Surgical outcomes after trauma pneumonectomy: Revisited

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BACKGROUND: Trauma pneumonectomy has been historically associated with an exceedingly high morbidity and mortality. The recent advent of standardized reporting and data-collecting measures has facilitated large volume data analysis on predictors and outcomes of trauma pneumonectomy. The purpose of this study is to describe patient characteristics and outcomes of the patients who underwent trauma pneumonectomy in the modern era and identify clinical factors associated with postoperative mortality.

METHODS: Data between 2007 and 2014 from the National Trauma Data Bank were used for analysis, which included patients with both blunt and penetrating trauma who underwent pneumonectomy within 24 hours after admission. Patient characteristics, injury data, and outcomes were analyzed. Postoperative survival was estimated using the Kaplan-Meier method. Multivariate logistic regression analysis was performed to identify variables associated with postoperative mortality.

RESULTS: A total of 261 patients were included for analysis. Of those, 163 (62.5%) patients sustained penetrating trauma. Less invasive lung resections were performed before pneumonectomy in 12.6% of patients. First 24-hour and in-hospital mortality were significantly higher in blunt trauma patients compared with penetrating trauma patients (54.1% vs. 34.1% and 77.6% vs. 49.1%, respectively; $p < 0.01$). In our multivariate logistic regression analysis, an admission Glasgow Coma Scale of less than 9 (odds ratio [OR], 2.16, 95% CI: 1.24–3.77, $p < 0.01$) and associated brain injury (OR, 2.11, 95% CI: 1.01–4.42, $p = 0.048$) were significantly associated with in-hospital death, whereas penetrating mechanism (OR, 0.36, 95% CI 0.19–0.70, $p < 0.01$) and less invasive lung resections before pneumonectomy (OR, 0.39, 95% CI: 0.17–0.87, $p = 0.02$) were significantly associated with survival to hospital discharge.

CONCLUSION: Trauma pneumonectomy remains a highly morbid procedure even in the modern era and should be reserved for carefully selected patients. (*J Trauma Acute Care Surg.* 2017;82: 927–932. Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Prognostic study, level IV.

KEY WORDS: Pneumonectomy; trauma; surgical outcomes; morbidity; mortality.

Most patients with both blunt and penetrating thoracic trauma can be successfully managed with tube thoracostomy and other supportive measures, whereas lung resections with various extents are required for the management of severe pulmonary or tracheobronchial injury.[1–4] One study showed that less than 0.1% of patients with blunt chest trauma and only 1.3% patients with penetrating chest trauma required any kind of lung resection.[5] In patients requiring lung resection after trauma, less invasive lung-sparing techniques (wedge resection and tractotomy) are associated with better postoperative outcomes compared to anatomic resections (lobectomy and pneumonectomy).[5–7]

Pneumonectomy, therefore, is rarely indicated for trauma in the modern era. Previous studies and case reports between the 1970s and 2000s repeatedly demonstrated very high mortality and morbidity after trauma pneumonectomy.[1–9] Furthermore, when pneumonectomy is performed in trauma patients with hemorrhagic shock, the mortality rate for pneumonectomy approaches 100%.[9] Poor outcomes after trauma pneumonectomy can be explained by significant, and oftentimes overwhelming cardiopulmonary stress, including a sudden increase in the pulmonary vascular resistance that can lead to severe right-sided heart failure.[10] Due to its rarity, very little is known about surgical outcomes after trauma pneumonectomy despite increasing knowledge and recent advances in resuscitation and postoperative management of this patient cohort in the intensive care unit (ICU).

The purpose of this study was to describe surgical outcomes in trauma patients requiring pneumonectomy using recently collected data from the National Trauma Data Bank (NTDB). We hypothesized that trauma pneumonectomy would be still associated with high postoperative mortality even in the modern era. In addition, we sought to identify independent risk factors associated with postpneumonectomy mortality.

