Practice Management Guidelines for Selective Nonoperative Management of Penetrating Abdominal Trauma

John J. Como, MD, Faran Bokhari, MD, William C. Chiu, MD, Therese M. Duane, MD, Michele R. Holevar, MD, Margaret A. Tandoh, MD, Rao R. Ivatury, MD, and Thomas M. Scalea, MD

Background: Although there is no debate that patients with peritonitis or hemodynamic instability should undergo urgent laparotomy after penetrating injury to the abdomen, it is also clear that certain stable patients without peritonitis may be managed without operation. The practice of deciding which patients may not need surgery after penetrating abdominal wounds has been termed selective management. This practice has been readily accepted during the past few decades with regard to abdominal stab wounds; however, controversy persists regarding gunshot wounds. Because of this, the Eastern Association for the Surgery of Trauma Practice Management Guidelines Committee set out to develop guidelines to analyze which patients may be managed safely without laparotomy after penetrating abdominal trauma. A secondary goal of this committee was to find which diagnostic adjuncts are useful in the determination of the need for surgical exploration.

Methods: A search of the National Library of Medicine and the National Institutes of Health MEDLINE database was performed using PubMed (www.pubmed.gov).

Results: The search retrieved English language articles concerning selective management of penetrating abdominal trauma and related topics from the years 1960 to 2007. These articles were then used to construct this set of practice management guidelines.

Conclusions: Although the rate of nontherapeutic laparotomies after penetrating wounds to the abdomen should be minimized, this should never be at the expense of a delay in the diagnosis and treatment of injury. With this in mind, a routine laparotomy is not indicated in hemodynamically stable patients with abdominal stab wounds without signs of peritonitis or diffuse abdominal tenderness. Likewise, it is also not routinely indicated in stable patients with abdominal gunshot wounds if the wounds are tangential and there are no peritoneal signs. Abdominopelvic computed tomography should be considered in patients selected for initial nonoperative management to facilitate initial management decisions. The majority of patients with penetrating abdominal trauma managed nonoperatively may be discharged after 24 hours of observation in the presence of a reliable abdominal examination and minimal to no abdominal tenderness. Diagnostic laparoscopy may be considered as a tool to evaluate diaphragmatic lacerations and peritoneal penetration in an effort to avoid unnecessary laparotomy.

Key Words: Practice management guidelines, Penetrating abdominal trauma, Selective nonoperative management, Nontherapeutic laparoctomy, Diagnostic peritoneal lavage.

(*J Trauma.* 2010;68: 721–733)

STATEMENT OF THE PROBLEM

Until the late 19th century, when Sims and others began recommending intervention, penetrating abdominal trauma was managed expectantly, with rest, wound dressings, bloodletting, and opium, with high mortality rates.[1] Around the time of World War I, operative management became the accepted standard for penetrating wounds to the abdomen. It has since been realized, however, that not all penetrating abdominal wounds require operation. As early as 1960, Shaftan[2] advocated "observant and expectant treatment" rather than mandatory laparotomy in the management of penetrating abdominal injury. This was reinforced in 1969 by Nance and Cohn[3] for the management of abdominal stab wounds (SWs). Since that time, selective nonoperative management (NOM) of SWs to the anterior abdomen has become more readily accepted. Gunshot wounds (GSWs) to the abdomen, however, are still commonly treated with mandatory exploration because of multiple reports emphasizing a high incidence of intra-abdominal injuries and the complications of a missed injury or an injury delayed in recognition and treatment.

The enthusiasm for nonoperative treatment is based on a high incidence of nontherapeutic or negative laparotomy from civilian, low-velocity wounding. Reports on the incidence of unnecessary laparotomy range from 23% to 53% for patients with SWs and 5.3% to 27% for patients with GSWs.[5] Complications develop in 2.5% to 41% of all trauma patients undergoing unnecessary laparotomy, and small bowel obstruction, pneumothorax, ileus, wound infection, myocardial infarction, visceral injury, and even death have been reported secondary to unnecessary laparotomy.[2–4] Even though unsubstantiated by data, there is a potential risk of transmission of blood-borne diseases to healthcare providers.

Practice management guidelines for NOM of penetrating abdominal trauma must be tempered with the maturity of the trauma center and the availability of a trauma team experienced in the evaluation of all diagnostic methods.

Submitted for publication June 4, 2007.
Accepted for publication December 14, 2009.

From the Division of Trauma, Critical Care, and Burns (J.J.C.), Department of Surgery, MetroHealth Medical Center, Cleveland, Ohio; Department of Surgery (F.B.), Stroger Hospital of Cook County, Chicago, Illinois; Department of Surgery (W.C.C., T.M.S.), R Adams Cowley Shock Trauma Center, University of Maryland Medical Center, Baltimore, Maryland; Department of Surgery (T.M.D., R.R.I.), Virginia Commonwealth University Medical Center, Richmond, Virginia; Department of Surgery (M.R.H.), Mount Sinai Hospital, Chicago, Illinois, and Department of Surgery (M.A.T.), Upstate Medical Center, Syracuse, New York.
Presented at the 22nd Annual Meeting of the Eastern Association for the Surgery of Trauma, January 13–17, 2009, Lake Buena Vista, Florida.
Address for reprints: John J. Como, MD, 2500 MetroHealth Dr., Suite H945, Cleveland, OH 44109; email: jcomo@metrohealth.org.

DOI: 10.1097/TA.0b013e3181cf7d07

Furthermore, it is important to recognize the importance of different mechanisms of injury (SWs vs. GSWs vs. shotgun wounds), the velocity of the agent (low vs. high), and the different regions of the abdomen (intraperitoneal, retroperitoneal, and thoracoabdominal areas). Aside from computed tomography (CT), none of the traditionally available ancillary diagnostic tests (diagnostic peritoneal lavage [DPL], ultrasonography, laparoscopy, etc.) are accurate in detecting retroperitoneal injury. CT, however, still may be inaccurate in the evaluation of the diaphragm. The lack of extensive experience with this modality at the present time should also be a consideration.

PROCESS

Identification of References

A computerized search of the National Library of Medicine and the National Institutes of Health MEDLINE database was undertaken using the Entrez PubMed (www.pubmed.gov) interface. The primary search strategy was developed to retrieve English language articles focusing on NOM of penetrating abdominal trauma starting in 1960 and continuing through 2007; review articles, letters to the editor, editorials, other items of general commentary, and case reports were excluded from the search. In general, multiple reports from the same institution were also excluded from the analysis, unless they analyzed different patient populations or different injuries. If two or more reports from the same institution are likely to have contained the same patients but both reports are deemed to be relevant, this is stated in the manuscript.

Quality of the References

Articles were classified as class I, II, or III according to the following definitions:

A. Class I: Prospective, randomized clinical trials.
B. Class II: Clinical studies in which data were collected prospectively or retrospective analyses based on clearly reliable data.
C. Class III: Studies based on retrospectively collected data.

Recommendations were classified as level 1, 2, or 3 according to the following definitions:

A. Level 1: The recommendation is convincingly justifiable based on the available scientific information alone. This recommendation is usually based on class I data; however, strong class II evidence may form the basis for a level 1 recommendation, especially, if the issue does not lend itself to testing in a randomized format. Conversely, low-quality or contradictory class I data may not be able to support a level 1 recommendation.
B. Level 2: The recommendation is reasonably justifiable by available scientific evidence and strongly supported by expert opinion. This recommendation is usually supported by class II data or a preponderance of class III evidence.
C. Level 3: The recommendation is supported by available data but adequate scientific evidence is lacking. This recommendation is generally supported by class III data. This type of recommendation is useful for educational purposes and in guiding future clinical research.

RECOMMENDATIONS

a. Patients who are hemodynamically unstable or who have diffuse abdominal tenderness should be taken emergently for laparotomy (level 1).
b. Patients who are hemodynamically stable with an unreliable clinical examination (i.e., brain injury, spinal cord injury, intoxication, or need for sedation or anesthesia) should have further diagnostic investigation performed for intraperitoneal injury or undergo exploratory laparotomy (level 1).
c. A routine laparotomy is not indicated in hemodynamically stable patients with abdominal SWs without signs of peritonitis or diffuse abdominal tenderness (away from the wounding site) in centers with surgical expertise (level 2).
d. A routine laparotomy is not indicated in hemodynamically stable patients with abdominal GSWs if the wounds are tangential and there are no peritoneal signs (level 2).
e. Serial physical examination is reliable in detecting significant injuries after penetrating trauma to the abdomen, if performed by experienced clinicians and preferably by the same team (level 2).
f. In patients selected for initial NOM, abdominopelvic CT should be strongly considered as a diagnostic tool to facilitate initial management decisions (level 2).
g. Patients with penetrating injury isolated to the right upper quadrant of the abdomen may be managed without laparotomy in the presence of stable vital signs, reliable examination, and minimal to no abdominal tenderness (level 3).
h. The majority of patients with penetrating abdominal trauma managed nonoperatively may be discharged after 24 hours of observation in the presence of a reliable abdominal examination and minimal to no abdominal tenderness (level 3).
i. Diagnostic laparoscopy may be considered as a tool to evaluate diaphragmatic lacerations and peritoneal penetration (level 2).

