World J. Surg. 23, 265–270, 1999

WORLD
Journal of
SURGERY

Noninvasive Evaluation of Blunt Abdominal Trauma: Prospective Study Using Diagnostic Algorithms to Minimize Nontherapeutic Laparotomy

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Abstract. A prospective study was performed to investigate the feasibility and benefit of evaluating blunt abdominal trauma (BAT) without diagnostic peritoneal lavage (DPL) or other invasive methods. Diagnostic algorithms were designed by using ultrasonography (US) as a screening method. For unstable patients, a free fluid ≥ 2 mm thickness on US images over any one of the intraperitoneal spaces (bilateral subphrenic, Morrison, and Douglas pouch) was used as an indicator for laparotomy. For stable patients, any intraabdominal free fluid detected by US was used as an indicator for further investigations. Computed tomography served as a principal complementary method. To further clarify the clinical results, the rate of nontherapeutic laparotomy (NTL) was compared with that from a previous 5-year review done before this study. During studying period of 1 year, 170 patients were consecutively enrolled. There was no delayed diagnosis, and 66 patients were found to have BAT; 17 patients were initial unstable, among whom 15 had free fluid shown by US and 13 patients had confirmed BAT. Eight of the unstable patients with free fluid on US were saved from NTL, of whom six had retroperitoneal hematoma. There was no NTL in unstable patients. Twenty-two patients underwent laparotomy. Two laparotomies done for a suspicion of bowel injury turned out to be NTL. The rate of NTL in the present study was significant lower than that in a previous review (9.1% vs. 32.2%, $p = 0.025$). Hence following well designed algorithms, noninvasive evaluation of BAT can proceed with safety, and NTL is minimized.

Rapid triage of blunt abdominal trauma (BAT) is a great challenge to surgeons facing patients with multisystem injuries. Diagnostic peritoneal lavage (DPL) has been used as the modality of choice to evaluate BAT for decades [1]. However, since the introduction of noninvasive methods, such as ultrasonography (US) or computed tomography (CT), DPL has gradually been superceded [2–11]. US has advantages over DPL in terms of its being noninvasive, rapid performance, and acceptance by conscious patients. CT has advantages over DPL in providing an anatomic diagnosis and detecting retroperitoneal injury. On the other hand, although the diagnosis of hemoperitoneum is not difficult by the versatile diagnostic methods, the indications of laparotomy may provide a dilemma because patients with BAT can be managed nonoperatively. Routine laparotomy in the presence of hemoperitoneum increases the incidence of nontherapeutic laparotomy (NTL), whereas nonoperative treatment carries the risk of delayed diagnosis of fatal injury. To obtain a balance between NTL and delayed diagnosis, a well designed diagnostic algorithm is necessary for rapid triage of BAT. Several algorithms have been proposed that use US, CT, and DPL [5, 7, 10, 12]. Because of their shortcomings of invasion, inducing some complications, and high nonspecific sensitivity, frequently resulting in NTL, the use of DPL and other invasive methods was excluded from our study [13, 14]. We believed that BAT could be evaluated noninvasively without delay. Algorithms were designed using noninvasive procedures exclusively. A prospective study was performed, and the clinical results were evaluated.

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Patients and Methods

Hospital and Facility

Veterans General Hospital, a university hospital and medical center in Taipei, has had an organized trauma center since 1987. The attending trauma surgeons were board-certified for general surgery and had sonography training course during their residency. All patients with significant injuries are evaluated and managed under the supervision of trauma surgeons. An ultrasonographic machine (Toshiba; SSA-240A) is part of the equipment in the emergency department; sonography is performed and reported by attending emergency medicine or trauma physicians. The authors involved in our study were attending trauma surgeons who have had more than 3 years experience performing and interpreting US for abdominal injury. CT is also available 24 hours a day in our emergency service.