PATIENTS AND METHODS

Patient Selection and Outcomes

Approval was obtained from the institutional review board at the University of Southern California. The NTDB was queried to identify all patients aged 16 years and older who underwent pneumonectomy for trauma (International Classification of Diseases [ICD]-9 codes 32.5 and 32.59) over a 7-year period (2007–2014). Patients transferred from an outside hospital and those that died upon arrival were excluded from the study. Variables extracted included patient demographics, comorbid conditions, injury mechanism, Abbreviated Injury Scale (AIS) for different body regions, injury severity score (ISS), and admission vital signs. Data regarding less invasive lung resections (wedge resection and/or lobectomy) before pneumonectomy and timing of each lung resection (hours from hospital admission) were also analyzed. Our primary outcome was in-hospital mortality. Secondary outcomes included 6-hour and 24-hour mortality, pulmonary complications, hospital length of stay, ICU length of stay, and ventilator days. Significant associated injury was defined as AIS greater than 2 in any body regions. Isolated chest injury was defined as chest trauma with no other associated injuries with an AIS greater than 2. Pulmonary hilar injury was defined as an injury to the pulmonary artery, vein, or main bronchus (AIS predot codes: 421002, 421004, 431006, 421008, 421099, 421202, 421204, 421206, 421299, 442602, 442604, 442606, 442608, 442610, 442699).

Statistical Analysis

Categorical variables were reported as percentages, while continuous variables were reported as medians with interquartile range. Continuous variables were also dichotomized using clinically relevant cutoff points. Survival curves were estimated by the Kaplan-Meier method. Postoperative survival rates were compared between blunt and penetrating injury using the log-rank test. Univariate analysis was performed to identify differences between two patient groups: survived to discharge versus death. The Mann-Whitney *U* test was used to compare continuous variables, whereas the Fisher's exact test or Pearson's χ^2 test was used to compare proportions for categorical variables. Multivariate logistic regression analysis was performed to identify independent predictors for in-hospital mortality. Multicollinearity testing was performed to identify the correlation between these variables. The accuracy of the test was calculated using the area under the curve with a 95% confidence interval (CI). Variables with p values less than 0.05 were considered significant.

RESULTS

A total of 261 patients (0.02% of all patients with blunt and penetrating trauma with AIS chest ≥1) were included for analysis. Of those, 62.5% underwent pneumonectomy after penetrating trauma (Table 1). The incidence of isolated thoracic injury was significantly higher in penetrating trauma patients (34.4% vs. 5.1%, $p < 0.001$). Blunt trauma patients had significantly higher ISS (37 vs. 21, $p < 0.001$). In addition, nearly half of blunt trauma patients sustained associated head injury (AIS ≥3) with decreased Glasgow Coma Scale (GCS) upon admission. In 78.9% of all cases, pneumonectomy was performed within 6 hours after admission. Less invasive lung resections (wedge resection and/or lobectomy) were performed before pneumonectomy in 12.6% of study patients. There was no significant difference in admission vital signs and severity of injuries between patients with and without less invasive lung resections before pneumonectomy.

Overall in-hospital mortality rate was 59.8% (Table 2). A blunt trauma mechanism was significantly associated with higher mortality compared to penetrating trauma (77.6% vs. 49.1%, $p < 0.001$). There were no significant differences in other outcomes, including hospital length of stay, ICU length of stay, and ventilator days between blunt and penetrating trauma patients. Postoperatively, 18 patients developed acute respiratory distress syndrome (ARDS). Of those, 10 (55.5%) patients survived discharge. Of 28 patients with pneumonia,

