The peril of thoracoabdominal firearm trauma: 984 civilian injuries reviewed

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BACKGROUND: Thoracoabdominal firearm injuries present major diagnostic and therapeutic challenges because of the risk for potential injury in multiple anatomic cavities and the attendant dilemma of determining the need for and correct sequencing of cavitary intervention. Injury patterns, management strategies, and outcomes of thoracoabdominal firearm trauma remain undescribed across a large population.

METHODS: All patients with thoracoabdominal firearm injury admitted to a major Level I trauma center during a 16-year period were reviewed.

RESULTS: The 984 study patients experienced severe injury burden; 25% (243 of 984) presented in cardiac arrest, and 75% (741 of 984) had an Abbreviated Injury Scale (AIS) score of 3 or greater in both the chest and the abdomen. Operative management occurred in 86% (638 of 741). Of the patients arriving alive, 68% (507 of 741) underwent laparotomy alone, 4% (27 of 741) underwent thoracotomy alone, and 14% (104 of 741) underwent dual-cavitary intervention. Negative laparotomy occurred in 3%. Diaphragmatic injury (DI) occurred in 63%. Seventy-five percent had either DI or hollow viscus injury. Cardiac injury was present in 33 patients arriving alive. Despite the use of trauma bay ultrasound, 44% of the patients with cardiac injury underwent initial laparotomy. In half of this group, ultrasound did not detect pericardial blood. The need for thoracotomy, either alone or as part of dual-cavitary intervention, was the strongest independent risk factor for mortality in those arriving alive.

CONCLUSION: Greater kinetic destructive potential drives the peril of thoracoabdominal firearm trauma, producing clinical challenges qualitatively and quantitatively different from nonfirearm injuries. Severe injury, on both sides of the diaphragm, generates high operative need with low rates of negative exploration. The need for emergent intervention and a high incidence of DI or hollow viscus injury limit opportunity for nonoperative management. Even with ultrasound, emergent preoperative diagnosis remains challenging, as the complex combination of intra-abdominal, thoracic, and diaphragmatic injuries can provoke misinterpretation of both radiologic and clinical data. Successful emergent management requires thorough assessment of all anatomic spaces, integrating ultrasonographic, radiologic, and clinical findings. (*J Trauma Acute Care Surg*. 2014;77: 684–691.

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The patient with thoracoabdominal penetrating injury presents major diagnostic and therapeutic challenges. High overall injury burden; the frequent need for rapid decision making in an unstable patient; the variable reliability of the physical examination as well as the potential for diaphragmatic injury (DI) to provoke misinterpretation of tube thoracostomy outputs and ultrasonographic data; and the surgical challenges of dual-cavitary intervention[1–5] all contribute to a high-risk clinical scenario that has been termed a situation of "double jeopardy."[6] Although this populations' clinical complexity has been recognized for more than two and a half decades, the subsequent literature has remained largely bereft of any further delineation of the factors contributing to this "jeopardy," and optimal diagnostic and management strategies, particularly for patients requiring emergent intervention, remain unclear. This same period has also witnessed the evolution of selective nonoperative management (NOM) approaches to penetrating injury as well as the proliferation of trauma bay ultrasonongraphy.[7–10] Bedside ultrasound has the potential to facilitate diagnosis and guide sequencing of dual-cavitary intervention, whereas the increasing adoption of NOM approaches in penetrating trauma adds a further layer of decision making complexity to an already challenging patient group.

The current study endeavors to further clarify the nature of "double jeopardy" in patients with penetrating thoracoabdominal trauma and to use these data to assist patient management. As clinical presentation, injury patterns, amenability to NOM, and outcomes significantly differ between stab wounds (SWs) and gunshot wounds (GSWs), the current review examines 984 consecutive patients with thoracoabdominal firearm injury in an attempt to define useful management strategies specific to this population.

TABLE 1. Population Demographics and Admission Physiologic Variables

Demographics and Vital Signs on Admission	Total (N = 984)	Patients Alive on Admission (n = 741)
Age, median (range), y	24 (16–83)	25 (16–87)
Age ≥ 55 y, n (%)	28 (3)	18 (2)
Male, n (%)	923 (94)	689 (93)
Hypotension: SBP ≤ 90 mm Hg, n (%)	246 (25)	91 (12)
Heart rate > 120 beats/min, n (%)	218 (22)	208 (28)
GCS score ≤ 8, n (%)	286 (29)	56 (8)
Cardiac arrest on admission	243 (25)	0
Injury severity, n (%)		
Head AIS score ≥ 3	38 (4)	27 (4)
Extremity AIS score ≥ 3	126 (13)	86 (12)
Both chest and abdominal AIS scores ≥ 3	741 (75)	551 (74)
ISS < 15	131 (13)	115 (16)
ISS, 15–24	216 (22)	202 (27)
ISS ≥ 25	637 (65)	424 (57)

Severe head injury defined as the presence of intracranial pathology or head AIS score of 3 or greater.

