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Original Contributions

AGE DOES NOT PREDICT FAILURE TO RESCUE FOLLOWING RESUSCITATIVE THORACOTOMY IN PENETRATING TRAUMA

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☐ **Abstract—Background: The limitations of resuscitative thoracotomy (RT) after penetrating trauma have been well documented, but there is a paucity of data on the effect age has on mortality. This begs the question as to the utility of RT in an aging patient population. We investigate the significance of age as a predictor for failure to rescue after RT in penetrating trauma. Objective: We sought to identify whether chronologic age has a measurable effect on rates of failure to rescue after RT. Methods: We performed a retrospective cohort analysis using the Trauma Quality Improvement Program from 2011 to 2015 including all pulseless patients undergoing RT after penetrating injury. Our primary outcome was failure to rescue defined as death in the emergency department after RT. Multivariate analyses were performed to identify the relationship between age and morality controlling for injury severity. Results: One thousand one hundred twelve RTs were performed during the study period with an overall failure to rescue rate of 61.8% (n = 687) within the emergency department and an in-hospital mortality rate of 96.9%, which is in line with national data. On univariate analysis, there was no significant association between age and mortality (*p* = 0.44). On multivariate analysis examining the interaction between age and mortality adjusting for injury severity, we found that chronologic age was not an independent predictor of death after RT. Conclusions: Age does not appear to be an independent predictor of failure to rescue after RT in penetrating trauma and should not be a sole determinant in procedural decision making.** **© 2021 Elsevier Inc. All rights reserved.**

☐ **Keywords—injury; resuscitative thoracotomy; trauma**

INTRODUCTION

Resuscitative thoracotomy (RT) after cardiac injury was first described in the 1960s, and since that time delineating its role in the care of the injured patient has been a point of contention (1). The application of and limitations associated with RT in the rescue of patients with exsanguinating injury has been well documented (2,3). Guidelines from the Western Trauma Association, the Eastern Association for the Surgery of Trauma, and the American College of Surgeons include patient physiology and time from injury to determine candidacy for RT (4–6). Patient demographics including age, however, are not included. Nevertheless, according to a 2016 study, 38.5% of surveyed surgeons consider patient age in their decision making (7).

Previous studies have shown an association between chronologic age and survival after RT, but most of these studies are single-center experiences spanning different eras of trauma management and resuscitation strategies. It is unclear if survivorship after RT in older patients is

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a consequence of age or decreasing functional reserve (i.e., frailty) (8,9). Notably, Gil et al. used the National Trauma Data Bank to evaluate survival after RT in blunt and penetrating injury and found no survival in patients ≥57 years of age (8). Increasingly, data indicate that frailty crosses age groups, suggesting that the effect of physiologic age vs. chronologic age needs to be addressed before determining futile care (10,11). Unfortunately, assessing frailty in real time is often impossible for patients presenting in extremis, and chronologic age remains the surrogate for physiologic reserve in determining candidacy for resuscitative thoracotomy.

The purpose of this study, therefore, is to investigate the significance of age as a predictor of failure to rescue after RT in penetrating trauma. Our aim is two-fold: 1) to define the rate of rescue after RT across all age groups with specific focus on older patients, and 2) to characterize practice patterns on a national scale in the modern era as a reflection of current resuscitation paradigms.

METHODS

Study Design

Our study was deemed exempt by the George Washington University institutional review board because of its retrospective analysis on deidentified patient data. The Trauma Quality Improvement Program (TQIP) database was used to identify all patients undergoing RT in the emergency department (ED) from January 1, 2011 through December 31, 2015. The TQIP database is a multi-institutional database assembled by the American College of Surgeons to identify areas of improvement in the care of trauma patients. This database incorporates >100 variables from >850 participating hospitals to assess trauma patient outcomes (more information can be found at https://www.facs.org/quality-programs/trauma/tqp/center-programs/tqip). Patients were included if they were ≥18 years of age and were identified as having undergone RT by the *International Classification of Diseases, 9th revision* (ICD-9) and ICD-10 procedural codes. We defined RT as any thoracotomy performed in the ED in patients who sustained penetrating or blunt mechanism of injury and who are in refractory hemorrhagic shock or pulseless with cardiopulmonary resuscitation time <15 min for penetrating injury or <5 min for blunt injury. Blunt trauma was excluded from our analysis because survival after RT is negligible. To ensure that our study population comprised thoracotomies performed in the ED for patients with refractory hemorrhagic shock, patients were only included if they underwent a thoracotomy within the first 15 min as denoted by the hospital procedure start time variable minus the ED/hospital arrival time and had no documented pulse on arrival.

