcome of in-hospital mortality (table 2) and were included in a multivariate logistic regression model.

After controlling for these covariates, there was no independent association between insertion location and in-hospital mortality (OR 1.8, 95% CI 0.30 to 11.50) (table 3).

When time to definitive hemorrhage control was added to the model, the number of observations decreased by 30% (106 to 74). In this smaller model, there was again no association between REBOA insertion location (ED vs. OR) and in-hospital mortality, and time to definitive hemorrhage control was not associated with in-hospital mortality when controlling for the other covariates (online supplementary file 1).

CI analysis demonstrated that a larger sample size would not have identified any clinically significant increase in mortality with OR placement (online supplementary file 2).

Table 1 Characteristics of patients undergoing OR vs. ED REBOA placement

	Total (n=305)	OR REBOA (n=58)	ED REBOA (n=247)	P value
Age	39 (26–57)	32.5 (22–51)	40.5 (27–58)	0.01
Sex				0.92
Male	233 (76.4)	44 (75.8)	189 (76.5)	
Female	72 (23.6)	14 (24.2)	58 (23.5)	
Mechanism				<0.001
Penetrating	59 (19.3)	21 (36.3)	38 (15.4)	
Blunt	243 (79.6)	37 (63.7)	206 (83.4)	
ISS		34 (25–42)	34 (25–45)	0.38
Admission SBP	82 (49–114)	110 (80–130)	80 (0–111)	<0.001
Admission HR	106 (69–130)	114 (92–132)	101 (52–129)	0.04
Admission GCS score	3 (3–13)	7 (3–15)	3 (3–9)	<0.001
Admission lactate	8.2 (5–11.8)	6.5 (3.9–10.8)	8.2 (5.2–12.1)	0.05
Prehospital CPR	89 (29.1)	2 (3.4)	87 (35.2)	<0.001
Time from admission to AO (min)	25 (15–46)	75 (36–110)	23 (14–27)	<0.001
Time to definitive hemorrhage control	91 (53–165)	116 (78–172)	79 (48–155)	0.01
Occlusion time (min)	32 (12.5–66)	33 (11–67)	30 (15–63)	0.61
pRBC (units)	12 (6–25)	16 (8–28)	12 (5–22)	0.06
Acute kidney injury	57 (18.7)	10 (17.2)	47 (19.0)	0.75
Mortality	191 (62.6)	21 (36.2)	170 (68.8)	<0.001

Data for non-parametric continuous variables expressed as median (IQR); categorical values expressed as n (%).

AO, aortic occlusion; CPR, cardiopulmonary resuscitation; ED, emergency department; GCS, Glasgow Coma Scale; HR, heart rate; ISS, Injury Severity Score; OR, operating room; pRBC, packed red blood cells; REBOA, resuscitative endovascular balloon occlusion of the aorta; SBP, systolic blood pressure.

DISCUSSION

In this analysis of the AORTA registry, we examined the use of intraoperative REBOA and characterized the relationship between REBOA placement location and mortality. We found that REBOA placement in the OR was not associated with increased in-hospital mortality in similarly injured patients. Interestingly, the total AO time was similar between the ED and OR groups despite longer time to definitive hemorrhage control in the OR group, and there was no difference in acute kidney injury as a marker of end-organ malperfusion.

Our study is the first to specifically characterize the use of OR REBOA and compare outcomes between ER and OR REBOA placement. Almost 20% of REBOA catheters in this analysis of

Table 2 Univariate analysis on the outcome of in-hospital mortality

	OR	95% CI	P value
Admission time to successful AO	0.98	0.981 to 0.996	0.002
Admission GCS score	0.78	0.743 to 0.834	<0.001
Admission HR	0.98	0.984 to 0.995	<0.001
Admission SBP	0.98	0.984 to 0.995	<0.001
ISS	1.02	1.006 to 1.045	0.009
Age	1.02	1.004 to 1.033	0.013
Admission lactate	1.1	1.034 to 1.175	0.003
CPR	9.3	4.064 to 21.189	<0.001
Location of AO (operating room)	0.53	0.393 to 0.737	<0.001

AO, aortic occlusion; CPR, cardiopulmonary resuscitation; GCS, Glasgow Coma Scale; HR, heart rate; ISS, Injury Severity Score; SBP, systolic blood pressure.