PATIENTS AND METHODS

All adult patients (≥16 years) experiencing thoracoabdominal GSWs who presented to the LAC + USC between January 1996 and November 2011 were reviewed. To minimize the selection bias resultant from retrospective identification of patients by known injuries only, and to better capture that group of patients presenting with the potential for injuries in both anatomic cavities, study enrollment was based on the presence of two or more, nonsuperficial external wounds involving both the chest and the abdomen (regardless of the presence of

TABLE 2. Management of Penetrating Thoracoabdominal Trauma

	Total (N = 984)	Patients Alive on Admission (n = 741)
No thoracotomy or laparotomy	145 (15%)	103 (14%)
Thoracotomies (total)	322 (33%)	131 (18%)
RT	227 (23%)	43 (6%)
OR thoracotomy	95 (10%)	88 (12%)
Laparotomies (total)	664 (68%)	611 (83%)
Laparotomy only	517 (53%)	507 (68%)
Thoracotomy and laparotomy	147 (15%)	104 (14%)
Laparotomy following RT	64 (7%)	28 (4%)

OR, Operating room; RT, Resuscitative thoracotomy.

underlying injury) as well as those with patients with any injury (regardless of severity) to both the thorax and the abdomen. Patient demographics, injury mechanism, admission vital signs, distribution of injuries, need for surgical procedures, incidence of massive transfusion (MT), mortality, as well as intensive care unit (ICU) and hospital lengths of stay (LOS) were abstracted from the institutional trauma registry. Missing registry data were reconciled through chart review.

Analysis examined the total population, as well as the subgroup of patients who arrived alive. Examination of surgical management strategies (no surgical procedure, tube thoracostomy alone, laparotomy alone, thoracotomy alone, or thoracotomy and laparotomy) was preformed. Both lateral thoracic incisions and median sternotomy were coded as "thoracotomy" in the institutional database. "Resuscitative thoracotomy" (RT) was defined as a thoracotomy performed outside the operating room for hemodynamic decompensation or cardiac arrest. The distribution and nature of intra-abdominal and intra-thoracic injuries were examined across the entire population as well as the subgroup arriving alive.

Injury distribution was classified by anatomic location and described across the total population and the subgroup arriving alive. In patients presenting alive, injuries were examined according to management strategy. The diagnosis and management of DI were separately examined. Patterns of presentation of cardiac and major thoracic injuries as well as their method of diagnosis and subsequent operative management, including the sequencing with abdominal surgery, were independently reviewed using chart and electronic records by two surgeon authors (R.J.B. and A.S.). Outcome data, such as mortality, need for MT (defined as ≥10 U of packed red blood cells in 24 hours), and LOS in the hospital and ICU, were described for the entire population as well as the subgroup arriving alive.

Mortality was classified by surgical intervention. Multivariate regression determined the independent factors for mortality in patients presenting alive. Bivariate analysis initially identified differences between survivors and nonsurvivors. Discordant factors at $p \leq 0.2$ on this analysis were then entered into a stepwise logistic regression model. Continuous variables were reported as mean (SD). Dichotomization to clinically relevant cutoff points for age (≥55 years vs. <55 years), Glasgow Coma Scale (GCS) score (≤8 vs. >8), systolic blood pressure (SBP) on admission (<90 mm Hg vs. ≥90 mm Hg), and Injury Severity Score (ISS) (≥25 vs. <25) was performed where appropriate. Categorical variables were reported as a

TABLE 3. Intrathoracic and Intra-abdominal Injuries

	All Patients (N = 984)	Alive on Admission (n = 741)	No Surgery (n = 103)	Thoracotomy Only (n = 27)	Laparotomy Only (n = 507)	Thoracotomy and Laparotomy (n = 104)
Chest						
Cardiac injury	135 (14%)	33 (5%)	0	7 (26%)	0	26 (25%)
Thoracic vascular injury	119 (12%)	51 (7%)	2 (2%)	11 (40%)	11 (2%)	27 (26%)
Thoracic aorta	49 (5%)	13 (2%)	0	2 (7%)	0	11 (11%)
Major vessel	47 (5%)	21 (3%)	0	8 (30%)	0	13 (3%)
Minor vessel	23 (2%)	17 (2%)	2 (2%)	3 (11%)	3 (1%)	9 (9%)
Lung injury	284 (29%)	154 (21%)	30 (29%)	17 (63%)	64 (13%)	43 (41%)
Abdomen						
Solid organs	764 (78%)	597 (81%)	75 (73%)	14 (52%)	419 (83%)	89 (86%)
Liver	589 (60%)	452 (61%)	61 (59%)	13 (48%)	299 (59%)	79 (76%)
Spleen	208 (21%)	169 (23%)	7 (7%)	2 (7%)	143 (28%)	17 (16%)
Kidney	206 (21%)	159 (22%)	15 (15%)	3 (11%)	120 (24%)	21 (20%)
Pancreas	100 (10%)	81 (11%)	1 (1%)	0	65 (13%)	15 (14%)
Hollow viscus	348 (35%)	323 (44%)	0	0	282 (56%)	41 (39%)
Stomach	198 (20%)	181 (24%)	0	0	157 (31%)	24 (23%)
Small bowel	124 (13%)	115 (16%)	0	0	97 (19%)	18 (17%)
Large bowel	162 (17%)	155 (20%)	0	0	138 (27%)	17 (16%)
Bladder	10 (1%)	8 (1%)	1 (1%)	0	7 (1%)	0
Major abdominal vascular injury	205 (21%)	132 (18%)	4 (4%)	10 (37%)	73 (14%)	45 (43%)
Diaphragm	604 (61%)	465 (63%)	23 (22%)	12 (44%)	366 (72%)	64 (62%)

