Trauma Surgery & Acute Care Open

Mortality in hypotensive trauma patients requiring laparotomy is related to degree of hypotension and provides evidence for focused interventions

James W Davis, Rachel C Dirks, David R Jeffcoach, Krista L Kaups, Lawrence P Sue, Jordan T Lilienstein, Mary M Wolfe, Amy M Kwok

Department of Surgery, University of California San Francisco Fresno, Fresno, California, USA

Correspondence to
Dr James W Davis; james.davis3@ucsf.edu

Received 24 February 2021
Accepted 23 May 2021

To cite: Davis JW, Dirks RC, Jeffcoach DR, *et al*. *Trauma Surg Acute Care Open* 2021;**6**:e000723.

ABSTRACT

Background Mortality in hypotensive patients requiring laparotomy is reported to be 46% and essentially unchanged in 20 years. Resuscitative endovascular balloon occlusion of the aorta (REBOA) has been incorporated into resuscitation protocols in an attempt to decrease mortality, but REBOA can have significant complications and its use in this patient group has not been validated. This study sought to determine the mortality rate for hypotensive patients requiring laparotomy and to evaluate the mortality risk related to the degree of hypotension. Additionally, this study sought to determine if there was a presenting systolic blood pressure (SBP) that was associated with a sharp increase in mortality to target the appropriate patient group most likely to benefit from focused interventions such as REBOA.

Methods The trauma registry at a level I trauma center was reviewed for patients undergoing emergent laparotomy from January 2007 to June 2020. Data included demographics, mechanism of injury, physiological data, Injury Severity Score, blood products transfused, and outcomes. Group comparisons were based on initial SBP (0 to 50 mm Hg, 60 to 69 mm Hg, 70 to 79 mm Hg, 80 to 89 mm Hg, and ≥90 mm Hg).

Results During the study period, 52 016 trauma patients were treated and 1174 required laparotomy within 90 min of arrival; 424 had an initial SBP of <90 mm Hg. The overall mortality rate was 18%, but mortality increased as SBP decreased (≥90=9%, 80 to 89=20%, 70 to 79=21%, 60 to 69=48%, 0 to 59=66%). Mortality increased sharply with SBP of <70 mm Hg.

Discussion Mortality rate increases with worsening hypotension and increases sharply with an SBP of <70 mm Hg. Further study on focused interventions such as REBOA should target this patient group.

Level of evidence Therapeutic/care management, level III.

INTRODUCTION

In 2002, Clarke *et al* published data describing mortality rates of 40% for trauma patients requiring laparotomy who arrived hypotensive with a systolic blood pressure (SBP) less than 90 mm Hg.[1] Since the publication of that study, numerous advancements in the care of hypotensive trauma patients have occurred, including further advancements in damage control laparotomy, balanced resuscitation, massive transfusion protocols, bedside ultrasonography, angioembolization, correction of coagulopathy and, most recently, the widespread implementation of resuscitative endovascular balloon occlusion of the aorta (REBOA).[2–6] In light of these changes, Harvin *et al* conducted a similar study at ten level I trauma centers across the USA in 2017 to investigate whether mortality had changed in 15 years.[2] Surprisingly, the results revealed an essentially unchanged mortality rate of 46% for the hypotensive patient population, with two-thirds of these deaths attributed to hemorrhage. A similar study of mortality with laparotomy for hypotensive trauma patients performed in the UK in 2018 showed a 48% mortality rate for civilian trauma.[7]

However, hypotension is not a binary variable (less than or greater than 90 mm Hg), and the mortality for hypotensive trauma patients requiring laparotomy is likely more nuanced than a single threshold number. REBOA has recently been incorporated into some trauma resuscitation protocols. One such protocol recommends consideration of REBOA for patients arriving with SBP of <90 mm Hg who are transient or non-responders to initial crystalloid resuscitation.[6] These algorithms have been proposed primarily based on comparison data with emergency department (ED) thoracotomy and have not been otherwise validated.[8 9]

The use of REBOA is not without risks. Major complications including injury to femoral vessels, arterial thrombus/embolus, limb loss, need for fasciotomy, balloon rupture, and mesenteric ischemia with prolonged deployment have all been reported.[10 11] Brenner *et al* published the largest single-center experience with REBOA use and found significant complications in 29%.[12] Joseph *et al* reported a greater rate of acute kidney injury and increased lower extremity amputation and mortality in patients with REBOA usage versus a matched cohort without REBOA in a study of the American College of Surgeons Trauma Quality Improvement (TQIP) database.[13]

The purpose of this study was to determine the mortality rate for hypotensive patients requiring laparotomy in a level I trauma center and to evaluate mortality risk related to degree of hypotension. Additionally, this study sought to determine if there was a presenting SBP that was associated with a sharp increase in mortality to target the appropriate patient group most likely to benefit from focused interventions such as REBOA.

