Current management of hemorrhage from severe pelvic fractures: Results of an American Association for the Surgery of Trauma multi-institutional trial

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BACKGROUND: There is no consensus as to the optimal treatment paradigm for patients presenting with hemorrhage from severe pelvic fracture. This study was established to determine the methods of hemorrhage control currently being used in clinical practice.

METHODS: This prospective, observational multi-center study enrolled patients with pelvic fracture from blunt trauma. Demographic data, admission vital signs, presence of shock on admission (systolic blood pressure < 90 mm Hg or heart rate > 120 beats per minute or base deficit < −5), method of hemorrhage control, transfusion requirements, and outcome were collected.

RESULTS: A total of 1,339 patients with pelvic fracture were enrolled from 11 Level I trauma centers. Fifty-seven percent of the patients were male, with a mean ± SD age of 47.1 ± 21.6 years, and Injury Severity Score (ISS) of 19.2 ± 12.7. In-hospital mortality was 9.0 %. Angioembolization and external fixator placement were the most common method of hemorrhage control used. A total of 128 patients (9.6%) underwent diagnostic angiography with contrast extravasation noted in 63 patients. Therapeutic angioembolization was performed on 79 patients (5.9%). There were 178 patients (13.3%) with pelvic fracture admitted in shock with a mean ± SD ISS of 28.2 ± 14.1. In the shock group, 44 patients (24.7%) underwent angiography to diagnose a pelvic source of bleeding with contrast extravasation found in 27 patients. Thirty patients (16.9%) were treated with therapeutic angioembolization. Resuscitative endovascular balloon occlusion of the aorta was performed on five patients in shock and used by only one of the participating centers. Mortality was 32.0% for patients with pelvic fracture admitted in shock.

CONCLUSION: Patients with pelvic fracture admitted in shock have high mortality. Several methods were used for hemorrhage control with significant variation across institutions. The use of resuscitative endovascular balloon occlusion of the aorta may prove to be an important adjunct in the treatment of patients with severe pelvic fracture in shock; however, it is in the early stages of evaluation and not currently used widely across trauma centers. (*J Trauma Acute Care Surg.* 2016;80: 717–725. Copyright © 2016 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Prognostic study, level II; therapeutic study, level III.

KEY WORDS: Pelvis; hemorrhage control; angioembolization; REBOA.

Patients presenting with hemodynamic instability associated with pelvic fractures constitute one of the biggest challenges for trauma surgeons. Traumatic pelvic fractures may result in serious hemorrhage, which can be associated with significant morbidity and mortality.[1,2] Bleeding from pelvic fractures can potentially arise from several sources including arterial injury, venous injury, and bleeding from fractured bone. Therefore, identifying patients at risk for severe hemorrhage from pelvic injury and deploying the optimal resources and treatment strategies to promptly control bleeding are critical.

The treatment of patients with severe pelvic fracture can include a multidisciplinary effort with interventions delivered in the trauma resuscitation bay, the operating room, or the interventional radiology (IR) suite.[3] Arterial injury caused by pelvic fracture may require therapeutic arterial embolization, which has been shown to be an important adjunct in the treatment of patients with pelvic hemorrhage.[4] Bleeding from fractured bone within the pelvis can be controlled with stabilization of the fracture using fixation techniques.[5] Preperitoneal pelvic packing in the operating room has been favored in some trauma centers in the United States to control hemorrhage from pelvic fracture by tamponading both venous and arterial sources of bleeding and is considered by many as a bridge to angiography.[6] However, recently, resuscitative endovascular balloon occlusion of the aorta (REBOA) has been considered as a means of hemorrhage control in patients with severe pelvic fracture in shock as a temporizing measure until definitive bleeding control can be obtained.[7,8]

Most patients that present in shock are bleeding from the chest and/or abdomen; therefore, the need for urgent pelvic hemorrhage control is a relatively infrequent occurrence after pelvic fracture, making comparative analysis of different methods of treatment difficult.[6,9] As a result, there have been no large studies comparing the effectiveness of each different method used to obtain hemorrhage control in patients with pelvic fracture. Currently, there is no consensus as to the optimal treatment paradigm for patients presenting with severe pelvic fracture.[10] It is clear that rapid hemorrhage control is associated with improved survival.[11] It is unclear, however, how often each method of hemorrhage control is used in Level I trauma centers across the United States. Therefore, a prospective multi-institutional observational study is critical to establish how each method is currently being used in clinical practice.

