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Research Article

Computed tomography in initially unstable thoracoabdominal trauma can safely enhance triage

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A R T I C L E I N F O

Keywords:
Thoracoabdominal trauma
Computed tomography
Transient responder
Hemodynamically Abnormal

A B S T R A C T

Introduction: Computed tomography (CT) imaging of hemodynamically abnormal trauma patients undergoing aggressive resuscitation is controversial. Our study investigated outcomes for hemodynamically abnormal thoracoabdominal trauma undergoing CT prior to definitive therapy.

Methods: Hemodynamically abnormal (HR≥120 bpm, SBP<90 mmHg) patients arriving to our Level I trauma center between 2015 and 2022 were reviewed. Patients with thoracoabdominal trauma achieving hemodynamic improvement (SBP≥90 mmHg) were included. Pediatric patients, pregnant patients, and traumatic arrests were excluded. After matching for baseline characteristics, CT findings, and operative details, clinical outcomes were tabulated. Primary outcomes included hospital length of stay (HLOS), intensive care unit length of stay (ICU LOS), ventilator days and mortality. Secondary outcomes included intraoperative data, transfusions, additional procedures, and complications

Results: A total of 235 patients met inclusion criteria. Thirty-six (15 %) were triaged directly to the OR while 199 (85 %) went to CT. The CT and OR groups were matched for injury burden (mean ISS OR group=21±2.6 vs. CT group=18.4 ± 0.8, $p = 0.24$). Overall, no difference in HLOS ($p = 0.3$), ICU LOS ($p = 0.9$), time on ventilator ($p = 0.4$) or mortality ($p = 0.5$) was observed. Patients undergoing CT needed less PRBCs (9.0 ± 2.6 vs. 3.4 ± 0.7 units) and FFP (5.1 ± 1.9 vs. 1.6 ± 0.4 units). The OR group patients had a higher probability of needing to undergo additional procedures (36 % vs. 12 %).

Conclusion: Hemodynamically abnormal thoracoabdominal trauma patients who are resuscitated to a SBP≥90 mmHg can safely undergo CT prior to definitive therapy.

Introduction

Computed tomography (CT) is an invaluable tool for the identification of injuries and for planning surgical intervention [1,2]. Traditional dogma asserts that there is no role for CT scan in the evaluation of a hemodynamically unstable patient as these patients require immediate triage to the operating room for definitive management[3]. However, several studies in the literature have found no risk, and in some cases benefit, to sending hemodynamically abnormal patients to CT prior to going to the operating room[4–8]. Some studies have shown that interventional techniques are associated with decreased mortality and complication rates in appropriately selected patients[5,6,9–14]. Moreover, in some cases, some studies suggest that the information gained from the CT scan may spare the patient from unnecessary invasive interventions altogether[4]. Unfortunately, consensus is lacking as the hemodynamically abnormal trauma population subset is variably defined in the literature.

The purpose of this study was to determine the utility of CT prior to definitive therapy in a hemodynamically abnormal trauma population with thoracoabdominal trauma. The aim of our study was to analyze differences in outcomes between patients that undergo CT prior to definitive therapy and those that proceed directly to surgery. We specifically sought to characterize the hemodynamically abnormal trauma population subsets in which CT may be beneficial before undergoing definitive care, specifically those with blunt versus penetrating mechanism and those classified as responders to resuscitation versus those

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classified as transient responders.

Methods

The study was deemed consistent with ethical medical research practices on human subjects from the University of Southern California *(IRB # HS 16–00,269)*.

Patient demographics

Hemodynamically abnormal patients with thoracoabdominal trauma arriving at our Level I trauma center from 2015 to 2022 were retrospectively reviewed. Thoracoabdominal trauma was defined as a patient with physical examination findings consistent with injury within the region of the clavicles superiorly to the pubic symphysis inferiorly, encompassing the entire anterior and posterior circumference of the thorax, abdomen and pelvis. Hemodynamically abnormal was defined as a patient possessing a heart rate ≥ 120 beats-per-minute (bpm) and/or systolic blood pressure (SBP) < 90 mmHg at the time of admission to the resuscitation bay. These specific heart rate and blood pressure thresholds were chosen as they were consistent with previous studies in the literature described as hemodynamically abnormal for trauma[3,15]. Patients with thoracoabdominal trauma that achieved hemodynamic improvement (SBP ≥ 90 mmHg on two sequential blood pressure measurements in the emergency room) and deemed eligible for CT were included. Patients were classified as transient responders if they were resuscitated to a SBP ≥ 90 mmHg and HR < 120 bpm but could not sustain a SBP ≥ 90 mmHg or HR<120 bpm with fluids or blood products. Pregnant patients, pediatric patients (age < 18), patients in extremis that underwent resuscitative thoracotomy or REBOA placement and patients with injuries outside the thoracoabdominal region were excluded[3]. Variables abstracted from the medical record included patient demographics (age (years), gender (% male), mechanism of injury – blunt vs. penetrating (%), injury severity score (ISS)), vital signs and physical examination on presentation, Extended Focused Abdominal Sonography for Trauma (E-FAST) findings, laboratory data, CT scan findings and operative findings (operation type, total operative time, crystalloid (milliliters) and blood product administration (units)). All CT findings were interpreted by a board-certified radiologist, and positive findings on imaging were confirmed by the operative record

