

The Role of Ultrasound in Penetrating Trauma

Jorge Sproviero¹

Abstract

A dramatic reduction of penetrating trauma is not to be expected in the near future, especially in some regions of the world. In order to identify the body structures damaged after stab or firearm wounds, complementary diagnostic studies play an essential role in assessing the severity of the case. The inclusion of ultrasound among the diagnostic tests for assessing abdominal injuries after blunt trauma because of its confident, repetitive, non-invasive, communicable, and low-cost means to obtain the relevant information is derived from rapidly widespread use of the method for other injury mechanisms, such as penetrating trauma. The excellent results in sensitivity and specificity obtained by ultrasound in the search of free fluid among patients with blunt trauma have pushed emergency physicians to try a similar implementation in the penetrating trauma setting. Ultrasonography enables experienced examiners to obtain diagnostic details from the injured patient. Regarding free fluid, it is possible to determine its presence and composition through the peritoneal aspiration after a sonoguided puncture. On the other hand, ultrasound is able to detect morphologic changes in solid organs after penetrating trauma. In order to reach these possibilities which are offered by the ultrasound technology, a planifying training and education program must be developed.

Key Words

Penetrating trauma · Ultrasound · Diagnose

Eur J Trauma Emerg Surg 2010;36:138–44

DOI 10.1007/s00068-009-9092-2

Introduction

The growth of violence recognizes different causes in each country. In Latin America, where the homicide rate is about 20 per 100,000 inhabitants, penetrating

trauma (PT) indicates socioeconomic difficulties, making this region one of the most violent in the world [1].

PT causes damage by interacting with body tissues, so after the initial evaluation of the patient, the surgeon is forced to determine the trajectory of the offending object in order to rule out organ and visceral wounds. Physical examination and imaging diagnostic studies are the classical armamentarium to assess the severity of the injuries in order to perform the appropriate treatment, which can be surgical or non-operative.

Regardless of the mechanism (blunt or penetrating trauma) and the diagnostic tool used (X-rays, ultrasound [US], computed tomography [CT], angiography), imaging procedures must be able to identify the typical pictures of a wound, which are represented by laceration/hematoma for solid organs and free fluid for hollow structures.

The evaluation of abdominal trauma with US has evolved in the last several decades [2]. Originally focused on free fluid assessment among patients with blunt abdominal trauma [3], US indications are now expanding in other trauma fields [4].

Supported by large medical evidence in the diagnosis of blunt thoracic and abdominal trauma patients, some trauma centers have considered it to be a good opportunity to utilize US in the PT setting [5, 6].

When using US to diagnose these injuries, we should take into consideration certain aspects: hemodynamic status of the victim, kinematic concepts, localization of the PT, and accessibility to the diagnostic facility. All of these factors should be added to the specific findings of the US study.

Aspects not Associated to the US Findings

Hemodynamic Status

US is the only imaging diagnostic tool that can be used in a hemodynamically abnormal patient with trunk trauma [7, 8].

¹Emergency Department, Hospital General de Agudos F. Santojanni, Buenos Aires, Argentina.

Received: May 19, 2009; revision accepted: September 24, 2009;
Published Online: November 19, 2009

Although these patients have clear surgical indication and need immediate urgent surgery, in the few minutes that elapse from their admission to the emergency room (ER), US examination can be done during the rush transfer to the operating room (OR). In these situations, the US examination will confirm the presence of free fluid in the cavity targeted (pericardial sac, pleural space, and peritoneal cavity), thus, helping triage priorities for the surgical access [9, 10].

On the other hand, in hemodynamically normal victims, US can be performed at the patient's bedside (ambulance, helicopter, ER, or OR) by means of fixed facilities displayed areas (shock room, trauma unit, intensive care unit [ICU], operating theater) or by portable units that go where the patient is located [10]. The findings identified lead to planning further diagnostic and therapeutic pathways.

Therefore, what guides the extension of the study is the hemodynamic status, as it should only be completed in normal hemodynamics; the opposite is the clear indication for immediate surgery.

Kinematic Concepts

Stab wounds (SW) generate tissue damage circumscribed to the path of the wound [11] and if no vital structures are involved, allow a thorough US complete examination, searching for direct and indirect signs of organ lesion.