PATIENTS AND METHODS

Patient Selection

This prospective, multicenter, observational study was conducted through the American Association for the Surgery of Trauma (AAST) Multi-Institutional Trials Committee. Patients were enrolled from 11 participating Level I trauma centers during

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This study was presented at the 74th annual meeting of the American Association for the Surgery of Trauma, September 9–12, 2015, in Las Vegas, Nevada.

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a 2-year period ending in January 2015. Data collection was approved by the institutional review board at each participating center. Adult trauma patients 18 years or older admitted to a Level I trauma center with pelvic fracture from blunt trauma were eligible for enrollment. Patients with isolated hip fractures, penetrating mechanism of injury, and pregnancy were excluded. Because this was an observational study, all diagnostic studies and clinical decisions were carried out at the discretion of the attending trauma surgeon and trauma center protocols at each participating center.

Patient Data Collection

Demographic data, injury mechanism, vital signs, and laboratory studies including pH, base deficit, and hematocrit were collected at the time of admission. Injury Severity Score (ISS) and the highest Abbreviated Injury Scale (AIS) score in each anatomic region were collected. Radiology studies performed were recorded including x-ray, pelvic computed tomography (CT) scan, pelvic CT angiography, and pelvic digital subtraction angiography. Methods of pelvic hemorrhage control including pelvic binder placement, angiographic embolization, external fixator placement, preperitoneal pelvic packing, and REBOA were collected. Transfusion of blood products, ventilator days, intensive care unit (ICU) and hospital lengths of stay (LOS), discharge disposition, and in-hospital mortality were also recorded. All data were collected through the AAST Multi-Institutional Trials online data entry system.

Data Analysis

The primary outcome assessed was the frequency of each method of hemorrhage control used for patients with pelvic fracture. A subset analysis was performed on patients admitted with hemodynamic instability (systolic blood pressure [SBP] < 90 mm Hg or heart rate [HR] > 120 beats per minute or base deficit > 6) caused by pelvic fracture to determine outcomes in this population of severely injured patients. Data are presented as the mean ± SD, the median ± interquartile range (IQR) or the raw percentage score, where appropriate. Data analysis was performed using IBM SPSS Statistics version 21.0 (Armonk, NY).

TABLE 1. Demographics of the Study Population

	All Pelvic Fractures
N	1,339
Age, y	47.1 ± 21.6
Male, n (%)	762 (56.9)
Mechanism, n (%)	
Motor vehicle crash	494 (36.9)
Fall	343 (25.6)
Pedestrian vs. auto	220 (16.4)
Motorcycle crash	149 (11.1)
Bicycle	22 (1.6)
All-terrain vehicle crash	14 (1.0)
Crush	13 (1.0)
Other	84 (6.3)
Admission vital signs	
SBP, mm Hg	126.1 ± 29.0
Heart rate	93.9 ± 23.7
Admission pH	7.31 ± 0.12
Admission base deficit	−3.9 ± 5.9
Admission GCS score	13.2 ± 3.8
ISS	17.0 (9.0–27.0)
Head AIS score ≥ 3, n (%)	266 (19.9)
Chest AIS score ≥ 3, n (%)	437 (32.6)
Abdomen AIS score ≥ 3, n (%)	278 (20.8)
Extremity AIS score ≥ 3, n (%)	672 (50.2)
ICU LOS, d	4.0 (2.0–10.0)
Ventilator, d	5.0 (2–10)
Hospital LOS, d	6.0 (3.0–13.0)
Discharge disposition, n (%)	
Home	587 (43.8)
Rehabilitation facility	287 (21.4)
Skilled nursing facility	229 (17.1)
Acute care facility	76 (5.7)
Other	39 (3.0)
Mortality (%)	121 (9.0)

Mean ± SD or median (IQR) where appropriate.
IQR, 25th and 75th IQR.

RESULTS

There were 46,716 trauma patients admitted at 11 Level I trauma centers during the study period. A total of 1,339 patients with pelvic fracture were enrolled (Table 1). The majority of patients were male (n = 762, 56.9%), with a mean age of 47.1 ± 21.6 years. The most common mechanism of injury was motor vehicle crash (36.9%) followed by falls, pedestrian versus auto, and motorcycle crash. The mean ISS was 19.2 ± 12.7. Patients with pelvic fracture had a mean ICU LOS of 8.2 ± 10.2 days and a mean hospital LOS of 10.9 ± 14.1 days. Less than 50% of the patients admitted with pelvic fracture were discharged home. The overall mortality was 9.0%.