TABLE 4. Clinical Outcomes in Penetrating Thoracoabdominal GSW Trauma

	Survival	MT	ICU LOS	Hospital LOS
All patients (N = 984)	624 (63%)	287 (29%)	4.4 (10.0)	12.5 (20.1)
All patients having RT (n = 227)*	7 (3%)	52 (23%)	0.3 (1.7)	1.9 (5.4)
All patients arriving alive (n = 741)	615 (83%)	246 (33%)	5.7 (11.1)	15.9 (21.9)
No surgical procedure (n = 103)	103 (100%)	4 (4%)	1.6 (3.3)	10.7 (9.4)
Thoracotomy only (n = 27)	7 (26%)	10 (37%)	1.0 (1.8)	4.0 (5.4)
RT (n = 15)	1 (7%)	5 (33%)	0.3 (0.8)	2.4 (4.6)
OR thoracotomy (n = 12)	6 (50%)	5 (42%)	1.8 (2.3)	6.0 (5.8)
Laparotomy only (n = 507)	464 (92%)	165 (33%)	6.8 (12.2)	18.7 (24.2)
Thoracotomy and laparotomy (n = 104)	41 (39%)	67 (64%)	5.6 (11.1)	10.6 (18.0)
Excluding RT (n = 76)	37 (49%)	49 (65%)	7.3 (12.5)	12.7 (19.2)

*Not all patients arriving without vital signs underwent an RT. In addition, 43 patients arriving alive arrested in the trauma bay and underwent RT.
OR, Operating room; RT, Resuscitative thoracotomy.

proportion or percentage of the total. Two-tailed *t* tests were used for comparison of continuous variables. SPSS for Windows, version 17 (Chicago, IL) was used for all analyses.

RESULTS

In total, 984 patients experienced thoracoabdominal GSW trauma over 16-years (Table 1). The vast majority (923 of 984, 94%) were male, with only a small percentage (28 of 984, 3%) of patients 55 years or older. Twenty-five percent (243 of 984) presented in cardiac arrest. Overall surgical need was high; only 15% (145 of 984) of the population did not undergo an operative procedure (Table 2). Laparotomy was the most common, occurring in 66% (664 of 984). Overall, thoracotomy incidence was 33% (322 of 984), but the majority of these procedures (71%, 227 of 322) were RTs for cardiac arrest or severe hemodynamic decompensation. RT was performed in 184 (76%) of 243 of those who presented without vital signs; none of these patients survived.

Patients arriving without vital signs were primarily distinguished by a higher incidence of thoracic trauma (Table 3). Cardiac, thoracic vascular, and thoracic aortic injuries occurred in 14% (135 of 984), 12% (119 of 984), and 5% (49 of 984) of all patients, compared with 5% (33 of 741), 7% (50 of 741), and 2% (12 of 741) of those arriving alive, respectively. Only a quarter (33 of 135) of all patients experiencing cardiac injury survived to emergency department presentation. In contrast to the patterns seen with thoracic trauma, intra-abdominal injury incidence was similar between the two groups (Table 3). Head injury was also similar between both groups of patients, with a head Abbreviated Injury Scale (AIS) score of 3 or greater occurring in 4% (Table 1).

For patients arriving alive, 12% (91 of 741) presented with an SBP of 90 mm Hg or lower, 28% (208 of 741) with a heart rate of 120 beats per minute or greater, and 8% (56 of 741) with a GCS score of 8 or lower. Injury severity in this group was high: 57% (424 of 741) had an Injury Severity Score (ISS) of 25 or greater, and 74% (551 of 741) had an AIS score of 3 or greater in both the chest and the abdomen (Table 1). Only 14% (103 of 784) did not undergo surgery (Table 2). Tube thoracostomy, as the only intervention, occurred in just 4% (31 of 741) or just less than a third (30%, 31 of 103) of those patients not having any other intervention. Laparotomy was the most common procedure overall, occurring in 83% (611 of 741). Thoracotomy incidence was 18% (131 of 741), with 33% (43 of 131) of these patients having RT for hemodynamic decompensation or cardiac arrest after initial presentation. A combined operative procedure (thoracotomy and laparotomy) occurred in a relatively small subset of patients (14%, 104 of 741). Excluding RTs, dual-cavitary intervention occurred in only 10% (76 of 741) (Table 2). Overall, 74% (548 of 741) of the patients arriving alive underwent an emergent operation, moving directly to the surgical suite from the trauma bay.