Outcomes analysis

Patients were stratified by mechanism of injury (blunt vs. penetrating) and responder status (responder to resuscitation vs. transient responder). Outcomes for each group were tabulated. Primary outcomes included hospital length of stay (HLOS - days), intensive care unit length of stay (ICU LOS – days), ventilator days and mortality (%). Secondary outcomes included intraoperative duration (minutes), transfusion burden (packed red blood cells (PRBC), units), fresh frozen plasma (FFP, units), platelets (units), cryoprecipitate (units), incidence of venous thromboembolism (VTE - %)), infectious complications (composite incidence of pneumonia (%), urinary tract infection (%), wound infection (%) and deep space infection (%)), and the need for additional procedures. The types of non-operative injuries or injuries deemed appropriate for angioembolization identified on CT were analyzed (rib fractures, pulmonary contusions, solid organ injuries, and thoracic and abdominal vascular injuries). Specific injuries representing unnecessary delay to definitive repair with pre-operative CT were cardiac injuries and hollow viscus injuries. Diaphragm ruptures were excluded and laparoscopic abdominal explorations for trauma were excluded.

Statistical methodology

Comparison among groups was performed via one-way analysis-of-variance (ANOVA). Univariate continuous data was compared by F-test for variance followed by an unpaired Student's *t*-test. Categorical data was analyzed via Chi Square analysis or Fisher's Exact Test, where appropriate. Statistical significance was denoted at a p value of 0.05 or less. To minimize Type II error comparisons, power analysis was performed at 80 % with an alpha of 0.05 for statistical measures deemed non-significant. Power estimates of population calculations (specifically mortality, HLOS, ventilator days, and ICU LOS) were compared to published averages available in the literature[4,6,18,21]. Data is represented as mean ± standard error of the mean (SEM) or percentage (%), as appropriate. Analysis was performed using SPSS software ver. 22.0 (IBM, Armonk, NY, USA) and R version 3.5.1 (Foundation for Statistical Computing, Vienna, Austria).

Results

Demographics of the study population are shown in Table 1. During the eight-year period, 235 patients were included in the study. The population was predominantly male, in their thirties, with blunt

Table 1
Study population.

	ER to definitive therapy (n = 36)	ER to CT (n = 199)	p value
Injury Severity Score	21 ± 2.6	18 ± 0.8	0.24
GCS	13 ± 0.6	14 ± 0.2	0.67
Heart Rate on Admission (BPM ± SEM)	114 ± 4.0	115 ± 1.7	0.91
Systolic BP on Admission (mmHg ± SEM)	105 ± 5.4	118 ± 2.0	0.02
Age (years ± SEM)	34 ± 2.2	40 ± 1.3	0.09
Percent Male	88 %	76 %	0.27
Percent Blunt Trauma	25 %	80 %	< 0.001
Percent with Peritonitis on Exam	11 %	0.5 %	< 0.001
Percent with Positive Fast	58 %	27 %	< 0.001
Time from ED Admit to Completion of Triage (Minutes ± SEM)	23 ± 4.8	63 ± 6.6	0.02
Time in CT Scanner (Minutes ±SEM)	N/A	43 ± 2.5	N/A
Blood Products in CT Scanner (Units ± SEM)	N/A	0.2 ± 0.04	N/A
Fluids in CT Scanner (mL ± SEM)	N/A	472 ± 44	N/A
Mean SBP in Scanner (mmHg ± SEM)	N/A	118 ± 1.9	N/A
Mean Pulse in Scanner (Beats per Minute ± SEM)	N/A	105 ± 1.8	N/A
Percent Unstable During Scan (%)	N/A	63 %	N/A
OR Time (Minutes ± SEM)	153 ± 14	138 ± 7.5	0.45
Primary Outcomes			
Mortality	11 %	8.3 %	0.54
Hospital Length of Stay (Days ± SEM)	19 ± 3.7	15 ± 1.5	0.34
ICU Length of Stay (Days ± SEM)	6.4 ± 1.3	6.7 ± 0.9	0.91
Days on Ventilator (Days ± SEM)	1.6 ± 0.4	3.2 ± 0.8	0.39
Secondary Outcomes			
Time to Normalization of Lactate (Hours ± SEM)	12 ± 3.2	6.4 ± 1.7	0.18
Blood Loss in OR (mL ± SEM)	1184 ± 223	1165 ± 1309	0.96
Crystalloid Utilized in OR (mL ± SEM)	2981 ± 312	3081 ± 421	0.86
Packed Red Blood Cells Utilized (Units ± SEM)	9.0 ± 2.6	3.4 ± 0.7	0.006
Fresh Frozen Plasma Utilized (Units ± SEM)	5.1 ± 2.0	1.6 ± 0.4	0.009
Platelets Utilized (Units ± SEM)	1.1 ± 0.5	0.5 ± 0.1	0.10
Cryoprecipitate Utilized (Units ± SEM)	1.1 ± 0.6	0.5 ± 0.2	0.28
Venous Thromboembolism Rate	8.3 %	6.1 %	0.60
Infection Rate	25 %	24 %	0.91
Need for Additional Procedures	36 %	12 %	0.0002