Designation of Algorithms

Two algorithms for BAT were designed (Figs. 1, 2). We defined positive sonographic findings in two ways: for patients with unstable vital signs (USVS) or patients with stable vital signs (SVS). The definition of USVS was systolic blood pressure less than 100 mmHg after stabilization of the airway and breathing, and SVS was that above or equal to 100 mmHg. In the group of USVS patients the positive sonogram was defined as ≥2 mm of

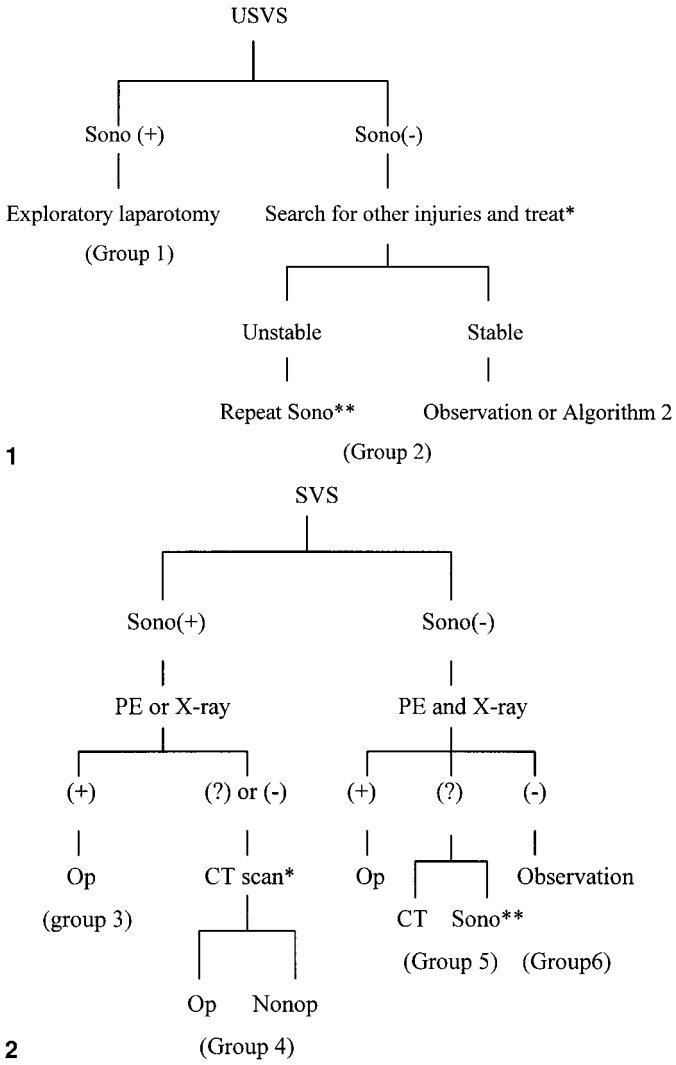

Fig. 1. Algorithm for patients with unstable vital signs (USVS). *Search for causes of hypotension other than intraperitoneal hemorrhage. **Laparotomy is performed when repeated sonogram (Sono) becomes Sono(+).

Fig. 2. Algorithm for patients with stable vital signs (SVS). *Operation (Op) or nonoperation (Nonop) depends on the findings of computed tomography (CT). **Repeated sonogram (Sono) when patients become unstable before the CT scan. PE: physical examination.

echolucent free fluid in any one intraperitoneal space (bilateral subphrenic, Morrison, or Douglas pouch); in case of less than 2 mm thickness, the sonogram was defined as negative. In the SVS group a positive sonogram was defined as any intraabdominal free fluid detected including an equivocal one (free fluid could not be definitively excluded); otherwise it was defined as negative. The physical examination (PE) was defined as positive if a peritoneal sign was obvious, as negative if the abdomen was soft without definite tenderness, and as equivocal if the finding was between the two extremes. Conventional radiology including plain film of the chest or abdomen was defined as positive if definite free air or a diaphragmatic rupture was noted; otherwise it was defined as negative. CT was performed by double contrast studies, and the report was given by radiologist. Any intraabdominal abnormal findings, including organ injury, free fluid, or a hematoma, were defined as positive CT findings.

Patients

Patients brought to our emergency department were initial resuscitated according to the ATLS guidelines provided by the American College of Surgeons. Patients who were suspected to have BAT were managed according the algorithms shown in Figures 1 and 2. Patients were followed until discharge or oral intake was well tolerated. Patients who did not live long enough for oral intake were excluded, except those who underwent exploratory laparotomy. The definition of *delayed diagnosis* was significant injury found after completing the diagnostic algorithms. The definition of *nontherapeutic laparotomy* (NTL) was laparotomy done with the findings of no injury or nonbleeding organ injuries, with no therapeutic procedure having been needed. To clarify the clinical results, the NTL rate over the previous 5 years in our hospital was reviewed, during which the indications of laparotomy depended on the trauma surgeon's decision by liberally using various diagnostic methods.