Patterns of injury and operative management are described in Table 3. Cardiac, thoracic vascular, and thoracic aortic injuries occurred in 5% (33 of 741), 7% (50 of 741), and 2% (12 of 741) of those arriving alive, respectively. Of the 33 patients arriving alive with cardiac injury, 42% (14 of 33) had additional major thoracic vascular injuries, while 85% (28 of 33) had additional major intra-abdominal trauma. Six patients (18%) had a non–full-thickness cardiac injury. Overall, 67% (22 of 33) of those arriving alive with cardiac injury presented with or developed an SBP of 90 mm Hg or lower during the assessment and 24% (8 of 33) arrested in the trauma bay prompting RT. Of the 25 patients who did not arrest during resuscitation (thereby prompting a RT), 24 (96%) had complete trauma assessment records for review. Full cavitary assessment

TABLE 5. Independent Predictors of Mortality for Patients Arriving Alive

Variable	AOR (95% CI)	R^2	*p*
Dual-cavity exploration	7.0 (3.4–14.4)	0.253	<0.001
Thoracotomy alone	30.6 (7.6–123.5)	0.132	<0.001
Major abdominal vessel injury	8.5 (4.3–16.9)	0.111	<0.001
GCS score ≤ 8	14.6 (5.1–41.6)	0.055	<0.001
ISS ≥ 25	5.7 (2.1–15.3)	0.042	0.001
Hypotension on admission	4.5 (2.1–9.4)	0.023	<0.001
Lung injury	3.1 (1.5–6.2)	0.013	0.002
Kidney injury	3.0 (1.5–6.3)	0.012	0.003
Need for MT	2.3 (1.2–4.5)	0.01	<0.001
Liver injury	2.6 (1.3–5.3)	0.007	0.010
Head injury	4.7 (1.3–16.9)	0.007	0.018

(cardiac and abdominal views) with ultrasound was performed and documented in 75% (18 of 24). Six of these patients had clear ultrasonographic evidence of cardiac injury and underwent an initial thoracic incision. However, despite the use of ultrasound, 44% (8 of 18) of this group (arriving alive with cardiac injury and receiving both cardiac and abdominal ultrasound assessment) underwent an initial abdominal incision. In four of eight of these patients, the ultrasound reported abdominal but no pericardial blood. All of these patients had upper abdominal solid organ injuries and DI. Of the remaining four ultrasounds, one study was reported as negative for injury. The corresponding chest radiograph detected no hemothorax but examiners reported a "significantly elevated right hemidiaphragm." At laparotomy, high-grade liver injuries and DI were noted. A positive pericardial window prompted sternotomy for right atrial and ventricular injury. One ultrasound was reported as "technically difficult" and did not contribute to diagnostic decision making. The final two ultrasounds reported equivocal pericardial blood. In all patients with cardiac injury who underwent initial abdominal incision despite having ultrasound, diagnosis was ultimately demonstrated through transdiaphragmatic pericardial window.

Solid organ injuries were the most commonly found intra-abdominal pathology in those arriving alive (81%, 597 of 741) and most commonly involved the liver (61%, 452 of 741), followed by the spleen (23%169 of 741) and the kidney (22%, 159 of 741). Intra-abdominal solid organ trauma required an organ-specific operative procedure in 50% (227 of 452) of liver, 60% (95 of 159) of renal, and 70% of splenic injuries. Although not requiring a specific solid organ procedure, a larger percentage of patients with these injuries (84%, 89%, and 94%, respectively) underwent laparotomy for exploration, damage-control packing, or associated injuries.

Hollow viscus injury (HVI) occurred in 44% (323 of 741) of the patients. Gastric injury was most common (24%, 181 of 741), followed by large (21%, 155 of 741) and small (16%, 181 of 741) bowel injury. DI occurred in 63% (465 of 741) of those alive on admission. A small percentage of these injuries (23 of 465, 5%) were right sided, detected by computed tomographic imaging in stable patients, and did not undergo repair. The remainder underwent open surgical repair. Overall, only seven patients (2%) were hemodynamically stable without the need for cavitary intervention and underwent diagnostic laparoscopy (DL). Two investigation results were negative, while the remaining five led to subsequent laparotomy. The vast majority (94%, 435 of 465) of DIs were diagnosed at operation. In total, 75% (551 of 741) of the patients arriving alive had either a DI or an HVI. Only 3% (18 of 611) of the patients arriving alive underwent a nontherapeutic or "negative" laparotomy.

Clinical outcomes are described in Table 4. Overall mortality was 37% (360 of 984). Only 3% (7 of 227) undergoing RT survived. There were no survivors in patients who arrested before hospital presentation. For those arriving alive, overall mortality was 17% (126 of 741). A third of this group (33%, 246 of 741) required MT. All of the patients who did not require surgery survived, as did 92% (464 of 507) of those patients undergoing only laparotomy. Mortality increased considerably with dual-cavitary intervention (61%, 63 of 104), even when patients undergoing RT were excluded (51%, 39 of 76). Dual-cavitary intervention was also associated with the highest incidence of MT (64.4%, 67 of 104). Mortality in those presenting alive with cardiac injury was 39% (13 of 33).

