ORIGINAL ARTICLE

Ultrasonography for the Diagnosis of Intraperitoneal Free Air in Chest-Abdominal-Pelvic Blunt Trauma and Critical Acute Abdominal Pain

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Objective: To clarify the usefulness of ultrasonography (US) as a diagnostic instrument for intraperitoneal free air (IPFA), which is thought to be useful in the fields of emergency medicine and traumatology.

Design: Prospective observational study.

Setting: Tertiary critical care and emergency center.

Patients: A total of 484 patients with severe chest-abdominal-pelvic blunt trauma or, in the absence of such trauma, severe acute abdominal pain were examined using US to detect IPFA. The exclusion criteria consisted of hemorrhagic shock with massive intraperitoneal fluid, penetrating or open abdominal trauma, and transfer to our center when general surgeons were absent.

Main Outcome Measures: The primary outcome measure was the sensitivity and specificity of US for the diagnosis of gastrointestinal perforation performed by gastroenterologic or general surgeons with more than 5 years of experience with US. A US diagnosis of IPFA was made if high-echoic spots in the ventral space of the liver were detected. Conclusive diagnosis of gastrointestinal perforation was made based on the operative findings or on radiologic and clinical observation for more than 4 days.

Results: Fifty-four patients were diagnosed as having gastrointestinal perforation. In patients with blunt abdominal trauma, sensitivity for the diagnosis of gastrointestinal perforation by US was 85.7% and specificity was 99.6%; in patients with severe acute abdominal pain, sensitivity was 85.0% and specificity was 100.0%.

Conclusion: Ultrasonography is useful for the diagnosis of IPFA with acute abdominal pain or blunt trauma, except in patients with gastrointestinal perforation without IPFA.

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ULTRASONOGRAPHY (US) IS a useful modality in the fields of emergency medicine and traumatology because it is mobile and does not require patients to be transferred for examination, it can be performed repeatedly, it can easily demonstrate fluid and blood retention, and it can be performed by only 1 physician without the help of a technician, making it a relatively low-cost diagnostic tool.[1-6] In these fields, US has classically been used to demonstrate intraperitoneal free fluid, which indicates peritonitis or hemorrhage[2-4] and some abdominal diseases, such as acute hepatobiliary disease. More recently, it has routinely been used to demonstrate the presence of intestinal diseases, such as obstruction and ischemia. In traumatology, US has been established as a first-choice modality in primary surveys for the detection of massive hemothorax, cardiac tamponade, and massive hemoperitoneum, known as FAST (focused assessment with sonography for trauma).[7] In many emergency departments, a low-frequency convex probe (3.5 MHz) is used for evaluating patients with abdominal trauma and nontraumatic patients with acute abdominal pain because it is simple, can be prepared quickly, and can be applied to all parts of the body at once without changing probes.[8,9] It has, however, been thought difficult to examine tissues and organs in or behind air. Although some researchers have occasionally found that US could detect pneumoperitoneum under restricted or experimental conditions,[10-15] it has not been common to use US to detect intraperitoneal free air (IPFA) in emergency departments.[16-19] In this study, we show the usefulness of US as a diagnostic instrument for IPFA and as a means of differentiating real IPFA from IPFA-like findings or false IPFA.

See Invited Critique at end of article

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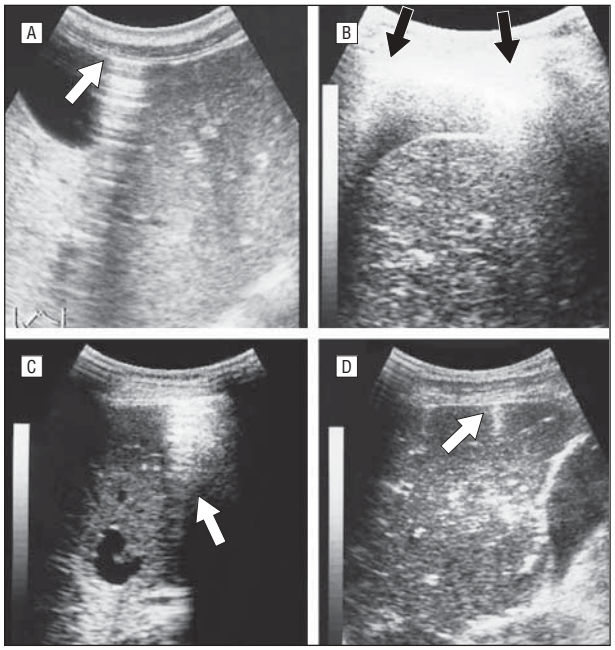

Figure 1. Ultrasonography findings showing intraperitoneal free air (IPFA) on the ventral surface of the left lobe of the liver (anterolateral of the upper abdomen), the shadows of which are easily movable with compression of the probe. The white and black arrows show IPFA originating just under the line of the peritoneum and a high-echoic shadow with multiple mirror images beside the gallbladder (A), a bulky homogeneous high-echoic shadow on the intraperitoneal free fluid on the right lobe of the liver (B), a bulky homogeneous shadow (C), and a small shadow on the surface of the liver (D).

