Determining the Need for Laparotomy in Penetrating Torso Trauma: A Prospective Study Using Triple-Contrast Enhanced Abdominopelvic Computed Tomography

William C. Chiu, MD, K. Shanmuganathan, MD, Stuart E. Mirvis, MD, and Thomas M. Scalea, MD

Background: The nontherapeutic laparotomy rate in penetrating abdominal trauma remains high and the morbidity rate in these cases is approximately 40%. Selective management, rather than mandatory laparotomy, has become a popular approach in both stab wounds and gunshot wounds. The advent of spiral technology has stimulated a reassessment of the role of computed tomography (CT) in many aspects of trauma care. We prospectively investigated the current utility of triple-contrast CT as a diagnostic tool to facilitate initial therapeutic management decisions in penetrating torso trauma.

Methods: We studied hemodynamically stable patients with penetrating injury to the torso (abdomen, pelvis, flank, back, or lower chest) without definite indication for laparotomy, admitted to our trauma center during the 1-year period from 7/99 through 6/00. Patients underwent triple-contrast enhanced spiral CT as the initial study. A positive CT scan was defined as any evidence of peritoneal violation (free air or fluid, contrast leak, or visceral injury). Patients with positive CT, except those with isolated solid viscous injury, underwent laparotomy. Patients with negative CT were observed.

Results: There were 75 consecutive patients studied: mean age 30 years (range 15–85 years); 67 (89%) male; 41 (55%) gunshot wound, 32 (43%) stab wound, 2 (3%) shotgun wound; mean admission systolic blood pressure 141 mm Hg (range 95–194 mm Hg); 26 (35%) had positive CT. In patients with positive CT, 18 (69%) had laparotomy: 15 therapeutic, 2 nontherapeutic, and 1 negative. Five patients had isolated hepatic injury and 2 had hepatic and diaphragm injury on CT and all were successfully managed without laparotomy. Of these seven patients, three had angiembolization and two had thoracoscopic diaphragm repair. In patients with negative CT, 47/49 (96%) had successful nonoperative management and 1 had negative laparotomy. The single CT-missed peritoneal violation had a left diaphragm injury at laparotomy. CT accurately predicted whether laparotomy was needed in 71/75 (95%) patients.

Conclusion: In penetrating torso trauma, triple-contrast abdominopelvic CT can accurately predict need for laparotomy, exclude peritoneal violation, and facilitate nonoperative management of hepatic injury. Adjunctive angiography and investigation for diaphragm injury may be prudent.

Key Words: Abdominal injury, Computed tomography, Exploratory laparotomy, Penetrating trauma, Selective management.


As early as 1960, Shaftan advocated the application of trained surgical judgment rather than mandatory laparotomy in the management of penetrating abdominal injury.1 This new approach to civilian penetrating trauma was prompted at that time by the high rate of nontherapeutic laparotomies and associated morbidity. Since then, selective management for patients with abdominal wounds has evolved to incorporate ancillary studies which supplement the findings of serial physical examination and provide objective data for decision-making. The common diagnostic tests included in algorithms for management of penetrating abdominal trauma have been local wound exploration (LWE), diagnostic peritoneal lavage (DPL), laparoscopy, and more recently, ultrasonography.2

The enthusiasm for using computed tomography (CT) in evaluating penetrating abdominal trauma has been limited by its reported low sensitivity in detecting gastrointestinal injuries and diaphragmatic injuries, but these studies were performed before the advent of spiral CT technology.3 In recent times there has been a renewed interest in applying CT scanning to evaluate penetrating injuries to body regions that have traditionally been investigated with other tests, such as the neck and mediastinum.4,5 The value of triple-contrast (oral, intravenous, and rectal) CT scanning in penetrating back and flank wounds for the evaluation of the retroperitoneum has already been established.6–8 Furthermore, a prospective study on CT scan in the evaluation of anterior stab wounds (SW) has been reported with favorable results.9

Although selective nonoperative management has been studied in the evaluation of anterior abdominal gunshot wounds (GSW), there has been no prospective study to date that extends the use of triple-contrast abdominopelvic CT as a routine test in this setting.10 Therefore, we prospectively investigated the utility of triple-contrast CT as a diagnostic

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From the Section of Trauma Surgery, R Adams Cowley Shock Trauma Center (W.C.C., T.M.S.), and the Department of Diagnostic Radiology, Division of Trauma Radiology (K.S., S.E.M.), University of Maryland School of Medicine, Baltimore, Maryland.
Address for reprints: William C. Chiu, MD, Section of Trauma Surgery, R Adams Cowley Shock Trauma Center, University of Maryland Medical System, 22 South Greene Street, Baltimore, MD 21201-1595; email: wchii@umm.edu.
tool to facilitate initial management decisions in hemodynamically stable patients with any penetrating torso wound. Our hypothesis was that triple-contrast CT would be a valuable test to determine the need for laparotomy in these patients.

**MATERIALS AND METHODS**

This study was approved by both the University of Maryland, Baltimore, Institutional Review Board and the R Adams Cowley Shock Trauma Center Research Committee. Full informed consent by the patient or parent/guardian/next-of-kin was obtained for each research subject. All consenting subjects have been included in this analysis.

The R Adams Cowley Shock Trauma Center is the designated Primary Adult Resource Center for trauma for the state of Maryland. All hemodynamically stable patients with a penetrating injury to the torso and without obvious indication for laparotomy were candidates for this study. This study encompassed patients admitted to our trauma center for the 1-year period from July 1999 through June 2000.