In patients arriving alive, multivariate logistic regression found that dual-cavitary exploration (adjusted odds ratio [AOR], 7.0; 95% confidence interval [CI], 3.4–14.4; $p < 0.001$), thoracotomy alone (AOR, 30.6; 95% CI, 7.6–123.5; $p < 0.001$), and the presence of major abdominal vascular injury (AOR, 8.5; 95% CI, 4.3–16.9; $p < 0.001$) were the biggest independent risk factors, followed by other more nonspecific markers of injury severity (Table 5).

DISCUSSION

The diagnostic and management challenges of concomitant penetrating chest and abdominal trauma have been widely appreciated since Hirshberg et al. coined the term *double jeopardy.*[6] This population's clinical complexity is derived from three related factors: a multiplied injury burden with high operative need; challenging clinical assessment, particularly in the face of DI; and the subsequent difficulty in determining the need for and the appropriate sequencing of dual-cavitary intervention. Few subsequent studies have furthered understanding of this injury pattern as they have involved small populations, focused on specific anatomic regions or combination of injuries, or primarily described surgical sequencing.[2,11–17]

Patients with thoracoabdominal GSWs are one of the most severely injured populations in trauma; 25% of this group presented in cardiac arrest, and 65% had an ISS of 25 or greater with three of four having an AIS score of 3 or greater in both the chest and the abdomen. This high acuity mandated operative intervention in 85%. In contrast, a similarly large (n = 617) cohort of patients with thoracoabdominal SWs found that 4% presented in cardiac arrest, 14% had an ISS of 25 or greater, and operative intervention occurred in 60%.[18]

The majority of GSW patients experiencing significant thoracic trauma (three quarters of those with cardiac or thoracic aortic injury and two thirds with thoracic vascular injury) arrested before hospital presentation, further substantiating the major contribution of thoracic injuries to on-scene mortality. For those arriving alive, the vast majority of injuries were abdominal. Laparotomy accounted for 82% of all surgeries, less frequent than the 89% and 90% incidence seen with thoracoabdominal SWs[18] or blunt trauma, respectively.[19] The relatively increased predominance of thoracotomy in the GSW population reflects the greater kinetic destructive power of firearms and a resultant greater incidence of serious, non–cardiac thoracic pathology. Thoracic injuries however were nearly always associated with significant intra-abdominal trauma; only 2% of the patients arriving alive and requiring surgery had an isolated non-RT. Thoracotomy, either alone or with laparotomy, was a significant risk factor for mortality in those arriving alive, reflecting both the prognostic significance of major intrathoracic injury as well as the use of this technique as a "salvage maneuver" in the presence of significant intra-abdominal hemorrhage (Table 5).

The evolution of penetrating injury NOM approaches has significantly impacted trauma management. In the initial review by Hirshberg et al.,[6] 36% (including both GSWs and SWs) underwent both thoracotomy and laparotomy. In contrast, our higher-risk population of exclusively GSWs saw dual-cavitary intervention rates less than half of that (15%). Differences in population size and selection may contribute to this variation, but the impact of evolved NOM protocols are also likely implicated. Operative intervention is typically required in only 14% and 57% of thoracic and anterior abdominal SWs, respectively.[20,21] In civilian patients presenting alive with GSWs, operative intervention is only required in 62% of abdominal and 20% of thoracic injuries.[8,22,23]

Although intra-abdominal solid organ injury was often managed without an organ-specific surgical procedure, the rate-limiting factor for NOM in this population is a 75% incidence of either DI or HVI. NOM may still be possible in a small percentage, but given this high-risk population's injury burden and associated potential for missed injury, strict adherence to the basic tenets of this approach and scrupulous monitoring are required.

DI is the hallmark of thoracoabdominal trauma and has significant impact on patient assessment, complicating interpretation of chest tube outputs, diagnostic peritoneal aspiration, and ultrasonography.[1,2,6,24,25] Sixty-three percent of those arriving alive had DI. In nearly all cases, diagnosis was made or confirmed at urgent exploration. Asymptomatic patients with penetrating thoracoabdominal trauma have been shown to have an occult DI incidence approaching 24% to 26%, when examined with DL.[26,27] These studies however featured relatively small numbers of patients with GSWs. The role for DL in GSWs is limited by emergent operative need and the frequency of associated injury. DI however can still occur in a very small percentage of patients without obvious clinical or immediate radiologic signs. Penetrating DI, typically small (approximately 2 cm), can remain elusive despite current computed tomographic imaging technology, making DL a still important, if infrequently needed, adjunct for the detection of occult DI in this population.[28,29] Perhaps, the most significant impact of DI in thoracoabdominal GSWs is its potential to compromise emergent diagnostic evaluation through violation of normal anatomic cavity separation and the consequent undermining of tube thoracostomy and radiographic and ultrasonographic data.

