Patient factors and operating room resuscitation predict mortality in traumatic abdominal aortic injury: A 20-year analysis

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Background: **Injuries to the abdominal aorta are rare and remain one of the most lethal causes of early death in trauma. The purposes of this study were to identify primary predictors of mortality and to examine the impact of a well-established operating room resuscitation protocol on survival in patients with traumatic aortic injury.**

Methods: **A 20-year retrospective review was performed of medical records and autopsy reports of trauma patients admitted with confirmed injury to the abdominal aorta. Data on patient demographics, admission characteristics, operative findings, and the initial location of resuscitation were collected. The main outcome measure was death.**

Results: **Abdominal aortic injuries were diagnosed in 60 patients. Their average age was 26.5 years, and the mean transport time was 10 minutes. The overall mortality rate (MR) was 73%. With the exclusion of 18 patients considered dead on arrival, the MR decreased to 61%. The mechanism of injury was blunt in 20% (MR 92%) and penetrating in 80% (MR 68%). Acidosis, defined as a pH <7.2 (MR 81%) or a base deficit >10 (MR 77%), was a predictor of death (*P* < .0001). Patients resuscitated directly in the operating room had a significantly lower MR (40%) than those resuscitated in the trauma room (MR 78%; *P* < .02). The lack of retroperitoneal tamponade (*P* < .02), the presence of associated intra-abdominal injuries (*P* < .001), and the location of aortic injury at the subdiaphragmatic (18%; MR 90%) or suprarenal location (37%; MR 71%; *P* < .005) at exploration resulted in significantly higher patient mortality. Surgical management consisted of primary repair in 26, end-to-end repair in 1, interposition graft in 8, or patch in 1. Resuscitative thoracotomy was performed in 27 patients (45%), with an overall MR of 92%.**

Conclusion: **Despite advances in fluid resuscitation, operative strategy, and transport during the past 20 years, the mortality of traumatic injury to the abdominal aorta remains high. Shock, acidosis, suprarenal aortic injury, and a lack of retroperitoneal tamponade all independently contribute to mortality and should raise the suspicion for a potentially lethal aortic injury in a severely injured patient. Rapid identification and resuscitation in the operating room may therefore be the only factors to improve current survival rates in such devastating injuries. (J Vasc Surg 2007;45:493-7.)**

Traumatic injury to the abdominal aorta is one of the most fatal injuries sustained by patients in modern times. Many victims die of exsanguinating hemorrhage on the scene or en route to the hospital. Those who do survive transport often arrive in a profound state of shock and require significant life-saving measures for both their aortic and often numerous associated injuries. These factors make the patient with traumatic aortic injury one of the most difficult and challenging to treat.[1-5]

Despite the use of newer techniques such as intravenous fluid restriction, damage control laparotomy, and aggressive rewarming, the incidence of death in this subgroup of patients remains high. Studies from our institution and others since 1996 have consistently reported mortality rates (MRs) of 50% to 78%.[1,6-8] The survival of these patients therefore depends on a high index of suspicion and early recognition of the aortic injury, followed by a prompt and organized plan for management. The purposes of this study were to identify primary predictors of mortality through a risk analysis of the association between potential outcome predictors and patient death and to examine the impact of a well-established resuscitation protocol, including resuscitation directly in the operating room (OR), on survival in patients with traumatic abdominal aortic injury.

METHODS

This study received approval from the Human Research Protections Program of the University of California, San Diego (UCSD) and from the Institutional Review Board. From January 1985 to January 2005, all patients admitted to the UCSD Medical Center, a level I trauma center, who sustained an abdominal aortic injury were identified through our trauma registry database and retrospectively reviewed. The presence of an abdominal aortic injury was identified at time of laparotomy or autopsy. Medical records and autopsy reports were used to supplement data collection. A postmortem examination was performed for every death. All deaths were reviewed and presented to the San Diego County Medical Audit Committee for preventability according to published criteria.[9]

Data obtained included demographics, mechanism of injury, transport time, trauma score, injury severity score (ISS), admission vital signs, the presence of shock at admis-

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Competition of interest: none.

This study was presented at the 2007 Western Vascular Conference, San Diego, Calif, Sept 16-19, 2006.

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0741-5214/$32.00

doi:10.1016/j.jvs.2006.11.018

sion (systolic blood pressure <90 mm Hg), location where the initial resuscitation took place, and mean time to operation.

