Routine computed tomography after recent operative exploration for penetrating trauma: What injuries do we miss?

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BACKGROUND: Patients with penetrating trauma who cannot be stabilized undergo operative intervention without preoperative imaging. In such cases, postoperative imaging may reveal additional injuries not identified during the initial operative exploration. The purpose of this study is to explore the utility of postoperative CT imaging in the setting of penetrating trauma.

METHODS: This was a retrospective analysis of patients with penetrating trauma treated at an urban Level 1 trauma center between 2010 and 2015. Patients were included if they underwent an emergent laparotomy without preoperative imaging. Patients were excluded if they had prior imaging or concomitant blunt injury. For the purposes of this study, occult injury was defined as a CT scan finding not mentioned in the first operative report. Descriptive statistics were used to compare patient characteristics who had received imaging immediately postoperatively with those who had not.

RESULTS: During the 5-year study period, 328 patients who had a laparotomy for penetrating trauma over the study period, 225 patients met the inclusion criteria. Seventy-three (32%) patients underwent CT scanning immediately postoperatively with occult injuries identified in 38 (52%) patients. The most frequent occult injuries were orthopedic (20 of 43) and genitourinary (9 of 43). Importantly, 10 (26%) of the 38 patients required an intervention for these occult injuries. Those selected for immediate postoperative imaging were more likely to have sustained gunshot wounds and were significantly more severely injured (higher Injury Severity Score and longer length of hospital stay) when compared to patients who did not receive immediate imaging.

CONCLUSION: We recommend the use of immediate postoperative CT after emergent laparotomy especially when there is a high index of suspicion for spine or genitourinary injuries and in patients who have sustained ballistic penetrating injuries.

LEVEL OF EVIDENCE: Therapeutic/care management, level IV; diagnostic tests or criteria, level IV.

KEY WORDS: Occult injury; penetrating trauma; CT imaging.

Whole-body computed tomography (CT) has been shown to decrease mortality in the trauma patient population.¹ The role of CT imaging after blunt trauma has been well established.^{1,2} Its use in penetrating trauma remains controversial, but it may have a role in carefully selected patients with isolated solid organ injuries who might be considered for nonoperative management.^{1,2} CT imaging has also been advocated in the initial evaluation of patients with anterior abdominal stab wounds without evidence of blood loss or peritonitis as a method of defining the trajectory of the injury.³ However, there are currently no data on the use of CT imaging in the immediate postoperative period. It has been well recognized that missed injuries are increased in the severely injured and multisystem trauma patient. Intensive care unit patients and those requiring emergent surgical procedures appear to have the highest risk of missed injury.⁴⁻⁶

Recently, CT imaging has increased in the early postoperative period in patients with penetrating thoracoabdominal

trauma.^{7,8} In general, we believe there are four main indications for using CT imaging in this setting:

1. To define the extent of an injury to a solid organ (particularly the liver).
2. To access for vascular injuries that might benefit from angiographic interventions.
3. To delineate the trajectory of a penetrating injury, particularly one that may involve more than one anatomic cavity.
4. To assist in the planning for a second operation after an initial damage control procedure.

In this study, we sought to review the indications for and results of the use of early postoperative CT imaging after thoracic or abdominal trauma at our center with particular attention to the injuries detected and their subsequent treatment. We hypothesize that a significant number of occult injuries would be identified and that we could further define the indications for the use of CT in the early postoperative period after surgical exploration for penetrating trauma.

PATIENTS AND METHODS

A retrospective analysis of an urban American College of Surgeons verified Level 1 trauma center surveillance registry was queried to identify patients with penetrating injuries between January 2010 and December 2015. The institutional review board on human research approved this study and waived

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TABLE 1. Epidemiological Data of Patients With Penetrating Trauma Requiring Exploratory Laparotomy

	Early CT (<24 Hours)	No Immediate CT
Demographic data	n = 73	n = 152
Age, y*	28 (22–38)	31 (9–81), $p = 0.06$
Male	67 (91.7)	140 (92.1), $p = 0.5$
GSW	55 (75.3)	44 (28.9), $p < 0.001$
ISS*	17 (10–26)	9 (1–34), $p < 0.001$
LOS, d*	11 (7–19)	7 (1–81), $p = 0.0001$
OA	11 (15)	21 (14), $p = 1.0$

All other data given as number of patients with parentheses indicating percentages.