A majority of the patients with pelvic fracture were diagnosed using pelvic x-ray (84.6%) and CT scan of the pelvis (Table 2). A pelvic binder was placed in 141 patients (10.5%). Angiography was performed in 9.6% of pelvic fracture patients to diagnose a pelvic source of bleeding, with contrast extravasation seen in 49.2% of patients. The most common indication for pelvic angiography was hemodynamic instability and concern for ongoing hemorrhage, followed by blush on CT scan and large pelvic hematoma seen on CT scan. Therapeutic angioembolization was performed in 79 patients (5.9%) admitted with pelvic fracture.

There were 178 patients (13.3%) with pelvic fracture that were admitted who met the criteria for shock (Table 3). The majority of these patients admitted in shock were male (n = 105, 59.0%) with a mean age of 44.0 ± 19.7 years. Motor vehicle crash was the most common mechanism of injury (42.7%). As expected, injury severity was increased in patients with pelvic fracture admitted in shock with a mean ISS of 28.2 ± 14.1. Associated injuries were common as demonstrated by a chest AIS score of 3 or higher in 49.4% of the patients and an abdominal AIS score of 3 or higher in 32.0% of the patients. Head injuries were also common with a head AIS score of 3 or higher in 38.8% of the patients and a mean Glasgow Coma Scale (GCS) of 9.3 ± 5.3.

A majority of the patients admitted with pelvic fracture that were in shock required blood transfusion, with 84.3%

TABLE 2. Pelvic Fracture Diagnosis/Management (N = 1,339 Patients)

Pelvic X-ray	1,133 (84.6%)
Pelvic binder	141 (10.5%)
CT scan	1,136 (84.8%)
CT angiogram	211 (15.8%)
Blush on CT scan (% of CT scan)	119 (10.5%)
Angiography	128 (9.6%)
Contrast extravasation on angiography (% of angiography)	63 (49.2%)
Therapeutic angioembolization	79 (5.9%)
Indication for angiogram (multiple indications may apply)	(% of angiography)
Ongoing hemorrhage	71 (55.5%)
Hemodynamic instability	69 (53.9%)
Blush on CT scan	61 (47.7%)
Large pelvic hematoma	49 (38.3%)
Fracture pattern	31 (24.2%)
Other	11 (8.6%)

transfused with packed red blood cells (PRBCs) (median, 7.5 U), 70.2% transfused with fresh frozen plasma (median, 6.0 U), and 49.4% transfused with platelets (median, 3.5 U). Only 21.9% of the patients were discharged home after their acute inpatient admission after injury, with 41.0% requiring ongoing care after discharge in a rehabilitation or skilled nursing facility (Table 4). Mortality was 32.0% for patients with pelvic fracture admitted in shock.

TABLE 3. Demographics of Patients Admitted in Shock (SBP < 90 mm Hg or HR > 120 Beats per Minute or Base Deficit > −5)

n (%)	178 (13.3)
Age, y	44.0 ± 19.7
Male, n (%)	105 (59.0)
Mechanism, n (%)	
Motor vehicle crash	76 (42.7)
Pedestrian vs. auto	34 (19.1)
Fall	31 (17.4)
Motorcycle crash	28 (15.2)
Crush	2 (1.1)
Bicycle	1 (0.6)
Other	6 (3.4)
Admission vital signs	
Systolic blood pressure, mm Hg	91.2 ± 33.5
Heart rate	115.9 ± 30.4
Admission pH	7.19 ± 0.14
Admission base deficit	−10.0 ± 6.3
Admission GCS score	9.3 ± 5.3
ISS	28.0 (17.0–38.0)
Head AIS score ≥ 3, n (%)	69 (38.8)
Chest AIS score ≥ 3, n (%)	88 (49.4)
Abdomen AIS score ≥ 3, n (%)	57 (32.0)
Extremity AIS score ≥ 3, n (%)	115 (64.6)

Mean ± SD or median (IQR) where appropriate.
IQR: 25th and 75th IQR.