The essence of the "double jeopardy" in thoracoabdominal trauma is the determination of which anatomic cavity demands initial emergent exploration, with missequenced cavitary intervention reported in 23% to 44%.[2,6,11] In SWs, operative sequencing primarily requires exclusion of cardiac injury as serious non–cardiac intrathoracic pathology is rare.[18] Trauma bay ultrasonography has been demonstrated highly effective for detecting cardiac injury, with reported sensitivity and specificity approaching 100%.[10,30] However, the more widespread patterns of injury seen in patients with thoracoabdominal GSWs may undermine the sensitivity of ultrasound for exclusion of cardiac injury. Despite the use of ultrasound, 44% of the patients in the current series who arrived alive with cardiac injury underwent an initial abdominal incision. In half of these patients (all of whom also had DI and significant upper abdominal solid organ injury), the ultrasound failed to detect pericardial blood. Decompression of pericardial tamponade into the pleural or mediastinal spaces is a known caveat of this technology, resulting in false-negative findings.[31,32] GSWs, with their higher kinetic energy, can be reasonably assumed to have higher incidence of significant pericardial disruption than SWs, which may account for the current findings. In addition, high DI incidence, allowing communication between thoracic and abdominal cavities, in combination with higher incidence of associated upper abdominal injuries (all resultant from the greater kinetic energy of GSWs compared with SWs) likely accounts for the decreased sensitivity for ultrasound seen in thoracoabdominal GSW trauma. GSW patients also demonstrate higher rates of noncardiac, serious intrathoracic pathology, with a rate of thoracic aortic injuries seven times greater than that seen in SWs.[18] These injuries produce large-volume hemothorax or mediastinal widening rather than tamponade, further complicating thoracic ultrasonographic and radiographic assessment.

The significantly increased incidence of diaphragmatic and visceral injuries, both above and below the diaphragm, seen in thoracoabdominal GSW compared with SWs produces significantly greater diagnostic challenges, further exacerbated by the pressure of even higher clinical acuity and the need for emergent intervention. Assumptions of cavitary integrity are even more suspect, with GSWs and fluid in one may originate from injury in the other. Reliable exclusion of thoracic injury therefore must take into account both the cardiac silhouette as well as multimodality assessment of all anatomic spaces, using adjunctive chest radiography or extended ultrasonographic evaluation.[33–35]

The development of a diagnostic algorithm to facilitate clinical management underpins the rationale for studying thoracoabdominal trauma. Recent examination of large populations with thoracoabdominal trauma has led to recommendations for both blunt and SW injury.[18,19] In patients with blunt thoracoabdominal trauma, injury patterns clearly mandate that abdominal exploration should be the initial response to a patient requiring emergent intervention without directive radiologic findings.[19] In patients with SWs, cardiac injury is the primary determinant of the need for thoracotomy, as major non–cardiac vascular injury or other significant thoracic trauma requiring surgical intervention is exceedingly rare.[18] The lesser kinetic energy involved in SWs results in less widespread patterns of injury, simplifying diagnostic assessment relative to GSWs. In SW patients, cardiac ultrasound and chest radiography in combination significantly assist surgical sequencing through their capability to exclude cardiac injury. Patients requiring emergent intervention that present with equivocal radiographic and ultrasonographic evidence of cardiac injury (but have potential for abdominal injury) should undergo laparotomy, with transdiaphragmatic pericardial window if a causative intra-abdominal injury is not immediately apparent.

In contrast, patients with thoracoabdominal GSWs present one of the most complex diagnostic challenges in penetrating trauma, secondary to higher incidences of non–cardiac intrathoracic pathology, major intra-abdominal injuries and DI, as well as greater potential for pericardial disruption in association with cardiac trauma. This combination of injuries results from the greater kinetic energy and destructive potential of firearms and severely undermines isolated interpretation of tube thoracostomy outputs, chest radiography, and ultrasonography, hindering the development of a simple management algorithm.

Despite these considerable challenges, the current review provides a number of observations to assist clinical management. An arresting patient or a patient demonstrating hard signs of cardiac or thoracic vascular injury clearly mandates emergent thoracotomy or sternotomy. The nonarresting but hemodynamically unstable patient however remains challenging. These patients will require complete, multimodality cavitary assessment, integrating clinical findings, chest radiography, and cardiac ultrasound.

The presence of hemothorax mandates immediate tube thoracostomy with ongoing output monitoring and repeat cardiac ultrasonography, as dynamic changes occur and clot formation may seal pericardial injury, leading to findings of tamponade not present on initial assessment. Chest tube output can result from either primary thoracic trauma or an intra-abdominal injury with concomitant DI and therefore must be carefully interpreted. Although most cardiac and serious thoracic injuries cause death before presentation and one fourth of arriving cardiac injuries will arrest and provoke RT during assessment, a significant percentage present with maintained circulation and equivocal or negative ultrasonographic signs. Given this populations' high incidence of significant and severe abdominal injuries, laparotomy seems to be the best initial intervention. In this series, only 2% of the patients arriving alive underwent isolated non-RT.