Statistical Analysis

The accuracy of US was evaluated according to the findings of laparotomy, CT, or clinical follow-up. Comparison of proportions was used to examine the NTL rates; $p < 0.05$ was accepted as significant.

Results

From March 1995 to February 1996 a total of 170 patients entered our study. There were 127 male and 43 female patients. The ages ranged from 18 to 82 years (37.6 ± 14.7 years, mean ± SD). The injury severity score ranged from 3 to 50 (11.6 ± 8.3, mean ± SD). Associated injuries included 32 head or spinal injuries, 23 chest injuries, and 45 bony fractures. The clinical conditions of patients could be categorized into six groups shown on the two algorithms and described as follows:

Group 1 (USVS and positive US; US ≥ 2 mm): Six patients were explored immediately, and no NTL was found. The major operative findings included one bladder and bowel injury, one kidney rupture, one spleen and pancreatic injury, one liver rupture, one tear of round ligament of uterus, and one pelvic hematoma with intraperitoneal rupture.

Group 2 (USVS and negative US; US < 2 mm): Four patients had extraabdominal bleeding sources, including one hemothorax, two long bone fractures, and one scalp laceration; two of them were seen to have intraperitoneal free fluid by US, and CT showed suspected liver injuries. Seven patients had pelvic hematomas with intraperitoneal fluid; six of them underwent subsequent CT that confirmed the diagnosis. One patient with pelvic hematoma underwent repeated US a half-hour later due to a recalcitrant response to resuscitation. The repeated sonogram became positive, and exploratory laparotomy was done showing a grade II liver laceration with continuous bleeding.

Group 3 (SVS, positive US, and positive PE or radiograph): Five patients were explored and showed four bowel injuries and

Table 1. Abdominal injuries in 170 patients.

Group	No. of patients					
	Total	With BAT	With op.	With nonop.	With intra.	With retro.
1	6	6	6	0	6	0
2	11	7	1	6	1	7
3	5	5	5	0	5	0
4	44	43	6	37	30	17
5	23	5	4	1	3	2
6	81	0	0	0	0	0
Total	170	66	22	44	45	26

BAT: blunt abdomen trauma; op.: operation; nonop.: nonoperative treatment; intra.: intraperitoneal injury; retro.: retroperitoneal injury.

one intraperitoneal bladder rupture. One of these patients had free air shown on the radiograph.

Group 4 (SVS, positive US, and negative/equivocal PE or radiograph): Forty-four patients were included. CT was arranged following US in this group. Three patients became unstable soon after the initial US study and were explored immediately; the operative findings revealed one spleen injury, one bowel injury with mesenteric tear, and one intraperitoneal urinary bladder rupture. The other 41 patients had a complete CT examination. The major injuries found on CT were as follows: 15 liver injuries including 7 grade II, 4 grade III, and 4 grade IV; 10 spleen injuries including 2 grade I, 4 grade II, and 4 grade III; 6 renal injuries; and 10 retroperitoneal hematomas. The grading was based on the Organ Injury Scale from the American Association for the Surgery of Trauma [15]. Bowel injuries were suspected in two patients from CT findings: Exploration showed one liver injury and one spleen injury with retroperitoneal hematoma; both injuries were nonbleeding despite the presence of moderate hemoperitoneum. No bowel injury was found, and the two laparotomies were considered nontherapeutic. One patient had negative findings on CT. Nonoperative treatment was applied in 38 patients. One patient with spleen injury failed. The successful rate of nonoperative treatment was 100% (14/14) for liver injury and 90% (9/10) for spleen injury.

Group 5 (SVS, negative US, and equivocal PE and radiograph): Twenty-three patients belonged to this group. One patient had a repeated US study because he became unstable before a CT examination. The repeat US was positive, and exploration revealed spleen injury. Eighteen patients with negative CT finding were followed without sequela. Four patients with positive CT findings included one kidney contusion, two small intestinal injuries, and one retroperitoneal duodenal perforation. Exploratory laparotomies were done for the three patients with bowel injury. The laparotomies confirmed the CT findings.

Group 6 (SVS, negative US, and negative PE and radiograph): Eighty-one patients were observed thereafter, and no subsequent abdominal injury was found.