The management of firearm wounds (FAW), on the other hand, is more complex, as one has to consider whether it is a single round, gunshot wounds (GSW) or multiple rounds, shotgun wounds (SGW), projectile energy (low and high), associate injuries by fragmentation (tumble and yaw), cavitation effects, etc. [12].

With SGW, it is imperative to determine the firing range, considering that those fired beyond a 6.3-m range (this is the distance between the firearm and the victim), the pellets will penetrate only up to the subcutaneous tissue level, with a very low probability of reaching a cavity and much less chance an organ. An acceptable way of calculating the penetration is to observe the degree of dispersion of the pellets. When it surpasses 50 cm in diameter, the distance from the victim to the offender is surely beyond 6 m, and the presence of intracavitary lesions is an exception. In these situations, the US examination of the cavities will be normal; hence, non-operative therapy can be established. This we could correlate with our cases, as did others [11].

Localization of PT

The trunk can be divided into three transverse zones, drawing lines through the nipples and at the umbilicus

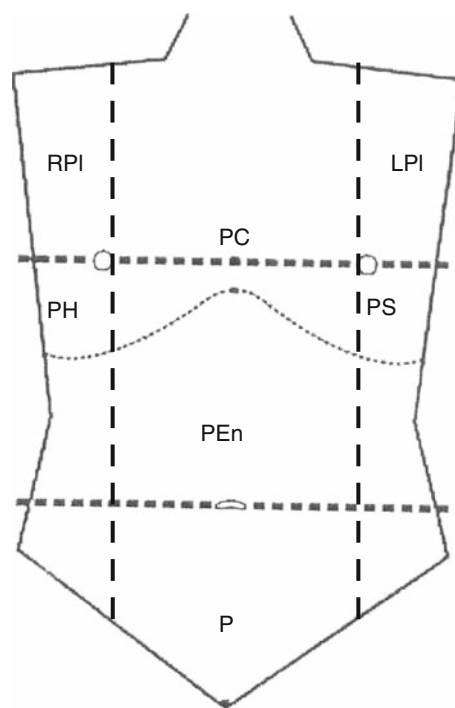


Figure 1. Division of the torso space. *RPI* right pleural space; *LPI* left pleural space; *PC* pericardic space; *PH* perihepatic space; *PEn* perienteric space; *PS* perisplenic space; *P* pelvis.

level (upper thorax, abdominothoracic area, and abdomen) [13]. We have adapted this compartmental torso division, adding two vertical lines running through the nipples, resulting in seven anatomical areas available to the sonographic approach (Figure 1).

It is a common practice in centers that manage these cases to mark the entrance and exit sites so as to foresee the structures direct or indirectly involved [14, 15]. Regarding the upper thorax, for those FAW located between both vertical lines (which include the cardiac area), it should be determined if the entrance and exit sites, or the bullet location for those cases without exit sites, compromise one hemithorax or not (Figures 2, 3, 4, 5).

When the penetrating object is confined to one hemithorax, it represents an anterior–posterior path, where the lateral (right and left) thirds of the upper thorax corresponds to the lungs, usually targeted as pleural collections (air, fluid-air), both detected by US [16, 17]. On the other hand, when the injury is in the central third (heart, great vessels) or transmediastinal (both hemithorax involved), US evaluation can identify pericardial effusions, but is insufficient in ruling out other injuries. In such a context, the patient should be studied by other diagnostic tools (CT scan, endoscopy, angiography, etc.), due to the fact that there is a high probability of associated lesions [18, 19] (Figure 6).



Figure 2. Gunshot wound (GSW). Entrance site on right hemithorax.



Figure 3. GSW. Exit site on right hemithorax.

In the abdomen, the wounds are examined clinically, searching for signs of peritonitis, and with US to rule out free fluid. If there are physical findings for peritonitis, surgery is indicated. If the finding is free fluid, this should be examined: a sample must be obtained through a sonoguided puncture for diagnostic peritoneal aspiration [20, 21].

Tangential wounds, or those that compromise the base (posterior segment) of the right hemithorax, are usually managed with non-operative treatment, with US follow up; this is not the case with low left hemithorax wounds, which will usually need a laparoscopic approach to rule out diaphragmatic involvement [15, 22, 23].