**Definitions**

The following anatomic landmarks define the inclusion zones we used for a penetrating wound to the torso: (1) lower chest—the sixth intercostal spaces cephalad, to the anterior axillary lines laterally, to the costal margins caudad; (2) abdomen—the costal margins cephalad, to the anterior axillary lines laterally, to the anterior superior iliac spines caudad; (3) flank—bilaterally, the sixth intercostal spaces cephalad, between the anterior axillary line and posterior axillary line, to the iliac crests caudad; (4) back—the sixth intercostal space cephalad, to the posterior axillary lines laterally, to the iliac crests caudad; and (5) pelvis—the iliac crests cephalad, to the inguinal ligaments and gluteal folds caudad.

Hemodynamic stability was defined as systolic blood pressure (SBP) ≥ 90 mm Hg and heart rate 50 to 110 beats per minute. Exclusion criteria included any patient determined to be hemodynamically unstable or having any of the following obvious indications for laparotomy: (1) overt evidence of peritoneal penetration on clinical examination; (2) peritonitis by physical examination; and (3) hematemesis or gross blood on rectal examination. Another exclusion criterion was known major allergy to intravenous contrast material.

**Triple-Contrast CT**

After initial assessment and intravenous access, patients were administered diatrizoate sodium oral contrast material (Hypaque Sodium powder 5 g/300 mL water, Nycomed Inc., Princeton, NJ). In preparation for rectal contrast administration, a Foley catheter (Dover Silicone Elastomer Coated Foley Catheter, 26 Fr, 30 mL balloon, Sherwood Medical, St. Louis, MO) was inserted into the rectal vault, balloon inflated with sterile water, and clamped. Upon transfer to the CT table, diatrizoate sodium contrast material (Hypaque Sodium powder 15 g/1000 mL water, Nycomed Inc.) that had been reconstituted in a 1000 mL capacity enema bag (CT Enema Administration Kit, E-Z-EM, Inc., Westbury, NY) was connected to the rectal catheter, administered by gravity flow, and catheter reclamped.

Intravenous contrast was achieved with a power-injected bolus of 150 mL of iohexol intravascular contrast material (Omnipaque Injection, 240 mg organic iodine/mL, nonionic, Nycomed Inc.), administered at 3 mL/sec with a scanning delay of 60 sec. CT scan of the abdomen and pelvis was obtained on a spiral instrument (Siemens Somatom Plus 4, Siemens Medical Systems) using a standard protocol from the lower chest (nipple line) to the upper thigh using a collimation of 8 mm and a table speed of 8 mm (pitch 1).

**Image Interpretation**

For purposes of study analysis, all CT images were interpreted by a dedicated team of attending trauma radiologists by consensus. The radiologists were blinded to the patients’ clinical course, results of ancillary tests, and operative findings. CT images were evaluated to determine the following items: (1) trajectory of the stab or missile; (2) presence or absence of peritoneal penetration; (3) intraperitoneal and retroperitoneal solid organ or hollow viscus injury; (4) urinary system injury; (5) vascular system injury; and (6) evidence to suggest diaphragmatic injury.

CT findings indicating peritoneal penetration included the following: (1) trajectory of the stab or missile clearly penetrating the peritoneal cavity; (2) free intraperitoneal fluid or air; (3) intraperitoneal extravasation of contrast material; and (4) injury to an intraperitoneal solid organ or hollow viscus. A positive CT scan was defined as one with any evidence of peritoneal violation, while a negative CT scan was one without peritoneal violation.

**Patient Management**

Patients underwent triple-contrast enhanced spiral CT as the initial study. Patients with positive CT, except those with isolated solid organ injury, underwent laparotomy. In those patients with isolated solid organ injury, the decision to perform laparotomy or an ancillary therapeutic maneuver was left to the discretion of the trauma team. Patients with negative CT were observed for approximately 12 hours with serial examinations before discharge.

While the blinded attending radiologist interpretation of the CT was used for study analysis, CT scans were also viewed by trauma team physicians and radiology residents at the point of patient care. The decision to perform laparotomy in any given patient may have been influenced by the initial unofficial interpretation of these physicians. These decision-making dynamics were not recorded in this study. Management of patients for the remainder of their hospital course was directed by the trauma team. All relevant adjunctive studies performed, any delayed diagnoses, any untoward events, and further therapeutic maneuvers were noted.
RESULTS

In the 1-year study period, our trauma center admitted 5689 trauma patients of which there were 863 (15%) with a penetrating injury. Of penetrating trauma patients, 197 (23%) had a torso wound and 182 (92%) of these patients were hemodynamically stable. After excluding patients with obvious indication for laparotomy and patients not consenting to research, ultimately, there were 75 (41%) consecutive patients studied. The mean age was 30 years (range 15–85 years). There were 67 (89%) males and 8 (11%) females. The mean admission SBP was 141 mm Hg (range 95–194 mm Hg).

Overall, 26 (35%) patients had a positive CT for peritoneal violation and 49 (65%) had a negative CT. In patients with positive CT, 18 (69%) had laparotomy: 15 therapeutic, 2 nontherapeutic, and 1 negative (Fig. 1). Five (19%) patients had isolated hepatic injury and two (8%) had hepatic and diaphragm injury on CT, and all were successfully managed without laparotomy (Fig. 2). Of these seven patients, three had angioembolization and two had video-assisted thoracoscopic surgery (VATS) diaphragm repair. The remaining one (4%) patient with positive CT for peritoneal violation had an anterior abdominal wall hematoma and local intraperitoneal blood. This patient was also successfully managed without laparotomy.

In patients with negative CT, 47/49 (96%) had successful nonoperative management (Figs. 3 and 4). The remaining two (4%) patients underwent laparotomy as a clinical decision made by the trauma team after initial preliminary assessment of CT. One of these patients had a negative laparotomy while the other patient was found to have a left diaphragm injury. This latter patient represented the only CT-missed (false negative) peritoneal violation.