SCIENTIFIC FOUNDATIONS

Indications for Laparotomy

Patients who are hemodynamically unstable or who have diffuse abdominal tenderness should be taken emergently for laparotomy. Patients who are hemodynamically stable with an unreliable clinical examination (i.e., brain injury, spinal cord injury, intoxication, or need for sedation or anesthesia) should have further diagnostic investigation performed for intraperitoneal injury or undergo exploratory laparotomy. These recommendations are convincingly justifiable based on the available scientific information; therefore, a level 1 recommendation is appropriate. In general, patients fitting the above profile were

excluded from NOM and were not included in the studies evaluated by this committee.

A routine laparotomy is not indicated in hemodynamically stable patients with abdominal SWs without signs of peritonitis or diffuse abdominal tenderness (away from the wounding site) in centers with surgical expertise. A routine laparotomy is not indicated in hemodynamically stable patients with abdominal GSWs if the wounds are tangential and there are no peritoneal signs. The remainder of this article will address those in whom a routine laparotomy is not indicated.

Physical Examination

Serial physical examination is reliable in detecting significant injuries after penetrating trauma to the abdomen, if performed by experienced clinicians and preferably by the same team. Patients requiring delayed laparotomy will develop peritoneal signs and symptoms.

Stab Wounds

Numerous series report the utility of selective management of abdominal SWs, and these date from the 1960s. The landmark publication that changed the general approach to the management of abdominal trauma was published by Shaftan[2] from the Kings County Hospital Center in Brooklyn in 1960. This was prompted by the observation that a high percentage of patients treated at this center from 1952 to 1954 had unnecessary laparotomy; one death was noted as the result of such an exploration. It was also noted that those who had no significant injuries, whether they received operation or not, had no abnormal abdominal physical findings. The decision whether to perform operation was thus noted to be the same as that used in nontraumatic general surgery patients, and the management of trauma patients in this regard was thus changed.

The Shaftan report, which included patients with GSWs and SWs, along with blunt trauma victims, investigated this new practice. One hundred eighty patients admitted with abdominal trauma from 1956 to 1958 were studied; 63% of these were penetrating injuries. Of the penetrating injuries, 92% of patients were victims of SWs. The decision to operate was based on the following: peritoneal irritation as manifested by tenderness, reduced or absent bowel sounds, spasm of the abdominal wall, or rebound tenderness were considered to be of primary importance, whereas secondary signs were hematemesis, blood per rectum, or a positive abdominal paracentesis. Two patients died on arrival, 125 were not treated surgically, and 53 patients underwent laparotomy. There was no mortality or morbidity in those treated nonoperatively; 40 of 53 patients who were explored had injuries justifying the procedure. It was thought that if strict adherence to indications for laparotomy in these patients had occurred, nine other laparotomies could have been avoided. Shaftan concluded that "the application of trained surgical judgment rather than dogma is the more rational and intelligent approach to the management of abdominal injury." The expectant policy toward these injuries was later termed "selective conservatism."

This policy was reinforced in the late 1960s by Nance and Cohn[3] from the Charity Hospital in New Orleans. A protocol of selective conservatism was adopted in 1967 after a large number of nontherapeutic laparotomies were noted after SWs to the abdomen. Two policies were compared: an earlier policy in which exploratory laparotomy was performed if a wound that possibly could have entered the abdominal cavity was present; and a newer policy in which the decision to operate on stabbing victims was made based on clinical grounds. Under the earlier policy, only 33% of those explored required repair of an intra-abdominal injury. In the 67% that had unnecessary laparotomy, the complication rate was 24%. Complications included splenic lacerations in four patients, small bowel injuries in three, two liver lacerations, and a colon injury which was later complicated by a fecal fistula. Other complications included wound infections in 25 patients, evisceration in 5, and intra-abdominal abscess in 3. One death was noted in a patient who died of septicemia 3 days after a negative laparotomy. Under the newer policy, 60% of patients were treated nonoperatively, all without complication. Three patients initially observed who later required laparotomy because of worsening clinical status were reported, all of whom were explored within 24 hours and had uneventful recoveries. Of the 48 laparotomies, 12 (25%) were unnecessary. In summary, the policy of operating on stabbing victims based on clinical status decreased unnecessary laparotomy, complication rate, and average hospital length of stay.

Friedmann[5] reviewed a cohort of 108 stabbing victims from 1956 through 1965 and found that a policy of mandatory laparotomy would have resulted in a negative laparotomy rate of 70%. Lee et al.[6] retrospectively reviewed 219 patients who suffered SWs to the abdomen between 1974 and 1983 who were managed selectively. The rate of negative or unnecessary laparotomies was 7.8%, whereas the false-negative initial examination rate was 5.5%; the overall accuracy of initial clinical presentation and examination was 88.6%. They reported one patient who died of sepsis who was not explored despite displaying clear indications for laparotomy and emphasized the importance of strict adherence to protocol if selective management is to be pursued. They concluded that their selective management algorithm was safe as long as it was strictly followed.

McAlvanah and Shaftan[7] reviewed the experience at Kings County Hospital Center from 1963 to 1971 and found that of 590 SWs, 414 (70.2%) were treated without operation; of the 176 patients who had operation, it was retrospectively deemed unnecessary in 36 (20.4%). Similar data were reported from Cook County Hospital during 1966.[8] Of 267 patients with SWs to the abdomen, 141 (52.8%) did not receive operation; this group had no mortality and no significant morbidity. Of the wounds penetrating the abdominal cavity that were explored, 20% did not have significant abdominal injury. In total, 65% of cases had no significant abdominal injury.

The concept was extended to SWs of the posterior abdomen by Ocampo et al.;[9] 473 patients with SWs to the flank and back were evaluated clinically, of whom 76% never

received surgery and of whom 6% had nontherapeutic laparotomy. In addition, of the 370 patients initially observed, 360 (97.3%) did not require laparotomy. Of note, intravenous pyelogram, local wound exploration (LWE), and peritoneal lavage were used rarely in indicated patients. It was concluded that clinical assessment alone sufficed in the management of these patients.

In 1980, Wilder and Kudchadkar[10] reported 403 cases of abdominal SWs which were selectively managed. Of these, 187 (46%) were managed with immediate operation because of clinical findings, and 216 (54%) were initially managed nonoperatively. Of the latter, 16 patients required subsequent operation after the appearance of peritoneal irritation with a maximum delay of 22 hours, with no mortality. The group concluded that the selective approach was safe.

A study by Robin et al.[11] published in 1989, also from Cook County Hospital, reported 333 patients with anterior abdominal SWs. Initial clinical assessment led to laparotomy in 165 (49.5%) of patients. Twenty-eight (16.7%) of the laparotomies were negative. Eighteen patients developed indications for operation after initial observation with a mean delay of 10.7 hours; of these, there were no deaths, one major complication that was not likely related to the delay, and four negative laparotomies. One hundred fifty patients (45.0%) were observed and discharged. It was concluded that most serious injuries would declare themselves on initial clinical assessment.

Gunshot Wounds

Although selective conservatism has become well accepted for patients with SWs, this concept remains controversial for GSW victims. In the 1960s, it was generally accepted that "GSWs of the abdomen should be explored as soon as the patient's condition permits."[8] In the decades since, the concept of mandatory laparotomy for GSWs to the abdomen has become less rigid. In the article by McAlvanah and Shaftan,[7] it was found that of 221 GSW victims, 101 (45.7%) were treated nonoperatively; of the 120 patients who received operation, 5 were found to have been unnecessary.

Dawidson et al.,[12] in 1976, reported 277 patients with abdominal GSW, all of whom underwent abdominal exploration. Forty patients (14%) were found to have no intra-abdominal injury. There was no mortality in this group, and morbidity was minor. It is emphasized that SWs and GSWs should be treated differently and concluded that although selective conservatism should be exercised in SW, mandatory laparotomy should remain the standard of care for GSWs.

In 1977, Lowe et al.[13] published a retrospective review of 362 patients with abdominal GSWs. It was found that 30.1% of these in retrospect did not have injuries requiring treatment. It was noted that this group in general had tangential injuries and had either no or minimal abdominal findings on examination. It was also found that of the 259 cases with penetration of the abdominal visceral cavity, 97.6% had injuries requiring repair or drainage, whereas there were found to be no such injuries in the 48 patients without peritoneal penetration. A mandatory laparotomy was recommended for all GSWs suspected of having penetrated the abdominal cavity.

Moore et al.,[14] in 1980, reported 245 patients with isolated GSW to the abdomen and lower chest and found that of 162 patients that had peritoneal penetration, 156 (96%) were found to have injury to abdominal organs. No patient had a visceral injury from an extraperitoneal wound. The rest were tangential injuries confined to the abdominal wall; these patients were observed for 24 hours, all without incident. This group concluded that for those patients with peritoneal penetration after GSW, laparotomy is mandatory; for those with tangential wounds, observation may be safely performed.

In 1991, Demetriades et al.[15] published a prospective series of 41 patients with minimal or equivocal abdominal signs after GSW to the abdomen that were managed nonoperatively. Seven required delayed laparotomy within 4 hours to 4 days (3 colon injuries, 3 small bowel injuries, and 1 liver injury); of these, two developed wound infection, one with abdominal dehiscence. There was no mortality or serious morbidity. The authors concluded that carefully selected patients with abdominal GSW can be safely managed nonoperatively.