METHODS

The Community Regional Medical Center is a 650-bed, American College of Surgeons-verified level I trauma center in Fresno, California, with approximately 4000 trauma admissions per year. The trauma registry was retrospectively reviewed for all trauma patients who underwent emergent laparotomy from January 2007 to June 2020. Patients undergoing non-emergent laparotomy (>90 min after arrival) and those missing data for SBP on arrival were excluded. Data recorded included demographics, mechanism of injury, physiological data on initial arrival, presenting laboratory values, Injury Severity Score (ISS), time to laparotomy (arrival to incision), blood products transfused, and outcomes. Group comparisons were based on initial SBP categories (0 mm Hg to 59 mm Hg, 60 mm Hg to 69 mm Hg, 70 mm Hg to 79 mm Hg, 80 mm Hg to 89 mm Hg, and ≥90 mm Hg), which were defined as the first manual blood pressure obtained by the hospital staff in the trauma bay. The primary outcome was in-hospital mortality.

Continuous data are presented as median (IQR) and categorical data are presented as percentages. Data were analyzed using χ^2 and Kruskal-Wallis tests with significance attributed to a p value of <0.05. Statistics were performed using the Statistical Package for Social Sciences V.23.0.

RESULTS

During the study period, 52 016 trauma patients were treated at Community Regional Medical Center and 2400 required laparotomies; 1162 underwent laparotomy greater than 90 min after arrival and 64 had missing initial SBP and were excluded from analysis. This left a study cohort of 1174 patients. The majority of patients were male (84%) with a median age of 30 years (IQR 22 years to 44 years). Penetrating trauma was the most common mechanism of injury (60%), and patients had a median ISS of 19 (IQR 10 to 29). Most patients arrived by ambulance (72%), followed by helicopter (23%) and private vehicle (5%). Median transport time was 11 min (IQR 7 min to 18 min). The ED length of stay (LOS) was 44 min (IQR 31 min to 60 min). The time to the start of laparotomy was 50 min in the normotensive group (IQR 37 min to 66 min) and slightly less in the hypotensive group at 42 min (IQR 32 min to 55 min) (p<0.001).

There were 425 patients (36%) with an initial SBP of less than 90 mm Hg. The majority of patients requiring emergent laparotomy in this group had a blunt mechanism of injury (58%) and an ISS of 26 (IQR 17 to 38).

Damage control procedures were performed in 218 patients (19%), 89 (12%) in normotensive patients and 129 (30%) in the hypotensive cohort (p<0.001). The overall mortality rate for all patients requiring emergent laparotomy was 18% (215), 9% in normotensive patients and 35% in the cohort with an initial SBP of <90 mm Hg (p<0.001).

The base deficit, Glasgow Coma Scale score, and ED LOS all decreased with decreasing category of SBP and the ISS increased. Patients with lower initial SBP had higher chest and abdominal ISSs (table 1).

The number of blood products transfused increased as SBP decreased (p<0.001) (table 2) and mortality increased with each interval decrease in blood pressure (p<0.001) (figure 1). The overall mortality for all patients with an admission SBP of <70 mm Hg was 59%.

Of the 215 mortalities, the cause of death was attributed to hemorrhage in 108 (50%), traumatic brain injury/central nervous system in 54 (25%), multisystem organ failure/sepsis in 42 (20%), cardiac (myocardial infarction and air embolus) in 7 (3%), and respiratory failure/acute respiratory distress syndrome in 4 (2%). In patients with an SBP of <70 mm Hg on admission, 66% of the deaths were attributed to hemorrhage.

There were 12 patients with REBOA use, with four deaths. The average SBP on arrival was 72 mm Hg (range 50 mm Hg to 92 mm Hg), with a BD of −12 and an ISS of 29.