*Data given as medians with parentheses indicating interquartile ranges.

the informed consent. All patients included in this study had penetrating thoracic and/or abdominal trauma and underwent emergent operative intervention. Patients were excluded if they had CT imaging before exploratory surgery, concomitant blunt trauma, isolated extremity injuries or expired during the perioperative period. For the purposes of this study, occult injuries were defined as those detected on postoperative imaging, but were not mentioned within the operative report. All operative reports were retrospectively reviewed by a board-certified general surgeon and/or trauma fellow. Emergency department x-rays were also reviewed and any fractures identified here were not included within the undiagnosed injuries identified by CT. Patients were stratified into groups based on whether or not they received CT imaging within 24 hours after trauma operative intervention (thoracotomy and/or laparotomy). Early CT (ECT) was defined as less than 24 hours into the hospital admission. Late CT (LCT) was defined as any patient who received a CT after 24 hours of admission. Indications for CT were determined either by the operative report, CT report or other physician documentation. Outcome measures included penetrating injury mechanism, Injury Severity Score (ISS), length of hospital stay (LOS), evidence of damage control treatment by the presence of an open abdomen (OA) and evidence of occult injury on CT. Specific data was also collected on indications for early or late CT. Statistical analysis comparing patients was performed using χ^2 test for categorical data and the unpaired Student's t test for continuous data. Logistic regression was used to determine the odds ratio for identifying a patient with an occult injury on ECT. The area under the receiver operating characteristics curve (AUROC), with 95% confidence interval [CI] was calculated for each significant ($p < 0.05$) covariate on univariate

TABLE 2. Early CT Indications

Early CT Indications	No. Patients (%)
Concern for retroperitoneal injury	34 (47)
No indication given	30 (41)
Limited surgical exploration (hostile abdomen/prior surgeries)	2 (2.7)
Evaluate extent of liver injury	2 (2.7)
Multiple wounds	2 (2.7)
Unexplained postoperative hypotension	2 (2.7)
Concern for esophageal injury	1 (1.4)

CT = computed tomography.

logistic regression. Pearson χ^2 and Hosmer-Lemeshow tests were performed to confirm goodness-of-fit. All analyses were performed with StataIC-12 (College Station, TX).

RESULTS

During this 5-year period, 326 patients underwent operative intervention for penetrating thoracic and/or abdominal trauma. Of these patients, 101 were excluded because they either received CT imaging before operative intervention, had concomitant blunt trauma, had an isolated extremity injury or expired during the immediate perioperative period. Of the remaining 225 patients, 73 (32%) underwent CT imaging in the early (ECT) postoperative period. The median time to imaging for the ECT cohort was 7 hours (interquartile range [IQR], 2–18). Within the study cohort, there was a group of patients who received imaging later than the first 24 hours of their hospital admission. We reviewed these results for evidence of missed or occult injury related to the initial trauma. This group was made up of 37 (16%) patients who obtained LCT. The median time to imaging in this group was 4 days (IQR, 1–10 days). There were 115 (51%) patients (ISS, 9; IQR, 1–26; LOS, 6 days; IQR, 1–20) who never received imaging and survived to discharge.

The group that received ECT was mostly men (92.9%) with a median age of 28 years (IQR, 22–38). The majority in this group had sustained a gunshot wound (GSW) (75.3%). The median injury severity score (ISS) for patients with ECT was 17 (IQR, 10–26) and LOS was 11 days (IQR, 7–19). Both of these variables were statistically significantly higher in the ECT group when compared to patients who did not undergo early postoperative imaging (Table 1). Within the study group, there were only 32 patients with an OA postoperatively; eleven of these underwent ECT. Indications for ECT were individually ascertained from the patient medical record. The most common indication for ECT was evidence or concern for a retroperitoneal injury that could not be sufficiently characterized intraoperatively (47%) (Table 2).