Since the conception of this study in 1985, initial patient resuscitation is carried out in either the trauma room or directly in the OR. The location of resuscitation is determined by established criteria after the initial patient report is received by the trauma nurse from emergency medical services. Because of the short transport times in San Diego County and the large mobilization of resources required for OR resuscitation (OR resus), once the initial decision on location is made, it is not changed despite potential patient improvement of decompensation during transport.

The institutional criteria for OR resus include traumatic amputation, impending airway compromise in penetrating neck injury, penetrating torso trauma with hemodynamic instability, hypotension unresponsive to fluid resuscitation, and cardiopulmonary resuscitation in progress. In the OR resus protocol, the patient is resuscitated on the OR table in the presence of additional staff, including an anesthesiologist for rapid intubation and OR staff for immediate operative intervention, if necessary.

Operative findings were also documented, including the presence of retroperitoneal tamponade, the type of surgical procedure used to manage the injury including the need for a resuscitative thoracotomy, and the number of associated abdominal injuries. The location of all aortic injuries was graded by the abdominal vasculature organ injury scale (OIS) of the American Association for the Surgery of Trauma.[10] The location of injury was defined as subdiaphragmatic, suprarenal (OIS = 5) or infrarenal (OIS = 4).

Death was defined as the primary outcome measure. Patients dead on arrival (DOA) were excluded from the mortality analysis. The statistical significance between variables and the MR was determined by χ^2, the Fisher exact test, or Student *t* test, where appropriate. Significance was defined as a value of $P < .05$. In addition, the odds ratio was calculated for categoric data and represents the relative risk of death occurring in the presence of a predisposing factor (ie, one of the above variables).

The independent contribution of each variable on patient mortality was assessed using a multiple logistic regression model. Variables with a $P < 0.1$ in the univariate analysis were included in the model.

RESULTS

During the 20-year study period (January 1985 to January 2005), 60 patients were admitted to the UCSD trauma service with abdominal aortic injuries. This population had an average age of 26.5 years (range, 15 to 52 years), and 47 were men (78%) and 13 were women (22%). The average transport time was 6.8 minutes by helicopter (11%) and 12.4 minutes (89%) by ground for a mean transport time of 10 minutes.

The mechanism of injury was blunt in 20% (n = 12; MR, 92%) and penetrating in 80% (n = 48; MR, 68.7%; Fig). Motor vehicle accidents carried the lowest mortality of the blunt injuries (MR = 67%), and pedestrians hit by vehicles and falls both resulted in a MR of 100%. Of those patients who sustained penetrating injury to the abdominal aorta, single stab wounds carried the lowest MR (35.7%), followed by multiple stab wounds (60%), single gun shot wounds (72.7%), multiple gun shot wounds (76%), and shot gun injuries (100%). The MR for all stab wounds was significantly lower than that for all blunt trauma combined ($P < .03$).

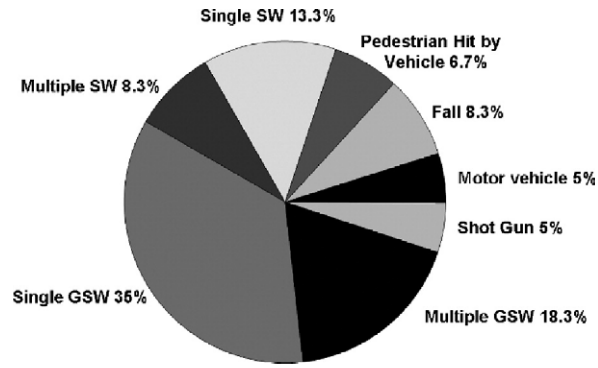

Fig. Mechanism of traumatic aortic injury in 60 patients. Penetrating mechanisms accounted for 80% (n = 48) of total aortic injuries, and 20% (n = 12) were secondary to blunt force. (*GSW,* Gunshot wound; *SW,* stab wound.)