Analysis by Wounding Mechanism

Of the 75 patients, 41 (55%) had GSW, 32 (43%) had SW, and 2 (3%) had shotgun wounds (SGW) (Table 1). In GSW patients, there were 17 (41%) with positive CT and 24 (59%) with negative CT. Laparotomy was performed in 13/41 (32%) GSW patients. One of these patients with neg-
ative CT underwent laparotomy for clinical reasons and no injury was found. Both SGW patients had negative CT and neither required laparotomy.

In SW patients, there were 9/32 (28%) with positive CT and 23/32 (72%) with negative CT. Laparotomy was performed in 7/32 (22%) SW patients. The single CT-missed peritoneal violation was a diaphragm injury in a SW patient.

Analysis by Number of Wounds

Of the 75 patients, 55 (73%) had a single torso wound, 15 (20%) had two torso wounds, 4 (5%) had three torso wounds, and only 1 (1%) patient had four torso wounds (Table 2). In patients with a single wound, there were 22 (40%) with positive CT and 33 (60%) with negative CT. Laparotomy was performed in 15/55 (27%) patients with single wounds. One of the therapeutic laparotomies was represented by the only patient with false negative CT.

In the 20/75 (27%) patients with two or more torso wounds, there were 4/20 (20%) with positive CT and 16/20 (80%) with negative CT. Laparotomy was performed in 5/20 (25%) patients with two or more torso wounds. There were no patients with two or more torso wounds having isolated solid organ injury. The single patient with four torso wounds had four GSW to the pelvis, had a positive CT, and underwent laparotomy for bladder injury.

Analysis by Wound Location

Of the 75 patients, 64 (85%) had wounds to a single torso region: 17 (23%) pelvis; 16 (21%) abdomen; 13 (17%) flank; and only 1 (1%) patient had four torso wounds (Table 2). In patients with a single wound, there were 22 (40%) with positive CT and 33 (60%) with negative CT. Laparotomy was performed in 15/55 (27%) patients with single wounds. One of the therapeutic laparotomies was represented by the only patient with false negative CT.

In the 20/75 (27%) patients with two or more torso wounds, there were 4/20 (20%) with positive CT and 16/20 (80%) with negative CT. Laparotomy was performed in 5/20 (25%) patients with two or more torso wounds. There were no patients with two or more torso wounds having isolated solid organ injury. The single patient with four torso wounds had four GSW to the pelvis, had a positive CT, and underwent laparotomy for bladder injury.

Table 1 Triple-Contrast Abdominopelvic CT Results and Patient Management Analyzed by Wounding Mechanism

<table>
<thead>
<tr>
<th></th>
<th>GSW (%)</th>
<th>SW (%)</th>
<th>SGW (%)</th>
</tr>
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<tbody>
<tr>
<td>Total patients</td>
<td>41 (55)</td>
<td>32 (43)</td>
<td>2 (3)</td>
</tr>
<tr>
<td>Positive CT</td>
<td>17 (41)</td>
<td>9 (28)</td>
<td>0</td>
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<tr>
<td>Negative CT</td>
<td>24 (59)</td>
<td>23 (72)</td>
<td>2 (100)</td>
</tr>
<tr>
<td>False negative CT</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total laparotomies</td>
<td>13 (65)</td>
<td>7 (35)</td>
<td>0</td>
</tr>
<tr>
<td>Therapeutic laparotomy</td>
<td>11 (85)</td>
<td>5 (71)</td>
<td>0</td>
</tr>
<tr>
<td>Nontherapeutic laparotomy</td>
<td>1 (8)</td>
<td>1 (14)</td>
<td>0</td>
</tr>
<tr>
<td>Negative laparotomy</td>
<td>1 (8)</td>
<td>1 (14)</td>
<td>0</td>
</tr>
<tr>
<td>Nonoperative hepatic injury</td>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Hepatic angioembolization</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>VATS diaphragm repair</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2 Triple-Contrast Abdominopelvic CT Results and Patient Management Analyzed by Number of Torso Wounds

<table>
<thead>
<tr>
<th></th>
<th>1 Wound (%)</th>
<th>2 or More Wounds (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total patients</td>
<td>55 (73)</td>
<td>20 (27)</td>
</tr>
<tr>
<td>Positive CT</td>
<td>22 (40)</td>
<td>4 (20)</td>
</tr>
<tr>
<td>Negative CT</td>
<td>33 (60)</td>
<td>16 (80)</td>
</tr>
<tr>
<td>False negative CT</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total laparotomies</td>
<td>15 (75)</td>
<td>5 (25)</td>
</tr>
<tr>
<td>Therapeutic laparotomy</td>
<td>12 (60)</td>
<td>4 (20)</td>
</tr>
<tr>
<td>Nontherapeutic laparotomy</td>
<td>2 (13)</td>
<td>0</td>
</tr>
<tr>
<td>Negative laparotomy</td>
<td>1 (7)</td>
<td>1 (20)</td>
</tr>
<tr>
<td>Nonoperative hepatic injury</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Hepatic angioembolization</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>VATS diaphragm repair</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

CT, computed tomography; GSW, gunshot wound; SW, stab wound; SGW, shotgun wound; VATS, video-assisted thoracoscopic surgery.

Fig. 3. Triple-contrast CT scan from a 28-year-old woman with a gunshot wound to the left flank. There is extensive subcutaneous air and muscle contusion along the left flank (arrow). There is no evidence of free intraperitoneal air or fluid. This patient was successfully managed nonoperatively.