TABLE 1. Patient Characteristics and Outcomes Stratified by Injury Mechanism

	Total Patients (n = 261)	Blunt (n = 98)	Penetrating (n = 163)	p Value
Median age (IQR)	25 (20–38)	24 (20–38)	25 (21–37)	0.50
>50 y	32 (12.3%)	14 (14.3%)	18 (11.0%)	0.44
Male sex	208 (80.0%)	68 (69.4%)	140 (86.4%)	0.001
Premorbid conditions				
Smoking	15 (5.7%)	5 (5.1%)	10 (6.1%)	0.73
Diabetes	3 (1.1%)	1 (1.0%)	2 (1.2%)	1.00
Hypertension	13 (5.0%)	3 (3.1%)	10 (6.1%)	0.38
Respiratory disease	6 (2.3%)	1 (1.0%)	5 (3.1%)	0.42
SBP <90 mm Hg	72 (27.6%)	23 (23.5%)	49 (30.1%)	0.25
Median HR (IQR)	122 (98–138)	121.5 (98–140)	122.5 (98–136)	0.65
Median GCS	7.0 (3–15)	3.5 (3–14)	9.5 (3–15)	0.057
GCS <9	133 (51.0%)	60 (61.2%)	73 (44.8%)	0.01
Isolated thoracic injury	61 (23.4%)	5 (5.1%)	56 (34.4%)	<0.001
Pulmonary hilar injury	72 (27.6%)	30 (30.6%)	42 (25.8%)	0.40
Associated injuries				
AIS head >2	58 (22.2%)	46 (46.9%)	12 (7.4%)	<0.001
AIS abdomen >2	58 (22.2%)	35 (35.7%)	23 (14.1%)	<0.001
AIS extremities >2	53 (20.3%)	34 (34.7%)	19 (11.7%)	<0.001
Median ISS (IQR)	26 (16–38)	37 (27–45)	21 (16–29)	<0.001
ISS >15	225 (86.2%)	94 (95.9%)	131 (80.4%)	<0.001
Procedures before pneumonectomy				
Wedge resection	9 (3.4%)	0 (0%)	9 (5.5%)	0.015
Lobectomy	25 (9.6%)	11 (11.2%)	14 (8.6%)	0.48
Time to pneumonectomy				
≤6 h	206 (78.9%)	68 (69.4%)	138 (84.7%)	0.003
In-hospital mortality	156 (59.8%)	76 (77.6%)	80 (49.1%)	<0.001
<6 h after admission	89 (34.0%)	41 (41.8%)	48 (29.4%)	0.041
<24 h after admission	109 (41.8%)	53 (54.1%)	56 (34.4%)	0.002
Median hospital length of stay (IQR)	18.5 (8–33.5)	20 (9–31)	16 (7–33.5)	0.57
Median ICU length of stay (IQR)	12 (4–23)	14 (6.5–26.5)	10 (4–21)	0.08
Median ventilator days (IQR)	7 (2.5–20)	6 (3–20)	7 (2–19)	0.77
Pulmonary complications*				
ARDS	10 (9.5%)	3 (13.6%)	7 (8.4%)	0.43
Pneumonia	25 (23.8%)	6 (27.3%)	19 (22.9%)	0.67
Empyema	4 (3.8%)	1 (4.5%)	3 (3.6%)	1.00
Pulmonary embolism	4 (3.8%)	1 (4.5%)	3 (3.6%)	1.00
Overall	35 (33.3%)	9 (40.9%)	26 (31.3%)	0.40

*Only patients who survived to discharge were included.
IQR, interquartile range; SBP, systolic blood pressure; HR, heart rate.