TABLE 4. Outcomes for Patients Admitted in Shock (SBP < 90 mm Hg or HR > 120 Beats per Minute or Base Deficit > −5)

n, (%)	178 (13.3)
ICU LOS, d	7.0 (3.0–15.5)
Ventilator, d	5.0 (2.0–11.0)
Hospital LOS, d	13.0 (5.0–23.8)
Patients requiring transfusion products, n (%)	
PRBC	150 (84.3)
Fresh frozen plasma	125 (70.2)
Platelets	88 (49.4)
Median units transfused (IQR)	
PRBC	7.5 (4.0–16.0)
Fresh frozen plasma	6.0 (3.0–11.5)
Platelets	3.5 (1.3–7.8)
Discharge Disposition, n (%)	
Home	39 (21.9)
Rehabilitation facility	34 (19.1)
Skilled nursing facility	27 (15.2)
Acute care facility	12 (6.7)
Other	9 (5.1)
Mortality, n (%)	57 (32.0)

Mean ± standard deviation or Median (IQR) where appropriate.
IQR, 25th and 75th IQR.

Of the 57 mortalities, there were 37 patients who did not receive an intervention for hemorrhage control. Of those, four patients were admitted with no recorded blood pressure, expired, and were likely not salvageable. There were 21 of 37 patients who had an LOS of less than 24 hours, also suggesting early, hemorrhage-related mortality. The issue of brain injury deaths is more difficult to analyze because of the presence of traumatic brain injury (TBI) in addition to high AIS injuries in other body areas. There were 10 of the 37 patients who did not receive an intervention for hemorrhage control that had a head AIS score of 5 on admission. These patients with severe TBI also had high extremity AIS injuries and received a median transfusion requirement of 10.5 U of PRBCs, suggesting the presence of significant hemorrhage in addition to TBI.

A pelvic binder was used in 33 patients (18.5%) admitted in shock. CT scan was used to diagnose a pelvic source of bleeding in a majority of patients admitted in shock (84.8%), with blush seen on CT scan imaging in 33 patients (Table 5). There were 44 patients (24.7%) with pelvic fracture admitted in shock who underwent angiography, with contrast extravasation demonstrated in 27 patients. The most common indication for angiography was hemodynamic instability and concern for ongoing hemorrhage. Therapeutic angioembolization was performed in 30 patients (16.9%), with pelvic fracture admitted with shock.

Angioembolization for arterial bleeding and external fixator placement for venous bleeding were the most common methods of hemorrhage control used when analyzing either all patients with pelvic fracture or the subset of patients admitted in shock (Table 6). Therapeutic angioembolization was performed in 79 patients with pelvic fracture. Angioembolization was used alone in 55 patients (4.1%) with pelvic fracture and was used in combination with another method of hemorrhage control,

TABLE 5. Pelvic Fracture Diagnosis/Management for Patients Admitted in Shock (n = 178 Patients)

Pelvic X-ray	161 (90.4%)
Pelvic binder	33 (18.5%)
CT scan	151 (84.8%)
Blush on CT scan (% of CT scan)	33 (21.9%)
Angiography	44 (24.7%)
Contrast extravasation on angiogram (% of angiography)	27 (61.4%)
Therapeutic angioembolization	30 (16.9%)
Indication for angiogram (multiple indications may apply)	(% of angiography)
Ongoing hemorrhage	31 (70.5%)
Hemodynamic instability	30 (68.2%)
Blush on CT scan	18 (40.9%)
Large pelvic hematoma	14 (31.8%)
Fracture pattern	10 (22.7%)
Other	1 (2.2%)

most commonly external fixator placement, in 24 patients (1.8%). Preperitoneal packing was used in 35 patients (2.6%) with pelvic fracture; in 20 patients this technique was used alone, while 15 patients were treated with preperitoneal pelvic packing in addition to another intervention for hemorrhage control. There were six patients who underwent preperitoneal pelvic packing before angioembolization.

Aortic balloon occlusion (REBOA) was performed in five hemodynamically unstable patients. REBOA was used in addition to another hemorrhage control method in four of the five patients, with one patient treated with REBOA and external fixator placement, one patient treated with REBOA and angioembolization, one patient treated with REBOA and preperitoneal pelvic packing, and one patient treated with REBOA and external fixator placement and angioembolization. In addition, REBOA was performed by only 1 of the 11 participating centers. Two of the patients treated with REBOA survived to discharge.