Statistical significance was determined at a p value of 0.05 or less (in bold).

mechanism. Thirty-six patients (15 %) went directly to the OR from the ED at triage and 199 patients (85 %) underwent CT prior to triage. The OR and CT groups were well matched for injury burden (mean ISS OR group = 19 ± 2.2 vs. CT group = 18 ± 0.8, $p = 0.9$), and GCS (13 ± 0.6 vs. CT group 14 ± 0.2, $p = 0.7$). More patients that went to the OR had peritonitis (11 % vs. 1 %, $p < 0.01$) and a positive FAST examination (58 % vs. 27 %, $p < 0.01$) compared to those that went to CT scan prior to triage. In the overall population, there was no difference in HLOS ($p = 0.3$), ICU LOS ($p = 0.9$), time on the ventilator ($p = 0.4$) or mortality ($p = 0.5$). Patients undergoing CT had decreased need for PRBCs (9.0 ± 2.6 vs. 3.4 ± 0.7 units, $p = 0.01$) and FFP (5.1 ± 1.9 vs. 1.6 ± 0.4 units, $p = 0.01$). The OR group patients were more likely to undergo additional procedures (36 % vs. 12 %, $p < 0.01$). All organ specific injuries were tabulated and are shown in Table 2.

Outcomes – blunt trauma

Outcomes for blunt trauma are shown in Table 3. Operative versus CT groups were well matched for age, ISS, GCS, and heart rate on admission. The OR group had significantly lower systolic blood pressure on admission (94 mmHg vs. 119 mmHg, $p = 0.01$). For blunt trauma patients that underwent CT ($n = 160$ patients) there was a significant difference in mortality (33 % vs. 10 %, $p = 0.03$), a decreased need for additional procedures (33 vs. 11 %, $p = 0.05$), as well as a decrease in overall transfusion burden of all blood products ($p < 0.05$ for all).

Among blunt injuries (N = 169 patients) the prevalence of non-operative thoracic injury (rib fractures and pulmonary contusions) was 31 %. Blunt injury patients requiring surgery that obtained unnecessary pre-operative CT included cardiac injury (1 %) and hollow viscus injury (8 %). Of these patients ($n = 16$), six had a negative FAST exam. Two of these patients went to CT which revealed pericardial effusion. One patient was an 82-year-old male presenting with diminished GCS, tachycardia and stable blood pressure. Due to absence of hypotension and negative FAST, the patient was taken to CT where it was discovered that he had a significant hemothorax and pericardial effusion. Chest tube placement resulted in stabilization of vitals, repeat formal echocardiogram verified no expansion of the effusion and the patient was ultimately managed non-operatively without thoracotomy or sternotomy. The second patient was a 72-year-old male who suffered an unwitnessed fall. The patient was hypotensive on arrival but responded to 2 units of PRBCs in the resuscitation bay. The initial FAST was negative. Due to the patient's negative FAST and an appropriate response with blood transfusion the patient was taken for imaging. In CT it was discovered that the patient had a pericardial effusion with significant cardiomegaly. After thorough review of the patient's medical history, it was subsequently determined that he was actively undergoing chemotherapy for leukemia, explaining the finding on CT. The patient was successfully managed non-operatively.

Table 2
Injury summary.

	OR (n = 36)	OR Injuries Needing Operative Repair	CT (n = 199)	CT Injuries Needing Operative Repair	Total Injuries
Cardiac	3	3	2	0	5
Pulmonary	4	4	46	0	50
Vascular: Thoracic	4	4	14	5	18
Esophagus	0	0	1	1	1
Liver	11	10	36	6	47
Spleen	6	6	15	5	21
GI	17	17	20	14	37
Intraperitoneal Bladder	0	0	2	2	2
Kidney	2	2	9	1	11
Pancreas	3	3	1	1	4
Pelvis Injury	3	3	9	1	12
Vascular: Abdominal	3	3	32	4	35

OR=Operating Room, CT=Computed Tomography.