Table 3 Multivariate logistic regression analysis on the outcome of in-hospital mortality

	OR	95% CI	P value
Admission time to successful AO	1.00	0.981 to 1.021	0.921
Admission GCS score	0.80	0.720 to 0.900	<0.001
Admission HR	1.01	0.996 to 1.028	0.158
Admission SBP	0.99	0.980 to 1.012	0.627
ISS	1.05	1.006 to 1.090	0.025
Age	1.06	1.021 to 1.101	0.002
Admission lactate	1.08	0.978 to 1.208	0.123
CPR	10.16	1.440 to 71.745	0.02
Location of AO (operating room)	1.8	0.295 to 11.498	0.513

Number of observations: 106.

AO, aortic occlusion; CPR, cardiopulmonary resuscitation; GCS, Glasgow Coma Scale; HR, heart rate; ISS, Injury Severity Score; SBP, systolic blood pressure.

the registry were placed in the OR, compared with 26% of catheters in a 2016 study using the same registry.¹⁶ Similar to this analysis, using the Aortic Balloon Occlusion Trauma Registry, which identifies REBOA patients from 13 hospitals and six countries across the world, Sadeghi *et al*¹⁸ found that 16% of catheters were placed in the OR and an additional 16% were placed in a hybrid-type setting.

REBOA use outside of the ED for non-trauma indications has been described.^{19–22} Studies that have evaluated the use of REBOA in non-trauma and combined trauma/non-trauma settings have noted a higher OR placement rate.^{9,23} In one study with a total of 11 patients undergoing REBOA placement, most commonly for ruptured visceral aneurysms and massive upper gastrointestinal bleeding, 82% of devices were placed in the OR.²³ The authors of that study found OR placement particularly helpful in patients with “hostile” abdomens.

The importance of rapid hemorrhage control has been well established in the trauma literature. Mortality in hypotensive trauma patients remains high and occurs early after presentation. Harvin *et al*²⁴ found that hypotensive trauma patients requiring emergent laparotomy (within 90 minutes of admission) had a 46% mortality; 65% of those deaths were related to hemorrhage. In another study looking at trauma deaths within 4 hours of admission, 50% of patients died within the first hour.¹⁵ In our study, OR placement was associated with longer time to AO (75 minutes vs. 23 minutes), although location of placement and time to AO were not associated with increased in-hospital mortality after controlling for admission physiology and GCS score. This is in contrast to earlier studies that have shown an association between increased time to hemorrhage control and mortality. Meizoso *et al*⁶ found that patients with hypotension with torso gunshot wounds, the majority of which were abdominal, had higher mortality if they arrived in the OR after 10 minutes; cumulative 50% mortality was at 16 minutes. Clarke *et al*⁷ found that hypotensive trauma patients with abdominal injuries requiring laparotomy had a 1% increase in the probability of death for every 3 minutes spent in the ED. Prolonged prehospital transfer times have also been associated with increased mortality in patients with torso injuries.²⁵ Our results could differ from those above because patients in the OR group were not hypotensive on arrival, although we attempted to control for this in our regression analysis. It is apparent that REBOA may be used according to patient physiology regardless of location.

None of the aforementioned studies included patients who underwent REBOA, and the effects of early temporary control

with balloon occlusion on outcomes prior to definitive operative intervention are less clear. Placement of REBOA catheters can take time, with one study showing a median time from procedure start to zone I occlusion of 474 seconds (7.9 minutes), compared with 317 seconds (5.3 minutes) for open AO.²⁶ Other studies have shown shorter open procedural times of <4 minutes.²⁷ Although the clinical significance of this time delay is unclear, any benefits of early temporary hemorrhage control with REBOA must be weighed against potential delays in definitive operative intervention especially if the REBOA procedure is challenging and/or unsuccessful. This may be particularly true of patients not truly in extremis.²⁸ One study has shown an association between longer times to the arterial access phase of REBOA placement and mortality.²⁹ Our results showed that time to definitive hemorrhage control was longer in patients who underwent OR placement, probably because these patients were stable in the ED. It can be assumed that catheter placement would not delay definitive control if placed during induction of anesthesia or even during the incision. Perhaps REBOA should be placed in the ED for “non-responders” but can be reserved for the OR in those with ongoing torso hemorrhage who initially respond to resuscitation measures.