Fig. 4. Axial section through the lower abdomen from a CT scan in a 39-year-old man who was impaled with a metal spike entering the right groin and exiting the left abdomen. There is subcutaneous air (arrow) and soft tissue swelling over the anterior abdomen. No free intraperitoneal air or fluid is evident.
11 (15%) back; and 7 (9%) lower chest. The remaining 11 (15%) patients had wounds to two torso regions. All patients with multiple wounds were confined to one or two torso regions. No patient had wounds to more than two regions. Details regarding wound location subset analysis are listed in Table 3.

Analysis by Abdominal Tenderness

Of the 75 patients, 61 (81%) had no anterior abdominal tenderness on physical examination and 14 (19%) had some tenderness (Table 4). In patients without tenderness, 17 (28%) had positive CT and 44 (72%) had negative CT. Laparotomy was performed in 12/61 (20%) nontender patients. The single CT-missed (false negative) diaphragm injury was in a nontender patient. All unnecessary laparotomies were performed in patients without abdominal tenderness.

In the patients with some abdominal tenderness, 9/14 (64%) had positive CT and 5/14 (36%) had negative CT. Laparotomy was performed in 8/14 (57%) of tender patients, all of which were therapeutic. There were no false negative CT scans in tender patients.

Two patients were noted to have diffuse abdominal tenderness. One of these patients had a positive CT and underwent therapeutic laparotomy. The other patient with diffuse tenderness had a 1-cm periumbilical SW and a negative CT. This patient was successfully managed with observation for 12 hours with resolution of pain.

Analysis of Need for Laparotomy

Of the 75 patients, 51 (68%) ultimately had no evidence of abdominal injury and 24 (32%) had abdominal injury identified, 16 of which needed operation. CT appropriately predicted the need for operation in 15/16 (94%) patients (Table 5). CT appropriately excluded abdominal injury in 48/49 (98%) patients. CT detected peritoneal violation in 3/26 (12%) patients undergoing unnecessary laparotomy. Two of these patients had nontherapeutic laparotomy and the other had negative laparotomy.

The blinded CT interpretations missed peritoneal violation in only 1/49 (2%) patients. This patient was found to have a left diaphragm injury at laparotomy. Laparotomy was performed in this patient because the CT interpretation by nonblinded physicians at the point of care appropriately suspected left diaphragm injury.

Analysis of Organ Injury

Of the 24 patients with abdominal injury, CT appropriately identified all injuries in 15 (63%) patients (Table 6). All injuries to the liver, spleen, pancreas, kidney, colon, rectum, bladder, and falciform ligament were appropriately identified. CT missed identifying diaphragm injury in 1/6 (17%) patients with this finding. Four patients had stomach injuries in which CT missed identifying three (75%). One was misidentified as a liver injury, another was misidentified as a mesenteric injury, and the third was missed altogether. Another patient was interpreted to have spleen and stomach injuries on CT, but only the spleen injury was detected at laparotomy. Still another patient was interpreted to have bladder and rectum injuries on CT, but only the bladder injury was detected at laparotomy. Four patients had small bowel injuries in which CT missed identifying only one (25%). One patient had a CT interpretation indeterminate for small bowel injury and was instead found to have an omental injury at laparotomy.

DISCUSSION

In the 1950s, as an extension of wartime experience, mandatory laparotomy was the standard of care for penetrating abdominal wounds, but it had later become evident that in civilian trauma situations, this practice yielded a substantial portion of unnecessary laparotomies.1 These operations were implicated as the cause of morbidity and death in many of these cases. From the 1960s through the 1980s, a movement toward the use of surgical judgment or selective management was evolving.11,12

As recently as 1990, a report by McConnell and Trunkey still advocated that all patients with GSW to the abdomen

Table 3 Triple-Contrast Abdominopelvic CT Results and Patient Management Analyzed by Entrance Wound Location

<table>
<thead>
<tr>
<th></th>
<th>Pelvis (%)</th>
<th>Abdomen (%)</th>
<th>Flank (%)</th>
<th>Back (%)</th>
<th>Lower Chest (%)</th>
<th>Two Locations (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total patients</td>
<td>17 (23)</td>
<td>16 (21)</td>
<td>13 (17)</td>
<td>11 (15)</td>
<td>7 (9)</td>
<td>11 (15)</td>
</tr>
<tr>
<td>Positive CT</td>
<td>3 (18)</td>
<td>10 (63)</td>
<td>4 (31)</td>
<td>1 (9)</td>
<td>5 (71)</td>
<td>3 (27)</td>
</tr>
<tr>
<td>Negative CT</td>
<td>14 (82)</td>
<td>6 (38)</td>
<td>9 (69)</td>
<td>10 (91)</td>
<td>2 (29)</td>
<td>8 (73)</td>
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<tr>
<td>False negative CT</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total laparotomies</td>
<td>3 (15)</td>
<td>6 (30)</td>
<td>3 (15)</td>
<td>1 (5)</td>
<td>3 (15)</td>
<td>4 (20)</td>
</tr>
<tr>
<td>Therapeutic laparotomy</td>
<td>3 (100)</td>
<td>4 (67)</td>
<td>2 (67)</td>
<td>1 (100)</td>
<td>3 (100)</td>
<td>3 (75)</td>
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<tr>
<td>Nontherapeutic laparotomy</td>
<td>0</td>
<td>1 (17)</td>
<td>1 (33)</td>
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<td>0</td>
</tr>
<tr>
<td>Negative laparotomy</td>
<td>0</td>
<td>1 (17)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1 (25)</td>
</tr>
<tr>
<td>Nonoperative hepatic injury</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Hepatic angioembolization</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>VATS diaphragm repair</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

CT, computed tomography; VATS, video-assisted thoracoscopic surgery.
showing that in 300 consecutive patients with penetrating
Abdominopelvic CT
Evidence of Peritoneal Violation on Triple-Contrast
scopic surgery.