Accessibility to the Diagnostic Facility

US is an excellent diagnostic procedure and gives confident, repetitive, communicable information at a

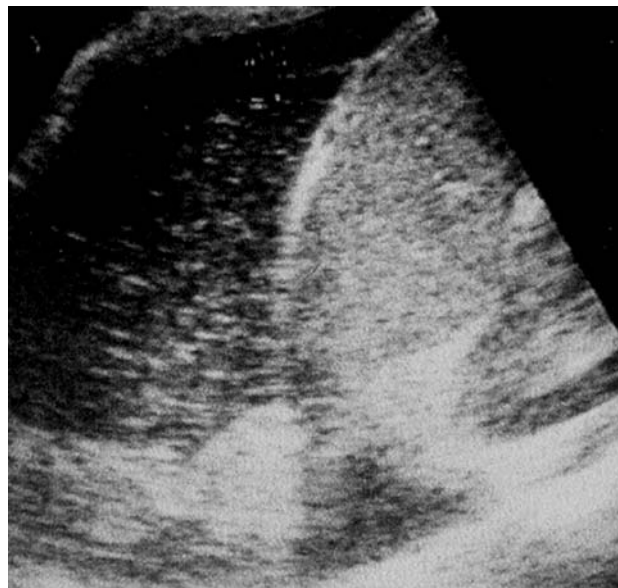


Figure 4. Ultrasound (US) examination. Free fluid in pleural space.

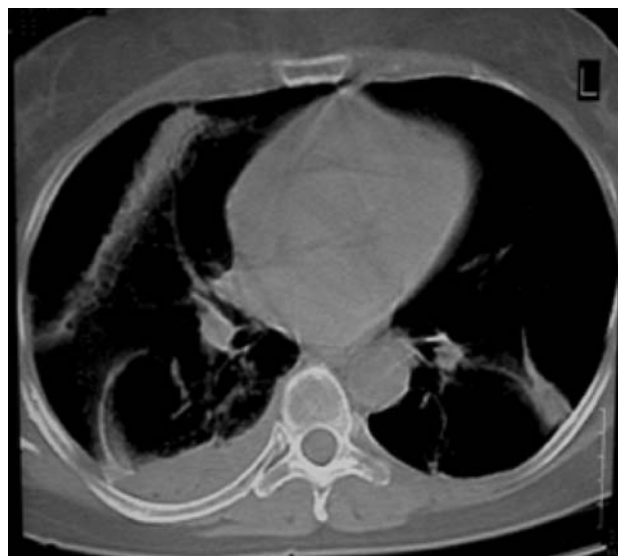


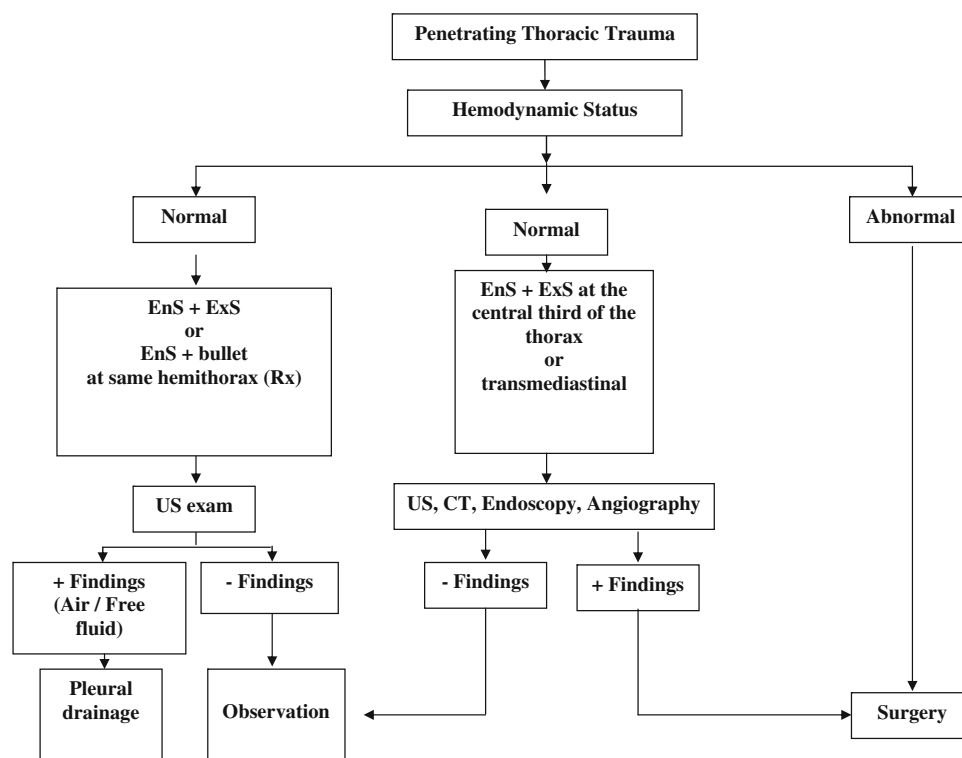
Figure 5. Computed tomography (CT) scan. Trajectory of the bullet.