Table 3
Outcomes stratified by mechanism (Blunt vs. Penetrating).

Blunt Trauma			
Primary Outcomes	OR (n = 9)	CT (n = 160)	p value
Mortality	33 %	10 %	0.03
Hospital Length of Stay (Days ± SEM)	18 ± 8.2	16 ± 1.8	0.78
ICU Length of Stay (Days ± SEM)	9.9 ± 4.2	7.4 ± 1.1	0.60
Days on Ventilator (Days ± SEM)	3.1 ± 1.4	3.7 ± 0.9	0.89
Secondary Outcomes			
Blood Loss in OR (mL ± SEM)	1189 ± 437	1381 ± 342	0.82
Crystalloid Utilized in OR (mL ± SEM)	2561 ± 794	3125 ± 442	0.61
Packed Red Blood Cells Utilized (Units ± SEM)	22 ± 8.8	3.9 ± 0.9	< 0.001
Fresh Frozen Plasma Utilized (Units ± SEM)	14 ± 6.8	1.8 ± 0.5	< 0.001
Platelets Utilized (Units ± SEM)	3.2 ± 1.6	0.6 ± 0.2	0.001
Cryoprecipitate Utilized (Units ± SEM)	3.0 ± 1.8	0.6 ± 0.2	0.04
Venous Thromboembolism Rate	11 %	6.9 %	0.63
Infection Rate	44 %	26 %	0.21
Need for Additional Procedures	33 %	11 %	0.05
Penetrating Trauma			
Primary Outcomes	OR (n = 26)	CT (n = 40)	p value
Mortality	4.0 %	0 %	0.23
Hospital Length of Stay (Days ± SEM)	19 ± 4.4	10 ± 1.9	0.05
ICU Length of Stay (Days ± SEM)	5.4 ± 1.0	3.5 ± 1.0	0.23
Days on Ventilator (Days ± SEM)	1.2 ± 0.3	1.2 ± 0.6	0.96
Secondary Outcomes			
Blood Loss in OR (mL ± SEM)	1218 ± 269	626 ± 143	0.16
Crystalloid Utilized in OR (mL ± SEM)	3096 ± 319	2967 ± 533	0.84
Packed Red Blood Cells Utilized (Units ± SEM)	4.5 ± 0.9	1.3 ± 0.4	< 0.001
Fresh Frozen Plasma Utilized (Units ± SEM)	2.2 ± 0.7	0.8 ± 0.3	0.05
Platelets Utilized (Units ± SEM)	0.4 ± 0.1	0.1 ± 0.1	0.02
Cryoprecipitate Utilized (Units ± SEM)	0.4 ± 0.4	0	0.21
Venous Thromboembolism Rate	7.6 %	5.3 %	0.33
Infection Rate	19 %	18 %	0.90
Need for Additional Procedures	39 %	13 %	0.02

Statistical significance was determined at a p value of 0.05 or less (in bold).

Outcomes – penetrating trauma

Outcomes for penetrating trauma are shown in Table 3. Operative versus CT groups were well matched for age, ISS, GCS, heart rate and systolic blood pressure on admission. For penetrating trauma patients that underwent CT ($n = 39$ patients) there was a significant difference in hospital length of stay (19 vs. 10 days, $p = 0.05$), a decreased need for additional procedures (39 vs. 13 %, $p = 0.02$) as well as a decrease in overall transfusion burden of PRBCs, FFP, and platelets ($p < 0.05$ for all).

Among penetrating injuries (N = 66 patients) the prevalence of non-operative thoracic injury (rib fractures and pulmonary contusions) was 12 %. Penetrating trauma patients that required definitive surgery representing an unnecessary delay to definitive repair with pre-operative CT included hollow viscus injuries (9 %). Of these patients ($n = 6$), three had a negative FAST exam prior to imaging.

Outcomes – responders to resuscitation

Outcomes for responders to resuscitations are shown in Table 4. Operative versus CT groups were well matched for age, ISS, GCS, heart rate and systolic blood pressure on admission. The OR group had

Table 4
Outcomes stratified by resuscitation status (Responders vs. Transient Responders).