The overall MR of patients with abdominal aortic injury was 73%. With the exclusion of 18 patients considered DOA, which accounted for 30% of the total deaths, the MR decreased to 61%. The MR did not significantly differ between patients admitted from 1985 to 1995 and from 1996 to 2005 (57% vs 71%; $P = .57$). The average ISS of DOA patients was 36, denoting the severity of their injuries. With the exclusion of patients DOA, 90% of patients admitted had a documented ISS >16. The MR of 77% in patients with an ISS >16 was significantly higher than the 20% MR for those with an ISS ≤16 ($P < .002$). By the same token, a trauma score of ≤10 (69%; MR, 79%) was also a predictor of mortality compared with those patients with a trauma score >10 (31%; MR, 18%; $P < .0001$).

The presence of shock at admission and acidosis have both been previously reported as contributors to morbidity and mortality after abdominal vascular injury.[6,11-14] On arrival at our institution, 69% of all patients were in shock (n = 29; MR, 83%; Table I). Of the 31% of patients who arrived hemodynamically stable, only 23% died ($P < .001$). Survivors also demonstrated less severe acidosis, characterized by a mean pH of 7.27 ± 0.04 and base deficit of 9.6 ± 1.9 vs nonsurvivors with an average pH of 7.05 ± 0.04 and base deficit of 17.9 ± 1.4. Acidosis, defined as a pH ≤7.2 (MR, 81%), or a base deficit ≥10 (MR, 77%) was a predictor of death ($P < .0001$).

The initial resuscitation was in the trauma bay for 22 patients (52%), and 20 (48%) were designated an OR resus. Despite a higher incidence of acidosis (mean pH 7.22 vs 7.09) in those patients undergoing OR resus, a significantly higher rate of survival (MR 40%) was observed in patients

Table I. Location of injury vs shock and mortality at admission

Location/OIS score	*Shock at admission (n/total)**	*In shock vs injury location (%)*	*Deaths (n)*	*MR (%)*
Subdiaphragmatic (OIS 5)	4/6	66.7	4	100
Suprarenal (OIS 5)	14/18	82.3	13	92.8
Infrarenal (OIS 4)	11/20	61.1	8	72.7

OIS, Organ injury scale; *MR,* mortality rate.
*Patients who were dead on arrival are excluded.

resuscitated in the OR vs those undergoing traditional resuscitation in the trauma room (MR 78%; $P < .02$) regardless of hemodynamic stability upon admission.

Decompensation occurred in 15 (68%) of the 22 patients who were initially hemodynamically stable at the start of transport and designated to undergo traditional resuscitation. They were in shock at the time of their admission to the trauma room and had a resulting MR of 100%. Of the 14 patients destined for OR resus, 70% continued to be hemodynamically unstable upon their admission, with a subsequent MR of 57% ($P < .006$).

All patients received an exploratory laparotomy during their admission. The mean time to laparotomy in the OR resus group was 10 ± 1 minutes (range, 8 to 12 minutes). In contrast, those patient resuscitated in the trauma room had a markedly longer mean time to laparotomy of 29 ± 6 minutes (range, 18 to 70 minutes; $P < .005$). On exploration, nonsurvivors had a markedly higher number of associated intra-abdominal injuries compared with those who survived (6 ± 1.1 versus 2 ± 0.3; $P < .001$). Concomitant injury to the inferior vena cava was observed in 15 patients (25%). The presence of a retroperitoneal hematoma was documented in 20 patients (48%), with 12 survivors (MR, 60%). Free bleeding into the abdominal cavity was seen in 22 patients (52%) and was an additional predictor of mortality (MR, 81%; $P < .02$). The location of aortic injury was graded according to the OIS. Mortality according to injury site is summarized in Table II. Survival was significantly higher in those patients with an infrarenal injury (OIS = 4) compared with those patients with injuries in the subdiaphragmatic or suprarenal aorta (OIS = 5; $P < .005$). The number of associated intra-abdominal injuries between patients who sustained an aortic injury classified as an OIS of 4 or 5 did not differ (3.4 ± 0.6 vs 3.7 ± .4, respectively; $P = 0.6$).

Resuscitative thoracotomy was performed in 27 patients (45%) and was another significant predictor of mortality (MR, 92%; $P < .0001$). The mortality associated with each operative intervention is summarized in Table III. There were 21 intraoperative deaths secondary to exsanguination and subsequent cardiac arrest (75%). Four of six postoperative deaths occurred ≤24 hours after admission.

All but two deaths were considered nonpreventable after peer review by the Medical Audit Committee. One was judged potentially preventable had a different operative technique been followed. In the second case, postoperative rupture of the aortic suture line occurred, and the patient exsanguinated before a second repair could be completed. This was deemed an error in surgical technique.