Duration of AO may be another factor that differs between location of REBOA placement. Increased time of balloon occlusion has been associated with increased inflammatory mediators, lactate levels, renal dysfunction, and liver necrosis in animal models.^{30,31} Saito *et al*³² showed that the mean duration of AO was shorter in survivors after REBOA placement (21 minutes vs. 35 minutes), although there are many possible explanations for this finding. In our study, the total time of occlusion was similar in the ED and OR groups. This is a surprising finding, as one would expect longer occlusion times for balloons deployed in the ED. One possible explanation is that clinicians are too aggressive in placing catheters in the ED in patients who may not actually require the procedure or may be placing catheters prophylactically without initial inflation of the balloon. In general, it is recommended that zone I occlusion not be performed if time to operative intervention is likely to exceed 15 minutes.³³ We did not find a difference between groups with respect to acute kidney injury, a surrogate of end-organ malperfusion during AO.

We acknowledge the limitations of this study. Although the AAST AORTA registry prospectively captures patients undergoing REBOA placement, data are retrospectively entered into the database and suffer from inherent limitations regarding missing data and time accuracy. In addition, there are factors that influence the decision to perform REBOA and placement location that are not captured in the registry, such as rapid changes in clinical condition, exact indications for placement (ie, transient responder vs. non-responder), provider judgment and experience, initial physiology and injury pattern, and availability of ORs or interventional suites. Full capture of the physiologic response to resuscitation or further decompensation is beyond the scope of the database. Differences in the outcomes related to location of REBOA placement could suffer from selection or survival bias. We attempted to mitigate some of this bias by controlling for the effects of admission physiology and GCS score in our logistic regression model.

CONCLUSIONS

Placement of REBOA catheters in the OR is relatively common and does not appear to be associated with increased in-hospital mortality despite longer times to AO and definite hemostasis when compared with catheters placed in the ED. These findings could be related to the complex interplay between time to temporary versus

definitive hemorrhage control. Future studies are needed to further elucidate the timeframe in which REBOA is most effective.

Author affiliations

¹Division of Traumatology, Surgical Critical Care and Emergency Surgery, Perelman School of Medicine at the University of Pennsylvania, Philadelphia, Pennsylvania, USA

²Division of General and Acute Care Surgery, University of Texas Southwestern Medical Center, Dallas, Texas, USA

³R Adams Cowley Shock Trauma Center, University of Maryland Medical Center, Baltimore, Maryland, USA

⁴Division of Trauma and Surgical Critical Care, University of Texas, Houston, Texas, USA

⁵Division of Surgical Critical Care and Trauma, Los Angeles County + University of Southern California Hospital, Los Angeles, California, USA

⁶Division of Trauma and Surgical Critical Care, San Antonio Military Medical Center/US Army Institute of Surgical Research, San Antonio, Texas, USA

⁷Department of Surgery, Grant Medical Center, Columbus, Ohio, USA

⁸Department of Surgery, Denver Health Medical Center, Denver, Colorado, USA

⁹Department of Surgery, Uniformed Services University of the Health Sciences, Bethesda, Maryland, USA