DISCUSSION

The goal of this multi-institutional study was to capture all patients admitted with pelvic fracture and gain an understanding of which methods of pelvic hemorrhage control are being used and how frequently these techniques are used. There are multiple methods that can be used to control hemorrhage in patients with pelvic fracture including pelvic fixation devices, pelvic angioembolization, preperitoneal pelvic packing, and REBOA. The method or methods selected often depend on clinical presentation, associated injuries, resource availability, and training. While pelvic fracture is a relatively common occurrence in trauma centers, patients presenting in shock caused by hemorrhage from pelvic fracture are less common. Initial treatment is directed at diagnosing significant pelvic fracture while evaluating for other sources of hemorrhage caused by the high incidence of associated injuries. While there is no debate regarding the need for urgent hemorrhage control for patients with ongoing bleeding from the pelvis, there is no consensus as to a standard algorithm for the treatment of patients with hemorrhagic shock and pelvic injury.[10,12,13]

In this study of 1,339 patients with pelvic fracture, we found an overall in-hospital mortality rate of 9.0%. This mortality rate is similar to a study of more than 24,000 patients with pelvic fracture during a 10-year period using the Nationwide Inpatient Sample that found an in-hospital mortality of 8.3%.[14] Interventions to address hemorrhage from a pelvic fracture source were used in 13.7% of the study population, with external fixator placement and angioembolization the most common methods used. Patients admitted with pelvic fracture experience significant disability as demonstrated by the fact that fewer than half of patients in this study were discharged home. Quality of life has been shown to be significantly diminished for patients after experiencing a pelvic fracture with a decrease in their perception of overall health status and frequent ongoing issues related to mobility, self-care, pain, urinary and sexual dysfunction, and anxiety-depression.[15]

In-hospital mortality was 32.0% in patients with pelvic fracture admitted in shock. Mortality rates for patients with pelvic fracture presenting with hemodynamic instability range between 21% and 50% in contemporary published series.[1,2,11,16,17] In this series of patients, injury severity was high in patients with pelvic fracture admitted in shock (mean ISS, 28.2), and associated injuries were common as demonstrated by a substantial number of patients with head, chest, and abdomen AIS scores of 3 or higher. These associated injuries may also require urgent operative intervention for hemorrhage control and may further influence the decision of the trauma surgeon to treat the patient in the operating room versus the IR suite.

In this study, we found that pelvic angiography was performed in 9.6% of all patients presenting with pelvic fracture. As expected, we found that pelvic angiography was used more frequently for patients admitted in shock. Digital subtraction angiography and therapeutic angioembolization has been used for decades to diagnose and treat patients with arterial injury caused by pelvic fracture. A study by Eastridge et al.[18] found that hypotensive patients with unstable pelvic fracture patterns were more likely to have hemorrhage from a pelvic source, suggesting that initial interventions should focus on angiography before laparotomy. The importance of prompt access to therapeutic angioembolization was demonstrated by Schwartz et al.[11] who reported that the time to IR was significantly increased during

TABLE 6. Pelvic Fracture Hemorrhage Control

	All Patients (N = 1,339), n (%)	Shock (n = 178), n (%)
No pelvic fracture intervention	1,156 (86.3)	121 (68.0)
Angioembolization alone	55 (4.1)	19 (10.7)
External fixator alone	78 (5.8)	17 (9.6)
Preperitoneal pelvic packing alone	20 (1.5)	6 (5.1)
Embolization + external fixator	11 (0.8)	6 (5.1)
Embolization + pelvic packing	6 (0.4)	2 (1.1)
External fixator + pelvic packing	3 (0.2)	1 (1.7)
Embolization + external fixator + pelvic packing	5 (0.4)	1 (0.6)
REBOA with or without any other	5 (0.4)	5 (2.8)

night hours and weekends compared with daytime hours. It is important to note that on multivariate regression analysis, they found that treatment on nights and weekends was associated with a near 100% increase in 30-day mortality, highlighting the importance of prompt intervention for patients with pelvic hemorrhage. The need for angiography for pelvic fracture patients can be variable between institutions.[19] A previous study of 819 patients admitted to a single Level I trauma center during a 9-year period found that only 3.8% of the patients with pelvic fracture required pelvic angiography, with even fewer patients treated with therapeutic embolization.[9]