In summary, 66 patients had abdominal injury confirmed by findings of either an image study or laparotomy (Table 1). There was no delayed diagnosis in the present study. Seventeen patients suspected to have BAT were initially unstable, among whom 15 patients had free fluid shown by the initial US scan, and 13 patients was confirmed to have BAT by laparotomy or CT. Eight of the unstable patients with a small amount of free intraperitoneal fluid (less than 2 mm on the US image) were saved from NTL, of whom six had also a retroperitoneal hematoma. There was no NTL in the group of unstable patients. A total of 22 patients underwent laparotomy. Two laparotomies were done because of suspected bowel injury but turned out to be an NTL despite the presence of solid organ injuries.

A retrospective review of BAT in our hospital before this study showed that 149 laparotomies were done over 5 years, of which 48 were nontherapeutic. The rate of NTL in review series was 32.2% and in present study 9.1%; the decrement was significant ($p = 0.025$).

The accuracy of US (including both initial and repeated scans) for the prediction of intraperitoneal injury was as follows: sensitivity 95.6% (43/45), specificity 97.6% (122/125), positive predictive value 93.4% (43/46), negative predictive value 98.3% (122/124), and total accuracy 97.0% (165/170).

Discussion

The accuracy and expeditiousness of US and the qualification of the sonographer in evaluating BAT have been discussed in several reports [5–10]. The accuracy of US in our study was compatible with that reported in the literature. The sonographers in the present study were surgeons. Surgeon-performed US further underscored the role of US as a primary screening method. The US machine, because of its portability, can be kept in the resuscitation room and the procedure repeated when clinical conditions warrant.

Several diagnostic algorithms using US as a screening method have been proposed [5, 7, 10, 12]. The clinical benefits related to patient's care have not been well clarified. Our study showed that using diagnostic algorithms improved the patient's care by decreasing NTLs and avoiding delayed diagnosis. In our diagnostic algorithms, US was also included as a screening method. There are some differences in our algorithms compared with others: The US interpretation for decision-making was defined in two ways according to the clinical condition of the patient, and diagnostic peritoneal lavage (DPL) or other invasive methods were not included in our algorithms as in others.

For the initial management of unstable, injured patients, the surgical decision for laparotomy is critical and lifesaving. Routine exploration in case of any free fluid detected by US in an unstable patient has been recommended by authors who proposed using US as a screening test for BAT; however, NTL in unstable patients may be worthless and even deleterious. As little as 30 to 100 ml of peritoneal fluid is readily detected by US [16, 17]. Such a small amount of fluid is demonstrated on the US image by a

thin, echolucent area always measuring less than 2 mm in thickness. There are some unstable patients in whom a small amount of free fluid is seen on the US image but in an insufficient amount to induce their instability. Causes other than intraperitoneal hemorrhage should be sought before pushing the patient into the operating theater for emergent laparotomy. Our study showed that some initially unstable patients with a small amount of intraperitoneal fluid could be saved from NTL; they were stabilized after fluid resuscitation, and further investigation could be done using CT to search for significant intraabdominal injury. Some authors also have suggested that a minimal amount of fluid with less than 2 mm thickness on US is not a positive finding and stressed repeating the US [18]. We performed the repeat US as soon as clinical conditions warranted (e.g., no extraperitoneal cause of bleeding, poor response to resuscitation, or change of vital signs). The ongoing intraperitoneal bleeding always culminated in sufficient free fluid to turn the US positive by our criteria, and laparotomy should be conducted. Our study showed that routine exploration in unstable patients with any intraperitoneal free fluid detected by initial US increases the use of NTL, especially in patients with retroperitoneal hematoma. The major blood loss was from extraperitoneal sites, and emergent laparotomy would not be helpful.

On the other hand, in stable, injured patients, emergent laparotomy usually is not indicated and nonoperative treatment can be successful despite the amount of intraperitoneal fluid. The major problem when evaluating these patients is overlooking significant injuries that frequently result in catastrophe. US did not have perfect sensitivity for bowel injury using the criterion of the presence of free fluid, as shown in our study (6/9, 66.7%). In addition to any suspected free fluid on US, questionable clinical findings deserved further study to avoid a missed diagnosis. CT was used as a principal complementary noninvasive method for stable patients in our study. In selected patients with solid organ injuries, nonoperative treatment can proceed with a high success rate after CT examination. Although it was not found in our study, a false-negative CT finding for bowel injury was reported previously, and subsequent follow-up was needed [19]. In contrast, there were two cases of false-positive CT results for bowel injury that incurred two NTL in our study. Intraperitoneal extraluminal air might be found after a chest injury, and even experienced radiologists might mistake fat as air on CT [20, 21]. It may be difficult to rule out bowel injury in the presence of associated intraabdominal injuries from emergent CT; any suspicious CT findings call for exploration.