Collaborators AAST AORTA Study Group: Jonny Morrison, MD, PhD; Thomas M. Scalea, MD University of Maryland / R Adams Cowley Shock Trauma Center Baltimore, MD, USA Laura J. Moore, MD, FACS; Jeanette M Podbielski, RN, CCRP; John B. Holcomb, MD; University of Texas Health Sciences Center—Houston Houston, TX, USA Kenji Inaba, MD; Alice Piccinini, MD Los Angeles County + University of Southern California Hospital Los Angeles, CA, USA David S. Kauvar, MD, FACS; Valorie L. Baggensstoss, MSN, RN; Catherine Rauschendorfer BSN, RN San Antonio Military Medical Center / US Army Institute of Surgical Research San Antonio, TX, USA Jeremy Cannon, MD; Mark Seamon, MD; Ryan Dumas, MD; Michael Vella, MD; Jessica Guzman University of Pennsylvania Philadelphia, PA, USA Chance Spalding, DO, PhD; Timothy W. Wolff, DO Ohio Health Columbus, Ohio, USA Chuck Fox, MD; Ernest Moore, MD Denver Health and Hospital Authority Denver, CO USA David Turay, MD; Cassra N. Arbabi, MD; Xian Luo-Owen, PhD Loma Linda University Medical Center Loma Linda, CA, USA David Skarupa, MD; Jennifer A. Mull, RN, CCRP; Joannis Baez Gonzalez University of Florida – Jacksonville Jacksonville, FL, USA Joseph Ibrahim, MD; Karen Safcsak RN, BSN Orlando Regional Medical Center Orlando, FL, USA Stephanie Gordy, MD; Michael Long, MD Ben Taub General Hospital / Baylor College of Medicine Houston, TX, USA Andrew W. Kirkpatrick, MD; Chad G. Ball, MD; Zhengwen Xiao, MD, MSc, PhD Foothills Medical Centre Calgary, Alberta, Canada Elizabeth Daur, MD Temple University Philadelphia, PA, USA Jennifer Knight, MD; Nicole Cornell, BS, MS West Virginia University Hospitals Morgantown, WV, USA Forrest “Dell” Moore, MD John Peter Smith Hospital Fort Worth, TX, USA Matthew Bloom, MD Cedars Sinai Hospital Los Angeles, CA, USA Nam T. Tran, MD; Eileen Bulger, MD University of Washington – Harborview Seattle, WA, USA Jeannette G. Ward, MS-CR Chandler Regional Medical Center Chandler, AZ, USA John K. Bini, MD; John Matsuura, MD; Joshua Pringle, MD; Karen Herzing, BSN, RN; Kaleigh Nolan, BS Wright State Research Institute - Miami Valley Hospital Dayton, OH, USA Nathaniel Poulin, MD; Vidant Medical Center Greenville, NC, USA William Teeter, MD University of North Carolina at Chapel Hill Chapel Hill, NC, USA Rachel Nygaard, PhD; Chad Richardson, MD; Joseph Skaja, MD; Derek Lombard, MD Hennepin Healthcare Minneapolis, MN, USA Reagan Bollig, MD; Brian Daley, MD; Niki Rasnake, BSN, RN, CEN University of Tennessee Medical Center Knoxville, TN, USA Marko Bukur, MD; Elizabeth Warnack, MD Bellevue Hospital /NYU New York, NY, USA Joseph Farhat, MD North Memorial Medical Center Minneapolis, MN, USA Robert M. Madayag, MD, FACS; Pamela Bourg, PhD, RN, TCRN, FAEN St. Anthony Hospital Lakewood, CO, USA.

Contributors All authors have made substantial contributions to this article, including conception and design of the study (MAV, RPD, JD, JWC), acquisition and analysis/interpretation of the data (MAV, RPD, JD, JM, TS, LM, JP, KI, AP, DSK, VLB, CS, CF, EEM, JWC), drafting of the article (MAV, RPD, JWC), and critical revisions (MAV, RPD, JD, JM, TS, LM, JP, KI, AP, DSK, VLB, CS, CF, EEM, JWC). All authors have reviewed and approved this final article.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests The following conflicts of interest pertain to Prytime Medical Devices: University of Pennsylvania Simulation Center (REBOA simulation equipment); EEM (research support); JM (clinical advisory board); CF (medical consultant); and CS (unpaid speaker).

Patient consent for publication Not required.

Ethics approval This project was approved by the University of Pennsylvania Institutional Review Board and by each institutional review board at participating sites.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