There were 20 patients in this group with pelvic fracture treated with preperitoneal pelvic packing alone and 15 patients with preperitoneal pelvic packing in addition to another method of hemorrhage control, most commonly angioembolization. Preperitoneal packing is performed through a low midline or low transverse incision to identify the preperitoneal space, which has often been dissected by the pelvic hematoma.[20] Laparotomy pads are placed on each side of the bladder to tamponade hemorrhage in the preperitoneal space. Proponents of preperitoneal pelvic packing cite advantages including the ability to tamponade venous and bony bleeding, the ability to temporize hemorrhage while waiting for the IR team to mobilize for potential angioembolization, and the benefits of prompt transport to the operating room where other injuries can be addressed, rather than the IR suite.[6,21] The ideal scenario to implement preperitoneal pelvic packing has yet to be clearly defined.[17] A small, prospective comparison of preperitoneal pelvic packing versus pelvic angiography for hemodynamically unstable patients demonstrated that patients treated with preperitoneal pelvic packing had shorter time to intervention and received fewer blood transfusions during the 24 hours after admission.[22] While the technique for performing preperitoneal pelvic packing has been widely disseminated as part of the educational curriculum of courses such as the American College of Surgeons' Committee on Trauma ASSET course, we found that the use of this technique was relatively rare in hemodynamically unstable patients with pelvic fracture as it was used in only 11 patients.

There was limited use of REBOA as a means of hemorrhage control in this study. REBOA has been proposed as an adjunct in the treatment of hemorrhagic shock.[23] Treatment with REBOA involves gaining arterial access via the femoral artery to deploy a balloon occlusive device into the aorta, temporizing hemorrhage while definitive bleeding control is obtained.[8] REBOA was initially shown to be effective in achieving pelvic hemorrhage control in animal models.[23–25] A case series was performed at two US trauma centers that included six patients treated with REBOA and was successful in increasing the mean SBP by 55 mm Hg after balloon occlusion.[7] Furthermore, REBOA was demonstrated to be safe with no complications related to the procedure. A retrospective review of 24 patients treated with REBOA for blunt injury in Japan demonstrated the feasibility of this technique as well as demonstrated a significant increase in mean SBP from 53.1 mm Hg to 98.0 mm Hg after balloon inflation.[26] This review reported three vascular complications including one external iliac artery injury and two cases of lower extremity ischemia after femoral artery access.

Because of the relatively small number of patients treated with REBOA for pelvic hemorrhage, the potential risk and benefits of this therapy are still being evaluated. When to deploy REBOA in the treatment algorithm for patients with pelvic hemorrhage is a matter of debate, including consideration for specific blood pressure parameters that might be most appropriate for the use of REBOA compared with other hemorrhage control techniques.[27–29] In addition, strategies to manage patients after hemorrhage temporized with REBOA is also a matter of conjecture, with discussion that is ongoing regarding the subsequent selection and timing of other hemorrhage control techniques including angiography and preperitoneal pelvic packing. Despite the interest in REBOA, there are several barriers to its wider use across trauma centers nationally and internationally. While there are several "early adopters" that have championed the use of REBOA,[7,26,30] the limited widespread use of this technique is supported by its infrequent use for hemorrhage control in this study. As continued training in REBOA and improvements in catheter based technology move this field forward, multi-institutional prospective studies will need to be performed to determine the technique's role in the care of patients with severe pelvic fracture.[8,27,31,32]

This study has limitations including its observational nature, which left clinical decision making to the individual trauma surgeons at each institution. The frequent occurrence of significant associated injuries in this population also makes it difficult to decipher the contribution of pelvic hemorrhage versus hemorrhage from other sources within the torso. The occurrence of procedural complications after each method of hemorrhage control cannot be analyzed because this was not included in the data collection.

In this study, we found that mortality in patients with pelvic fracture is high and treatment paradigms are variable. This suggests an opportunity for improvement in the care of these seriously injured patients. Findings from this study demonstrate no clear relationship between the choice of hemorrhage control intervention used and the patient's clinical status. This suggests variability in management strategies across the participating centers and demonstrates the lack of consensus by trauma surgeons as to the optimal algorithm for hemorrhage control interventions. This field will continue to evolve as future improvements in training and technology advance the tools at the disposal of the trauma surgeon and will hopefully lead to future trials to define the optimal treatment paradigm for hemorrhage control in patients with pelvic fracture.

AUTHORSHIP

T.W.C and R.Co. designed the study. All authors contributed to the data collection. T.W.C and R.Co. performed the data analysis. All authors contributed to data interpretation and critical revision of the manuscript.

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DISCLOSURE

The authors declare no conflicts of interest.