Multivariate analysis and determination of independent predictors of patient mortality are summarized in Table IV. When adjusted for all other variables, a base deficit of ≥10, pH of ≤7.2, shock upon admission, lack of retroperitoneal tamponade, an OIS of 5, and initial resuscitation in the trauma room all remained statistically significant.

DISCUSSION

Traumatic injury to the abdominal aorta is fairly uncommon but highly lethal. Despite advances in fluid resuscitation, knowledge of coagulopathy, and the increased use of damage control laparotomy in the past 20 years, recently published MRs and those observed in this study, which range from 50% to 78%, do not differ from the first report by DeBakey et al[15,16] documenting abdominal aortic injury and associated mortality during World War II in 1946. Nonetheless, patients sustaining aortic trauma often arrive at modern trauma centers with signs of life because of rapid transport and improvements in prehospital emergency care. Therefore, although MRs remain unchanged, the potential chances for individual survival depend on the recognition of patient characteristics associated with potentially lethal injuries and the institution of a standardized patient management protocol focused on immediate intervention.

In this series, many of the patient factors found to be independent predictors of survival have been previously documented by other studies examining traumatic injuries to the aorta and abdominal vasculature. The presence of shock and acidosis at admission have been the factors most frequently cited as a determinants of mortality.[1-8,11-15,17,18] The number of associated injuries has also been previously correlated with outcome.[1,6,17,19] We observed that scoring systems such as the ISS and trauma score can be used as prognostic factors in abdominal aortic trauma, reflecting the basic concept that patients who are injured more severely and have more pronounced physiologic derangements secondary to shock have higher MRs.

The presence of a retroperitoneal hematoma, which tamponades ongoing exsanguination and increases the time the surgeon is allowed for operative control of the vessel, has also been previously shown to have a positive impact on survival.[6,12,17,20,21] This tamponade effect may explain why patients in this study who sustained a single stab wound to the aorta and minimal retroperitoneal damage have increased survival rates compared with those who sustained blunt mechanisms of injury in which the dense periaortic tissues that often play a role in containing the retroperitoneal hematoma are oftentimes disrupted.

The correlation between abdominal aortic injury location, OIS, and death has been demonstrated in earlier publications and confirmed by our recent analysis.[1,6,13] The number of associated intra-abdominal injuries did not differ in patients with aortic injuries at different anatomic

Table II. Location of injury vs mortality

Location (OIS score)	*N*	*Total deaths*	*Overall MR (%)*	*DOA*	*Deaths (non-DOA)*	*MR (%)**
Subdiaphragmatic (OIS 5)	11	10	91	5	5	90
Suprarenal (OIS 5)	22	17	77	3	14	70.5
Infrarenal (OIS 4)	27	17	63	10	7	41.1†

OIS, Organ injury score; *MR,* mortality rate; *DOA,* dead on arrival.
*Patients DOA were excluded.
†$P < .05$, infrarenal vs subdiaphragmatic and suprarenal

Table III. Operative repair vs location of aortic injury

Repair	*Subdiaphragmatic (OIS 5)*	*Suprarenal (OIS 5)*	*Infrarenal (OIS 4)*	*MR (%)*
Aortorrhaphy	6	7	13	33
Graft	1	6	1	83
Patch	0	0	1	0
End-to-end anastomosis	0	0	1	100
None	3	6	9	100
Total	10	19	9	61.2

OIS, Organ injury score; *MR,* mortality rate.

Table IV. Multivariate analysis of independent risk factors for mortality

Factor	P	*Odds ratio*
Base deficit ≥10	.001	17.5
pH ≤7.2	.001	17.3
Trauma room resuscitation	.02	6.8
Shock at admission	.001	15
Lack of retroperitoneal tamponade	.03	1.9
Organ injury score = 5	.05	4.5

locations; thus, the increased MR observed with subdiaphragmatic and suprarenal injuries vs those in the infrarenal location may be a result of the difficult and time-consuming techniques necessary for operative exposure near the diaphragm or celiac plexus.