METHODS

We used US to prospectively examine IPFA in the following patients transferred to the Critical Care and Emergency Center, Yokohama City University Medical Center, during the past 5 years: (1) those with severe chest-abdominal-pelvic blunt trauma, that is, patients considered to require "road and go" treatment by emergency medical technicians and (2) nontraumatic patients with severe acute abdominal pain who require an immediate decision about urgent laparotomy. Because the Critical Care and Emergency Center treats only severe traumatic and nontraumatic patients showing shock, respiratory distress, and conscious disorder, all patients who are transferred to the Critical Care and Emergency Center are triaged and are thought to be in critical condition by emergency medical technicians. Examinations for IPFA, FAST, and other routine examinations of intraperitoneal free fluid, pleural fluid, abdominal major vessels, liver, gallbladder, spleen, pancreas, small and large bowels, urinary bladder, and bilateral kidneys in patients with chest-abdominal-pelvic blunt trauma and nontraumatic patients with acute abdominal pain are performed by physicians exclusive to the Critical Care and Emergency Center. We do not call on specialists from other centers or departments in Yokohama City University Medical Center or on-call physicians to perform US.

INCLUSION AND EXCLUSION CRITERIA

The inclusion criteria consisted of severe chest-abdominal-pelvic blunt trauma and, in the absence of such trauma, severe acute abdominal pain. The exclusion criteria consisted of hemorrhagic shock with massive intraperitoneal fluid, which indicated an immediate operation without any other examination; penetrating abdominal trauma or blunt abdominal trauma with rupture or lacerations of the abdominal wall; and transfer to the Critical Care and Emergency Center when gastroenterologic or general surgeons familiar with US were absent, for example, at night when the night-duty medical team (4 or 5 specialists, such as an intensivist, an orthopedic surgeon, and a cardiologist) does not include a gastroenterologic or general surgeon.

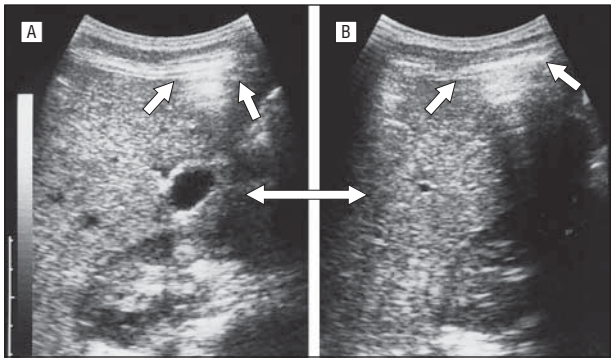

Figure 2. Ultrasonography findings showing air in the gastrointestinal tract (duodenum) mimicking intraperitoneal free air (IPFA) (arrows), which can be easily differentiated from IPFA because it never overlaps the ventral surface of the liver.

US TECHNIQUE

All the US examinations were performed by gastroenterologic or general surgeons experienced in gastroenterologic surgery, other general surgery, and trauma surgery. These surgeons were familiar with the use of US and had been using abdominal US for more than 5 years in fields other than emergency medicine and traumatology, such as gastroenterology, gastroenterologic surgery, general internal medicine, and general surgery.[20,21] In Japan, trainees in these fields usually perform US by themselves as part of their daily work with patients in outpatient departments (eg, approximately 10 patients for 3 or 4 hours a week) and with admitted patients (eg, for approximately 15 or 30 minutes per patient, but only a few patients, every day) and are trained by supervisors in their early third or fourth postgraduate year on the job. They try to detect all they can by US, particularly normal images, normal morphologic features, and normal anatomy, in each examination, even those of greater length (approximately 15 or 30 minutes) and not to focus solely on the necessary and abnormal parts with the objective of speed alone. That is, those experienced in US are very familiar with normal images, normal morphologic features, and normal anatomy and, thus, are able to quickly detect abnormalities. We label individuals who are familiar with normal images and anatomy in US as "skilled in US" because we have no certification system for US skill in Japan.