Responders to Resuscitation			
Primary Outcomes	OR (n = 23)	CT (n = 101)	p value
Mortality	8.7 %	5.9 %	0.63
Hospital Length of Stay (Days ± SEM)	19 ± 5.1	12 ± 1.7	0.08
ICU Length of Stay (Days ± SEM)	5.7 ± 1.5	5.5 ± 1.4	0.95
Days on Ventilator (Days ± SEM)	1.1 ± 0.4	3.3 ± 1.4	0.45
Secondary Outcomes			
Blood Loss in OR (mL ± SEM)	1164 ± 288	796 ± 204	0.34
Crystaloid Utilized in OR (mL ± SEM)	3457 ± 333	3884 ± 754	0.34
Packed Red Blood Cells Utilized (Units ± SEM)	8.1 ± 3.4	2.3 ± 0.8	0.02
Fresh Frozen Plasma Utilized (Units ± SEM)	4.0 + 1.7	0.9 ± 0.3	0.01
Platelets Utilized (Units ± SEM)	1.0 ± 0.6	0.3 ± 0.1	0.07
Cryoprecipitate Utilized (Units ± SEM)	1.6 ± 0.9	0.4 ± 0.3	0.14
Venous Thromboembolism Rate	8.7 %	6.0 %	0.63
Infection Rate	22 %	22 %	0.99
Need for Additional Procedures	44 %	8.9 %	< 0.001
Transient Responders			
Primary Outcomes	OR (n = 13)	CT (n = 98)	P value
Mortality	17 %	11 %	0.57
Hospital Length of Stay (Days ± SEM)	18 ± 5.4	19 ± 2.4	0.89
ICU Length of Stay (Days ± SEM)	7.7 ± 2.5	7.9 ± 1.1	0.89
Days on Ventilator (Days ± SEM)	2.6 ± 1.0	3.0 ± 0.6	0.78
Secondary Outcomes			
Blood Loss in OR (mL ± SEM)	1222 ± 347	1416 ± 498	0.80
Crystaloid Utilized in OR (mL ± SEM)	2108 ± 553	2556 ± 485	0.58
Packed Red Blood Cells Utilized (Units ± SEM)	11 ± 3.8	4.6 ± 1.2	0.09
Fresh Frozen Plasma Utilized (Units ± SEM)	7.4 ± 4.6	2.4 ± 0.8	0.08
Platelets Utilized (Units ± SEM)	1.4 ± 0.7	0.7 ± 0.2	0.36
Cryoprecipitate Utilized (Units ± SEM)	0.2 ± 0.2	0.5 ± 0.3	0.65
Venous Thromboembolism Rate	7.7 %	6.2 %	0.83
Infection Rate	31 %	27 %	0.75
Need for Additional Procedures	23 %	14 %	0.41

Statistical significance was determined at a p value of 0.05 or less (in bold).

significantly more penetrating trauma (87 % vs. 24 %, $p < 0.001$). For responders to resuscitation that underwent CT ($n = 101$ patients) there was a decreased need for additional procedures (44 vs. 9 %, $p < 0.001$) as well as a decrease in overall transfusion burden of PRBCs and FFP ($p < 0.05$ for both).

Among responders to resuscitation (N = 124 patients) the prevalence of non-operative thoracic injuries (rib fractures and pulmonary contusions) was 28 %. Blunt trauma patients that underwent unnecessary pre-operative CT included cardiac injury (1 %) and hollow viscus injury (7 %). Of these patients ($n = 10$), 3 had a negative FAST exam. The cardiac injury that went to the CT scanner was the 72-year-old man previously discussed.

Outcomes – transient responders

Outcomes for transient responders are shown in Table 4. Operative versus CT groups were well matched for age, ISS, GCS and heart rate on admission. The OR group had significantly lower systolic blood pressure on admission (88 mmHg vs. 112 mmHg, $p = 0.006$) and significantly more of these patients had a penetrating mechanism (54 % vs. 15 %, $p = 0.001$). For transient responders that underwent CT ($n = 98$ patients) there were no differences in primary or secondary outcomes.

Among transient responders (N = 111 patients) the prevalence of non-operative thoracic injuries (rib fractures and pulmonary contusions) was 21 %. Blunt trauma patients that required definitive surgery that underwent pre-operative CT included cardiac injury (1 %) and hollow viscus injury (10 %). Of these patients ($n = 12$), six had a negative FAST exam. The cardiac injury was the 82-year-old man previously discussed.

A summary of major findings with regard to blunt and penetrating injuries, responders vs. transient responders, is shown in Fig. 1.

Discussion

In our hemodynamically abnormal trauma population (overall 85 % were triaged to CT, 15 % were triaged to OR) we observed no significant difference in mortality, ICU length of stay, time on ventilator, or total hospitalization between groups. No significant differences in operative time, operative blood loss, or complications (infection or thromboembolism) were found. However, we found that patients that went to CT prior to OR had a reduced transfusion burden and a significantly lower chance of follow-up procedures being done. Additionally, our data suggests that blunt trauma may specifically benefit from a CT scan obtained prior to definitive therapy, as it was associated with a decrease in mortality in this subgroup (but not hospitalization), as well as penetrating injuries that undergo scanning, as this conferred decreased hospitalization (but not mortality). The differences in mortality and hospitalization between blunt and penetrating injuries may be due to the lethality of a penetrating injury that dies in the field (no mortality benefit) and a survivor bias among those that survive (which don't need operations but stay for observation). Looking at the operative injury profiles in Table 2, this would make sense, as most operative injuries were cardiac-thoracic-vascular in nature and the majority of the CT injuries managed successfully were abdomino-pelvic in nature. Another discriminating feature to consider in these patients is the responder from the transient responder, as a significant number of blunt injuries (51 % of cases) benefitted from scanning whereas a smaller proportion (35 %) of the penetrating injuries benefitted from scanning. This would suggest a lower threshold for OR in patients with penetrating mechanism that are transient responders (particularly those with high pre-test probabilities of intrathoracic injury), as there are fewer that potentially benefit from this triage strategy.