low cost; even for those centers with limited financial budgets [19]. In those centers which manage trauma victims and have limitations or difficulties to access certain diagnostic tools and procedures (CT scan, hemodynamic suite, etc.), sonography should be a routine tool in the emergency department [2, 18].

US Findings

US is an essentially morphologic diagnostic imaging tool.

Figure 6. Suggested algorithm for the use of ultrasound (US) in penetrating thoracic trauma (*EnS* entrance site; *ExS* exit site; *US* ultrasound; *CT* computed tomography).



PT changes the internal structure of tissues and organs in two ways: lacerations and hematoma/contusion.

US detects free fluid collections that deposit in virtual anatomic spaces which become real. Free fluid represents the consequence of trauma on organs and tissues, that is why it is considered to be a lesions-positive marker [9]. Therefore, the sonographic finding of free fluid challenges the US operator to determine the anatomic spaces occupied (quantitative aspect) and define its composition (qualitative aspect). It is of good practice to report the anatomic spaces occupied by free fluid.

In the thoracic cavity, collections can occupy three spaces: one central (pericardial sac) and two laterals (right and left pleural spaces). More recently, US has gained support to diagnose air in the pleural space. The absence of the 'sliding lung' and 'comet tail' features are characteristics of pneumothorax during the sonographic study [16, 17].

In the abdomen, the following spaces are mentioned: the two central, small bowel loops and pelvic (Douglas), spaces; lateral, subphrenic (right and left), Morrison (hepatorenal), and splenorenal spaces.

The written form is simplified to the Focused Assessment with Sonography for Trauma (FAST)

protocol (pericardial sac, perihepatic, perisplenic, and pelvic) [9].

The detailed description of occupied spaces needs to be stated in the US examination report sheet, but in no way should this bear conclusions about the hemodynamic status of the patient. In other words, the hemodynamic abnormality does not always correlate with the number of occupied spaces.

The finding of free fluid should push the US operator to further identify the biochemical characteristics of that fluid (qualitative aspect).

A US-guided needle sample will retrieve peritoneal fluid that can be sent to the laboratory for analysis (diagnostic peritoneal aspiration). The presence of blood, in normal hemodynamic conditions, allows a non-operative therapy [24–26], but the finding of bile, enteric fluid, urine, etc., suggests a hollow organ injury and redirects the patient for surgery.

If, for any reason, the US-guided needle sample cannot be performed, then a contrast CT scan should be ordered.

Hematoma or contusion stand for liquid collection within the tissue borders of the organ targeted. If the US examination of solid organs evaluates shape, size, contour, structure, and echogenicity, one should expect that, in the setting of PT, these parameters to be abnormal. Then, it can be possible to identify by US



Figure 7. GSW to the liver. US examination. Changes in echogenicity (hypoechoic area, contusion) on the right liver (segment VII). Free fluid in pleural space.