The group at Los Angeles County and University of Southern California Medical Center subsequently published a number of articles about GSWs to different regions of the abdomen. A prospective study investigating GSWs to the anterior abdomen (defined as the area between the costal margins and the inguinal ligaments and between the anterior axillary lines) was published by Demetriades et al.[15] in 1997. Patients were admitted between March 1994 and June 1995. Observation was selected if the patient was stable, without peritonitis, and without severe head or spinal cord injury. Of 106 patients in this group, 14 underwent delayed operation (13 for increasing tenderness and 1 for continued bleeding), of which 5 were therapeutic. Four of these patients had colon injuries managed by primary repair. Only one of these had a subsequent complication: a psoas abscess that required percutaneous drainage. One patient with liver and right kidney injuries was observed for 48 hours in violation of the institutional protocol and developed abdominal compartment syndrome and acute respiratory distress syndrome. The sensitivity of the initial negative physical examination was 97.1%. The mean hospital stay in the group with nontherapeutic operations was 6.4 days, and the complication rate was 27.6%. Of the total of 309 patients in the series, 92 (29.8%) were successfully managed nonoperatively.

Velmahos et al.[16] published a series of prospective studies in 1997 and 1998. In all of these, patients with hemodynamic instability or peritonitis underwent urgent operation. The first of these studies involved GSWs to the back. From September 1994 to August 1995, of 130 patients initially observed because of a negative clinical examination, 4 (3%) underwent delayed laparotomy after developing abdominal tenderness, all of which were nontherapeutic. The authors also reported a patient with a left posterior chest GSW that was explored although there were no clinical signs because of a policy of aggressive evaluation of suspected diaphragm injuries. A left diaphragm injury was found and

repaired. The sensitivity and specificity of initial clinical examination in detecting significant intra-abdominal injuries were 100% and 95%, respectively. Similar findings were reported on patients with GSWs to the buttocks and those with transpelvic GSWs in two separate reports by this same institution; in both of these, it was found that the sensitivity of clinical examination was 100% in detecting the need for laparotomy.[17,18]

A retrospective review of 792 patients with abdominal GSW treated with selective NOM during an 8-year period (1993–2000) was published by Velmahos et al.[19] in 2001. Of note, this study would have included some of the patients in the aforementioned studies. During observation, 80 (10%) patients developed symptoms and required a delayed laparotomy. Fifty-seven (72%) laparotomies were therapeutic. Five (6.3%) suffered complications potentially related to the delay in laparotomy, which were managed successfully. Seven hundred twelve (90%) were successfully managed nonoperatively. If patients had been managed by routine laparotomy, the unnecessary laparotomy rate would have been 47% (39% for anterior and 74% for posterior abdominal GSW). Patients without surgery had significantly shorter hospital length of stay and lower hospital charges.

In summary, there is little debate that selective management is appropriate in SW patients who are stable and without peritonitis, but controversy remains in the application of these same principles to GSW victims. Much of the data regarding clinical examination alone in the selective management of the patient with a GSW to the abdomen is from the same set of authors and the same institution. In general, adjunctive tests are used when NOM of these patients is attempted, and this will be detailed later in this article.

Morbidity of Nontherapeutic Laparotomy

Mandatory laparotomy for penetrating abdominal trauma detects some unexpected injuries earlier and more accurately but results in a higher nontherapeutic laparotomy rate, longer hospital stays, and increased hospital costs. The morbidity of the nontherapeutic laparotomy in the trauma patient has been recognized for decades; thus, unnecessary explorations should be avoided if possible. Conversely, the risks of delayed operative intervention are prohibitive and must be absolutely avoided.[20] The decision whether to operate on the patient who has sustained a penetrating wound to the abdomen must take both of these points into account.

Lowe et al.,[13] in 1972, reported a series of 245 patients (16.2% of all laparotomies) who did not have any significant visceral injury after laparotomy for trauma (almost all penetrating); of these, 178 (72.6%) were completely negative for injury.[13] Four patients (1.6%) were thought to have died as a result of their unnecessary laparotomies. Total complication rate was 20.4% and included wound infection in 6 patients, evisceration in 4, and ileus in 10. Pulmonary complications, such as atelectasis, pneumonia, and effusion, were also common. A study from Harlem Hospital, published in 1974, reported a 43.9% negative exploration rate after penetrating abdominal trauma, with a complication rate of 8.7%, chiefly pulmonary complications and wound infections.[21]

A prospective series of 372 operations performed on 368 patients with penetrating injuries to the abdomen, chest, neck, and extremities was reported by Demetriades et al.[22] There were 46 negative or nontherapeutic operations. Eleven percent of patients with nontherapeutic operations developed major complications because of anesthesia or operation (pancreatitis, aspiration pneumonia, wound infection, deep venous thrombosis, and pneumonia). Hospital length of stay was 4.1 days for those with uncomplicated nontherapeutic operations and 21.2 days for those with complications. The authors concluded that nontherapeutic operations for penetrating trauma carry a significant morbidity rate, and they advocated a policy of selective conservatism.

Hasaniya et al.[23] performed a retrospective study to look at complications of nontherapeutic laparotomies. Two hundred thirty of these were identified. The incidence of significant complications directly related to the anesthesia or operation was 8.2%. One patient with a major thoracic injury died secondary to complications of a nontherapeutic laparotomy. The average hospital stay for uncomplicated nontherapeutic operations was 5.1 days and for patients with complications 11.9 days.

Renz and Feliciano,[4] in 1995, reported a prospective case series of 254 patients with unnecessary laparotomies for trauma. Complications occurred in 41.3% of patients and included atelectasis (15.7%), postoperative hypertension that required medical treatment (11.0%), pleural effusion (9.8%), pneumothorax (5.1%), prolonged ileus (4.3%), pneumonia (3.9%), surgical wound infection (3.2%), small bowel obstruction (2.4%), urinary tract infection (1.9%), and others. The mortality rate for the entire series was 0.8% and was unrelated to unnecessary laparotomy.

In 1996, Leppaniemi and Haapiainen[24] published a prospective, randomized (not blinded) trial on the safety and cost-effectiveness of selective NOM in patients with abdominal SWs not requiring immediate laparotomy. Fifty-one patients not requiring immediate laparotomy for hemodynamic instability, generalized peritonitis, or evisceration were randomly assigned to mandatory laparotomy or expectant NOM. The morbidity rate was 19% after mandatory laparotomy and 8% after observation. Four patients (17%) managed nonoperatively required delayed laparotomy. Suture repair of colon injuries was performed at 6 hours and 18 hours after the injury in two patients; one patient underwent laparotomy for hemorrhage 44 hours after the injury and was found to have a liver laceration that was not actively bleeding and 1.4 L of blood in the abdomen (no further details are given, but this seems to have been an nontherapeutic laparotomy); and a fourth patient was discharged home but presented again 52 days later with empyema and was found to have a missed left diaphragm injury through which the stomach had partially herniated and perforated (truly a missed injury). About $2,800 was saved for every patient who underwent successful NOM. Mandatory laparotomy detects some unexpected organ injuries earlier and more accurately but results in a high nontherapeutic laparotomy rate.

In the same year, Renz and Feliciano[25] performed a prospective case series and found that unnecessary laparoto-

mies for trauma resulted in a significant length of stay. Two hundred fifty-four patients had unnecessary laparotomy for trauma from 1988 to 1991. The mean length of stay for 81 patients with negative laparotomies and no associated injuries was 4.7 days. The presence of a complication or an associated injury significantly prolonged the length of stay.

Haan et al.[26] from the University of Maryland reported 50 patients who had nontherapeutic laparotomies performed, primarily because of penetrating trauma. The nontherapeutic rate in this series was 6%. Significant complications were found in ~12%. Total length of stay was 5 days in those who had no other significant associated injuries. Overall mortality was 4%, but in all cases was unrelated to the nontherapeutic laparotomy. It was concluded that the overall rate of nontherapeutic laparotomy had decreased with the increased use of triple-contrast CT to evaluate penetrating injury to the abdomen; nontherapeutic laparotomy was associated with a significant increase in length of stay.

Although it is established that unnecessary laparotomy should be avoided if possible, it is important to emphasize that the decision on whether to perform a laparotomy favors not missing injury over the morbidity of a negative laparotomy.

Use of CT

In patients selected for initial NOM, abdominopelvic CT should be strongly considered as a diagnostic tool to facilitate initial management decisions. This recommendation is supported by a number of class II studies.

The original use of CT in penetrating abdominal trauma was in the assessment of SWs to the flank and back. This was first reported by Phillips et al.[27] in 1986. This group reported 56 stable patients without peritonitis and with a negative peritoneal lavage that had penetrating trauma to the flank and back and were evaluated with CT enema. There were 16 GSWs and 40 SWs. Twelve of these scans were found to be negative, six were considered indications for angiography, in 30 the penetrating wounds were well delineated and it was thought that these patients were appropriate for NOM, and in eight cases specific viscera were thought to be at risk, two of which led to surgical exploration, both of which were nontherapeutic. Overall, 52 of the 56 patients (92%) were successfully managed nonoperatively; of the other four patients, two had nontherapeutic laparotomy, one signed out against advice and was lost to follow-up, and one had a successful repair of a renal artery injury. The authors concluded that CT enema reliably identified injuries in this patient population.