Variables of interest included age, sex, race or ethnicity, injury severity score (ISS), location of injury, and mortality. Location of injury was created as a binary yes/no variable categorized by body region using the Abbreviated Injury Scale score. Regions were sorted into abdomen, chest, extremity, and head. A composite binary variable of multiple injured vs. single injured was created by designating multiple injury to any patient sustaining wounds in ≥2 different body regions identified by Abbreviated Injury Scale region. Mortality was subdivided into death within the ED after RT and death during hospitalization for those that survived beyond the ED phase of care.

Failure to rescue was our primary outcome of interest and was defined as death within the ED despite RT. Our secondary outcome of interest was mortality after admission. Data distribution was checked for normality using skewness and kurtosis. Data were analyzed as the mean and standard deviation for continuous variables and as proportions for categorical variables. For analysis of variance in ISS and mortality, age groups were divided into 5-year increments. The Student's t-test, χ^2 test, or Fisher exact test were used where appropriate to assess the univariate association between age and mortality both in the ED and after admission in survivors. An a priori power analysis was conducted using the sample size of our data set using different assumptions of possible effect sizes for mortality between age groups. Specifically, using various effect sizes for differences in mortality rates we found that we were powered to detect large difference in ED mortality (ranging from 30% in the youngest patients to 55% in the oldest), yielding a $\beta = 0.92$ (95% confidence interval [CI] 0.90–0.94). This was iterated several times using morality ranges of 25% to 48%, 30% to 52%, 30% to 50%, and 30% to 48% yielding power of 0.91 (95% CI 0.89–0.93), 0.84 (95% CI 0.81–0.86), and 0.75 (95% CI 0.72–0.78), respectively. This demonstrated that for large effect sizes, we were sufficiently powered. Multivariate logistic regression analysis was used to determine the odds ratios (ORs) and 95% CIs of age's effect on mortality in both the ED and following hospitalization adjusting for injury severity and multiplicity of injury. Data analysis was performed using SAS software (v 9.3; SAS Institute, Inc, Cary, NC) with $p \leq 0.05$ considered statistically significant.

RESULTS

We identified 1464 patients who underwent RT during the study period of which 1112 (75%) underwent RT after penetrating injury. When examining the distribution of RT performed by age group, 96% of thoracotomies (n = 1064) were performed in patients ≤55 years of age and 98.8% of thoracotomies (n = 1099) were performed

Table 1. Baseline Patient and Injury Characteristics

	Overall (N = 1112)
Age (years), mean ± SD	31.9 ± 11.9
Male gender, n (%)	1019 (91.6)
RT performed, n (%)	
≤55 years of age	1064 (95.7)
≤65 years of age	1099 (98.8)
Race, n (%)	
African American	612 (55.0)
White	259 (23.3)
Hispanic	218 (19.6)
Asian	15 (1.3)
Other	8 (0.7)

RT = resuscitative thoracotomy, SD = standard deviation.

in patients <65 years of age. The mean age was 31.9 ± 11.9 years with 91.6% of patients being male (n = 1019). Patient ethnicity consisted of African Americans (55%, n = 612), whites (23%, n = 259), and Hispanics (20%, n = 259) (Table 1).