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DISCUSSION

Dr. Walter Biffl (Denver, Colorado): Management of patients with unstable pelvic fractures can be incredibly challenging. The patients are bleeding. They are coagulopathic. They typically have severe associated injuries. We try to coordinate care with an orthopaedic surgeon and, sometimes, an interventional radiologist. And, more frequently than we would like, this doesn't go well and patients die.

In this paper, investigators from the AAST Multi-Institutional Trials Committee have sought to determine what methods of hemorrhage control are currently used in patients with pelvic fractures.

Now I have two disclosures. The first is that I bring a bias to my review in that I like algorithms, a logical sequence of steps with clear decision points based on guiding principles of management.

We published an algorithm in 2001 that implemented a couple of key points. One was hemostatic resuscitation and pelvic binding upfront as well as early determination of the need for a laparotomy. We also got orthopedic surgeons and interventional radiologists involved early to determine the need and timing for angioembolization and external fixation. Our mortality in the unstable patients with pelvic fractures decreased from 31% to 15% with this algorithm and I believe the data because I reviewed all the records myself.

Subsequently, we employed pelvic packing for patients with recalcitrant shock and, more recently, REBOA. So my bias in this is that I believe in these interventions performed in a timely manner. And I was looking for that in this paper.

My second disclosure is that I read this paper while drinking a glass of wine after a night on call and my wife will tell you that is never a good idea. And it probably explains why I started thinking of the character Nuke LaLoosh, the fire balling pitcher in the movie *Bull Durham*.

Those of you who know the movie know that his pitching, as well as his love making, were described as being "all over the place." And I was reading this paper thinking, "This is all over the place. There is no standardization. There is no orderly application of any of these principles."

But some of the data that stood out focusing on the patients in shock include the following: 84% received blood, which is reasonable. Not all the indices of shock correlate with the need for transfusion. But only 19% of these patients had pelvic binding.

Now, in our algorithm and the WT algorithm that Dr. Costantini showed, 100% of patients get those interventions immediately in the ED. In addition, 85% of the patients in shock had CT scans. And in our algorithm and in the WT algorithm, that comes at the end, after all the other interventions.

So my first question is, how many of the institutions out of the 11 had algorithms? And why don't you think everybody followed one?

On the other hand, there were a number of findings that raise a question of how many patients actually had significant pelvic bleeding. The mortality was 30%. But 68% of the patients in shock had no pelvic intervention, only 19% had external fixation or packing.

Now, 40% of the patients had potentially severe TBI with a head AIS greater than three, so my next question is: what was the attributable mortality? If patients are dying of exsanguination or MOF I think you need to look at your care. But, otherwise, maybe everything is done just right.

Finally, the numbers are small but do you have a feel for the hemostatic efficacy of packing or fixation or angioembolization? My sense is that they are all complimentary and that is how they are used in many places. But I would like you to comment on that.

This study clearly opens the door for further research. If we start with a pelvic binder and hemostatic resuscitation, maybe add a REBOA for the severely hypotensive patients, maybe we can begin to determine the role and efficacy of the other interventions.

I congratulate the authors for their efforts and look forward to the next phase of this investigation. And I thank the AAST for the privilege of the podium.

Dr. Paula Ferrada (Richmond, Virginia): Wonderful paper. I was wondering if you had a chance to look in the timing from injury to control of bleeding and if that had any effect on the outcome as well as what type of resuscitation the patients in shock received. Did they receive a 1:1 resuscitation? Was it low-volume resuscitation? And if that had any influence on the outcome. Thank you.

Dr. Charles Wiles, III (Buffalo, New York): Again, I thought this was a marvelous paper. Points of clarification: What exactly did external fixation mean? Was that all types of external fixation? Was it external fixation with pins and struts? Was it any variety of clamps and so forth? Thank you.

Dr. Reuven Rabinovici (Boston, Massachusetts): I was surprised by the small number of patients treated with packing and REBOA combined. It seems that more papers were written on these topics than patients treated with these methodologies. My question is do you have any specific information regarding the indications for patients who were treated with REBOA or packing and their outcome compared with those who were not?

Dr. Kevin Schuster (New Haven, Connecticut): My orthopaedic traumatologists have taught me that nothing stops bleeding faster than a percutaneous SI screw, so I was curious how many patients in your study received that as an emergency intervention.

Dr. Carl Hauser (Boston, Massachusetts): We are never going to figure out what the best way is to use trans-catheter therapies until we can do them ourselves. That's when what gets done will begin to depend on what's right for the patient rather than doctor convenience and availability.