Physical Examination
Absence of Anterior Abdominal Tenderness on Initial
and Patient Management Analyzed by Presence or
component of most management algorithms. LWE and DPL
were ultimately successful.

Early laparotomy, 92/106 (87%) of nonoperative patients
underwent CT. While 60% of their patients met criteria for
abdomen.10 In this study, the main diagnostic tool was serial
SW using admission CT and found that CT detected
peritoneal penetration and identified solid organ injury well,
with 52 (92%) were successfully managed nonoperatively.6
Himmelman et al. prospectively studied 88 stable patients
with penetrating wounds to the back or flank with DPL
followed by triple-contrast CT.8 In their series, 77/88 (88%) total patients or 77/79 (97%) patients with non-high-risk CT
scans were observed without complication. Hauser et al.
studied 40 patients with penetrating posterior injuries with
triple-contrast CT.7 In their series, 34 (85%) patients had
negative CT and all were discharged uneventfully.

Rehm et al. prospectively studied patients with abdomi-
nal SW using admission CT and found that CT detected
peritoneal penetration and identified solid organ injury well,
while it was unreliable in detection of bowel injury and
diaphragmatic injury.9 Ginzburg et al. conducted a retrospec-
tive review of 83 patients with gunshot wounds to the abdo-
men or flank and found that 68 (82%) of patients had either
true positive or true negative CT.21 They recommended
laparoscopy to further evaluate those patients with indeter-
going laparoscopy to further evaluate those patients with indeter-
minate CT results. The results of our prospective study were
similar to these previous studies in regard to success of
selective management and the accuracy of CT, but we have
extended the application of triple-contrast CT to patients with

need a celiotomy.13 They cited a series by Feliciano et al.
showing that in 300 consecutive patients with penetrating
GSW of the abdomen, the most frequent cause of death was
perioperative shock.14 They concluded that rapid operative
techniques lead to fewer complications and better survival. In
1995, Renz and Feliciano then reported a study emphasizing
the significant morbidity and complications associated with
unnecessary laparotomies for trauma.15 They found a comp-
lication rate of 41% in a series of 254 trauma patients
undergoing unnecessary laparotomy.

More recently, Demetriades et al., in 1997, reported a
large prospective selective nonoperative management, proto-
col-guided study of 309 patients with GSW of the anterior
abdomen.10 In this study, the main diagnostic tool was serial
physical examination, and only 19 (6%) of these patients
underwent CT. While 60% of their patients met criteria for
early laparotomy, 92/106 (87%) of nonoperative patients
were ultimately successful.

To improve the success rate of nonoperative manage-
ment, two ancillary maneuvers have become an important
component of most management algorithms. LWE and DPL
are both techniques to determine evidence of peritoneal vi-
olation. The invasive nature of both of these tests are a disad-
antage, prompting recent enthusiasm in the application of
ultrasonography and CT. Another disadvantage is that both
LWE and DPL have been associated with high false positive
rates. Positive LWE alone has reported negative laparotomy
rates between 14% and 45%.16 Still another drawback of DPL
in penetrating trauma is the controversy over the exact red
blood cell (RBC) count that should be considered positive.
Merlotti et al. showed that a RBC count of 10,000 cells/mm³
resulted in a 14% false positive rate, while liberalizing the
RBC count to 100,000 cells/mm³ increased the false negative
rate to 11%.17

Diagnostic laparoscopy has also been proposed as a
useful diagnostic tool in penetrating trauma.18 Studies have
reported the ability to determine peritoneal penetration or the
presence of insignificant injuries not requiring laparotomy
using this technique. Therapeutic suturing of diaphragm in-
juries has also been reported during diagnostic laparoscopy,
maintaining a minimally invasive surgical approach. A major
concern of this technique is the potential for missed injury.
Rossi et al. reported a prospective series in which 19% of
patients had significant injuries found at the time of laparot-
yomy that were not detected by laparoscopy, including liver,
pancreas, stomach, duodenum, small bowel, mesentery, ure-
ter, and bladder injuries.19

The current role for triple-contrast CT in penetrating
trauma is the evaluation of patients with suspected retroper-
toneal injury. Meyer et al. performed a study of 205 patients
with SW to the back using double-contrast CT.20 In this
series, 169 (82%) patients had a negative CT scan and all
were observed without any sequelae. They reported an accu-
racy of 97% for patients with SW to the back. Phillips et al.
reported a study of 56 patients with penetrating trauma to the
flank or back undergoing contrast-enhanced CT enema, of
which 52 (92%) were successfully managed nonoperatively.6

<table>
<thead>
<tr>
<th>No.</th>
<th>%</th>
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<tbody>
<tr>
<td>Sensitivity</td>
<td>15/16</td>
</tr>
<tr>
<td>Specificity</td>
<td>56/59</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>15/18</td>
</tr>
<tr>
<td>Negative predictive value</td>
<td>56/57</td>
</tr>
<tr>
<td>Accuracy</td>
<td>71/75</td>
</tr>
</tbody>
</table>

CT, computed tomography.
either SW or GSW, included wounds in any region of the torso, and did not combine CT with an ancillary test.

Results from this study showed that triple-contrast abdominopelvic CT had a high overall sensitivity (94%), specificity (95%), and accuracy (95%) for predicting the need for laparotomy in penetrating torso wounds. Only one patient with a negative CT was discovered to have a diaphragm injury at laparotomy, for a negative predictive value (NPV) of 98%. This patient had two stab wounds to the left flank. At the point of care, the CT scan was preliminarily interpreted as suspicious for diaphragm injury, prompting exploratory laparotomy. The data used for analysis in this study was interpretation by attending radiologists blinded to clinical events, in which this patient’s CT scan was negative. This finding suggests that allowing clinical correlation to assist image interpretation may improve accuracy. In this study, we can speculate that there may have been no false negative readings with clinical correlation.