The average ISS was 30.5 ± 3.5 and was not significantly associated with age ($p = 0.56$). Multiply injured patients represented 63.6% (n = 707) of the study cohort leaving 36.4% (n = 405) of patients with single site injury. The most common sites of injury included the chest (n = 927, 83.4%), abdomen (n = 489, 44.0%), extremity (n = 450, 40.5%), and head (n = 270, 24.3%). In both groups, chest injuries were the most common type of penetrating injury, though chest injuries occurred at a higher incidence in multiply injured patients (74% vs. 89%, $p < 0.001$).

Six hundred ninety-four patients died in the ED, yielding a 61.8% failure to rescue rate (Figures 1 and 2). The likelihood of failure to rescue after RT, however, was not significantly associated with age ($p = 0.44$; Figure 3). In those ≥55 years of age, 48 RTs were performed with

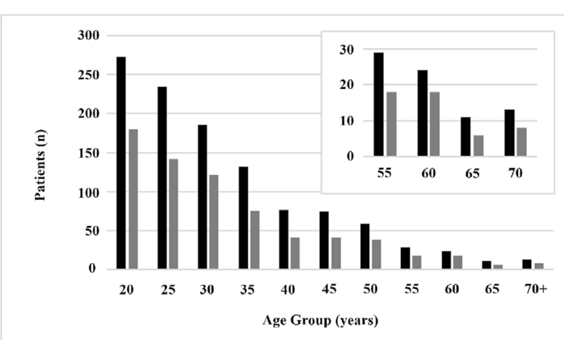


Figure 1. Histogram showing group size and mortality of resuscitative thoracotomies (RTs) performed in the emergency department and after hospitalization. The inset (upper right) shows the number of RTs performed within the emergency department. Black bars show all RTs performed. Gray bars show those that died in the emergency department.

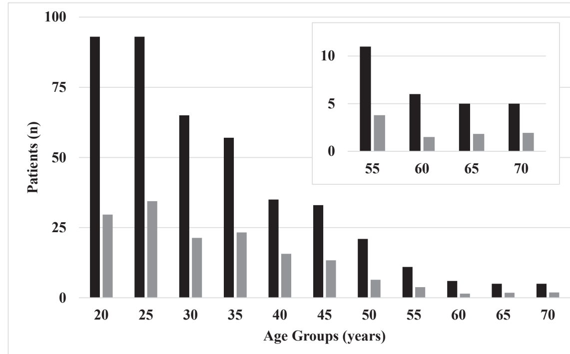
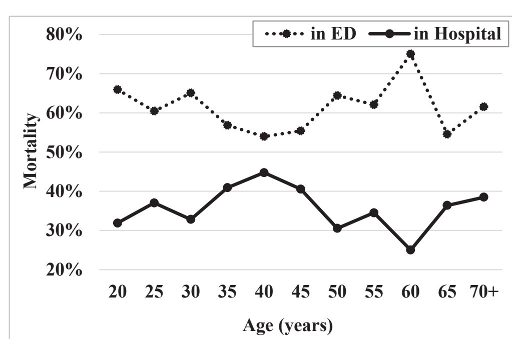


Figure 2. Histogram showing group size and mortality of resuscitative thoracotomies (RTs) performed in the hospital. The inset (upper right) shows the number of RTs performed within the hospital for those who survived RT to admission. Black bars show all RTs performed. Gray bars show those that died in the emergency department.

32 patients who died, yielding a failure to rescue rate similar to age groups <55 years of age (66.7% vs. 61.7%, $p = 0.48$). Likewise, in those ≥65 of age, 8 patients died out of 13 RTs performed, yielding a failure to rescue rate similar to those < 65 years of age (61.5% vs. 61.9%, $p = 0.71$). We did not analyze groups ≥70 years of age given the low occurrence of RT from penetrating trauma.

Among the 418 patients who survived to admission, in-hospital mortality was 93.3% (n = 390). This yielded an overall mortality of 96.9% (n = 1077). In those who initially survived RT and were subsequently admitted to the hospital, mortality was not significantly associated with age ($p = 0.60$; Figure 3). This held true in those ≥55 years pf age (67.2% vs. 63.7%, $p = 0.68$) and those ≥65 years of age (61.5% vs. 63.9%, $p = 0.85$).