TABLE 2. Clinical Factors Associated With Postoperative Mortality

	Survived (n = 105)	Death (n = 156)	*p* Value
Median age (IQR)	25 (21–39)	25 (20–36.5)	0.58
>50 y	13 (12.4%)	19 (12.2%)	0.96
Male sex	85 (81.7%)	123 (78.8%)	0.57
Penetrating injury	83 (79.0%)	80 (51.3%)	<0.001
SBP <90 mm Hg	30 (28.6%)	42 (26.9%)	0.77
HR >120 bpm	59 (56.2%)	81 (51.9%)	0.50
GCS <9	39 (37.1%)	94 (60.3%)	<0.001
Isolated thoracic injury	31 (29.5%)	30 (19.2%)	0.054
Pulmonary hilar injury	27 (25.7%)	45 (28.8%)	0.58
Associated injuries			
AIS head >2	12 (11.4%)	46 (29.5%)	0.001
AIS abdomen >2	18 (17.1%)	40 (25.6%)	0.11
AIS extremities >2	14 (13.3%)	39 (25.0%)	0.022
Median ISS (IQR)	21 (16–29)	30 (21–45)	<0.001
ISS >15	82 (78.1%)	143 (91.7%)	0.002
Procedures before pneumonectomy			
Wedge resection	7 (6.7%)	2 (1.3%)	0.033
Lobectomy	14 (13.3%)	11 (7.1%)	0.09
Wedge and/or lobectomy	20 (19.0%)	13 (8.3%)	0.011
Time to pneumonectomy			
≤6 h	79 (75.2%)	127 (81.4%)	0.23

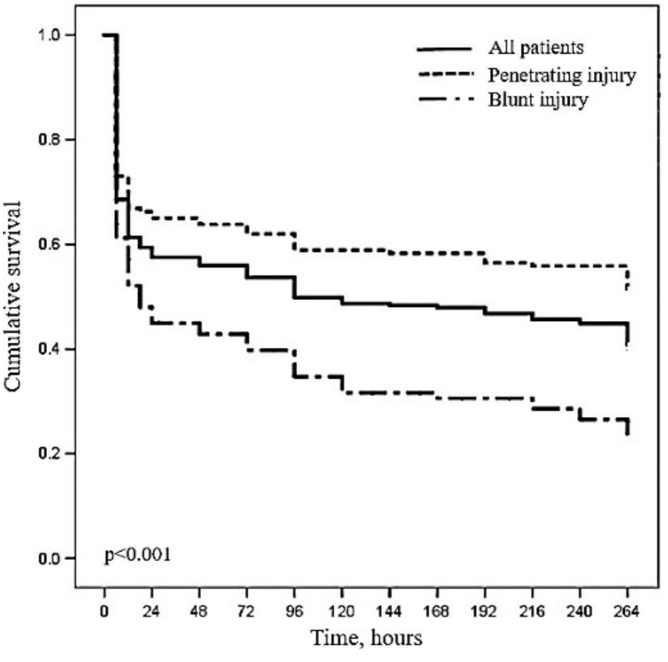
25 (89.3%) patients were discharged alive. Nearly half of patients with isolated thoracic injury died during their hospital stay (30 of 61, 49.2%). Figure 1 demonstrates the Kaplan-Meier curve of the cumulative risk of postoperative mortality. Of note, 57.1% and 69.9% of all deaths occurred within 6 hours and 24 hours after admission, respectively. Both 6-hour and 24-hour patient survival rates were significantly higher in penetrating injury patients. After adjusting for clinically significant covariates in the logistic regression analysis, associated head injury (AIS >2) and admission GCS less than 9 were significantly associated with an increased risk of in-hospital mortality (odds ratio, 2.11 and 2.16, respectively, $p < 0.05$) (Fig. 2). In contrast, penetrating mechanism and wedge resection and/or lobectomy before total pneumonectomy were significantly associated with higher odds of survival to hospital discharge.