In 1989, Fletcher et al.[28] reported a prospective series of 205 patients with SWs to the flank and back. CT with oral and intravenous contrast was obtained on all of these, with NOM possible in 155 (75.6%). It was concluded that CT was reliable in SWs to the back. Similarly, Meyer et al.[29] found that CT with oral and intravenous contrast had a sensitivity of 89%, a specificity of 98%, and an accuracy of 97% in the evaluation of SWs to the back. In 1997, Kirton et al.[30] performed a registry review on patients with back and flank SWs who were evaluated with CT with contrast enema. None of the 92 low-risk patients required surgery or had sequelae. Six of the 53 patients with high-risk scans had laparotomy (2 because of CT findings and 4 because of evolving signs). CT predicted surgical findings in all six.

Himmelman et al.[31] found that a negative triple contrast CT had 100% sensitivity for retroperitoneal injury after penetrating trauma to the back and flank. Eighty-eight patients were enrolled prospectively. Five of nine patients with high-risk scans had laparotomy, and two had injuries. Seventy-seven patients with non-high-risk scans were observed without complication.

The use of CT in other portions of the abdomen has also been studied. In 1989, Duncan et al.[32] reported 98 patients with transpelvic GSWs, of whom 40 (40.8%) were managed nonoperatively. A combination of DPL, angiography, cystography, proctoscopy, and CT enema were used in the evaluation of these patients. All these patients were discharged without complication.

Munera et al.[33] performed a prospective study of 47 patients with abdominal GSW who received a triple-contrast helical CT. CT scan disclosed nothing abnormal in 20 patients. These patients were treated nonoperatively. One injury was missed at CT (a cecal wall contusion that was repaired). It was concluded that in stable patients with GSWs to the abdomen in whom there is no indication for immediate surgery, triple-contrast helical CT can help reduce the number of cases of unnecessary or nontherapeutic laparotomy (accuracy of 96%).

Another prospective study of triple-contrast helical CT in 200 patients with penetrating torso trauma was published by Shanmuganathan et al.[34] in 2004 Two patients with negative CT findings failed to improve with observation and underwent therapeutic laparotomy. In one, an actively bleeding left upper quadrant mesenteric hematoma and a left diaphragm injury were found; in the other, a left diaphragm injury was found. Twenty-one of 23 patients with isolated liver injury had successful nonsurgical management. Angioembolization was performed on four of these patients. None of the six patients with renal injury required surgery. CT had 97% sensitivity (66 of 68 patients), 98% specificity (130 of 132 patients), and 98% accuracy (196 of 200 patients) for peritoneal violation. The authors concluded that triple-contrast helical CT accurately demonstrates peritoneal violation and visceral injury in patients with penetrating torso wounds. The accuracy of CT for diagnosis of left diaphragm injuries requires further study.

The use of CT in patients with abdominal GSW selected for NOM was reported by Velmahos et al.[35] in 2005. One hundred patients with nontangential abdominal GSWs selected for NOM during a 23-month period had single-contrast CT scan and were prospectively followed. Twenty-six of these patients required laparotomy, and this was nontherapeutic in five (19%). Three CT scans were false-positive and resulted in nontherapeutic laparotomies without postoperative complications. Two scans were false-negative and resulted in delayed laparotomies performed at 121 minutes and 307 minutes after arrival; hollow viscus injuries were found, and no postoperative complications ensued. The sensitivity and specificity of CT scanning was 90.5% and 96%, respectively. The authors concluded that CT scanning was safe and useful in this patient population.

The role of CT in the evaluation of the anterior abdominal SWs was investigated by Salim et al.[36] in a 2006 publication. One hundred fifty-six stable patients without peritonitis or omental evisceration were enrolled during a 24-month period. CT was obtained based on attending preference. Nineteen of 67 patients (28%) of patients in the CT group had a positive CT, and laparotomy was performed in 10 of these patients. Of the 48 patients with a negative CT, 3 underwent laparoscopy to assess the diaphragm (with one repair), whereas 2 underwent laparotomy for clinical deterioration with negative results. The negative predictive value of CT was found to be 100%.

Right Upper Quadrant Penetrating Injury

Patients with penetrating injury isolated to the right upper quadrant of the abdomen may be managed without laparotomy in the presence of stable vital signs, reliable examination, and minimal to no abdominal tenderness. This is supported by class II and class III evidence, but the numbers of patients are small.

NOM of penetrating liver injuries was first reported by Demetriades et al.[37] in 1986. Twenty-one patients with penetrating wounds over the right upper quadrant of the abdomen were reported. Liver involvement was suggested by the location of the wound, if there was penetration of the peritoneum, and if an abdominal paracentesis was positive for blood or if the patient was shocked or pale. All had a soft abdomen, mild tenderness over the liver region, and good bowel sounds. All were treated nonoperatively with observation and blood transfusions, if necessary. There was no mortality or morbidity in this group.

Chmielewski et al.[38] reported prospectively on 12 patients with a single GSW to the right upper quadrant, stable vital signs, reliable examination, and minimal or no abdominal tenderness. All were successfully observed. One nontherapeutic laparotomy was performed secondary to abdominal tenderness.

Demetriades et al.[39] performed a retrospective review of GSW to the liver from August 1994 to January 1998. Sixteen stable patients were selected for NOM. Five patients in the observed group underwent delayed laparotomy for peritonitis (4 patients with liver injuries) and abdominal compartment syndrome (1 patient who had received 6 units of blood in violation of the recommended policy). This patient with abdominal compartment syndrome was noted earlier in this article.[20] Except for a missed right diaphragm injury, there were no missed injuries in the 16 patients. Except for the patient with abdominal compartment syndrome who developed multiple complications and one patient in the nonoperative group who developed a biloma which was successfully drained percutaneously, all patients had uneventful recoveries.

In 1994, Renz and Feliciano[40] published a prospective series of stable patients with GSW to the right thoracoabdomen. Thirteen patients were identified. Twelve of these had CT. All patients had a right hemothorax treated with a chest tube. Complications included atelectasis (n = 4), a small persistent pneumothorax (n = 2), and pneumonia (n = 1). None required laparotomy. It was concluded that stable patients without peritonitis after sustaining a GSW to the right thoracoabdomen can be managed nonsurgically with a low incidence of minor intrathoracic complications.

Demetriades et al.[41] subsequently reported a prospective series of 43 patients who suffered penetrating abdominal trauma from May 2004 to January 2006, did not have immediate criteria for operation, and had evidence of solid organ but not hollow viscus injury on CT. Thirty-two of these patients had injuries to the liver. Four patients with a contrast blush underwent angioembolization of the liver. Forty-one of these patients were successfully managed without laparotomy without complication; two required delayed laparotomy, both 41 hours after admission, and survived without complication. Two underwent laparoscopic evaluation for suspected left diaphragm lacerations, and both had laparoscopic repair of these injuries. In all, 28.4% of patients with penetrating trauma to the liver, mostly GSWs, were safely managed nonoperatively.

Penetrating Renal Trauma

Most of the experience with NOM of penetrating solid organ injury has been with liver injury; there is, however, also data on NOM of kidney injuries. Routine exploration of these injuries may result in loss of a kidney that otherwise might not have needed removal.

The concept of NOM of penetrating kidney injuries was reported in 1983 by Heyns et al.,[42] who found that a policy of mandatory operation on all patients with SWs and hematuria led to unnecessary surgery in 61% of cases. In the same year, Bernath et al.[43] reported 34 patients in whom NOM was selected after confirmed SWs to the kidney; 82% having no sequelae, and 18% requiring delayed nephrectomy. Carroll and McAninch[44] reported eight cases of successful NOM of penetrating kidney injuries in 1985, using CT as a guide. Heyns et al.[45] subsequently reported a prospective series in which 23 patients with SWs to the kidney were managed without operation, with a paucity of complication.

Heyns and Vollenhoven,[46] in 1992 performed a retrospective review of 95 patients with renal SWs. Patients with SWs and hematuria were selected for surgical exploration if they had signs of severe blood loss, an associated intra-abdominal laceration, or a major abnormality on an intravenous urogram. Sixty patients were in the NOM group, and 35 were in the operative group. Only four patients underwent nontherapeutic laparotomy. Complications, however, developed in 12 of 60 patients (20%) in the nonoperative group and consisted mainly of secondary hemorrhage caused by an arteriovenous fistula or pseudoaneurysm. Management consisted of embolization in six, nephrectomy in two, heminephrectomy in one, open ligation of a fistula in one, and spontaneous resolution in two. The authors concluded by stating that certain groups should be more aggressively selected for surgery, and that angioembolization may be a useful adjunct to NOM.

In 1998, Velmahos et al.[47] reviewed the records of 52 consecutive patients with renal GSWs. Renal injuries were explored only if they involved the hilum or were accompanied by signs of continued bleeding. Thirty-two patients underwent renal exploration, with 17 requiring nephrectomy.

In the remaining 20 patients, renal exploration was successfully avoided. No kidneys were lost unnecessarily as a result of this policy. One renal complication was identified in a patient managed nonoperatively. A patient developed hematuria 1 month after injury. CT revealed lack of upper pole perfusion on the injured side. The patient underwent a successful partial nephrectomy.