One question that is often raised is the role of the physical examination and FAST. In thoracoabdominal trauma, traditional indications for needing an operation in the setting of unstable hemodynamics include peritonitis and a positive FAST. However, physical examination in trauma is notoriously insensitive and non-specific[16,17]. In our study, 53 patients in the CT group had a positive FAST (27 %) and of these, 51 % were triaged to a trial of non-operative management or selective angioembolization and 26 % ultimately required no intervention throughout their hospitalization. Most of the patients had vital signs that were manageable in CT scan with mild resuscitation and 0 % died as a result of hemodynamic instability in the scanner. Missed hollow viscus injuries comprised 0.9 % ($n = 2$) of our study population, both declared clinically with observation and neither died because of the failure to initially triage to the operating room. The truly lethal injury not to be mistaken prior to CT scan is a cardiac injury ($n = 2/235$, 0.9 % of the study population). In these two cases, mis-triage to CT may have occurred due to a concomitant medical diagnosis in the setting of trauma (malignant effusion) and sonographic operator error. Serial FAST examinations or formal echocardiogram in the ED may have prevented the mis-triage of these two patients. As opposed to penetrating box injuries or other presentations that yield a high pre-test probability for cardiac injury, surgeons should exercise caution before interpreting equivocal FAST examination results in the chest in patients with significant medical comorbidities and good reason to have chronic thoracic disease.

Our findings are in agreement with a study from South America which similarly found no significant difference in mortality between patients who undergo CT prior to operation and those who do not[4]. In the study, patients were enrolled based on their classification as hemodynamically unstable (SBP < 100, HR>100, or ≥4 units PRBC given