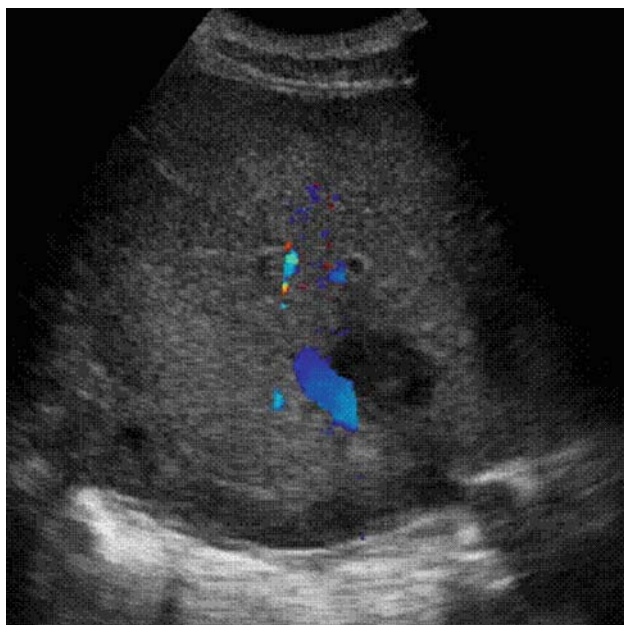


Figure 8. GSW to the liver. US examination (Doppler). Displacement of the right hepatic vein.



Figure 9. GSW to the kidney. US examination. Changes in size, shape, and echogenicity (hypoechoic area, contusion). *Transverse view.*



Figure 10. GSW to the kidney. US examination. Changes in size, shape, and echogenicity (hypoechoic area, contusion). *Length view.*

changes in size and shape in the involved organs that modify their volume [8, 27]. Contours (borders) will cease to be smooth and appear irregular, homogeneous tissues will become heterogeneous structures, showing US areas of different echogenicity (hypo or hyper-echoic), instead of their usual pattern. On certain occasions, parenchymal collections can displace internal structures, developing mass effect and modifying its normal architecture. This situation can also be captured by US [8, 27].

Morphologic changes caused to solid organs (liver, spleen, and kidney) by penetrating trunk trauma can

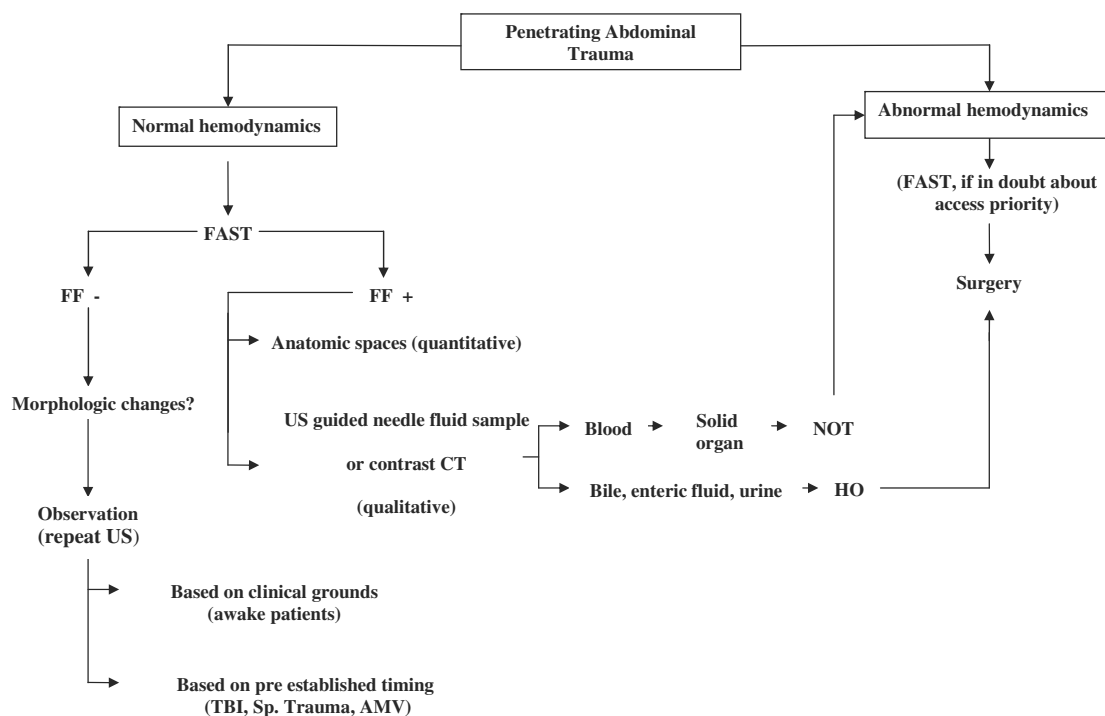


Figure 11. Suggested algorithm for the use of US in penetrating abdominal trauma (*FAST* Focused Assessment with Sonography for Trauma; *FF* free fluid; *US* ultrasound; *CT* computed tomography; *NOT* non-operative therapy; *HO* hollow organ; *TBI* traumatic brain injury; *Sp. Trauma* spine trauma; *AMV* assisted mechanical ventilation).

be detected by US with high sensitivity and specificity for those lower severity grades (grades I–IV of the AAST classification), which, by the way, account for 70–80% of admissions. Grades V and VI usually have surgical interventional validation, pointing out the identification of free fluid.