In the prospective analysis of abdominal solid organ injuries published by Demetriades et al.[41] in 2006, it was found that 14.9% of all penetrating kidney injuries were managed successfully without operation and that 30.4% of those with penetrating renal trauma had no other significant intra-abdominal injuries.

At the present time, there is not a large amount of data on the NOM of penetrating renal trauma, and although there are reports of penetrating wounds to the kidneys being managed without laparotomy, it is not possible to make a formal recommendation at this time. Further study on this topic is necessary.

Duration of Observation

The majority of patients with penetrating abdominal trauma managed nonoperatively may be discharged after 24 hours of observation in the presence of a reliable abdominal examination and minimal to no abdominal tenderness. A number of observations and studies support this recommendation.

Alzamel and Cohn[48] published a chart review of 650 asymptomatic patients with abdominal SWs who were admitted for serial examination. Fifteen of 650 left against medical advice within 6 hours of presentation. Sixty-eight of 635 underwent exploratory laparotomy. All patients who needed surgery were identified within 12 hours of presentation. Twenty-three (33%) underwent surgery within 2 hours; 26 (38%) between 2 hours and 4 hours; 9 (13%) between 4 hours and 6 hours; 9 (13%) between 6 hours and 10 hours; and 1 (1.4%) at 12 hours. The authors conclude that asymptomatic patients with abdominal SWs may be discharged after 12 hours of observation with little likelihood of missed injury.

Velmahos et al.,[17] in their article about GSWs to the buttocks, found that observation of patients for >24 hours was unnecessary if they are stable, are able to tolerate a regular diet, and complain of no symptoms. In an article on the NOM of 1,856 patients with abdominal GSW, Velmahos et al.[19] observed that of 80 patients who required delayed laparotomy; only 1 patient required it after 24 hours of observation and this patient was a policy guideline violation, in that a patient with a GSW to the liver and right kidney with a falling hematocrit was transfused instead of being taken to surgery. In a subsequent study, again by Velmahos et al.,[35] now using CT in addition to physical examination, it was found that laparotomy guided by CT findings was performed within an average of 4.5 hours and a maximum of 13 hours.

Ginzburg et al.[49] published a retrospective study of 83 patients using triple contrast CT to rule out injury after a GSW to abdomen or flank. CT scans were classified as positive, equivocal, or negative. The 53 patients with negative studies were observed for 23 hours, with a 100% true negative rate. After this, patients were either discharged home or transferred to other services for treatment of associated injuries. No patient with a negative CT had a missed injury using this protocol.

Local Wound Exploration

LWE has been used in a number of series to rule out penetration of the anterior fascia; if a patient has no penetration of the anterior fascia, the patient may be safely discharged from the emergency department. Thompson and Moore[50] found that LWE followed by DPL when peritoneal violation was deemed likely after SWs resulted in an 8% unnecessary laparotomy rate. This resulted in 97 patients being discharged home directly from the emergency department after a wound exploration which showed that the posterior fascia was not violated. None of these patients required subsequent exploration for their injuries. Most authors, however, have investigated only the anterior fascia when performing LWE.[51–54] If the fascia has been penetrated, however, a diagnostic dilemma ensues, because mandatory laparotomy after anterior fascial penetration has been reported as negative in almost 50%.[51]

Patients with abdominal SWs may have intra-abdominal injury ruled out by LWE demonstrating that the anterior abdominal fascia has not been penetrated. If there is no other reason for hospital admission, these patients may then be sent home. If the anterior fascia has been penetrated, further diagnostic testing to rule out intraperitoneal injuries requiring operation is a better option than mandatory laparotomy.

Angiography

Angiography may be necessary as an adjunct to initial NOM of penetrating abdominal trauma. Although well established in the NOM of blunt solid organ injury, only a few reports have described the use of angiography after penetrating abdominal trauma. Angiography was described as an adjunct to the NOM of kidney injuries by Heyns and Van Vollenhoven[46] in 1992. Velmahos et al.[55] in 1999 described 40 patients undergoing angiography after penetrating abdominal trauma. Six of these patients had angiography performed during NOM; the rest had this performed as an adjunct to surgery. Three of the six patients managed nonoperatively had successful angioembolization: one liver injury and two renal injuries. Shanmuganathan et al.[34] reported four patients with liver injuries who were managed with angioembolization but not with operation. Demetriades et al.[41] reported four patients who had NOM of liver injury, with angioembolization playing a crucial role. Further study is needed on the use of angiography and angioembolization in this patient population before a formal recommendation can be made.

Diagnostic Peritoneal Lavage

There are a number of articles that have investigated DPL as a means to assess the need for surgery after penetrating abdominal trauma.[56–62] DPL was first reported in 1965 as a technique to evaluate patients injured by severe blunt abdominal trauma.[63] The original description involved examination of the peritoneal lavage perfusate for hemoglobin concentration, amylase activity, and bacteria by a gram-stained smear. During the next 30 years, the open method of DPL evolved to include both semiopen and closed tech-

niques. These newer methods incorporated a guidewire technique, depending on whether a skin incision was used.

DPL was an attractive diagnostic tool, because the initial physical examination was deemed to be unreliable in the setting of abdominal trauma. The advantages of DPL were that it was very sensitive for the detection of hemoperitoneum and that a result could be obtained rapidly. The most commonly used findings leading to a positive result in blunt trauma were either a gross-positive aspirate or a lavage fluid red blood cell (RBC) count >100,000 cells/mm^3.

Abdominal paracentesis for blood in the setting of penetrating abdominal trauma was described by Shaftan[2] in the 1960s. The use of DPL as an adjunct in management of penetrating abdominal trauma was subsequently reported by Thal[64] in 1977. In penetrating trauma series since then, there has been a large variability in the criteria for a positive study. Departure from the threshold for blunt trauma was influenced by two main considerations. A greater proportion of penetrating abdominal injuries required a therapeutic laparotomy, relative to blunt trauma. Also, in penetrating mechanisms, there was a greater risk of having a low-hemorrhage injury that still required operative repair. Because of this, the recommended thresholds for positivity have ranged from 1,000[54,58] to 100,000[50,52] RBC/mm^3. Thompson and Moore[65] stated that DPL should be used for GSWs only if there is a question of peritoneal penetration; thus, the RBC threshold should probably be lower than that for SWs; they suggested 5,000 RBC/mm^3. The threshold should also be lower for injuries of the thoracoabdominal area because of the concern for diaphragm injury.

Feliciano et al.[52] reported a series of 500 patients with abdominal SWs who were stable without peritonitis or evisceration. These patients underwent LWE, and if this was positive for penetration of the anterior fascia, a peritoneal tap was performed. If gross blood, feces, bile, or food material was returned, the patient underwent laparotomy; otherwise, a lavage using 1,000 mL of normal saline solution was performed. The lavage was considered positive if there were >100,000 RBCs/mm^3, >500 white blood cells/mm^3, or if the amylase level was elevated. The accuracy of this technique was found to be 91.2%, with a sensitivity of 96.3% and a specificity of 88.2%. The authors concluded that this technique reduced unnecessary laparotomies and was rapid, safe, and highly cost-effective.

Chihombori et al.[57] reported 162 patients seen with SWs to the anterior abdomen, back, and flank in 1987. Stable patients without peritonitis or evisceration were selected for NOM. All underwent tap and lavage, and those with back and flank wound underwent CT enema. A lavage was considered to be positive if the RBC count was >2,000 or if the white blood cell count was >500. Of the 126 who underwent tap and lavage, there were no false-positives and only one false-negative study. This group concluded that their treatment algorithm could be applied with a high degree of sensitivity and specificity.

A subsequent study by Nagy et al.[60] looking at patients sustaining GSWs to the abdomen used a DPL threshold of 10,000 RBCs/mm^3. DPL was performed on all patients sustaining GSWs in whom peritoneal penetration was unclear. A total of 429 DPLs were performed for this indication, of which 150 were positive. Six of these DPLs were found to be false-positive. There were 279 patients with DPL counts <10,000 RBCs/mm^3. Two of these developed peritoneal signs and had therapeutic laparotomies; the other 277 had true negative tests and were discharged from the hospital after a minimum of 24 hours of observation. There were three complications (1.2%) including two mesenteric lacerations and an ovarian injury, all of which required laparotomy. Overall, the accuracy, sensitivity, and specificity of DPL in this study were reported as 98%, 99%, and 98%, respectively.

Finally, Gonzalez et al.[58] prospectively enrolled 86 stable patients with abdominal SWs without evisceration into a study examining DPL with a positivity threshold of 1,000 RBCs/mm^3. Those below this threshold (n = 44) were either sent home or admitted for indications other than the SW, whereas the rest (n = 38) were admitted for observation. Four patients were explored for a white blood cell DPL count of >500/mm^3. No patient with a DPL count <1,000 RBCs/mm^3 required laparotomy or had a complication of the SW. Of those admitted for observation, eight (21%) developed physical findings and had laparotomy, of which five were therapeutic. The authors concluded that their algorithm allowed safe discharge of these patients from the emergency department and that observation of the rest allowed for low laparotomy rates and minimal complications.