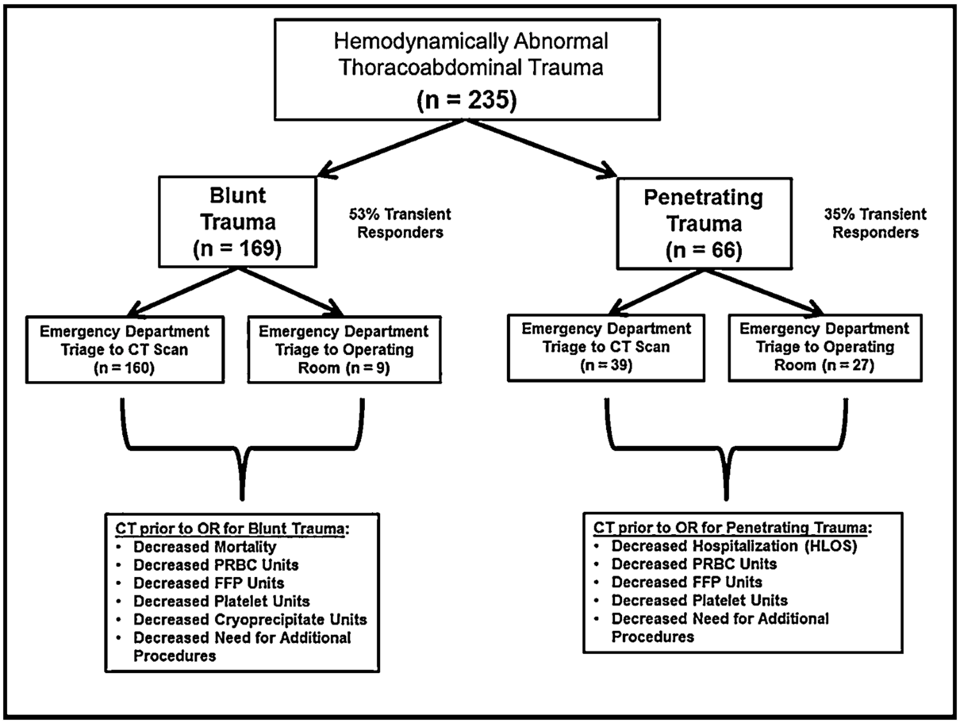

Fig. 1. Summary of Major Findings. The potential benefit of scanning hemodynamically abnormal trauma patients is depicted above. In both blunt and penetrating settings, significant benefit is seen regarding transfusion burden. With regard to hemodynamically abnormal blunt trauma there may be a mortality benefit with regard to obtaining CT scan prior to definitive therapy, whereas with penetrating trauma, prolonged hospitalization is avoided by CT. The differences in mortality and hospitalization between blunt and penetrating injuries may be due to the lethality of a penetrating injury that dies in the field (no mortality benefit) and a survivor bias among those that survive (which don't need operations but stay for observation). A significant difference between responders and transient responders was observed ($p = 0.02$). Among blunt trauma victims, 53 % were transient responders (CT group $n = 83/160$ (52 %), OR group $n = 6/9$ (67 %). Among penetrating trauma victims, 35 % were transient responders (CT group 15/39 (38 %), OR group 8/27 (30 %)). This would suggest a lower threshold for OR in transient responder patients with penetrating mechanism (particularly those with high pre-test probabilities of intrathoracic injury). Scans may enhance injury identification, triage patients to non-operative management or angioembolization and/or obviate the need for intervention altogether in appropriately selected cases.

in ED). Although our study did not include PRBC usage as an inclusion criteria, our more stringent criteria with regards to SBP and HR are in general agreement with a broader definition of hemodynamically abnormal, and the findings of our study support the argument that significant hemodynamic disturbances on presentation is not necessarily an indicator that CT scan is unfeasible or that an operation is mandatory[7,19,20].

A recent multicenter clinical trial from Europe compared a pan-CT protocol versus a standard workup with selective imaging for trauma (REACT-2). The study found that pan-CT had no effect on mortality and was also associated with faster scan times and faster time to diagnosis [18]. The authors did note, however, that 1 % of pan-scan patients experienced adverse events which ultimately led to death in those cases. There were several differences between this study and ours, specifically regarding the dichotomization of our groups. Our hemodynamic thresholds included a more severely compromised population at admission (SBP $<$ 90 vs. SBP $\leq$ 100), excluding more subjective criteria such as GCS and estimated blood loss. We limited injuries to the thoracoabdominal region. Our study population contained significantly more patients with penetrating mechanism (28 % vs. 2 %). We excluded physical examination inclusion criteria they used as a proxy for severe injury and/or instability. We separated our population by patients that did not go to CT versus those that did, regardless of whether they underwent whole body CT or selective imaging. We chose to discriminate the responder from the transient responder. A specific difference from their study and ours was that no patients coded in our CT scanner and no patients suffered adverse outcomes because of being scanned. While CT may be a benign process based on our data, surgeons must be aware of the risks of delaying time to definitive treatment prior to making the triage decision to go to the CT scanner directly from the ED.

Another retrospective study found a significant decrease in mortality following the introduction of a pan-scan imaging protocol for trauma patients that were well resuscitated prior to definitive triage. Similar to our series, all of the patients that underwent CT were resuscitated to a systolic blood pressure of 90 mmHg[5]. A criticism of that study was that patients undergoing CT had a higher mean ISS than those who did not, although it is unclear whether these patients had more severe injuries or simply a greater number of injuries distributed across body regions. Compared to our population, the patients undergoing CT in that study had both a lower mean GCS and higher ISS (mean GCS = 11 vs. 14, mean ISS = 28 vs. 18), which makes sense as we focused on thoracoabdominal trauma and excluded other body regions, such as the head, which may have lowered our GCS scores and decreased our mean ISS scores. Our study also differed from the aforementioned study in that we analyzed both blunt and penetrating trauma, compared to theirs which was solely blunt.

In disagreement, one meta-analysis found that although sending trauma patients to CT for pan scan decreased mortality, there was a significant increase in time spent on a ventilator (0.96x) as well as an increased incidence of multi-organ failure (1.44x)[10]. However, this analysis differs significantly from ours in that patients were classified as undergoing whole body CT (WBCT) versus non-WBCT, meaning patients who underwent selective CT were mixed with patients who underwent no CT studies (we separated strictly scan vs. no-scan). This may help explain the finding of increased ventilator time as WBCT is a longer radiological study that may require sedation and intubation of the patient to complete, thus increasing ventilator time. Additionally, the authors of that study claim that the decision to scan or not scan may have nothing to do with the increased incidence of multi-organ failure, as the patients developing organ failure are survivors that received excellent prehospital care, not patients that decompensated and developed organ failure because of the scan. Instead of the decision to scan or not scan, what may be more germane to the discussion is the importance of CT scan availability, proximity and speed of image acquisition, which may adversely affect outcomes if not performed in an expedient way[21]. The ability to obtain a CT scan at our institution is multifactorial – in addition to distance (our scanner is <50 feet away from the resuscitation bay) prolonged resuscitation and scanner unavailability may play a role in the delay to definitive care. In our study, the average resuscitation time was 23 min for OR patients vs. 63 min for CT patients ($p = 0.02$), and the patients were in the scanner for a mean time of 43 min. Despite this, we saw no adverse events of sending our patients to CT and we demonstrated that scanning hemodynamically abnormal trauma may not compromise outcomes.