ORCID iD

Jonathan Morrison <http://orcid.org/0000-0001-7462-8456>

REFERENCES

- Spinnella PC. Zero preventable deaths after traumatic injury: an achievable goal. *J Trauma Acute Care Surg* 2017;82:S2–8.
- Pfeifer R, Tarkin IS, Roccos B, Pape H-C. Patterns of mortality and causes of death in polytrauma patients—has anything changed? *Injury* 2009;40:907–11.
- Kauvar DS, Lefering R, Wade CE. Impact of hemorrhage on trauma outcome: an overview of epidemiology, clinical presentations, and therapeutic considerations. *J Trauma* 2006;60:S3–11.
- Morrison JJ, Rasmussen TE. Noncompressible torso hemorrhage: a review with contemporary definitions and management strategies. *Surg Clin North Am* 2012;92:843–58.
- Holcomb JB. Transport time and Preoperating room hemostatic interventions are important: improving outcomes after severe truncal injury. *Crit Care Med* 2018;46:447–53.
- Meizoso JP, Ray JJ, Karcutskie CA, Allen CJ, Zakrisson TL, Pust GD, Koru-Sengul T, Ginzburg E, Pizano LR, Schulman CI, et al. Effect of time to operation on mortality for hypotensive patients with gunshot wounds to the torso: the golden 10 minutes. *J Trauma Acute Care Surg* 2016;81:685–91.
- Clarke JR, Trooskin SZ, Doshi PJ, Greenwald L, Mode CJ. Time to laparotomy for intra-abdominal bleeding from trauma does affect survival for delays up to 90 minutes. *J Trauma* 2002;52:420–5.
- Brenner M, Inaba K, Aiolfi A, DuBose J, Fabian T, Bee T, Holcomb JB, Moore L, Skarupa D, Scalea TM, et al. Resuscitative Endovascular Balloon Occlusion of the Aorta and Resuscitative Thoracotomy in Select Patients with Hemorrhagic Shock: Early Results from the American Association for the Surgery of Trauma's Aortic Occlusion in Resuscitation for Trauma and Acute Care Surgery Registry. *J Am Coll Surg* 2018;226:730–40.
- Brenner M, Teeter W, Hoehn M, Pasley J, Hu P, Yang S, Romagnoli A, Diaz J, Stein D, Scalea T, et al. Use of resuscitative endovascular balloon occlusion of the aorta for proximal aortic control in patients with severe hemorrhage and arrest. *JAMA Surg* 2018;153:130–5.
- Brenner ML, Moore LJ, DuBose JJ, Tyson GH, McNutt MK, Albarado RP, Holcomb JB, Scalea TM, Rasmussen TE. A clinical series of resuscitative endovascular balloon occlusion of the aorta for hemorrhage control and resuscitation. *J Trauma Acute Care Surg* 2013;75:506–11.
- Moore LJ, Brenner M, Kozar RA, Pasley J, Wade CE, Baraniuk MS, Scalea T, Holcomb JB. Implementation of resuscitative endovascular balloon occlusion of the aorta as an alternative to resuscitative thoracotomy for noncompressible truncal hemorrhage. *J Trauma Acute Care Surg* 2015;79:523–32.
- Morrison JJ, Morrison JJ, Galgon RE, Jansen JO, Jansen JO, Cannon JW, Rasmussen TE, Rasmussen TE, Eliason JL. A systematic review of the use of resuscitative endovascular balloon occlusion of the aorta in the management of hemorrhagic shock. *J Trauma Acute Care Surg* 2016;80:324–34.
- Qasim Z, Brenner M, Menaker J, Scalea T. Resuscitative endovascular balloon occlusion of the aorta. *Resuscitation* 2015;96:275–9.
- Stannard A, Eliason JL, Rasmussen TE. Resuscitative endovascular balloon occlusion of the aorta (REBOA) as an adjunct for hemorrhagic shock. *J Trauma* 2011;71:1869–72.
- Remick KN, Schwab CW, Smith BP, Monshizadeh A, Kim PK, Reilly PM. Defining the optimal time to the operating room may salvage early trauma deaths. *J Trauma Acute Care Surg* 2014;76:1251–8.
- DuBose JJ, Scalea TM, Brenner M, Skiada D, Inaba K, Cannon J, Moore L, Holcomb J, Turay D, Arbabi CN, et al. The AAST prospective aortic occlusion for resuscitation in trauma and acute care surgery (aorta) registry: data on contemporary utilization and outcomes of aortic occlusion and resuscitative balloon occlusion of the aorta (REBOA). *J Trauma Acute Care Surg* 2016;81:409–19.
- Lee EC, Whitehead AL, Jacques RM, Julious SA. The statistical interpretation of pilot trials: should significance thresholds be reconsidered? *BMC Med Res Methodol* 2014;14:41.
- Sadeghi M, Nilsson KF, Larzon T, Pirouzram A, Toivola A, Skoog P, Idoguchi K, Kon Y, Ishida T, Matsumara Y, et al. The use of aortic balloon occlusion in traumatic shock: first report from the ABO trauma registry. *Eur J Trauma Emerg Surg* 2018;44:491–501.
- Ordoñez CA, Manzano-Nunez R, Parra MW, Rasmussen TE, Nieto AJ, Herrera-Escobar JP, Fernandez P, Naranjo MP, Garcia AF, Carvajal JA, et al. Prophylactic use of resuscitative endovascular balloon occlusion of the aorta in women with abnormal