DISCUSSION

Mortality in trauma patients requiring laparotomy has been an area of significant concern for decades. In 1975, Cowley noted that delays in treatment led to higher mortality and referred to the 'golden hour'.[14] Meizoso *et al* noted that time to hemorrhage control for hypotensive patients with gunshot wounds to the torso was critical and proposed the 'golden 10 min'.[15] Clarke *et al* demonstrated an overall mortality rate of 40% but also noted an increasing mortality with every 10 mm Hg decrease in blood pressure at time of presentation.[1] The mortality rate was similar to the present study for patients with SBP of <70 mm Hg. However, the present study included patients with SBP of 0 on admission (55). For patients in shock with an SBP of 70–89 mm Hg, the mortality in Clarke *et al*'s study was significantly greater (38% vs 20%, p<0.001).[1]

The study by Harvin *et al*[2] showed essentially no change from the seminal paper by Clark *et al*[1] despite almost 20 years of trauma center and system development. However, mortality rates for these hypotensive patients at the various trauma centers had a wide range (25% to 80%).[2] That report spurred a similar study from the UK, with 46% mortality in hypotensive patients requiring laparotomy.[7] The overall mortality for patients

Table 1 Patient demographics by initial systolic blood pressure

	≥90 mm Hg (n=749)	80–89 mm Hg (n=157)	70–79 mm Hg (n=108)	60–69 mm Hg (n=64)	0–59 mm Hg (n=96)	P value
Age (years), median (IQR)	29 (21–40)	32 (22–48)	35 (24–48)	31 (22–49)	34 (26–50)	<0.001
Male sex, n (%)	651 (87)	121 (77)	84 (78)	48 (75)	78 (81)	0.002
Blunt injury, n (%)	223 (30)	91 (58)	57 (53%)	40 (62)	57 (59)	<0.001
GCS, median (IQR)	15 (15–15)	15 (10–15)	14 (7–15)	13 (3–15)	3 (3–8)	<0.001
Base deficit, median (IQR)	−4 (−6 to −2)	−6 (−9 to −4)	−8 (−11 to −5)	−8 (−11 to −5)	−10 (−15 to −6)	<0.001
ED LOS (min), median (IQR)	47 (32–65)	44 (31–58)	37 (28–49)	41 (26–56)	34 (26–44)	<0.001
ISS, median (IQR)	16 (9–26)	25 (16–34)	25 (17–34)	32 (19–47)	30 (20–41)	<0.001
AIS head, median (IQR)	0 (0–0)	0 (0–2)	0 (0–2)	0 (0–4)	0 (0–2)	<0.001
AIS chest, median (IQR)	0 (0–3)	2 (0–3)	2 (0–3)	3 (2–4)	3 (0–4)	<0.001
AIS abdomen, median (IQR)	3 (2–4)	3 (2–4)	3 (2–4)	3 (2–4)	4 (3–5)	<0.001

AIS, Abbreviated Injury Scale; ED, emergency department; GCS, Glasgow Coma Scale; ISS, Injury Severity Score; LOS, length of stay.

Table 2 Outcomes by initial systolic blood pressure

	≥90 mm Hg (n=749)	80–89 mm Hg (n=157)	70–79 mm Hg (n=108)	60–69 mm Hg (n=64)	0–59 mm Hg (n=96)	P value
Blood products (first 24 hours), median (IQR)	0 (0–8)	13 (4–26)	16 (6–30)	14 (7–37)	24 (16–57)	<0.001
Mortality, n (%)	67 (9)	31 (20)	23 (21)	31 (48)	63 (66)	<0.001
Mortality from hemorrhage, n (%)	21 (31)	13 (42)	13 (57)	10 (32)	51 (81)	<0.001
Time to death (hours), median (IQR)	29 (4–184)	37 (4–151)	6 (2–35)	44 (4–138)	2 (1–6)	<0.001
ICU LOS (survivors), median (IQR)	0 (0–3)	4 (0–10)	6 (2–15)	7 (1–23)	12 (4–25)	<0.001
Hospital LOS (survivors), median (IQR)	6 (4–13)	13 (7–22)	17 (8–28)	12 (7–34)	27 (13–46)	<0.001

ICU, intensive care unit; LOS, length of stay.

undergoing emergency trauma laparotomy in the current study was 18%, which is similar to that previously reported (21%).[2] However, in the current study, the mortality rate for the hypotensive subset of patients (35%) was less than the rate reported by Harvin *et al* (46%),[2] despite similar ISSs. Additionally, the number of patients with hemorrhage as the cause of death (50%) was also significantly less (60%, p=0.021).[2] The current study suggests that, while still substantial, the mortality rate for hypotensive trauma patients requiring laparotomy has improved from the early 2000s. Additionally, the data show that the risk of mortality in patients requiring emergent laparotomy after trauma increases in proportion to the degree of hypotension. Additionally, there is a significant inflection point with rapid increase in mortality with an initial SBP f <70 mm Hg.