Next, we wanted to compare the ECT group with the LCT group, because this group served as a type of control to determine whether imaging in the postoperative phase would identify occult injuries regardless of the clinical reasoning for obtaining additional imaging. The LCT group consisted of mostly male patients (90.2%) with a median age of 38 (IQR, 24–46). Nineteen patients (46.3%) sustained a GSW and had an ISS of 13

TABLE 3. Epidemiological Data of Patients With Penetrating Trauma Requiring Exploratory Laparotomy That Had Early or Late CT Imaging During Their Hospital Admission

Table 3.	Early CT	Late CT
Demographic data	n = 74	n = 37
Age, y*	28 (22–38)	38 (24–46), $p = 0.12$
Male	67 (91.7)	37 (90.2), $p = 0.21$
GSW	55 (75.3)	19 (46.3), $p = 0.02$
ISS*	17 (10–26)	13 (4–26), $p = 0.02$
LOS, d*	11 (7–19)	12 (5–37), $p = 0.3$
Occult injury	39 (52.7)	8 (21.6), $p = 0.002$

*Data given as medians with parentheses indicating interquartile ranges.

TABLE 4. Late CT Indications

Late CT Indications	No. Patients (%)
Workup of ileus	12 (36)
Urology imaging recommendations/urogram after known injuries	5 (14)
New neurologic deficit or concern for spine injury	4 (11)
Dyspnea/rule out pulmonary embolism	4 (11)
Fever work-up	3 (8.1)
Follow-up of known significant liver laceration	2 (5.4)
Unexplained decrease in hematocrit	2 (5.4)
Unexplained postoperative hypotension	1 (2.7)
Persistent pneumothorax	1 (2.7)
Evaluate for possible esophageal injury	1 (2.7)
Vascular evaluation	1 (2.7)
Unknown indication	1 (2.7)

(IQR, 8–21). The length of stay did not differ between ECT and LCT patients. Occult injuries were found in 38 ECT patients (52.1%) and eight LCT patients (21.6%; $p = 0.002$) (Table 3). Of the LCT cohort, work up for ileus was the most common indication (36%) (Table 4).

A total of 43 injuries were detected in the 38 ECT patients where additional injuries were identified. The vast majority of injuries included orthopedic injuries (20) and genitourinary injuries.⁹ There were some new solid organ injuries⁷ and vascular injuries⁷ identified as well. Ten patients (26.3%) had injuries that required intervention. Interventional radiology was required for four patients with evidence of arterial extravasation, and seven required operative intervention for orthopedic or genitourinary injuries, including one patient with an unstable spine fracture.

Of the eight LCT patients who had occult injuries identified, there were nine newly diagnosed injuries. Seven (77.8%) were orthopedic injuries, one genitourinary injury and one vascular injury. No new solid organ injuries were found in this group. Two of the eight patients in the LCT cohort had occult injuries identified that required intervention.

Since there were differences between ISS, injury patterns and LOS between ECT and the non-ECT groups, we performed a logistic regression. On univariate analysis, ISS (odds ratio, 1.06; 95% CI, 1.01–1.11; $p = 0.009$; AUROC, 0.7; 95% CI, 0.59–0.83) injury mechanism (GSW) (odds ratio, 8.48; 95% CI, 2.21–32.5; $p = 0.002$; AUROC, 0.7; 95% CI, 0.58–0.76), and LOS (odds ratio, 1.05; 95% CI, 1.01–1.10; $p = 0.02$; AUROC, 0.7; 95% CI, 0.58–0.82) were associated with finding an occult injury on ECT. On multivariate analysis, only injury mechanism was associated with occult injury (odds ratio, 10.4; 95% CI, 2.02–53.9; $p = 0.005$; AUROC = 0.8; Hosmer-Lemeshow = 7.6; $p = 0.48$). However, in the LCT group neither ISS (odds ratio, 0.52; 95% CI, –0.097 to 0.168; $p = 0.61$) nor injury mechanism (odds ratio, 1.59; 95% CI, –4.27 to 0.439; $p = 0.11$) were found to predict occult injuries.

We calculated the risk ratio of certain hypothesized high-risk injury patterns and found that only GSW involving the retroperitoneum (RR, 5.1) and GSW to the pelvis (RR, 7.4) were positively associated with an increased risk of finding occult injuries on CT.