Singularly injured patients had higher rates of failure to rescue compared with patients with multiple injuries (68.6% vs. 58.6%, $p < 0.001$) despite ISSs showing the converse relationship (27.3 ± 23.9 vs. 34.3 ± 22.1, $p < 0.001$). Of the 418 patients who survived RT and were admitted to the hospital, 70.1% (n = 293) sustained



ED = emergency room

Figure 3. Univariate association between age and mortality in the emergency department (ED) and after hospitalization.

Table 2. Injury Characteristics and Outcomes

		Injury Type		
	Overall	Single	Multiple	*p* Value
Injury severity score, mean ± SD	30.5 ± 3.5	27.3 ± 23.9	34.3 ± 22.1	<0.001
Injury site, n (%)				
Chest	927 (83.4)	296 (74)	631 (89)	<0.001
Abdomen	489 (44.0)	59 (15)	430 (61)	<0.001
Head	270 (24.3)	10 (3)	260 (37)	<0.001
Extremity	450 (40.5)	15 (4)	435 (62)	<0.001
Other	194 (17.5)	18 (5)	176 (25)	<0.001

SD = standard deviation.
Percentages obtained for those that died during hospitalization calculated from total n who survived beyond resuscitative thoracotomy (overall, N = 418 patients; multiple injuries, n = 293; single injuries, n = 125).

multiple injuries while 29.8% (n = 125) sustained a single-site injury (Table 2). Of survivors, mortality rates were similar between patients with multiple injuries and those with single injuries (95% vs. 90%, $p = 0.06$; Table 3). To identify if specific sites of injury had a significant association with mortality across age groups, we examined the univariate association between injury site against age and found no significant association with site of injury and mortality across age groups.

Finally, we performed 2 multivariate analyses to examine the adjusted interaction between mortality and age. The first analysis adjusted for ISS and found that age was not an independent predictor for mortality across age groups (Figure 4). The second multivariate analysis co-adjusted for multiplicity of injury as well as injury severity and similarly showed that age was not a significant predictor of death, though it should be noted that in the 60- and 70-year-old age groups, the mortality event rate was too low to adjust for both dependent variables (Figure 5).

DISCUSSION

Our study design was pragmatic in construction to reflect real-world circumstances in the trauma bay. For patients requiring immediate intervention, physicians are typically blinded to pre-existing patient comorbidities and functional status and are left with an assumption regarding probability of survival based on injury mechanism, severity, and location as well as presenting vital signs. While ideally a frailty index could be calculated on every patient in the trauma bay, there is seldom time to obtain a medical history before the need for intervention. Therefore, our study looked at chronologic age as a surrogate for markers of physiologic reserve as this can be estimated in real time and added to the decision-making process regarding probability of rescue.

Our study is the first to suggest that chronologic age is not an independent determinant of survival after RT. This is in opposition to our initial testing hypothesis, which stated that there would be an age range at which RT would become futile. In those who survived to admission, subanalysis suggests that age alone does not predict death. Moreover, our data describe that although the incidence of RT after penetrating trauma in the >65-year-old population is low, they do occur and have documented survival. This serves as an important commentary on real-world practice in the trauma community in the modern age.

Our study showed an overall mortality rate of 96.9%, yielding a 3.1% rate of survival to discharge. Conversely, our rate of failure to rescue was 61.8%, which translates to a near 38% success rate in recapturing patients who have lost vitals. Our analysis shows that within all age groups there is documented survival, which is a distinction from previously published works (8,12). In a retrospective cohort analysis of the National Trauma Data Bank, Gil et al. found no survival benefit for patients >57 years of age in either blunt or penetrating mechanisms (8). Similar to our study, their data showed an overall mortality rate of 92.9% with a failure to rescue rate of 65.6%. A separate analysis of TQIP performed by Joseph et al. examined utilization of and survival trends for RT for both blunt and penetrating mechanisms of injury