Efforts to improve outcomes in trauma laparotomy have included damage control resuscitation and limiting crystalloid,[4] in addition to seeking 'novel interventions in the field or ED…to lengthen that critical window to allow greater time to operative hemorrhage control'.[2] One such intervention is REBOA, which has had an increased interest for use in hypotensive trauma patients.[9 12 14] A suggested algorithm for REBOA use recommends that trauma patients with an SBP of <90 mm Hg are possible candidates for REBOA use.[6 10 16] This algorithm has found some acceptance in the trauma community, but, to our knowledge, there is no literature validating this treatment algorithm or proposing possible evidence-based improvements. Validation of this algorithm is needed, as studies have demonstrated both significant rates and severity of complications associated with REBOA. In recent studies, Joseph *et al* reported a greater rate of acute kidney injury (10.7% vs 3.2%, p=0.02), greater lower extremity amputation (3.6% vs 0.7%, p=0.04) and higher mortality (35.7 vs 18.9%, p=0.04) in patients with REBOA usage versus a matched cohort without REBOA in a study of the American College of Surgeons TQIP database.[13]

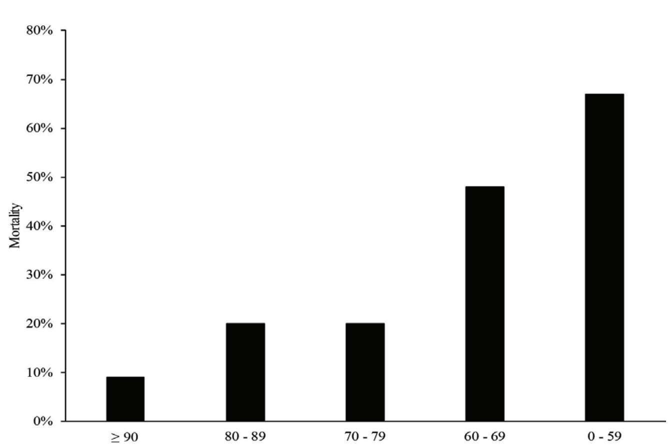

Figure 1 Degree of hypotension and mortality.

Brenner *et al* found complications in 29% of patients with REBOA use in the largest single institution study to date, including a death from bowel necrosis, lower extremity amputations (3 after fasciotomy and attempted limb salvage), need for vascular repair/reconstruction (2 patch angioplasty and 1 bifurcated graft), ipsilateral thrombectomies (9 patients), fasciotomy (11 patients), and balloon rupture (2 patients).[12] Additionally, Brenner *et al* noted REBOA balloons malpositioned and requiring adjustment in 12 patients, not included in this complication rate.

Morbidity and mortality are not equivalent, but the significant risk of complication associated with REBOA and the non-binary correlation of mortality with hypotension need to be considered when proposing an algorithm for the use of REBOA. Indeed, Bulger *et al* noted that no high-grade evidence demonstrates that REBOA improves outcomes or survival compared with standard treatment of severe traumatic hemorrhage and that REBOA carries a significant risk of life-threatening and limb-threatening complications.[17]

This is a single-center study and prone to all the limitations of a retrospective analysis. The multicenter trial that spurred this study was performed over 2 years at 12 level I trauma centers but used the same methodology.[2] This study period spans 14 years, and a number of the improvements in trauma care (balanced resuscitation, massive transfusion protocols, and access to angioembolization) occurred during this time. However, the outcomes at our institution for this patient group were stable over the study period. The use of REBOA in our institution was limited and direct comparisons to complication rates in other institutions could not be made. The rates of REBOA-related complications vary widely in published reports, from 0% to 29%,[8 9 12 18–21] but can be significant. Again, morbidity and mortality are not equivalent, but consideration needs to be given to the group of patients most likely to benefit from high-risk interventions.

CONCLUSIONS

This study demonstrates that the overall mortality rate for emergency trauma laparotomy is 18%, and in patients arriving at the trauma center with an SBP of <90 mm Hg, mortality is 35%. Mortality rate increases with worsening hypotension and increases sharply with an SBP of <70 mm Hg. Further study on focused interventions such as REBOA should target this patient group.

Contributors JWD and RCD: study concept, design, data collection, analysis, manuscript writing and critical revision. DRJ: data collection, data analysis, and manuscript writing. KLK, LPS, JTL, MMW, and AMK: critical revision of manuscript.

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 None declared.

Patient consent for publication Not required.