Despite an excellent NPV in this study, we still had three unnecessary laparotomies in patients with CT positive for peritoneal violation—two of these nontherapeutic and one negative for any abdominal injury—for a positive predictive value (PPV) of 83% and unnecessary laparotomy rate of 17%. Both patients with nontherapeutic laparotomy had single stab wounds and operative findings confirmed peritoneal violation in both. One patient had a falciform ligament contusion and the other had an omental contusion. The patient with negative laparotomy also had a single stab wound with right pneumothorax and CT evidence of pneumoperitoneum. At operation, no peritoneal violation and no abdominal injury were found.

While our results show that spiral CT determination of peritoneal violation is accurate, the diagnosis of individual organ injury remains inconclusive. The traditional concerns regarding individual organ assessment with conventional CT remains with spiral CT technology. In our study, CT appropriately identified all injuries to solid organs, including liver, spleen, pancreas, and kidney.

All injuries to the colon, rectum, and bladder were also appropriately identified. We believe this latter finding is augmented by good rectal contrast administration. Four patients had small bowel injuries and only one of these was not diagnosed on CT. Fortunately in this patient, CT was positive for peritoneal penetration, prompting exploratory laparotomy. It was disappointing to find that CT missed diagnosing 75% of stomach injuries. It seems that it would be more likely to miss small bowel injury rather than stomach injury due to potential inadequate opacification with contrast agent. It remains unclear why stomach injuries were more difficult to identify by CT in our study.

While the exact identification of all abdominal injuries using a diagnostic test would be ideal, it seems that CT is pretty good, but not perfect. However, it may not be essential to identify all injuries using a test if that test appropriately predicts the need for laparotomy. Furthermore, CT is capable

### Table 6 Determining Individual Organ Injury on Triple-Contrast Abdominopelvic CT in 24 Patients with Abdominal Injury

<table>
<thead>
<tr>
<th>Patient</th>
<th>CT Result</th>
<th>Injuries by CT</th>
<th>Management</th>
<th>Injuries Documented</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.M.</td>
<td>Positive</td>
<td>Falciform</td>
<td>Laparotomy</td>
<td>Same as CT</td>
</tr>
<tr>
<td>N.C.</td>
<td>Positive</td>
<td>Colon, kidney, liver</td>
<td>Laparotomy</td>
<td>Same as CT</td>
</tr>
<tr>
<td>C.H.</td>
<td>Positive</td>
<td>Diaphragm, liver</td>
<td>Laparotomy</td>
<td>Same as CT</td>
</tr>
<tr>
<td>D.St.</td>
<td>Positive</td>
<td>Liver</td>
<td>Laparotomy</td>
<td>Stomach</td>
</tr>
<tr>
<td>E.J.</td>
<td>Positive</td>
<td>Diaphragm, liver</td>
<td>Angio and VATS</td>
<td>Same as CT</td>
</tr>
<tr>
<td>R.H.</td>
<td>Positive</td>
<td>Small bowel?</td>
<td>Laparotomy</td>
<td>Omentum</td>
</tr>
<tr>
<td>W.S.</td>
<td>Positive</td>
<td>Spleen</td>
<td>Laparotomy</td>
<td>Same as CT</td>
</tr>
<tr>
<td>S.R.</td>
<td>Positive</td>
<td>Liver</td>
<td>Angio</td>
<td>Same as CT</td>
</tr>
<tr>
<td>B.P.</td>
<td>Positive</td>
<td>Liver, small bowel</td>
<td>Laparotomy</td>
<td>Same as CT</td>
</tr>
<tr>
<td>J.D.</td>
<td>Positive</td>
<td>Diaphragm, liver</td>
<td>Angio and VATS</td>
<td>Same as CT</td>
</tr>
<tr>
<td>A.M.</td>
<td>Positive</td>
<td>Rectum, small bowel</td>
<td>Laparotomy</td>
<td>Same as CT</td>
</tr>
<tr>
<td>W.P.</td>
<td>Positive</td>
<td>Liver</td>
<td>Observation</td>
<td>—</td>
</tr>
<tr>
<td>D.Sa.</td>
<td>Positive</td>
<td>Diaphragm, stomach</td>
<td>Laparotomy</td>
<td>Same as CT</td>
</tr>
<tr>
<td>J.C.</td>
<td>Positive</td>
<td>Rectum</td>
<td>Laparotomy</td>
<td>Same as CT</td>
</tr>
<tr>
<td>J.L.</td>
<td>Positive</td>
<td>None</td>
<td>Laparotomy</td>
<td>Small bowel, stomach</td>
</tr>
<tr>
<td>T.A.</td>
<td>Positive</td>
<td>Liver</td>
<td>Observation</td>
<td>—</td>
</tr>
<tr>
<td>A.P.</td>
<td>Positive</td>
<td>Liver</td>
<td>Observation</td>
<td>—</td>
</tr>
<tr>
<td>P.J.</td>
<td>Positive</td>
<td>Mesentery</td>
<td>Laparotomy</td>
<td>Stomach</td>
</tr>
<tr>
<td>D.P.</td>
<td>Positive</td>
<td>Pancreas</td>
<td>Laparotomy</td>
<td>Same as CT</td>
</tr>
<tr>
<td>A.H.</td>
<td>Negative</td>
<td>None</td>
<td>Laparotomy</td>
<td>Diaphragm</td>
</tr>
<tr>
<td>D.G.</td>
<td>Positive</td>
<td>Liver</td>
<td>Observation</td>
<td>—</td>
</tr>
<tr>
<td>N.T.</td>
<td>Positive</td>
<td>Diaphragm, spleen, stomach</td>
<td>Laparotomy</td>
<td>Diaphragm, spleen</td>
</tr>
<tr>
<td>M.H.</td>
<td>Positive</td>
<td>Bladder, rectum</td>
<td>Laparotomy</td>
<td>Bladder</td>
</tr>
<tr>
<td>T.E.</td>
<td>Positive</td>
<td>Small bowel</td>
<td>Laparotomy</td>
<td>Same as CT</td>
</tr>
</tbody>
</table>