The goal of these prognostic factors as a whole is to alert the surgeon to a potentially lethal injury; however, most cannot be modified for the purpose of increasing patient survival. Although it has been assumed that decreasing length of time from admission to operation would result in a decrease in mortality,[17,18,22,23] few studies, with the exception of the one by Halpern and Aldrete[19] and our own, emphasize the importance of a structured protocol as a potential strategy for reducing death after aortic trauma.

At first glance it may seem that our institutional protocol was not followed strictly because both hemodynamically stable and unstable patients were encountered in both the trauma room and the OR. We must emphasize, however, that the decision on the location of resuscitation is determined by the first report given to our institution. The decision is not altered despite changes in the patient's condition in transport to avoid confusion on behalf of the treatment team in the face of such short transport times. Therefore, patients who were designated initially as hemodynamically stable and subsequently decompensated are triaged to the trauma room, and patients who were initially hypotensive but later respond to fluid administration or in whom vitals could not initially be obtained are admitted directly to the OR.

The trauma room and the OR designed for resuscitation have equivalent equipment to deal with critical patients, such as fluid warmers and rapid infusion devices, making differences in resources unlikely to account for the significant differences we observed in mortality. To our knowledge, our study is the first to present an institutional OR resuscitation protocol that results in an increase in survival in patients after aortic trauma by minimizing the delay between admission and laparotomy.

These results seem promising, but this study is retrospective in nature, has a small sample size, and is the experience of a single institution, which limits its interpretation. The variations in surgical skills and experience of each operating physician may also affect patient outcome, but the particular advantages of any one surgeon are difficult to prove. Only two deaths in 20 years were considered potentially preventable; therefore, the contribution of individual surgeon experience to our analysis is minimal.

The operative approach to traumatic abdominal aortic injury and associated retroperitoneal hematomas should be performed in a timely manner and follow the methodology popularized by Feliciano.[4,5,24] In this organized approach, the location of the retroperitoneal hematoma, or zone, dictates the exposure method. Exposure to the aortic hiatus, celiac plexus, origin of the superior mesenteric artery, and the left renal vascular pedicle can be obtained through medial rotation of the left sided viscera anterior to the kidney. As an alternative, an extended Kocher maneuver, with medial mobilization of the right colon, hepatic flexure, duodenum, and head of the pancreas, can more quickly expose the suprarenal aorta between the celiac axis and the superior mesenteric artery but not the aortic hiatus. Exposure to the infrarenal aorta includes the reflection of the transverse colon cephalad, eviscerating the small bowel to the right, and transecting the ligament of Treitz and associated tissues until the left renal vein is located.[15]

The basic principles of vascular and trauma surgery should be strictly adhered to, including adequate proximal and distal control, the use of primary repair when possible, avoidance of tension and narrowing at the repair site, and the prevention of clot embolization. The use of heparin is not routine and is contraindicated in the face of concomitant factors such as blunt solid organ and closed head injuries.

With the rapid development of endovascular techniques and graft technology in recent years, the potential application of stents for aortic repair after trauma has been investigated. In studies by Berthet et al[25] and Teruya et al,[26] stent grafts have been successful in the repair of abdominal aortic dissection after blunt trauma, making it a viable alternative in hemodynamically stable patients. The shortest time period to intervention in any of the cases published is 2 hours, making this impractical for patients admitted to the hospital in extremis with severe blunt injury or penetrating aortic trauma. As is often the case with these critically injured patients, the diagnosis of aortic injury may not be discovered until a retroperitoneal hematoma or free bleeding into the peritoneum is encountered during exploratory laparotomy, which necessitates an operative repair in the face of ongoing exsanguination rather than endovascular stent placement.

CONCLUSION

The presence of shock, acidosis, associated intra-abdominal injuries, and a lack of retroperitoneal tamponade are all significant predictors of mortality after abdominal aortic trauma. Therefore, despite the persistence of high mortality rates, the implementation of a standardized OR resuscitation protocol has the potential to significantly increase survival in this critically injured patient population.

AUTHOR CONTRIBUTIONS

Conception and design: JD, ES, PS, DH, BP, RC
Analysis and interpretation: JD, DF, RC
Data collection: JD, DF, ES, PS
Writing the article: JD, RC
Critical revision of the article: RC
Final approval of the article: DH, RC, BP
Statistical analysis: DF, RC
Obtained funding: DH, BP, RC
Overall responsibility: JD

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Submitted Aug 29, 2006; accepted Nov 4, 2006.