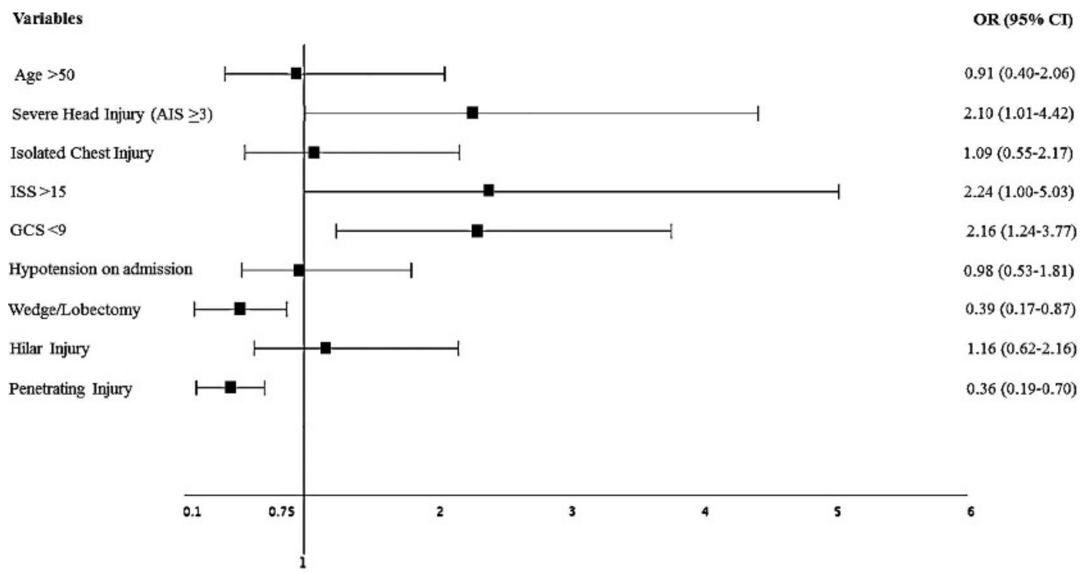
DISCUSSION

In this current study, which uses a recent large national database, we found that the mortality risk after trauma pneumonectomy remains high despite improvements in the management of thoracic trauma. The majority of mortality cases were within the early postoperative period. On the other hand, patients who survived the first 24 hours were more likely to survive to hospital discharge. To our knowledge, this study includes the largest number of patients who underwent pneumonectomy after blunt or penetrating trauma. Our results suggest that this morbid trauma procedure should be performed in carefully selected patients and to pursue less-invasive, lung-sparing procedures when possible.

Similar to injury patterns in other body regions, the concept of damage control surgery has been applied in the last few decades to the operative management of severe thoracic injury.[11–14] Rapid lung-sparing procedures including pulmonary tractotomy, nonanatomic lung resections using linear staplers followed by temporary thoracic closure are indicated in patients with severe coagulopathy, acidosis, and hypothermia.[15] Furthermore, in the early 1990s, a rapid simultaneously stapled pneumonectomy using a TA stapler was proposed by Hirshberg et al.[16] for patients with significant hemodynamic instability due to life-threatening major pulmonary vascular and/or bronchial injuries. Nonetheless, poor outcomes of these patients undergoing trauma pneumonectomy persisted in a series of 77 trauma pneumonectomy cases in the early 2000s.[8] Martin et al.[5] used a 2003 version of the NTDB to show a significantly higher mortality rate in trauma pneumonectomy patients compared to wedge resection or lobectomy (62% in total patients and 53% in patients with isolated lung injury). A decade after these reports, our study using a newer version of the NTDB showed essentially same results (59.8% in total patients and 49.2% in patients with isolated lung injury).

In addition to trauma cases, pneumonectomy is also performed for various benign or malignant lung diseases, mainly in an elective manner. Historically and anecdotally, outcomes for nontrauma patients who underwent a pneumonectomy seemed more favorable.[17] However, the operative mortality rate after pneumonectomy for nontrauma cases has been reported as high as 29%.[18] Bernard et al.[17] reviewed 639 patients who underwent pneumonectomy for malignancy and found that preexisting hematologic disease and completion pneumonectomy were significantly associated with postoperative mortality. Of 45 (7.0%) mortality cases, the most common cause of death was pneumonia and ARDS. In a single-center retrospetive study,





Klapper et al.[18] reported a significantly higher mortality rate in patients requiring urgent or emergent pneumonectomy for benign lung disease compared with elective surgery. Even after excluding trauma cases (7% of all cases), perioperative mortality after urgent or emergent pneumonectomy was nearly 50%. Because of its small sample size, no other clinical factors were significantly associated with mortality.