Table 3. Outcomes

		Injury Type		
Outcome, n (%)	Overall	Single	Multiple	*p* Value
Failure to rescue	687 (61.8)	273 (68.6)	414 (58.6)	0.001
Died during hospitalization	390 (93.3)	112 (90.0)	278 (94.9)	0.06
Overall mortality	1077 (96.9)	385 (96.7)	692 (97.9)	0.25

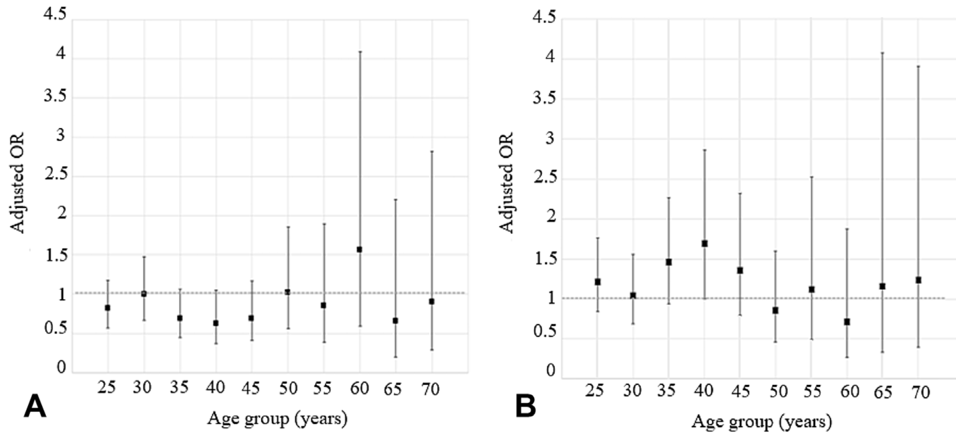


Figure 4. Association between age and mortality adjusting for injury severity score. Multivariate analysis adjusting for injury severity score in both the (A) emergency department and (B) after hospitalization. OR = odds ratio.

and found that while utilization of RT has decreased over time, survival has increased (13). In contrast to our study, they identified a 68% rescue rate and an overall survival of 9.6%. Moreover, they identified age <60 years as an independent predictor of survival while reporting a decline in survival in patients >50 years of age with blunt trauma and no survivors in those >70 years of age. Their study, however, included patients with signs of life on arrival to the ED and only one third required cardiopulmonary resuscitation before arrival, both of which likely contributed to higher survival.

Our theory that there was an age at which failure to rescue approached 100% was also predicated on injury pattern with the thought that a patient with multiple injuries would have a higher mortality in older age groups. We found the converse to be true, with single-injury patients having a significantly higher failure to rescue rate than patients with multiple injuries but a similar overall mortality for those rescued after hospitalization. This early difference in rescue rates is likely attributable to the nature of wounding patterns in each injury pattern cohort and the tendency of ISSs to undertriage mortality in single cavity injury (14). Interestingly, chest injuries accounted for most of the wounds in the single-injury cohort while patients with multiple injuries were likely to have injuries in nearly all body regions.

Our findings are suggestive of the growing body of research showing that chronologic age alone is often not the primary determinant in patient outcomes after trauma (13,15,16). Physiologic age (i.e., frailty) is an independent predictor of outcomes with higher rates of failure to rescue in trauma (17). Over 5 years, 48 RTs were performed on those ≥55 years of age with a near 34% rescue rate. For those that survived to admission, there was documented survival of ≥1 patient in each 5-year increment group. With more than a third of surveyed surgeons considering age in their decision to perform a RT, further studies are needed to define reproducible and