When the concept of selective management, rather than mandatory laparotomy for hemodynamically stable patients, began to receive more attention, the noninvasive tools became more popular adjuncts, and DPL became more often reserved for unstable patients requiring rapid diagnosis. Most of the studies regarding DPL in this review are from the early to mid-1990s, with few recent studies. The more recent literature suggests that DPL now seems to be increasingly replaced by the use of other diagnostic modalities, such as CT and Focused Abdominal Sonography for Trauma (FAST). Because of these factors, we did not make any evidence-based recommendations regarding the use of DPL in this review.

Ultrasound

There are few articles on the use of ultrasound (US) in the NOM of patients with penetrating abdominal trauma. Only one addresses the use of FAST, and the conclusion is that additional diagnostic studies need to be performed in the face of a negative FAST to rule out occult injury.[66] Of the two other studies investigating US, one described radiologist-interpreted US and the other described US to evaluate penetration of the abdominal wall.[67,68] There are not enough data to make a recommendation about the use of US in this patient population.

Visceral or Omental Evisceration (SWs)

Visceral or omental evisceration through an abdominal SW in a patient with stable clinical signs and without evidence of peritonitis is a relative rather than absolute indication for exploratory laparotomy. Most, but not all of these patients will require laparotomy. This is supported by class II

and class III evidence; however, the data on this topic are not strong enough to support a formal recommendation.

In 1980, Thompson et al.[69] reported 17 patients who had omental evisceration after SWs to the abdomen; all these patients underwent laparotomy. Five (29%) of these patients had no evidence of intraperitoneal injury. A study by Huizenga et al.,[70] published in 1987, disputes this as 28 of 30 stabbed patients (93%) with omental evisceration but without signs of peritonitis had nontherapeutic laparotomies. In 1996, McFarlane[71] reported a small series of patients (n = 14) with anterior abdominal SWs and omental evisceration who were observed. There were no late complications or missed visceral injuries requiring laparotomy. All these authors argue that omental evisceration should not mandate laparotomy.

A series by Granson et al.[72] published in 1983 reported 100 patients with omental evisceration after a SW to the abdomen; all received laparotomy and major intraperitoneal injuries were found in 69 cases. Burnweit and Thal[73] reported a series from Parkland Memorial Hospital in 1986 of patients with evisceration. Of those with visceral evisceration, 31 of 34 patients (91%) had serious intra-abdominal injuries; of those with omental evisceration, 86 of 115 patients (75%) had such injuries. Medina et al.[74] reported 75 patients with omental and bowel evisceration after SWs; 82.7% of the group had major intra-abdominal injuries. This group of authors argues for mandatory laparotomy in patients with evisceration.

Arikan et al.[75] published a prospective, nonrandomized series of 52 hemodynamically stable patients with abdominal SWs and either visceral or omental evisceration, who were treated either with exploratory laparotomy or wound exploration and wound closure under local anesthesia. Patients with obviously perforated hollow viscera or peritonitis were excluded. Seven of 31 patients treated selectively required delayed operation, of which 2 (6.5%) were negative. Of the 21 patients treated with a routine laparotomy, 7 (33%) were nontherapeutic. Of the routine laparotomy group, 19% (4 of 21) had complications, but only one patient with a nontherapeutic laparotomy had a complication (bleeding through the suture line controlled by simple suturing). The complication rate in the selective group was 3.2% (1 case of small bowel obstruction managed nonoperatively). The mean length of stay was 137 hours in the routine exploration group versus 81 hours in the selective group ($p < 0.001$). The authors concluded that selective observation is safe and superior to routine laparotomy for the treatment of penetrating abdominal SWs with omental evisceration.

On the other hand, Nagy et al.[76] found that of the 81 patients admitted with evisceration after an abdominal SW, 63 patients (78%) had an intra-abdominal injury that required repair, and this was true whether the evisceration was of an organ or omentum. This group thus recommended that evisceration should prompt laparotomy.

To summarize, there have been reports of patients with omental and even visceral evisceration after SWs being managed without laparotomy. There are arguments both for and against routine exploration. Because the literature on this topic is not decisive, a formal recommendation on this topic cannot be formulated. Until further data are available, these patients are probably best served by laparotomy.

Role of Laparoscopy/Evaluation of Diaphragm Injury

Diagnostic laparoscopy may be considered as a tool to evaluate diaphragmatic lacerations and peritoneal penetration. Although technically not "nonoperative management," it is important to consider this modality as a means of limiting nontherapeutic laparotomy, which is the focus of the majority of this article. A number of publications show that DL may limit the number of negative or nontherapeutic laparotomies.[77–84] DL may also be necessary to rule out diaphragmatic injuries in appropriate patients.[79,81,82,85]

DL is a technique that has been described since the 1960s[77,80] as a method to minimize unnecessary laparotomies. Review of seven prospective studies comparing DL to exploratory laparotomy has consistently found DL to have a specificity of 98% to 100%.[51,79,81,84,86–88] However, in a prospective study published by Demetriades et al.[89] in 1987, of 476 patients with peritoneal penetration, 27.6% had no significant abdominal injury. Ditmars and Bongard[86] showed that of 38 patients with laparoscopically proven parietal peritoneal penetration, 17 (45%) had a nontherapeutic laparotomy. Cherry et al.[90] reported a nontherapeutic laparotomy rate after laparoscopy showing penetration of the peritoneum of 44.4%. The nontherapeutic laparotomy rate after a laparoscopy positive for peritoneal penetration remains a concern. Another major concern with the use of DL is missed injury. Ivatury et al.[81] noted that the sensitivity for hollow viscus injury was only 18%; DL may be inadequate to rule out these types of injuries once peritoneal penetration has been confirmed. This sensitivity has the potential to improve with increasing experience with this technique.

Probably the most widely accepted role for DL is in the evaluation of the hemodynamically stable patient without indication for laparotomy with a penetrating wound to the left thoracoabdominal area. This is important, as Madden et al.[91] reported that the mortality from the delayed recognition of incarcerated diaphragmatic injury after a SW to this area was 36%. Friese et al.[79] found that DL had a specificity, sensitivity, and negative predictive value of 100%, 87.5%, and 96.8% in evaluation of the diaphragm after penetrating trauma. In patients in whom penetration does occur, some authors have had success with further observation instead of open exploration when the injuries have been isolated to the right upper quadrant and liver.[77,81,84,86] Observation is not appropriate for wounds located in the left upper quadrant, however.

A number of reports cite missed diaphragm injuries.[16,34,39,92,93] The consequences of missed diaphragmatic injuries include potential herniation and strangulation of viscera through the diaphragmatic defect, which may occur many months after the initial injury.[93] Murray et al.[85] studied 110 patients with penetrating left thoracoabdominal wounds (94 SWs and 16 GSWs) and found that the incidence of occult diaphragmatic injuries was high at 24%. The incidence of diaphragmatic injuries was 21% in those with a normal chest roentgenogram as opposed to 31% in those with a hemothorax or pneumothorax, and so a normal chest roent-

genogram does not rule out diaphragmatic injury. These diaphragmatic injuries would not have been diagnosed without DL, according to the authors. McQuay and Britt[82] reported 80 patients with penetrating thoracoabdominal injuries who had DL to rule out diaphragmatic injury. Fifty-eight patients (72.5%) had a negative DL and were spared laparotomy. The other 22 had diaphragmatic injury and underwent laparotomy; in these patients, 17 (77.2%) were found to have other injuries requiring intervention. Other series have reported laparoscopic repair of diaphragmatic injuries.[41,78,94] In the series reported by Demetriades et al., patients had DL >8 hours after admission so that repair of the diaphragm could be then performed laparoscopically without worry of missed hollow viscus injuries.

DL should be strongly considered in patients with penetrating trauma to the left thoracoabdominal area who have no other indications for laparotomy to rule out and to potentially repair diaphragmatic injuries. Potential negative aspects of DL include its cost and the need for general anesthesia. The use of DL to identify hollow viscus injuries is not recommended at the present time.[81,89,95]

Applicability

Prudent judgment should be exercised in deciding to apply NOM of penetrating abdominal trauma. It may need to be used more cautiously in medical centers with little trauma experience and few trauma resources. This is especially true for GSWs and close-range shotgun wounds of the abdomen. Serial examination, if chosen, should be performed frequently and preferably by the same surgeon. Pain medications should be given with caution, if at all, to avoid masking the physical examination of the abdomen. If a patient should develop abdominal pain or hemodynamic instability, NOM should be abandoned and the patient taken to surgery emergently. CT may be helpful in evaluation of the retroperitoneum and in selected patients with GSWs of the abdomen. DL is of proven benefit for left thoracoabdominal penetration to detect diaphragmatic injury. Ancillary diagnostic tests such as DPL may be helpful in detecting intraperitoneal injuries.

A diagnostic dilemma is encountered in the evaluable patient with a nontangential abdominal GSW who has no generalized abdominal tenderness and is hemodynamically stable. Some surgeons would operate on such a patient routinely, whereas others would offer a trial of NOM. The degree of expertise and structure of the trauma center (e.g., inhouse senior coverage, monitored bed, etc.) plays a role. In addition, CT or DL may be of help.