For those patients with pedicle compromise lesions grades V–VI, Doppler mode is a powerful tool in assessing vascular repair and immediate follow up and outcome. The Doppler signal evaluates flow or its absence, and its direction, velocity (slow, fast), and characteristics (normal, turbulence). All of these data can be obtained by the different features of the Doppler technique (audio, color, and spectral update). The Power Angio tool helps in the assessment of surgical impact on parenchyma (Figures 7, 8, 9, 10).

It must be noted that US sensitivity and specificity for free fluid and solid organ injury detection is over 93% in both cases [20].

Those cases in which US does not show evidence of abnormal findings, and the patient sustains normal hemodynamics status, are scanned by serial US [28, 29].

If the patient is alert and awake, the US study can be based either on clinical grounds (onset of abdominal pain,

diminished urine rate, abnormal laboratory reports, etc.) or on a prearranged timing. In such cases, it is reasonable to perform US every 2 h during the first 6 h of admission [22]; then, the injured is started on oral intake. Associate head or spinal trauma, or patients under assisted mechanical ventilation, can be handled with the same assessment protocol and bear no exception to our US trauma surveillance (Figure 11).

The patient will then be discharged between 12 and 24 h later, if the hemodynamic normality is sustained, having no clinical signs or symptoms of peritonitis, and with negative US examinations (it is wise to perform a US examination before discharge).

The role of US in PT is expanding rapidly. Although there is growing evidence about new approaches with this diagnostic complementary method (traumatic pneumothorax, prehospital US examination, contrast-enhanced US, 3D approach, etc.), its use requires a clear educational, training, and credentialing process [2, 20].

Conclusions

The management of trunk trauma patients, and especially those with penetrating trauma (PT), has changed

in the recent years, due mainly to a systematic assessment approach (ATLS guidelines) and the liberal use of diagnostic imaging tools. Ultrasound (US) examination is still awaiting further studies to accept a universal protocol of management for this complex trauma population.

Conflict of interest statement

The authors declare that there is no actual or potential conflict of interest in relation to this article.