- placentation: a systematic review, meta-analysis, and case series. *J Trauma Acute Care Surg* 2018;84:809–18.
- 20 Weltz AS, Harris DG, O'Neill NA, O'Meara LB, Brenner ML, Diaz JJ. The use of resuscitative endovascular balloon occlusion of the aorta to control hemorrhagic shock during video-assisted retroperitoneal debridement or infected necrotizing pancreatitis. *Int J Surg Case Rep* 2015;13:15–18.
 - 21 Tsurukiri J, Akamine I, Sato T, Sakurai M, Okumura E, Moriya M, Yamanaka H, Ohta S. Resuscitative endovascular balloon occlusion of the aorta for uncontrolled haemorrhagic shock as an adjunct to haemostatic procedures in the acute care setting. *Scand J Trauma Resusc Emerg Med* 2016;24:13.
 - 22 Rosenthal MD, Raza A, Markle S, Croft CA, Mohr AM, Smith RS. The novel use of resuscitative endovascular balloon occlusion of the aorta to explore a retroperitoneal hematoma in a hemodynamically unstable patient. *Am Surg* 2017;83:337–40.
 - 23 Hoehn MR, Hansraj NZ, Pasley AM, Brenner M, Cox SR, Pasley JD, Diaz JJ, Scalea T. Resuscitative endovascular balloon occlusion of the aorta for non-traumatic intra-abdominal hemorrhage. *Eur J Trauma Emerg Surg* 2019;45:713–8.
 - 24 Harvin JA, Maxim T, Inaba K, Martinez-Aguilar MA, King DR, Choudhry AJ, Zielinski MD, Akinyeye S, Todd SR, Griffin RL, et al. Mortality after emergent trauma laparotomy: a multicenter, retrospective study. *J Trauma Acute Care Surg* 2017;83:464–8.
 - 25 Alarhayem AQ, Myers JG, Dent D, Liao L, Muir M, Mueller D, Nicholson S, Cestero R, Johnson MC, Stewart R, et al. Time is the enemy: Mortality in trauma patients with hemorrhage from torso injury occurs long before the "golden hour". *Am J Surg* 2016;212:1101–5.
 - 26 Romagnoli A, Teeter W, Pasley J, Hu P, Hoehn M, Stein D, Scalea T, Brenner M. Time to aortic occlusion: it's all about access. *J Trauma Acute Care Surg* 2017;83:1161–4.
 - 27 Dumas RP, Chreiman KM, Seamon MJ, Cannon JW, Reilly PM, Christie JD, Holena DN. Benchmarking emergency department thoracotomy: using trauma video review to generate procedural norms. *Injury* 2018;49:1687–92.
 - 28 Biffi WL, Fox CJ, Moore EE. The role of REBOA in the control of Exsanguinating torso hemorrhage. *J Trauma Acute Care Surg* 2015;78:1054–8.
 - 29 Matsumura Y, Matsumoto J, Kondo H, Idoguchi K, Ishida T, Okada Y, Kon Y, Oka K, Ishida K, Toyoda Y, et al. Early arterial access for resuscitative endovascular balloon occlusion of the aorta is related to survival outcome in trauma. *J Trauma Acute Care Surg* 2018;85:507–11.
 - 30 Markov NP, Percival TJ, Morrison JJ, Ross JD, Scott DJ, Spencer JR, Rasmussen TE. Physiologic tolerance of descending thoracic aortic balloon occlusion in a swine model of hemorrhagic shock. *Surgery* 2013;153:848–56.
 - 31 Morrison JJ, Ross JD, Markov NP, Scott DJ, Spencer JR, Rasmussen TE. The inflammatory sequelae of aortic balloon occlusion in hemorrhagic shock. *J Surg Res* 2014;191:423–31.
 - 32 Saito N, Matsumoto H, Yagi T, Hara Y, Hayashida K, Motomura T, Mashiko K, Iida H, Yokota H, Wagatsuma Y, et al. Evaluation of the safety and feasibility of resuscitative endovascular balloon occlusion of the aorta. *J Trauma Acute Care Surg* 2015;78:897–904.
 - 33 Brenner M, Bulger EM, Perina DG, Henry S, Kang CS, Rotondo MF, Chang MC, Weireter LJ, Coburn M, Winchell RJ, et al. Joint statement from the American College of surgeons Committee on trauma (ACS cot) and the American College of emergency physicians (ACEP) regarding the clinical use of resuscitative endovascular balloon occlusion of the aorta (REBOA). *Trauma Surg Acute Care Open* 2018;3:e000154.