Pneumonectomy for trauma patients is almost universally performed in an either urgent or emergent manner. Detailed preoperative evaluation and optimization of surgical candidates cannot be reasonably performed. Furthermore, a surgical decision whether to perform a pneumonectomy has to be made in an expeditious manner before the patient develops any signs of physiological derrangement. Our data suggest that for blunt trauma patients with decreased GCS with suspected brain injury, pneumonectomy might need to be deferred as an initial damage control operation and alternative damage-control techniques used, such as hilar occulusion with a vascular clamp or en masse ligature.[12] In contrast, patients with an isolated penetrating wound to the pulmonary hilum might be an adequate candidate for a primary pneumonectomy.

Another strength of this study is that we analyzed the timing of death after trauma pneumonectomy. Notably, we found that more than half of patients died within 6 hours and 70% died within 24 hours after admission in both blunt and penetrating patient groups. These results suggest that, in addition to selecting appropriate patients for pneumonectomy, it would be imperative to provide comprehensive, tailored ICU care in the immediate postoeprative period for better patient outcomes. Despite widely accepted "damage control resuscitation," uncontollable hemorrhage due to overall high injury burden in patients with multisystem trauma still appears to be one of the main causes of death after trauma pneumonectomy. In addition, a high incidence of early mortality in patients even with isolated thoracic injury might also contribute to other known, early complications, such as right heart failure or air embolism.[5,8,10] Infectious complications are known to be associated with worse outcome after pneumonectomy.[18] Our analyses similarly found a high incidence of postoperative pulmonary complications, including ARDS with refractory hypoxia and heart failure. Severe refractory hypoxia can worsen right heart failure, which makes postoperative care of these patients extremely challenging.

We believe that novel findings in our study, notably the specific risk factors in blunt and penetrating trauma patients that favor (or dissuade) trauma pneumonectomy, will raise further discussions about risk stratification and patient selection. Of those that survive, there remain potential options in postoperative care including ventilatory modes or extracorporeal membrane oxygenation. Particularly for patients who developed severe respiratory failure due to pneumonia or ARDS in the remaining lung, the use of extracorporeal membrane oxygenation has become a valuable option in both military and civilian settings.

There are several limitations to this study. First, the cause of death could not be identified in this patient cohort. In the majority of patients who died within 24 hours after admission, either major hemorrhage, air embolism, or right heart failure was likely the primary cause of death. After 24 to 48 hours, patients may have died of multiple, potential etilogies including associated traumatic brain injury, or other major complications related to significant injury burden. Second, although pulmonary hilar injury is the most common indication for trauma pneumonectomy, we found that only 27.6% of our study patients had hilar injuries. Despite using ICD-9 predot codes, we may not have fully captured patients with hilar injuries if these injuries were not properly coded in the NTDB. Third, we were unable to evaluate the impact of the laterality of pneumonectomy on outcomes. A right-side pneumonectomy is significantly associated with a higher mortality in nontrauma cases, although the underlying mechanism remains unclear.[19] The use of the newer ICD-10 codes in future data sets could potentially stratify the risk of specific laterality in the trauma pneumonectomy. Lastly, we were not able to include detailed data of perioperative management including fluid resuscitation, ventilatory management, and hemodynamic support. The lack of transfusion data in the NTDB precluded us from exploring the impact of resuscitation in the operating room and ICU on patient outcomes. Future prospective studies are warranted to explore an ideal perioperative resuscitation strategy after trauma pneumonectomy.

CONCLUSION

Despite recent advances in trauma care, surgical outcomes after pneumonectomy remain unsatisfying. Although trauma pneumonectomy is rarely indicated, operating surgeons should take multiple clinical factors into consideration before proceeding with this highly morbid procedure.

AUTHORSHIP

K.M., A.A., C.P., D.R., A.S., E.B., K.I., D.D. participated in the study concept, design. K.M., A.A., C.P., D.R. participated in the data collection and analysis. K.M., A.A., C.P., D.R. participated in writing. A.S., E.B., K.I., D.D. participated in the critical revision.

DISCLOSURE

The authors declare no conflicts of interest.

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