CT, computed tomography; Angio, angioembolization; VATS, video-assisted thoracic surgery.
of identifying injuries that are amenable to nonoperative management, such as liver injuries.

Until the 1990s, selective nonoperative management was an option only for patients found to not have peritoneal penetration. In 1994, Renz and Feliciano reported a prospective study in which hemodynamically stable patients with GSW to the right thoracoabdomen were managed nonoperatively, including seven patients with hepatic injuries. This important article challenged the convention that all visceral injuries from GSW required exploration. In our study, we have also met with success with nonoperative management of isolated hepatic injury from GSW, but we have introduced the concept of adjunctive angioembolization to enhance hemorrhage control.

In our study, all diaphragm injuries were seen in patients with either a flank or lower chest wound. In readings blinded to clinical events, CT missed one diaphragmatic injury subsequently found at laparotomy. This patient also had associated hemothorax, inferring transdiaphragmatic trajectory of the weapon. Both patients with hepatic and diaphragm injury underwent VATS for repair. It seems prudent that all patients undergoing nonoperative management of isolated hepatic injury having associated hemothorax should be evaluated for associated diaphragm injury. While it is unclear what is the natural history of small wounds to the right diaphragm, there is still a potential for extension of injury size and risk of abdominal content herniation. At this time, it is still the convention to surgically repair all known traumatic wounds of the diaphragm, although this may be a concept that could be challenged in future research.

In subset analysis, we examined patients by wounding mechanism, number of torso wounds, entrance wound location, and presence or absence of abdominal tenderness. There was a substantial portion of both GSW and SW patients in this study. In either group, negative CT scans were more frequent than positive CT scans, more so in SW than in GSW. The 59% negative CT rate in GSW patients reinforces the concept that mandatory laparotomy is unnecessary in these patients. Furthermore, five patients with hepatic GSW were able to be managed without laparotomy.

Our results show that the number of wounds should not dictate the decision for laparotomy. Regardless of the number of wounds, negative CT scans outnumbered positive CT scans. While the only patient with four wounds had a positive CT, three of four patients with three wounds had negative CT. It should be noted that all patients with isolated hepatic injury and nonoperative management had single torso wounds.

Upon analysis of entrance wound location, we noted that the torso regions with greater proportion of positive CT scans to negative CT scans were the abdomen (63%;38%) and lower chest (71%;29%). Two of the unnecessary laparotomies were in patients with abdominal SW and positive CT, giving this region the lowest PPV. The highest PPV was in patients with wounds of the lower chest, with no unnecessary laparotomies in patients with positive CT. The highest NPV was in patients with pelvic wounds, leading to 82% negative CT and no false negatives. The accuracy of CT for patients with wounds in two locations still seemed acceptable, although the only false negative CT was in a patient with stab wounds to the back and flank.

Patients having abdominal tenderness more often had positive CT than negative CT, while those without tenderness had a greater proportion of negative CT. CT appears to have been helpful in 36% of patients with tenderness in avoiding laparotomy, while 28% of nontender patients had positive CT. These findings reinforce the unreliability of initial physical examination findings in assessing the trauma patient.

CONCLUSION

In hemodynamically stable patients with penetrating torso trauma, selective nonoperative management, rather than mandatory laparotomy, should be the rule. Selective management is effective in both GSW and SW patients, regardless of entrance wound location, in patients with multiple torso wounds, and in patients with or without anterior abdominal tenderness on initial physical examination.

Triple-contrast enhanced abdominopelvic CT can accurately exclude peritoneal violation, avoiding unnecessary operation in the majority of patients without definite need for laparotomy. When CT is positive for peritoneal violation, it can accurately predict need for laparotomy and facilitate nonoperative management of isolated hepatic injury, with or without the adjunctive use of angioembolization. Caution must still be maintained in diagnosing individual hollow viscous injury by CT, although the diagnosis of colorectal injury is augmented with adequate rectal contrast. Finally, evaluating for associated diaphragm injury in patients with both abdominal injury and hemothorax may be prudent.

REFERENCES

DISCUSSION

Dr. Salvatore J. Sclafani (Brooklyn, New York): Dr. Chiu and his colleagues share with us their experience using triple contrast CT for the evaluation of trauma penetrations in stable patients without clinical manifestations of peritonitis, gastrointestinal hemorrhage, or obvious peritoneal penetration.

The authors considered CT to be positive if it showed any evidence of peritoneal violation, which as I said, manifested as peritoneal trajectory, intraperitoneal air or fluid, solid visceral injury, or intraperitoneal contrast extravasation.

The group from Maryland confirmed previous reports that have documented the efficacy of CT with an enema for the evaluation of asymptomatic penetrations of the back and flank, while also extending its usefulness in some patients with anterior thoracoabdominal penetrations. More importantly, they show that the prospective decision to operate or not, based upon the interpretation of the CT by the MIEMSS traumatologist and the University of Maryland radiology residents, in conjunction with their clinical assessment, was comparable or better than the daytime retrospective analysis of the outstanding trauma radiologists who work at their institution.