Initial laparotomy allows quick assessment and stabilization of the abdominal cavity. Rapid cardiac evaluation is then possible with a transdiaphragmatic pericardial window, a maneuver that should be performed early and routinely, delayed only by the presence of uncontrolled, severe abdominal vascular injury. Arrest in this latter setting should prompt emergent RT, allowing both exclusion of cardiac injury and aortic control when the arrest is caused by catastrophic intra-abdominal bleeding. The incidence of negative laparotomy in this high-risk population will be almost negligible, and this approach, when performed in a patient with maintained circulation, allows rapid detection of cardiac injury and easy extension of cavitary exploration.

A recent South African series described their experience with subxiphoid pericardial window in 50 patients with thoracoabdominal trauma who presented with an indication for laparotomy and the potential for cardiac injury.[36] Although this technique has a sensitivity and negative predictive value of nearly 100%, with a low complication rate (2% in their series), we continue to advocate for the transdiaphragmatic approach in this population. Transdiaphragmatic pericardial window is easily learned; requires no additional retraction, skin incision, or further dissection; and can be very quickly performed by a single surgeon with minimal disruption to the flow of abdominal exploration. One caveat to the transdiaphragmatic technique is the presence of significant intra-abdominal contamination, which argues for an extra-abdominal approach to decrease the risk of cross-cavity contamination.

CONCLUSION

The peril of thoracoabdominal firearm trauma has important qualitative and quantitative distinctions from the "double jeopardy" faced by clinicians in nonfirearm injury. The greater kinetic energy of firearms results in high incidence of significant injury on both sides of as well as to the diaphragm. Nearly 9 of 10 of those arriving alive require surgical intervention, typically emergent, with very low rates of negative cavitary exploration finding. NOM is still feasible but greatly limited by a 75% incidence of either DI or HVI. Even with ultrasound, emergent diagnosis of injury remains complicated, mandating careful, multimodality assessment of all anatomic spaces. Based on injury patterns, laparotomy with transdiaphragmatic pericardial window seems to be the optimal management approach for patients with hemodynamic instability who do not have clear hard signs of cardiac or thoracic vascular injury. Despite these observations, this populations' significant and complex injury burden is likely to continue to challenge diagnosis for even the most experienced clinicians.

AUTHORSHIP

R.J.B., D.D., K.I., O.O., and P.G.T. designed the study. R.J.B., O.O., and E.K. performed the literature search. O.O., E.K., K.C. , and A.S. performed the data collection. O.O., R.J.B., E.K., A.S., and E.K. performed the data analysis. R.J.B., K.I., D.D., P.G.T., and A.S. performed the data interpretation. R.J.B., O.O., and A.S. created the manuscript. R.J.B., D.D., K.I., P.G.T., O.O., E.K., A.S., and K.C. provided critical review of the manuscript.

DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

1. Hirshberg A, Thomson SR, Bade PG, Huizinga WKJ. Pitfalls in the management of penetrating chest trauma. *Am J Surg*. 1989;157:372–375.
2. Asensio JA, Arroyo H, Veloz W, et al. Penetrating thoracoabdominal injuries: ongoing dilemma—which cavity and when? *World J Surg*. 2002; 26:539–543.
3. Bergeron E, Lavoie A, Razek T, Belcaid A, Lessard J, Clas D. Penetrating thoracoabdominal injuries in Quebec: implications for surgical training and maintenance of competence. *Can J Surg*. 2005;48:284–288.
4. Hirshberg A, Thomson SR, Huizinga WK. Reliability of physical examination in penetrating chest injuries. *Injury*. 1988;19:407–409.
5. Bokhari F, Brakenridge S, Nagy K, et al. Prospective evaluation of the sensitivity of physical examination in chest trauma. *J Trauma*. 2002;53: 1135–1138.
6. Hirshberg A, Wall MJ, Allen MK, Mattox KL. Double jeopardy: thoracoabdominal injuries requiring surgical intervention in both chest and abdomen. *J Trauma*. 1995;39:225–229; discussion 229–231.
7. Pryor JP, Reilly PM, Dabrowski GP, Grossman MD, Schwab CW. Nonoperative management of abdominal gunshot wounds. *Ann Emerg Med*. 2004;43:344–353.
8. Velmahos GC, Demetriades D, Toutouzas KG, et al. Selective nonoperative management in 1,856 patients with abdominal gunshot wounds: should routine laparotomy still be the standard of care? *Ann Surg*. 2001; 234:395–402; discussion 402–403.
9. Rozycki GS, Feliciano DV, Schmidt JA, et al. The role of surgeon-performed ultrasound in patients with possible cardiac wounds. *Ann Surg*. 1996;223:737–744; discussion 744–746.
10. Rozycki GS, Ballard RB, Feliciano DV, Schmidt JA, Pennington SD. Surgeon-performed ultrasound for the assessment of truncal injuries: lessons learned from 1540 patients. *Ann Surg*. 1998;228:557–567.
11. Clarke DL, Gall TMH, Thomson SR. Double jeopardy revisited: clinical decision making in unstable patients with, thoraco-abdominal stab wounds and, potential injuries in multiple body cavities. *Injury*. 2011;42:478–481.
12. Borlase BC, Metcalf RK, Moore EE, Manart FD. Penetrating wounds to the anterior chest: analysis of thoracotomy and laparotomy. *Am J Surg*. 1986;152:649–653.
13. Saadia R, Degiannis E, Levy RD. Management of combined penetrating cardiac and abdominal trauma. *Injury*. 1997;28:343–347.