The fact that we did not include DPL in our algorithms has been supported by our results. Using DPL in unstable patients did not help make surgical decisions because hemoperitoneum could be easily detected by US. In stable patients, using DPL had the drawback of missing bowel injury [22, 23]. Had DPL been used, our two patients would not have been saved from NTL owing to the presence of significant hemoperitoneum. Furthermore, if DPL had been included in our algorithms, the incidence of NTL would have increased because many patients, unstable or stable, had hemoperitoneum, which would have resulted in a positive DPL. Although nonoperative treatment can proceed even in the presence of a positive DPL, flushing blood from the catheter frequently lessens the surgeon's confidence; moreover, the painful incision through which the catheter is inserted interferes with the physical examination thereafter. Furthermore, subsequent CT loses its complementary function because the presence of fluid and air induced by the DPL procedure confuses the interpretation of the image. Although use of DPL may increase NTLs, the decrease in NTLs in our study could not be completely explained by the exclusion of DPL. Hemoperitoneum detected by various methods could be used as an indicator for exploration, as with our surgeons before the present study. The proposed algorithms provide a safe clinical pathway for decreasing NTLs and avoiding delayed diagnosis.

Conclusions

Our series did not include all kinds of injury, but the results are promising. It may be too early to say we can eliminate the use of DPL in the emergency room (ER) because many ERs do not have 24-hour availability of US and CT. However, our results, using well designed diagnostic algorithms, showed that noninvasive evaluation of BAT can be performed in injured patients without delay and can minimize the use of nontherapeutic laparotomy.

Résumé

Le but de cette étude prospective a été de déterminer la faisabilité et les avantages d'une évaluation des traumatisés fermés sans l'aide de la dialyse péritonéale ni d'autres moyens invasifs. Des algorithmes diagnostiques ont été élaborés en utilisant l'échographie comme moyen de dépistage. Pour les patients hémodynamiquement instables, la présence d'un épanchement libre (2 mm sur l'échographie dans un des espaces intrapéritonéaux (une des deux espaces sousphréniques, l'espace de Morrison et le cul-de-sac de Douglas) a été l'indication d'une laparotomie. Pour le patient stable, la présence d'un épanchement intra-abdominal libre détecté par l'échographie, quelle que soit sa localisation, a été l'indication de poursuivre les études diagnostiques, essentiellement par la tomodensitométrie (TDM). Pour clarifier d'avantage les résultats cliniques, on a comparé le taux de laparotomie non-thérapeutique (LNT) dans cette étude (170 patients consécutifs vus pendant un an) à celui d'une étude antérieure (pendant 5 ans). Il n'y avait aucun retard diagnostique et on a trouvé 66 patients ayant une lésion intra-abdominale. Il y avait 17 patients hémodynamiquement instables, dont 15 ayant un épanchement libre détecté par l'échographie: 13 de ces patients avaient une lésion traumatique de l'abdomen. Une LNT a été évitée chez huit des patients instables qui avaient un épanchement libre à l'échographie, parmi lesquels six avaient un hématome rétropéritonéal. Il n'y avait aucune LNT chez les patients instables. Au total, 22 patients ont eu une laparotomie. Deux de ces laparotomies, réalisées pour suspicion de lésion intestinale, ont été négatives. Le taux de laparotomie négative dans cette étude était significativement plus bas que celui de l'étude antérieure (9.1% vs. 32.2%, $p = 0.025$). En conclusion, selon un algorithme bien établi, l'évaluation non-invasive des traumatismes fermés de l'abdomen peut être réalisée en toute sécurité. Le taux de LNT est ainsi diminué.

Resumen

Se efectúa un estudio prospectivo para evaluar el diagnóstico de certeza en traumatismos cerrados de abdomen (BAT), sin recurrir a la punción-lavado peritoneal, ni a otros métodos invasivos. Se