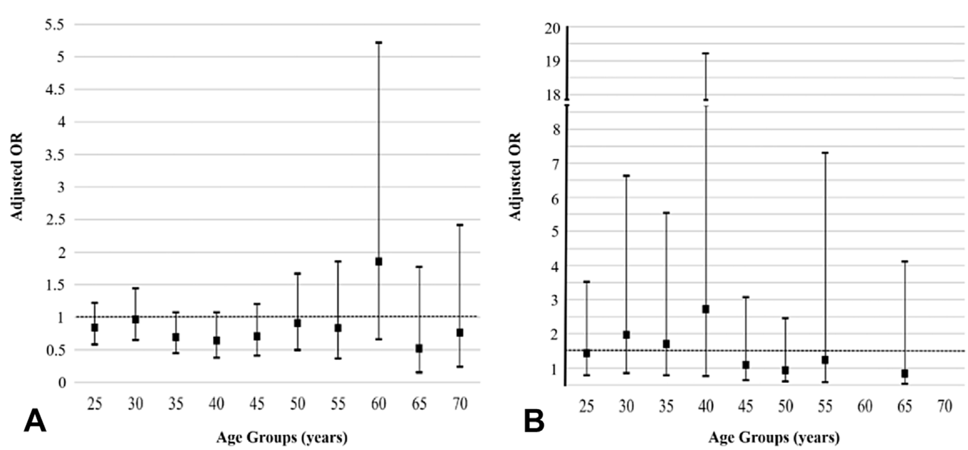


Figure 5. Association between age and mortality adjusting for injury severity and multiplicity of injury. Multivariate analysis adjusting for injury severity score and multiplicity of injury in both the (A) emergency department and (B) after hospitalization. OR = odds ratio.

validated ways to triage frailty in patients who are in extremis (7).

Limitations

This study has several limitations. First, it is subject to the limitations inherent to all retrospective database analyses, including errors in coding and missing data. Furthermore, the TQIP database itself is not a random sample and similar to other retrospective databases may have constraints in its generalizability to the general population. Perhaps the most salient limitation is the small sample size within the older age groups, which likely represents a selection bias in who and who would not undergo RT because of age. Though we conducted an a prior power analysis to assess whether we would be able to detect changes in mortality across age groups, we were only powered to show large differences in mortality but would otherwise be unable to show smaller changes. Nevertheless, our data set shows the largest possible sample size given our inclusion criteria. Given the rarity of thoracotomy in penetrating trauma, and that patients ≥65 years of age have lower rates of penetrating trauma, conducting a study sufficiently powered to detect small to moderate changes in mortality would be difficult. We feel this study provides equipoise for future analyses of national databanks in an effort to yield higher analytical and statistical power. While difficult to address however, our study represents a review of a national cohort spanning half a decade and therefore represents the largest possible assemblage of cases within our inclusion criteria. The lack of a standard definition of RT within TQIP may pose potential bias as defining an RT requires ICD codes, pulselessness, and time stamps to secondarily designate recorded thoracotomies as resuscitative. However, it is unlikely that a thoracotomy performed on a pulseless penetrating trauma patient within 15 min of arrival would be reserved for indications other than resuscitative.

CONCLUSIONS

Age does not appear to be an independent predictor of failure to rescue or survival after RT in penetrating trauma and should not be the sole determinant determining candidacy for RT. The decision to perform a RT in penetrating trauma should incorporate multiple indicators of salvageability, including patient physiology, injury pattern, and markers of frailty. Further studies are needed to identify such metrics.