14. Borja AR, Ransdell H. Treatment of thoracoabdominal gunshot wounds in civilian practice. Experience with forty-four cases. *Am J Surg*. 1971;121: 580–582.
15. Jacob OJ. Penetrating thoracoabdominal injuries with arrows: experience with 63 patients. *Aust N Z J Surg*. 1995;65:394–397.
16. Carrick MM, Morrison CA, Alexis DJ, et al. Thoracoabdominal shotgun wounds: an evaluation of factors associated with the need for surgical intervention. *Am J Surg*. 2009;198:64–69.
17. Donaldson LA, Findlay IG, Smith A. A retrospective review of 89 stab wounds to the abdomen and chest. *Br J Surg*. 1981;68:793–796.
18. Berg RJ, Karamanos E, Inaba K, Okoye O, Teixeira PG, Demetriades D. The persistent diagnostic challenge of thoracoabdominal stab wounds. *J Trauma Acute Care Surg*. 2014;76:418–423.
19. Berg RJ, Okoye O, Teixeira PG, Inaba K, Demetriades D. The double jeopardy of blunt thoracoabdominal trauma. *Arch Surg*. 2012;147:498–504.
20. Demetriades D, Rabinowitz B. Indications for operation in abdominal stab wounds. A prospective study of 651 patients. *Ann Surg*. 1987;205: 129–132.
21. Demetriades D, Rabinowitz B, Markides N. Indications for thoracotomy in stab injuries of the chest: a prospective study of 543 patients. *Br J Surg*. 1986;73:888–890.
22. Oparah SS, Mandal AK. Penetrating gunshot wounds of the chest in civilian practice: experience with 250 consecutive cases. *Br J Surg*. 1978;65:45–48.
23. Demetriades D, Velmahos GC. Penetrating injuries of the chest: indications for operation. *Scand J Surg*. 2002;91:41–45.
24. Wall MJ, Hirshberg A, Mattox KL. Pitfalls in the care of the injured patient. *Curr Probl Surg*. 1998;35:1019–1074.
25. Murray JA, Berne J, Asensio JA. Penetrating thoracoabdominal trauma. *Emerg Med Clin North Am*. 1998;16:107–128.
26. Murray JA, Demetriades D, Asensio JA, et al. Occult injuries to the diaphragm: prospective evaluation of laparoscopy in penetrating injuries to the left lower chest. *J Am Coll Surg*. 1998;187:626–630.
27. Murray JA, Demetriades D, Cornwell EE, et al. Penetrating left thoracoabdominal trauma: the incidence and clinical presentation of diaphragm injuries. *J Trauma*. 1997;43:624–626.
28. Zarour AM, El-Menyar A, Al-Thani H, Scalea TM, Chiu WC. Presentations and outcomes in patients with traumatic diaphragmatic injury: a 15-year experience. *J Trauma Acute Care Surg*. 2013;74:1392–1398; quiz 1611.
29. Parreira JG, Rasslan S, Utiyama EM. Controversies in the management of asymptomatic patients sustaining penetrating thoracoabdominal wounds. *Clinics (Sao Paulo)*. 2008;63:695–700.
30. Rozycki GS, Feliciano DV, Ochsner MG, et al. The role of ultrasound in patients with possible penetrating cardiac wounds: a prospective multicenter study. *J Trauma*. 1999;46:543–551; discussion 551–552.
31. Ball CG, Williams BH, Wyrzykowski AD, Nicholas JM, Rozycki GS, Feliciano DV. A caveat to the performance of pericardial ultrasound in patients with penetrating cardiac wounds. *J Trauma*. 2009;67:1123–1124.
32. Cull JD, Bokhari F. Penetrating chest injury in the setting of a hemothorax: should pericardial windows replace echocardiograms? *Am Surg*. 2013;79: E56–E57.
33. Rozycki GS, Pennington SD, Feliciano DV. Surgeon-performed ultrasound in the critical care setting: its use as an extension of the physical examination to detect pleural effusion. *J Trauma*. 2001;50:636–642.
34. Rowan KR, Kirkpatrick AW, Liu D, Forkheim KE, Mayo JR, Nicolaou S. Traumatic pneumothorax detection with thoracic US: correlation with chest radiography and CT—initial experience. *Radiology*. 2002;225: 210–214.
35. Kirkpatrick AW, Sirois M, Laupland KB, et al. Hand-held thoracic sonography for detecting post-traumatic pneumothoraces: the extended focused assessment with sonography for trauma (EFAST). *J Trauma*. 2004; 57:288–295.
36. Hommes M, Nicol AJ, van der Stock J, Kodde I, Navsaria PH. Subxiphoid pericardial window to exclude occult cardiac injury after penetrating thoracoabdominal trauma. *Br J Surg*. 2013;100:1454–1458.