FUTURE INVESTIGATIONS

Randomized trials would be useful in investigating this topic further but are unlikely to be practical because many patients would be subjected to unnecessary laparotomies for the purposes of the research. The role of CT in elucidating the need for laparotomy after penetrating trauma requires further study; in particular, the role of CT in identifying diaphragmatic injuries needs to be investigated further. Although there is no debate about the need to repair penetrating injuries to the left diaphragm, further study is required regarding the right diaphragm. NOM of penetrating solid organ injuries, such as to the liver and kidneys, requires further study. The role of interventional radiology and angioembolization in the NOM of penetrating abdominal trauma needs to be elucidated further, as does the role of DL in avoiding unnecessary laparotomy.

REFERENCES

1. Loria FL. Historical aspects of penetrating wounds of the abdomen. *Int Abstracts Surg.* 1948;87:521–549.
2. Shaftan GW. Indications for operation in abdominal trauma. *Am J Surg.* 1960;99:657–664.
3. Nance FC, Cohn I Jr. Surgical management in the management of stab wounds of the abdomen: a retrospective and prospective analysis based on a study of 600 stabbed patients. *Ann Surg.* 1969;170:569–580.
4. Renz BM, Feliciano DV. Unnecessary laparotomies for trauma: a prospective study of morbidity. *J Trauma.* 1995;38:350–356.
5. Friedmann P. Selective management of stab wounds of the abdomen. *Arch Surg.* 1968;96:292–295.
6. Lee WC, Uddo JF, Nance FC. Surgical judgment in the management of abdominal stab wounds: utilizing clinical criteria from a 10-year experience. *Ann Surg.* 1984;199:549–554.
7. McAlvanah MJ, Shaftan GW. Selective conservatism in penetrating abdominal wounds: a continuing reappraisal. *J Trauma.* 1978;18:206–212.
8. Printen KJ, Freeark RJ, Shoemaker WC. Conservative management of penetrating abdominal wounds. *Arch Surg.* 1968;96:899–901.
9. Ocampo H, Yamaguchi M, Mackabee J, Ordog G, Fleming A. Selective management of posterior stab wounds. *JAMA.* 1987;79:283–288.
10. Wilder JR, Kudchadkar A. Stab wounds of the abdomen: observe or explore? *JAMA.* 1980;243:2503–2505.
11. Robin AP, Andrews JR, Lange DA, Roberts RR, Moskal M, Barrett JA. Selective management of anterior abdominal stab wounds. *J Trauma.* 1989;29:1684–1689.
12. Dawidson I, Miller E, Litwin MS. Gunshot wounds to the abdomen: a review of 277 cases. *Arch Surg.* 1976;111:862–865.
13. Lowe RJ, Boyd DR, Folk FA, Baker RJ. The negative laparotomy for abdominal trauma. *J Trauma.* 1972;12:853–861.
14. Moore EE, Moore JB, van Duzer-Moore S, Thompson JS. Mandatory laparotomy for gunshot wounds penetrating the abdomen. *Am J Surg.* 1980;140:847–851.
15. Demetriades D, Charalambides D, Lakhoo M, Pantanowitz D. Gunshot wound of the abdomen: role of selective conservative management. *Br J Surg.* 1991;78:220–222.
16. Velmahos GC, Demetriades D, Faianini E, et al. A selective approach to the management of gunshot wounds to the back. *Am J Surg.* 1997;174:342–346.
17. Velmahos GC, Demetriades D, Cornwell EE, Asensio J, Belzberg H, Berne TV. Gunshot wounds to the buttocks: predicting the need for operation. *Dis Colon Rectum.* 1997;40:307–311.
18. Velmahos GC, Demetriades D, Cornwell EE III. Transpelvic gunshot wounds: routine laparotomy or selective management? *World J Surg.* 1998;22:1034–1038.
19. Velmahos GC, Demetriades D, Toutouzas KG, et al. Selective nonoperative management in 1,856 patients with abdominal gunshot wounds: should routine laparotomy still be the standard of care? *Ann Surg.* 2001;234:395–403.
20. Demetriades D, Velmahos G, Cornwall E III, et al. Selective nonoperative management of gunshot wounds of the anterior abdomen. *Arch Surg.* 1997;132:178–183.
21. Forde KA, Ganepola GA. Is mandatory exploration for penetrating abdominal trauma extinct? The morbidity and mortality of negative exploration in a large municipal hospital. *J Trauma.* 1974;14:764–766.
22. Demetriades D, Vandenbossche P, Ritz M, Goodmann D, Kowalszik J. Non-therapeutic operations for penetrating trauma: early morbidity and mortality. *Br J Surg.* 1993;80:860–861.
23. Hasaniya N, Demetriades D, Stephens A, Dubrowskiz R, Berne T. Early morbidity and mortality of non-therapeutic operations for penetrating trauma. *Am Surg.* 1994;60:744–747.