References

- Ayres RL. Crime and violence as development issues in Latin America and the Caribbean. World Bank Latin America and Caribbean Studies. Washington, DC: The World Bank, 1998.
- Rose JS. Ultrasound in abdominal trauma. *Emerg Med Clin North Am* 2004;22:581–99.
- Kristensen JK, Buemann B, Kühl E. Ultrasonic scanning in the diagnosis of splenic haematomas. *Acta Chir Scand* 1971;137:653–7.
- Rozycki GS, Ballard RB, Feliciano DV, Schmidt JA, Pennington SD. Surgeon-performed ultrasound for the assessment of truncal injuries: lessons learned from 1540 patients. *Ann Surg* 1998;228:557–67.
- Rozycki GS, Feliciano DV, Ochsner MG, Knudson MM, Hoyt DB, Davis F, Hammerman D, Figueredo V, Harviel JD, Han DC, Schmidt JA. The role of ultrasound in patients with possible penetrating cardiac wounds: a prospective multicenter study. *J Trauma* 1999;46:543–51.
- Boulanger BR, Kearney PA, Tsuei B, Ochoa JB. The routine use of sonography in penetrating torso injury is beneficial. *J Trauma* 2001;51:320–5.
- Ma OJ, Mateer JR. Trauma ultrasound examination versus chest radiography in the detection of hemothorax. *Ann Emerg Med* 1997;29:312–6.
- Sato M, Yoshii H. Reevaluation of ultrasonography for solid-organ injury in blunt abdominal trauma. *J Ultrasound Med* 2004;23:1583–96.
- Scalea TM, Rodríguez A, Chiu WC, Brenneman FD, Fallon WF Jr, Kato K, McKenney MG, Nerlich ML, Ochsner MG, Yoshii H. Focused Assessment with Sonography for Trauma (FAST): results from an international consensus conference. *J Trauma* 1999;46:466–72.
- Kirkpatrick AW, Sirois M, Laupland KB, Goldstein L, Brown DR, Simons RK, Dulchavsky S, Boulanger BR. Prospective evaluation of hand-held focused abdominal sonography for trauma (FAST) in blunt abdominal trauma. *Can J Surg* 2005;48:453–60.
- Ferrada R, Birolini D. New concepts in the management of patients with penetrating abdominal wounds. *Surg Clin North Am* 1999;79:1331–56.
- Fackler ML, Surinchak JS, Malinowski JA, Bowen RE. Bullet fragmentation: a major cause of tissue disruption. *J Trauma* 1984;24:35–9.
- Hirshberg A, Wall MJ Jr, Mattox KL. Bullet trajectory predicts the need for damage control: an artificial neural network model. *J Trauma* 2002;52:852–8.
- Gracias VH, Reilly PM, Philpott J, Klein WP, Lee SY, Singer M, Schwab CW. Computed tomography in the evaluation of penetrating neck trauma: a preliminary study. *Arch Surg* 2001;136:1231–5.
- Velmahos GC, Demetriades D, Toutouzas KG, Sarkisyan G, Chan LS, Ishak R, Alo K, Vassiliou P, Murray JA, Salim A, Asensio J, Belzberg H, Katkhouda N, Berne TV. Selective nonoperative management in 1,856 patients with abdominal gunshot wounds: should routine laparotomy still be the standard of care? *Ann Surg* 2001;234:393–403.
- Goodman TR, Traill ZC, Phillips AJ, Berger J, Gleeson FV. Ultrasound detection of pneumothorax. *Clin Radiol* 1999;54:736–9.
- Chan SSW. Emergency bedside ultrasound to detect pneumothorax. *Acad Emerg Med* 2003;10:91–4.
- Ferrada R. Penetrating cardiac trauma. *Panam J Trauma* 2004;11:30–4.
- Branney SW, Moore EE, Cantrill SV, Burch JM, Terry SJ. Ultrasound based key clinical pathway reduces the use of hospital resources for the evaluation of blunt abdominal trauma. *J Trauma* 1997;42:1086–90.
- Rozycki GS, Shackford SR. Ultrasound, what every trauma surgeon should know. *J Trauma* 1996;40:1–4.
- Kuncir EJ, Velmahos GC. Diagnostic peritoneal aspiration – the foster child of DPL: a prospective observational study. *Int J Surg* 2007;5:167–71.
- Röthlin MA, Näf R, Amgwerd M, Candinas D, Frick T, Trentz O. Ultrasound in blunt abdominal and thoracic trauma. *J Trauma* 1993;34:488–95.
- Scalea T. Nonoperative management of gunshot wounds. *Panam J Trauma* 2004;11:20–2.
- Demetriades D, Hadjizacharia P, Constantinou C, Brown C, Inaba K, Rhee P, Salim A. Selective nonoperative management of penetrating abdominal solid organ injuries. *Ann Surg* 2006;244:620–8.
- Isenhour JL, Marx J. Advances in abdominal trauma. *Emerg Med Clin North Am* 2007;25:713–33.
- Pryor JP, Reilly PM, Dabrowski GP, Grossman MD, Schwab CW. Nonoperative management of abdominal gunshot wounds. *Ann Emerg Med* 2004;43:344–53.
- Brown MA, Casola G, Sirlin CB, Hoyt DB. Importance of evaluating organ parenchyma during screening abdominal ultrasonography after blunt trauma. *J Ultrasound Med* 2001;20:577–83.
- Blackbourne LH, Soffer D, McKenney M, Amortegui J, Schulman CI, Crookes B, Habib F, Benjamin R, Lopez PP, Namias N, Lynn M, Cohn SM. Secondary ultrasound examination increases the sensitivity of the FAST exam in blunt trauma. *J Trauma* 2004;57:934–8.
- McGahan JP, Richards J, Gillen M. The focused abdominal sonography for trauma scan: pearls and pitfalls. *J Ultrasound Med* 2002;21:789–800.

Address for Correspondence

Jorge Sprovierio
Emergency Department
Hospital General de Agudos F. Santojanni
Pilar 950
Buenos Aires-1408
Argentina
e-mail: j_sprovierio@yahoo.com.ar