DISCUSSION

The role of CT continues to evolve for penetrating trauma. For blunt trauma, there is support for early whole-body CT to assist with diagnosis of injuries with evidence that it can increase survival.^{1,2,9} For penetrating trauma this is a controversial idea. There is a growing body of literature to suggest that some injury patterns especially patients who are hemodynamically normal can be imaged and even managed nonoperatively.^{9,10} In the immediate postoperative period the practice of obtaining whole-body or “pan-CT” is expanding with little data to encourage or refute this practice.¹¹ At our institution, the majority do not obtain imaging preoperatively in the setting of penetrating trauma. Obtaining imaging postoperatively largely remains at the discretion of the operating surgeon.

To our knowledge, this is the first study to evaluate the utility of postlaparotomy CT in the setting of penetrating trauma victims only. Most recently, there have been two studies surrounding

Proposed Flow Diagram from Imaging in the Post-Operative Period after Penetrating Trauma

ECT=early computed tomography; y= years; GSW= gun shot wound; SW=stab wound

Figure 1. A proposed flow diagram of when to consider early CT (ECT) in postoperative trauma patients after penetrating trauma.

the utility of early CT in the perioperative period for trauma patients. Both of these studies included patients with blunt and penetrating trauma and their conclusions differed in regards to the extent of significant injuries found with additional imaging.^{7,8} Weis et al.⁷ found little difference in their populations who did or did not receive imaging in respect to the severity of illness or need for additional interventions. Conversely, Haste et al.⁸ showed that 21% of their patients had additional injuries within the surgical field that were not identified during laparotomy. Additionally, eight (8.9%) patients had injuries that required an intervention. This study included both blunt and penetrating trauma patients from two different institutions, although the majority of their patients (73%) had sustained penetrating injuries. Moreover, 50% of their study group had undiagnosed fractures identified by CT.

In our study, CT appears to offer several advantages in the early perioperative period with nearly 45% of these patients having an occult injury diagnosed with additional imaging. In this study, patients who received early imaging differ significantly when compared to their nonimaged counterparts. These patients were more likely to have sustained an injury from a firearm versus a stab wound. In addition, patients with ballistic injuries were more prone to multiple injuries especially fractures (all 28 occult fractures) and retroperitoneal injuries (10 of 11 GU injuries) sustained a GSW. In addition, the surgical exploration is not the ideal method to identify, diagnose, or characterize spinal or pelvic fractures, but CT imaging can do just that. Furthermore, since many seriously injured patients undergo a damage control approach initially, imaging may help guide the second-look operation. We propose that patients with penetrating transaxial trauma especially from firearm injuries be considered for ECT as part of their tertiary survey. Additional characteristics that may benefit from early imaging include damage-control procedures and penetrating injuries involving the regions of the chest, retroperitoneum or pelvis. Taking into account our calculated risk ratio of certain ballistic injury patterns associated with occult injuries, we have proposed a flow diagram that can guide decision-making in the postoperative setting (Figure 1).

The limitations of this study are those inherent to any study with a retrospective methodology. First, there is a small sample size and it is limited to a single institution; this may limit generalizability. We did not take into consideration the number of injuries present during their initial evaluation or the type of ballistic injuries (low, medium or high muzzle velocity) or other properties of firearm injuries that contribute to tissue damage. Provider practice patterns range as does surgical experience and there exists no strict protocol for imaging indications at this institution. Another important critique is the substantial difference that exists between our cohort population in respect to ISS and LOS. There exists an inherent bias because of the nature of the study design.

In conclusion, early CT imaging in the perioperative period does provides useful information and guides further interventions. Severely injured patients with ballistic injuries are at high risk for undiagnosed injuries even after exploratory surgery.

CT imaging should be considered soon after surgery to guide management. We believe that a prospective, multicenter observational study is indicated to evaluate the utility of ECT in the setting of penetrating trauma especially in patients with certain injury patterns involving any retroperitoneal zones which appear to have a high risk for occult injuries. The practicality of any imaging after penetrating trauma particularly firearm injuries should involve a protocol-driven study.

AUTHORSHIP

A.E.M. contributed to study design, data acquisition, and analysis and drafting the article. C.A.W. contributed to study design, data acquisition and revising the article. A.G.C. contributed to study design, interpretation of data and critical revision. A.C. contributed to study design and critical revision. B.A.C. contributed to study design and critical revision. M.M.K. contributed to the study design, interpretation of data, and critical revision.

DISCLOSURE

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