While the night time interpretation and clinical correlation are exemplary, the failure to include the clinical decision dynamics, which led to the real-time decisions to operate or not, is unfortunate. I would like to know how often clinical decisions overrode the initial interpretation of the CT. Was there any variance between the so-called expert retrospective interpretation and the prospective readings at the point of care?

These results also clearly show that while solid visceral penetrating injuries are readily diagnosed, the specific identification of hollow visceral injuries and the detection of diaphragmatic tears remains imperfect and elusive by this technique. It was because of these concerns that our initial studies by Tom Phillips et al. on this subject excluded peritoneal penetration by peritoneal lavage rather than CT.

It is reassuring to learn that CT need not necessarily identify every hollow visceral injury to predict the need for laparotomy. With the use of CT, the authors avoided laparotomy in more than two-thirds of these patients, including one-third of the patients with anterior thoracoabdominal penetrations without complications and with an acceptable negative or nontherapeutic laparotomy rate of about 4% in that group of patients.

I enjoyed the paper very much. It was very well written, read very well, and was very well designed and very thorough. It left me with few criticisms and very few questions. I would like to thank the Association for the opportunity to review this paper.

Dr. Ronald J. Simon (Bronx, New York): I enjoyed the paper very much and, just to be brief, I have followed Dr. Scalea’s interest in rectal contrast throughout my career and unfortunately, my radiologic colleagues are not quite so interested in using rectal contrast. I really haven’t been able to convince them. I am just wondering, did rectal contrast ever add anything to any of your studies? The one study that you presented that showed extravasation of rectal contrast also had free air and hematoma, which is more or less what we use.

Also, on the stab wound to the pelvis, the CT scan that you showed, the patient did not have any rectal contrast, so I am wondering, did rectal contrast ever add anything to any of your studies? The one study that you presented that showed extravasation of rectal contrast also had free air and hematoma, which is more or less what we use.

You observed the nonoperative patients for 12 hours and sent them out. What was your follow-up for delayed presentations of injuries? How many went across town to Hopkins and how many went around the corner to the University of Maryland’s ER? Thank you.
Dr. Rao R. Ivatury (Richmond, Virginia): Tom, as I understand it, now you are trying to enlarge your interest in triple-contrast enema from back and flank wounds to all abdominal wounds. I would submit that sometimes the penetration can be extremely tricky, and I would like to know exactly—you showed about 20 patients who had flank and back wounds—in how many you have found triple-contrast useful.

I would submit that in all the other patients, as we have shown, that if you use laparoscopy, but not missed abdominal injuries, you will detect penetration. You will be able to do selective management with much fewer missed abdominal and missed organ injuries. I would submit again one last cautionary approach that this is a little bit premature of your declarative conclusions.

With all due respect, 75 patients is too small a number to say that this is going to be extremely accurate and will not miss any injuries. Thank you.

Dr. Thomas A. Santora (Philadelphia, Pennsylvania): Though it’s a laudable endpoint to try to find the appropriate patients to operate on, I, likewise, am confused.

The last CT scan you showed, you said that patient had diffuse tenderness, and I think we have learned long ago that 95% of patients with penetrating wounds to the abdominal cavity have significant injuries requiring operation. I caution everyone about the generalization of this study. I question whether or not the time to operation has an influence. Can you share with us some of the potential complications of these patients? Specifically, was there an increased rate of septic complications? Thank you.

Dr. Eric R. Frykberg (Jacksonville, Florida): Bill, could you clarify for me, there were not many stab wounds. Do you actually operate on stab wounds alone with no other indication for laparotomy, just for peritoneal penetration? It seems that you do. If so, why, given the long history dating back to Dr. Shaftan’s work in the 1950s of successful observation just with physical examination alone of these? Thank you.

Dr. William C. Chiu (closing): I would like to thank Dr. Sclafani for the wonderful comments and the discussants for their interest in our study. With regard to Dr. Sclafani’s comments, there were two patients with negative CT scans that underwent laparotomy before an official reading of the CT scan. These patients underwent laparotomy based on the clinical decision by the trauma team reading of the CT scan and radiology residents.

One of these proved to be nontherapeutic and the other proved to be a therapeutic laparotomy with a diaphragm repair, so that the preliminary reading and clinical correlation combined may have a great impact on the determination of laparotomy need or not.

In terms of rectal contrast, we believe that it was very helpful in looking at our patients’ injuries. In our study, there were no colon, rectal, or bladder injuries that were missed. Instead, the missed injuries were of diaphragm, stomach, and small bowel.

In terms of follow-up, this is actually an ongoing study that we have continued based on our results. We have only gotten approximately half of the patients with documented follow-up of over 7 days. Some of our nonoperative patients that were discharged on the same day were lost to follow-up.

In terms of adjunctive studies, we acknowledge that laparoscopy or DPL or local wound exploration are also helpful and would add information to decide on injuries or the need for laparotomy. Instead, our study points to CT as an initial diagnostic study, and we actually have performed adjunctive studies based on clinical need on some of these patients.

In terms of patients with diffuse tenderness, we had two that underwent initial CT scan and one clearly had a therapeutic laparotomy based on a CT scan that was positive. The other, interestingly enough, had a totally negative CT scan and was successfully managed without laparotomy. So, the initial physical examination sometimes is unreliable.

Finally, we do not operate on patients simply because of stab wounds, but we use the same clinical criteria for gunshot wounds and, at present, this may incorporate using local wound exploration or DPL in our algorithm. I would like to again thank the Association for the opportunity to present our study.