Ethics approval This study was approved by the Community Medical Centers Institutional Review Board (IRB# 2017089) with a waiver for patient consent.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information. Data was obtained from the institutional trauma registry and all relevant data is included in the article.

ORCID iD
Krista L Kaups http://orcid.org/0000-0002-0823-6902

REFERENCES

1 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.
2 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.
3 Duchesne JC, Kimonis K, Marr AB, Rennie KV, Wahl G, Wells JE, Islam TM, Meade P, Stuke L, Barbeau JM, *et al*. Damage control resuscitation in combination with damage control laparotomy: a survival advantage. *J Trauma* 2010;69:46–52.
4 Joseph B, Azim A, Zangbar B, Bauman Z, O'Keeffe T, Ibraheem K, Kulvatunyou N, Tang A, Latifi R, Rhee P. Improving mortality in trauma laparotomy through the evolution of damage control resuscitation: analysis of 1,030 consecutive trauma laparotomies. *J Trauma Acute Care Surg* 2017;82:328–33.
5 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.
6 Moore LJ, Martin CD, Harvin JA, Wade CE, Holcomb JB. Resuscitative endovascular balloon occlusion of the aorta for control of noncompressible truncal hemorrhage in the abdomen and pelvis. *Am J Surg* 2016;212:1222–30.
7 Marsden M, Carden R, Navaratne L, Smith IM, Penn-Barwell JG, Kraven LM, Brohi K, Tai NRM, Bowley DM. Outcomes following trauma laparotomy for hypotensive trauma patients: a UK military and civilian perspective. *J Trauma Acute Care Surg* 2018;85:620–5.
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.
9 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.
10 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:e000154–3.
11 Rasmussen TE, Eliason JL. Military-civilian partnership in device innovation: development, commercialization and application of resuscitative endovascular balloon occlusion of the aorta. *J Trauma Acute Care Surg* 2017;83:732–5.
12 Brenner M, Teeter W, Hoehn M, Pasley J, Hu P, Yang S, Romagnoli A, Diaz J, Stein D, Scalea T. Use of resuscitative endovascular balloon occlusion of the aorta for proximal aortic control in patients with severe hemorrhage and arrest. *JAMA Surg* 2018;153:500–8.
13 Joseph B, Zeeshan M, Sakran JV, Hamidi M, Kulvatunyou N, Khan M, O'Keeffe T, Rhee P. Nationwide analysis of resuscitative endovascular balloon occlusion of the aorta in civilian trauma. *JAMA Surg* 2019;154:500–8.
14 Cowley RA. A total emergency medical system for the state of Maryland. *Md State Med J* 1975;24:37–45.
15 Meizoso JP, Ray JJ, Karcutskie CA, Allen CJ, Zakrison 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.
16 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.
17 Bulger EM, Perina DG, Qasim Z, Beldowicz B, Brenner M, Guyette F, Rowe D, Kang CS, Gurney J, DuBose J, *et al*. Clinical use of resuscitative endovascular balloon occlusion of the aorta (REBOA) in civilian trauma systems in the USA, 2019: a joint statement from the American College of surgeons Committee on trauma, the American College of emergency physicians, the National association of emergency medical services physicians and the National association of emergency medical technicians. *Trauma Surg Acute Care Open* 2019;4:e000376.
18 Wasicek PJ, Teeter WA, Yang S, Hu P, Hoehn MR, Stein DM, Scalea TM, Brenner ML. Life over limb: lower extremity ischemia in the setting of resuscitative endovascular balloon occlusion of the aorta (REBOA). *Am Surg* 2018;84:971–7.
19 Ribeiro Junior MAF, Feng CYD, Nguyen ATM, Rodrigues VC, Bechara GEK, de-Moura RR, Brenner M. The complications associated with resuscitative endovascular balloon occlusion of the aorta (REBOA). *World J Emerg Surg* 2018;13:20.
20 Saito N, Matsumoto H, Yagi T, Hara Y, Hayashida K, Motomura T, Mashiko K, Iida H, Yokota H, Wagatsuma Y. Evaluation of the safety and feasibility of resuscitative endovascular balloon occlusion of the aorta. *J Trauma Acute Care Surg* 2015;78:897–904.
21 Hadley JB, Coleman JR, Moore EE, Lawless R, Burlew CC, Platnick B, Pieracci FM, Hoehn MR, Coleman JJ, Campion E, *et al*. Strategies for successful implementation of resuscitative endovascular balloon occlusion of the aorta (REBOA) in an urban level I trauma center. *J Trauma Acute Care Surg* 2021. [Epub ahead of print: 27 Mar 2021].