Dr. Todd W. Costantini (San Diego, California): Dr. Biffl, thank you for your comments. I am a big baseball fan and have seen *Bull Durham* numerous times. I really enjoyed the Nuke LaLoosh reference, although ideally not in reference to the management of pelvic fracture as described in our manuscript.

You asked why trauma centers didn't follow an algorithm in their care of patients with pelvic fracture. As you know, each trauma center has their own individual algorithm for the management of pelvic fracture that are different in varying degrees to the algorithms published by your group and others. There is clearly variation between centers based on the patient's clinical scenario, and the resources that are available which differ between day and night, weekday and weekend. A recent study out of UT Houston nicely demonstrated that the treatment strategy for pelvic hemorrhage control may be altered by resource availability on nights and weekends and has a significant impact on outcome.

This study was designed to take a pulse of what is going on at trauma centers across the country. And if the criticism is that people aren't following currently published algorithms, then that's an important issue to consider. If trauma centers aren't following algorithms as they are written now, maybe we need to rethink those algorithms or think about how we can refine algorithms to improve care to these patients.

You asked the key question, which is why do the patients admitted with pelvic fracture die. And that was, obviously, something we were interested in trying to determine. When

you look at the deaths in our data set, approximately half of the patients died without receiving any intervention for pelvic fracture hemorrhage control. Of those patients with pelvic fracture that did not undergo an intervention for pelvic fracture hemorrhage control, approximately 60% died within 24 hours, suggesting early death due to bleeding, often with hemorrhage from from multiple sources. Patients with severe pelvic fracture often present with significant associated injuries in the chest and abdomen as noted by the high number of patients with chest and/or abdomen AIS greater than 3. Therefore, it can be challenging to define the contribution of hemorrhage from a pelvic source versus the chest or abdomen in a patient with multiple severe injuries.

As you noted, traumatic brain injury was a frequent cause of death in this series. Of the patients that survived more than 24 hours and did not get a pelvic fracture hemorrhage control intervention, most of the deaths had AIS 4 or 5 consistent with severe traumatic brain injury.

You also asked about the hemostatic efficacy of pelvic packing or angioembolization, we actually did collect data on time to hemorrhage control. The number of patients treated with preperitoneal pelvic packing are so small it is hard to make any real comparisons. We just didn't see that many of them. And so it is difficult to know how well the pelvic packing worked and when hemorrhage control occurred.

Dr. Ferrada, you asked about time to control of bleeding. Again, we collected that data. We are hoping in a subsequent paper to look at the combination of pelvic fracture patterns and the methods that were used to control bleeding and time to hemorrhage control. With very small numbers of patients treated with several of these hemorrhage control interventions it may be difficult to make conclusions as to which method resulted in the most rapid control of bleeding. We collected blood product transfusion data and found good compliance with 1:1 transfusion strategies. Unfortunately, we do not have the amount of crystalloid infused as part of this data set and, therefore, I cannot comment on the resuscitation strategy and its impact on outcome.

Dr. Wiles asked a question about what types of external fixator were placed. The decision regarding what type of pelvic fixator was used was left to the discretion of the participating centers. We did not specify a certain kind of external fixator. Patients included in the external fixator group included any form of mechanical stabilization.

Dr. Rabinovici asked a question about the limited use of REBOA and pelvic packing and their outcomes compared to patients treated with other interventions. The question of outcomes after treatment with REBOA compared to other interventions is difficult to answer based on the small number of patients treated with REBOA. There were five patients treated with REBOA in this study. Two of those patients ended up exsanguinating fairly quickly. The remaining three had some combination of pelvic packing and angioembolization. You are correct in noting that the use of REBOA seems to be limited with the exception of a few centers that have led early efforts to utilize REBOA as a treatment for patient with pelvic fractures admitted in shock. With advances in training and technology, it is likely that REBOA will be used more widely in the future. Additional multi-center studies will be needed to better define the role for REBOA in patients admitted with hemorrhagic shock.

And then, finally, Dr. Schuster asked about SI screw placement. This is a great question. We had initially included SI screw placement in our data collection set. Unfortunately, the use of SI screw for hemorrhage control and the use of SI screw placement as a means of definitive fixation got confused in the data collection process so it was difficult to analyze the role of SI screw placement for hemorrhage control in this study.

Hopefully this is the first in a series of studies from this pelvic fracture study group that can begin to address some of the important issues related to the care of patients with pelvic fracture that were discussed today. Thank you.