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REFERENCES

1. Baue AE. Immediate thoracotomy for a stab wound of the heart. JAMA 1963;186:521.
2. Moore EE, Knudson MM, Burlew CC, et al. Defining the limits of resuscitative emergency department thoracotomy: a contemporary Western Trauma Association perspective. J Trauma Acute Care Surg 2011;70:334–9.
3. Powell DW, Moore EE, Cothren CC, et al. Is emergency department resuscitative thoracotomy futile care for the critically injured patient requiring prehospital cardiopulmonary resuscitation? J Am Coll Surg 2004;199:211–5.
4. Burlew CC, Moore EE, Moore FA, et al. Western Trauma Association critical decisions in trauma: resuscitative thoracotomy. J Trauma Acute Care Surg 2012;73:1359–63.
5. Working Group, Ad Hoc Subcommittee on Outcomes, American College of Surgeon Committee on Trauma. Practice management guidelines for emergency department thoracotomy. J Am Coll Surg 2001;193:343–5.
6. Seamon MJ, Haut ER, Van Arendonk K, et al. An evidence-based approach to patient selection for emergency department thoracotomy: a practice management guideline from the Eastern Association for the Surgery of Trauma. J Trauma Acute Care Surg 2015;79:159–73.
7. Dennis BM, Medvecz AJ, Gunter OL, Guillamondegui OD. Survey of trauma surgeon practice of emergency department thoracotomy. Am J Surg 2016;212:440–5.
8. Gil AL, Abstadt MJ, Kothari AN, Javorski MJ, Gonzalez RP, Luchette FA. The National Trauma Data Bank story for emergency dep artment thoracotomy: how old is too old? Surgery 2018;163:515–21.
9. Bonne S, Schuerer DJ. Trauma in the older adult: epidemiology and evolving geriatric trauma principles. Clin Geriatr Med 2013;29:137–50.
10. Joseph B, Pandit V, Zangbar B, et al. Validating trauma-specific frailty index for geriatric patients: a prospective analysis. J Am Coll Surg 2014;219:10–171.
11. Holcomb JB, Tilley BC, Baraniuk S, et al. Transfusion of plasma, platelets, and red blood cells in a 1:1:1 vs a 1:1:2 ratio and mortality in patients with severe trauma: the PROPPR randomized clinical trial. JAMA 2015;313:471–82.
12. Joseph B, Khan M, Jehan F, Latifi R, Rhee P. Improving survival after an emergency resuscitative thoracotomy: a 5-year review of the Trauma Quality Improvement Program. Trauma Surg Acute Care Open 2018;3:e000201.
13. Joseph B, Pandit V, Zangbar B, et al. Superiority of frailty over age in predicting outcomes among geriatric trauma patients: a prospective analysis. JAMA Surg 2014;149:766–72.
14. Rowell SE, Barbosa RR, Diggs BS, et al. Specific abbreviated injury scale values are responsible for the underestimation of mortality in penetrating trauma patients by the injury severity score. J Trauma Acute Care Surg 2011;71(2 suppl 3):S384–8.
15. Joseph B, Jokar TO, Hassan A, et al. Redefining the association between old age and poor outcomes after trauma: the impact of frailty syndrome. J Trauma Acute Care Surg 2017;82:575–81.
16. Maxwell CA, Patel MB, Suarez-Rodriguez LC, Miller RS. Frailty and prognostication in geriatric surgery and trauma. Clin Geriatr Med 2019;35:13–26.
17. Joseph B, Phelan H, Hassan A, et al. The impact of frailty on failure-to-rescue in geriatric trauma patients: a prospective study. J Trauma Acute Care Surg 2016;81:1150–5.

ARTICLE SUMMARY

1. Why is this topic important?

Since established as a potential salvage for pulseless hemorrhagic shock after penetrating injury, defining the limits of resuscitative thoracotomy has been marred by studies encumbered with small sample sizes or single-center analyses. Though intuitively advancing age would appear to be a relative contraindication, data supporting this are varied. Given that wounding pattern, time since pulselessness, and an approximation of age are the only data points available for triaging, further inquiry into the effect of age on survival is paramount to determining the utility of resuscitative thoracotomy in older patients.

2. What does this study attempt to show?

This study attempts to show that chronologic age has a measurable effect on rate of rescue after pulselessness in penetrating trauma, and that in certain age ranges the rate of rescue approaches 0%, indicating futile care.

3. What are the key findings?

Contrary to our initial testing hypothesis that a complete failure to rescue would be encountered in older patients, we found that chronologic age was not independently associated with morality across all age groups.

4. How is patient care impacted?

This is a substantive finding because it may indicate that patient salvageability may be independent of patient age, with our assumption that physiological age bears more on survivability than chronologic age. As such, the determination to pursue resuscitative thoracotomy should not solely rely on the approximation of chronologic age. Further study needs to be undertaken to identify what other readily assessable factors in the trauma bay may portend dismal prognosis and thus help delineate candidacy for resuscitative thoracotomy.