diseño un algoritmo diagnóstico basado en la ecografía abdominal. En pacientes con constantes vitales inestables, la presencia de líquido libre (≥ 2 ml de grosor) detectado ecográficamente en cualquiera de uno de los espacios intraperitoneales (subfrénico, Morrison o fondo de saco de Douglas), se consideró como una indicación absoluta de laparotomía. En pacientes estables la presencia de líquido libre intraabdominal implicó la necesidad de realizar otros estudios diagnósticos. La tomografía axial computerizada (CT) fue la técnica diagnóstica complementaria más empleada. Para valorar los resultados clínicos, con relación al número de laparotomías en blanco (NTL), se efectuó un estudio comparativo con los casos clínicos recopilados cinco años antes del presente trabajo. Durante el periodo de esta investigación (1 año), se estudiaron 170 pacientes, sin que ello implicase ningún retraso diagnóstico; 66 pacientes, se diagnosticaron de traumatismo cerrado de abdomen (BAT). En 17 pacientes, que al ingreso presentaron constantes vitales inestables, la exploración ecografía, en 15 de ellos, mostró niveles líquidos libres, confirmándose en 13, la existencia de BAT. En 8 pacientes hemodinámicamente inestables y con líquido libre detectado ecográficamente, se evitó una laparotomía en blanco: seis de ellos presentaban un hematoma retroperitoneal. No se efectuó ninguna laparotomía en blanco (NTL), en pacientes inestables. Se realizaron en total 22 laparotomías; dos con sospecha de lesión intestinal, resultaron ser laparotomías en blanco (NTL). El tanto por ciento de NTL en nuestro estudio, fue significativamente menor que el observado en estudios previos (9.1% vs. 32.2%; p = 0.025). Conclusión: si se utilizan algoritmos bien diseñados, la evaluación no invasiva de los BAT, ofrece una gran seguridad diagnóstica.

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Invited Commentary

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As a noninvasive examination, surgeon-performed ultrasonography (US) is quickly becoming a frequently used test to assess injured patients in trauma centers throughout the world [1–9]. Whenever a "new" modality is introduced into the surgeon's diagnostic armamentarium, multiple methodologically sound studies are needed to define its role. In this manuscript, the authors are to be congratulated for examining the use of US and computed tomography (CT) for the evaluation of patients admitted with the diagnosis of potential intraabdominal injury secondary to blunt trauma. Their work brings us closer to determining where focused US examinations are most accurate and valuable to the surgeon for assessing and managing injured patients.

When examining this study, however, several points should be noted: (1) The US examination used by the authors differs from that in other studies [1, 2, 4, 10] because the splenorenal recess

was not imaged. (2) The time of the performance of the examination is not specified. This point is important because bleeding is an ongoing process, and a US examination may be initially negative and then later convert to a positive test. (3) The indications for and the timing of the repeat examinations are not clearly indicated. (4) The definition of a positive US study in hemodynamically unstable patients was defined as $\geq$ 2 mm echolucent free fluid (blood) in any one of the four spaces imaged.

Because of these important differences, a comparison with other studies is difficult. For example, some authors recommend frequent repeat examinations, some as soon as 30 minutes after admission and then 2 two hours [8, 9]. This regimen, however, may not be practical for a busy trauma service. Although additional prospective studies should be performed to determine if the interval for and utility of repeat US examinations could be better defined, the specific parameters for repeat examinations should be stated so their data can be accurately assessed. In the study of Huang et al., the need for laparotomy in *any* patient was determined if the area of echolucent fluid (blood) was *more* than 2 mm. This was based on the instillation of crystalloid into the peritoneal cavity with a comparison of US images before and after infusion to estimate the amount of intraabdominal free fluid [11].

Similar to other diagnostic tests, US is not universally applicable to all injured patients. In this study, however, the authors included patients who had equivocal examinations and then compared the outcomes with those whose examinations were adequate. Equally important for sound study design is that the decision matrix for the use of a diagnostic modality should incorporate information based on the mechanism of injury and not only the hemodynamic stability of the patient and the availability of expertise needed for the test [12]. For example, the finding of a seat-belt sign across the abdominal region may be associated with perforated small bowel with only a small amount of fluid and minimal hemoperitoneum. This fluid may be too minimal to be detected by US [13], but the diagnosis can be made by an abnormal white blood cell count in the DPL effluent. Although the authors performed two laparotomies for this suspected diagnosis, both of which were nontherapeutic, these numbers are too few to consider deleting DPL as a valuable diagnostic test for the evaluation of these patients.

Another issue is that patients who did not live long enough to tolerate oral intake were excluded from the study, yet there is no mention of postmortem examinations to demonstrate that injuries were not missed.

Although the authors have made an attempt to define further the niche for US in the trauma setting, this study design raises important questions. Considering these issues, it is premature to consider the deletion of DPL as a valuable test for the evaluation of injured patients.

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