24. Leppaniemi AK, Haapiainen RK. Selective nonoperative management of abdominal stab wounds: prospective, randomized study. *World J Surg.* 1996;20:1101–1105.
25. Renz BM, Feliciano DV. The length of hospital stay after an unnecessary laparotomy for trauma: a prospective study. *J Trauma.* 1996;40: 187–190.
26. Haan J, Kole K, Brunetti A, Kramer M, Scalea TM. Nontherapeutic laparotomies revisited. *Am Surg.* 2003;69:562–565.
27. Phillips T, Sclafani SJ, Goldstein A, Scalea T, Panetta T, Shaftan G. Use of the contrast-enhanced CT enema in the management of penetrating trauma to the flank and back. *J Trauma.* 1986;26:593–601.
28. Fletcher TB, Setiawan H, Harrell RS, Redman HC. Posterior abdominal stab wounds: role of CT evaluation. *Radiology.* 1989;173:621–625.
29. Meyer DM, Thal ER, Weigelt JA, Redman HC. The role of abdominal CT in the evaluation of stab wounds to the back. *J Trauma.* 1989;29: 1226–1230.
30. Kirton OC, Wint D, Thrasher B, Windsor J, Echenique A, Hudson-Civetta J. Stab wounds to the back and flank in the hemodynamically stable patient: a decision algorithm based on contrast-enhanced computed tomography with colonic opacification. *Am J Surg.* 1997;173: 189–193.
31. Himmelman RG, Martin M, Gilkey S, Barrett JA. Triple contrast CT scans in penetrating back and flank trauma. *J Trauma.* 1991;31:852–855.
32. Duncan AO, Phillips TF, Scalea TM, Maltz SB, Atweh NA, Sclafani SJ. Management of transpelvic gunshot wounds. *J Trauma.* 1989;29:1335–1340.
33. Munera F, Morales C, Soto JA, et al. Gunshot wounds of the abdomen: evaluation of stable patients with triple-contrast helical CT. *Radiology.* 2004;231:399–405.
34. Shanmuganathan K, Mirvis SE, Chiu WC, Killeen KL, Hogan GJ, Scalea TM. Penetrating torso trauma: triple-contrast helical CT in peritoneal violation and organ injury—a prospective study in 200 patients. *Radiology.* 2004;231:775–784.
35. Velmahos GC, Constantinou C, Tillou A, Brown CV, Salim A, Demetriades D. Abdominal computed tomographic scan for patients with gunshot wounds to the abdomen selected for nonoperative management. *J Trauma.* 2005;59:1155–1161.
36. Salim A, Sangthong B, Martin M, et al. Use of computed tomography in anterior abdominal stab wounds. *Arch Surg.* 2006;141:745–752.
37. Demetriades D, Rabinowitz B, Sofianos C. Non-operative management of penetrating liver injuries: a prospective study. *Br J Surg.* 1986;73: 736–737.
38. Chmielewski GW, Nicholas JM, Dulchavsky SA, Diebel LN. Nonoperative management of gunshot wounds of the abdomen. *Am Surg.* 1995;61:665–668.
39. Demetriades D, Gomez H, Chahwan S, et al. Gunshot injuries to the liver: the role of selective nonoperative management. *J Am Coll Surg.* 1999;188:343–348.
40. Renz BM, Feliciano DV. Gunshot wounds of the right thoracoabdomen: a prospective study of nonoperative management. *J Trauma.* 1994;37: 737–744.
41. Demetriades D, Hadjizacharia P, Constantinou C, et al. Selective nonoperative management of penetrating abdominal solid organ injuries. *Ann Surg.* 2006;244:620–628.
42. Heyns CF, de Klerk DP, de Kock ML. Stab wounds associated with hematuria—a review of 67 cases. *J Urol.* 1983;130:228–231.
43. Bernath AS, Schutte H, Fernandez RR, Addonizio JC. Stab wounds of the kidney: conservative management in flank penetration. *J Urol.* 1983;129:468–490.
44. Carroll PR, McAninch JW. Operative indications in penetrating renal trauma. *J Trauma.* 1985;25:587–593.
45. Heyns CF, de Klerk DP, de Kok ML. Nonoperative management of renal stab wounds. *J Urol.* 1985: 239–242.
46. Heyns CF, Van Vollenhoven P. Selective surgical management of renal stab wounds. *Br J Urol.* 1992;69:351–357.
47. Velmahos GC, Demetriades D, Cornwell EE III, et al. Selective management of renal gunshot wounds. *Br J Surg.* 1998;85:1121–1124.
48. Alzamel HA, Cohn SM. When is it safe to discharge asymptomatic patients with abdominal stab wounds? *J Trauma.* 2005;58:523–525.
49. Ginzburg E, Carrillo EH, Kopelman T, et al. The role of computed tomography in selective management of gunshot wounds to the abdomen and flank. *J Trauma.* 1998;45:1005–1009.
50. Thompson JS, Moore EE. Peritoneal lavage in the evaluation of penetrating abdominal trauma. *Surg Gynecol Obstet.* 1981;153:861–863.
51. Fabian TC, Croce MA, Stewart RM, Pritchard FE, Minard G, Kudsk KA. A prospective analysis of diagnostic laparoscopy in trauma. *Ann Surg.* 1993;217:557–565.
52. Feliciano DV, Bitondo CG, Steed G, Mattox KL, Burch JM, Jordan GL Jr. Five hundred open taps or lavages in patients with abdominal stab wounds. *Am J Surg.* 1984;148:772–777.
53. Miller FB, Cryer HM, Chilikuri S, Creech P, Richardson JD. Negative findings on laparotomy for trauma. *South Med J.* 1989;82:1231–1234.
54. Oreskovich MR, Carrico CJ. Stab wounds of the abdomen: analysis of a management plan using local wound exploration and a quantitative peritoneal lavage. *Ann Surg.* 1983;1978:411–417.
55. Velmahos GC, Demetriades D, Chahwan S, et al. Angiographic embolization for arrest of bleeding after penetrating trauma to the abdomen. *Am J Surg.* 1999;178:367–373.
56. Boyle EM Jr, Maier RV, Salazar JD, et al. Diagnosis of injuries after stab wounds to the flank and back. *J Trauma.* 1997;42:260–265.
57. Chihombori A, Hoover EL, Phillips T, Sclafani S, Scalea T, Jaffe BM. Role of diagnostic techniques in the initial evaluation of stab wounds to the anterior abdomen, back, and flank. *J Natl Med Assoc.* 1991;83:137–140.
58. Gonzalez RP, Turk B, Falimirski, Holevar MR. Abdominal stab wounds: diagnostic peritoneal lavage criteria for emergency room discharge. *J Trauma.* 2001;51:939–943.
59. Keleman JJ III, Martin RR, Obney JA, Jenkins D, Kissinger DP. Evaluation of diagnostic peritoneal lavage in stable patients with gunshot wounds to the abdomen. *Arch Surg.* 1997;132:909–913.
60. Nagy KK, Krosner SM, Joseph KT, Roberts RR, Smith RF, Barrett J. A method of determining peritoneal penetration in gunshot wounds to the abdomen. *J Trauma.* 1997;43:242–246.
61. Rosemurgy AS II, Albrink MH, Olson SM, et al. Abdominal stab wound protocol: prospective study documents applicability for widespread use. *Am Surg.* 1995;61:112–116.
62. Taviloglu K, Gunay K, Ertekin C, Calis A, Türel O. Abdominal stab wounds: the role of selective management. *Eur J Surg.* 1998;164:17–21.
63. Root HD, Hauser CW, McKinley CR, Lafave JW, Mendiola RP Jr. Diagnostic peritoneal lavage. *Surgery.* 1965;57:633–637.
64. Thal ER. Evaluation of peritoneal lavage and local exploration in lower chest and abdominal stab wounds. *J Trauma.* 1977;17:642–648.
65. Merlotti GJ, Dillon BC, Lange DA, Robin AP, Barrett JA. Peritoneal lavage in penetrating thoraco-abdominal trauma. *J Trauma.* 1988;28: 17–23.
66. Udobi KF, Rodriguez A, Chiu WC, Scalea TM. Role of ultrasonography in penetrating abdominal trauma: a prospective clinical study. *J Trauma.* 2001;50:475–479.
67. Bokhari F, Nagy K, Roberts R, et al. The ultrasound screen for penetrating truncal trauma. *Am Surg.* 2004;70:316–321.
68. Soto JA, Morales C, Munera F, Sanabria A, Guevara JM, Suárez T. Penetrating stab wounds to the abdomen: use of serial US and contrast-enhanced CT in stable patients. *Radiology.* 2001;220:365–371.
69. Thompson JS, Moore EE, van Duzer-Moore S, Moore JB, Galloway AC. The evolution of abdominal stab wound management. *J Trauma.* 1980; 20:478–484.
70. Huizenga WKJ, Baker LW, Mishali ZW. Selective management of abdominal and thoracic stab wounds with established peritoneal penetration: the eviscerated omentum. *Am J Surg.* 1987;153:564–568.
71. McFarlane ME. Non-operative management of stab wounds to the abdomen with omental evisceration. *J R Coll Surg Einb.* 1996;41:239–240.
72. Granson MA, Donovan AJ. Abdominal stab wound with omental evisceration. *Arch Surg.* 1983;118:57–59.
73. Burnweit CA, Thal ER. Significance of omental evisceration in abdominal stab wounds. *Am J Surg.* 1986;154:670–673.
74. Medina M, Ivatury RR, Stahl WM. Omental evisceration through an abdominal stab wound: is exploratory laparotomy mandatory? *Can J Surg.* 1984;27:399–401.
75. Arikan S, Kocakusak A, Yucel AF, Adas G. A prospective comparison of the selective observation and routine exploration methods for penetrating abdominal stab wounds with organ or omentum evisceration. *J Trauma.* 2005;58:526–532.

76. Nagy K, Roberts R, Joseph K, An G, Barrett J. Evisceration after abdominal stab wounds: is laparotomy required? *J Trauma.* 1999;47: 622–626.
77. Carnevale N, Baron N, Delany HM. Peritoneoscopy as an aid to diagnosis of abdominal trauma: a preliminary report. *J Trauma.* 1977; 17:634–641.
78. Ertekin C, Onaran Y, Güloğlu R, Günay K, Taviloğlu K. The use of laparoscopy as a primary diagnostic and therapeutic method in penetrating wounds of the lower thoracal region. *Surg Laparosc Endosc.* 1998; 8:26–29.
79. Friese RS, Coln CE, Gentilello LM. Laparoscopy is sufficient to exclude occult diaphragm injury after penetrating abdominal trauma. *J Trauma.* 2005 58:789–792.
80. Heselson J. Peritoneoscopy in abdominal trauma. *S Afr J Surg.* 1970;8: 53–60.
81. Ivatury RR, Simon RJ, Stahl WM. A critical evaluation of laparoscopy in penetrating abdominal trauma. *J Trauma.* 1993;34:822–828.
82. McQuay N Jr, Britt LD. Laparoscopy in the evaluation of penetrating thoracoabdominal trauma. *Am Surg.* 2003;69:788–791.
83. Ortega AE, Tang A, Froes ET, Asensio JA, Katkhouda N, Demetriades D. Laparoscopic evaluation of penetrating thoracoabdominal traumatic injuries. *Surg Endosc.* 1996;10:19–22.
84. Sosa JL, Arrillaga A, Puente I, Sleeman D, Ginzburg E, Martin L. Laparoscopy in 121 consecutive patients with abdominal gunshot wounds. *J Trauma.* 1995;39:501–506.
85. Murray JA, Demetriades D, Asensio JA, et al. Occult injuries to the diaphragm: prospective evaluation of laparoscopy in penetrating injuries to the left lower chest. *J Am Coll Surg.* 1998;187:626–630.
86. Ditmars ML, Bongard F. Laparoscopy for triage of penetrating trauma: the decision to explore. *J Laparoendosc Surg.* 1996;6:285–291.
87. Ahmed N, Whelan J, Brownlee J, Chari V, Chung R. The contribution of laparoscopy in evaluation of penetrating abdominal wounds. *J Am Coll Surg.* 2005;201:213–216.
88. Rossi P, Mullins D, Thal E. Role of laparoscopy in the evaluation of abdominal trauma. *Am J Surg.* 1993;166:707–711.
89. Demetriades D, Rabinowitz B. Indications for operation in abdominal stab wounds: a prospective study of 651 patients. *Ann Surg.* 1987;205: 129–132.
90. Cherry RA, Eachempati SR, Hydo LJ, Barie PS. The role of laparoscopy in penetrating abdominal stab wounds. *Surg Laparosc Endosc Percutan Tech.* 2005;15:14–17.
91. Madden MR, Paull DE, Finkelstein JL, et al. Occult diaphragmatic injury from stab wounds to the lower chest and abdomen. *J Trauma.* 1989;29:292–298.
92. Chiu WC, Shanmuganathan K, Mirvis SE, Scalea TM. Determining the need for laparotomy in penetrating torso trauma: a prospective study using triple-contrast enhanced abdominopelvic computed tomography. *J Trauma.* 2001;51:860–869.
93. Leppäniemi A, Haapiainen R. Occult diaphragmatic injuries caused by stab wounds. *J Trauma.* 2003;55:646–650.
94. Zantut LF, Ivatury RR, Smith RS, et al. Diagnostic and therapeutic laparoscopy for penetrating abdominal trauma: a multicenter experience. *J Trauma.* 1997;42:825–831.
95. Livingston DH, Tortella BJ, Blackwood J, Machiedo GW, Rush BF Jr. The role of laparoscopy in abdominal trauma. *J Trauma.* 1992;33:471–475.