Our study supports recent literature that on-table "CT-resuscitation" is feasible in selected patients. Arguments against CT resuscitation include an inability to attenuate surgical hemorrhage in the CT scanner that should have been managed in the operating room from the start. However, in two series outcomes in hypotensive trauma patients that underwent CT resuscitation prior to definitive therapy showed no difference in mortality[6] and time to definitive treatment[16]. In our study, of patients that went to CT, 63 % developed some type of hemodynamic abnormality while being scanned (SBP < 90 mmHg and/or HR > 120 bpm). Many of these patients underwent adequate resuscitation to a SBP of greater than 90 mmHg with small amounts of fluid and blood products while inside the scanner (mean crystalloid 472 ± 44 ml, mean blood products 0.2 ± 0.04 units). This may have persuaded the trauma surgeon to continue the scan and not rush to the OR, potentially triaging the patient to non-operative or interventional management. Considering this data and in the context of the studies published above we postulate that selected hemodynamically abnormal patients not only survive the scanner, but may benefit from its utilization[7,9,19]. Furthermore, techniques such as resuscitative endovascular balloon occlusion of the aorta (REBOA), may help temporarily attenuate hemorrhage so that CT is a safer, more feasible option[22].

In addition to physical examination, the role of adjunctive studies (FAST and DPA) with respect to the need for CT in hemodynamically abnormal trauma is likewise debated. Positive FAST examinations in our study were more likely to go straight to the OR (58 % of the OR group vs. 27 % of the CT group, $p < 0.01$), consistent with findings in the literature [23]. However, in both the CT and OR groups, there were more negative FAST exams than there were patients with no cavitary injuries identified by laparotomy (3 negative laparotomy cases in the OR group, 2 in the CT group). This finding is in agreement with other studies that concluded that a negative FAST is not sufficient to exclude significant injury in trauma and that patients may benefit from CT to truly exclude life-threatening injuries[24,25]. Furthermore, our findings indicate that hemodynamically abnormal patients with a positive FAST are not necessarily harmed by undergoing CT prior to definitive management. In our study, there were 22 injuries (5 liver, 5 abdominal vascular, 4 spleen, 4 pulmonary, 1 thoracic vascular, 1 cardiac, 1 pelvic, and 1 kidney) that generated a positive FAST, but were able to be managed non-operatively or by interventional radiology due to CT findings. Our findings agreed with a study that concluded that trauma patients who are hypotensive on admission (SBP < 90 mmHg) and have a positive FAST benefit from CT as it does not reduce mortality, but does reduce transfusion volume, the odds of having an emergency surgery, and increases the likelihood of utilizing less invasive treatments such as interventional radiology[9].

Our study contributes to the current body of literature in that although there are multiple studies that analyze the impact of selective CT vs whole body CT, ours is one of few that explores the triage decision of going to the CT scanner versus foregoing it altogether. Furthermore, our study uses hemodynamic criteria that are stricter than many studies and includes significant data on penetrating trauma. This study suffers from the traditional limitations of retrospective research including significant selection bias and what may be argued a unique patient population representing a selected demographic. Additionally, this study was performed at a Level 1 Trauma Center, where moving a patient from the trauma bay to the CT scanner can be accomplished in a matter of minutes. At institutions that do not see high volume trauma, it is important to recognize the limitation of potentially not having an efficient team to get the patient a CT scan in a timely manner. Systems that are not built for rapid assessment, transportation, and efficient imaging may find that CT scans prior to operative intervention in hemodynamically abnormal patients could end up causing harm to the patient via delay in care. Moreover, while CT is one critical component of surgical decision-making, there may have been inherent differences in the way individual trauma surgeons managed hemodynamically abnormal trauma and these decisions are not protocolized strictly at our institution. The threshold to tolerate hemodynamic perturbations and interpretations of a response to resuscitation is cultivated by a surgeon's personal experience. Future prospective studies are mandated to evaluate the effect of resuscitative measures in the ED on the benefits and risks of CT before operation. Although our data demonstrate that CT is a useful and safe tool in the evaluation of hemodynamically abnormal patients, the importance of physical exam and study adjuncts, and most of all common sense, should not be forgotten in determining the need for urgent operation[26].

Conclusion

Hemodynamically unstable thoracoabdominal trauma may benefit from CT scanning prior to definitive therapy. Imaging was associated with decreased transfusion burden and need for additional surgical procedures without affecting morbidity or mortality.

CRediT authorship contribution statement

Anna White: Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Lindsey Loss:** Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **John Carney:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Christopher Barrett:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Conceptualization. **Kazuhide Matsushima:** Writing – review & editing, Writing – original draft, Validation, Methodology, Data curation, Conceptualization. **Kenji Inaba:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology. **Aaron Strumwasser:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Reynold Henry:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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