In the Critical Care and Emergency Center, all patients with severe trauma with or without chest-abdominal-pelvic injury and nontraumatic patients with severe acute abdominal pain were examined by means of US before abdominal radiography and abdominal computed tomography (CT) were performed. All US examinations were performed using a Toshiba ultrasound machine (Capasee II; Toshiba Medical Systems Ltd, New York, New York) and a 3.5-MHz convex probe. A US diagnosis of IPFA was made if a high-echoic spot or area with a high-echoic tail and a mirror image ventral space of the lateral segment of the left lobe of the liver and an anterolateral space of the right lobe, which can easily move and change its image due to compression, was detected (**Figure 1**). Air in the lung can be differentiated from IPFA by differentiating the layer of the high-echoic line of the pleura and peritoneum and by observ-

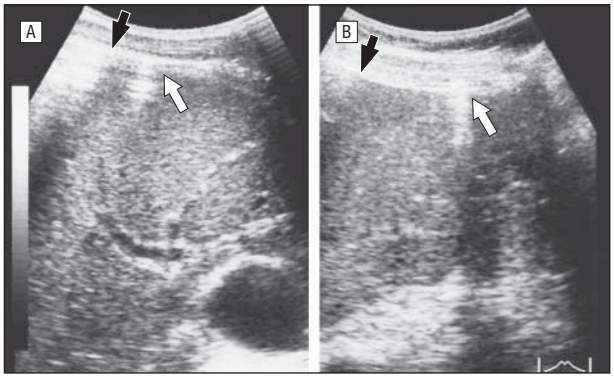

Figure 3. Ultrasonography findings showing subcutaneous emphysema (A) and intermuscular emphysema (B) mimicking intraperitoneal free air (IPFA) (white arrows in both A and B), which can be differentiated from IPFA by the origin of the shadow in the peritoneal wall or immovability in response to compression of the probe. The shadow of the lung (black arrows) can be observed by differentiating the layer of the high-echoic line of the pleura and peritoneum and by observing its relationship with respiration.

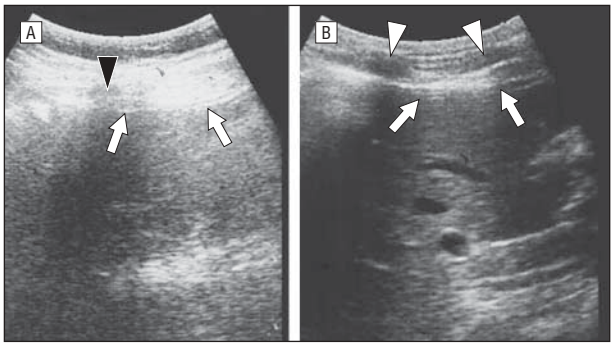

Figure 4. A and B, Ultrasonography findings show that the contrast between the shadow of the rib (arrowheads) and liver is also mimicking intraperitoneal free air (arrows point to the space between the ribs), which can be easily differentiated.

ing its relationship with respiration. Air in the gastrointestinal tract can be easily differentiated from IPFA by identifying air that never overlaps the ventral surface of the liver (**Figure 2**). Subcutaneous and intermuscular emphysema can be differentiated by immovability in response to compression of the probe (**Figure 3**). The contrast between the shadow of the rib and liver is also mimicking IPFA but can be easily differentiated from IPFA in **Figure 4**. Although air in the large intestine in Chilaiditi syndrome may be presented on the ventral surface of the liver, it can be easily differentiated from IPFA by noting the continuity between the intracolonic air and air on the liver surface, by differentiating the layer of the high-echoic line of intracolonic air from the peritoneum, and by the form of the air image that is made by the colonic haustra.

Conclusive diagnosis of gastrointestinal perforation was made based on operative, CT (Xvision-SP, TSX-002A/7A, single-helical old-type with a size 8 bit; Toshiba), and plane abdominal radiographic examination findings or on clinical observation for more than 4 days without worsening of the peritoneal signs or general condition and without changes in the laboratory data indicating systemic inflammation.

RESULTS

Four hundred eighty-four patients (289 with severe blunt trauma and 195 with nontraumatic severe acute abdominal pain) who fulfilled the inclusion criteria were enrolled in this study. Two hundred thirty-seven patients were excluded because the night-duty medical team did not include a gastroenterologic or general surgeon. The time required to complete the US examination, including a routine examination, was 2 to 3 minutes. Fifty-four patients were conclusively diagnosed as having gastrointestinal perforation based on operative or other findings (**Table 1**). The IPFA was not visualized, even by CT, in 3 patients with gastrointestinal perforation. Of the traumatic gastrointestinal perforation cases, 3 of these patients' injuries were caused by motor vehicle crashes and none by seatbelts.

Table 1. Location of the Perforation Site in 54 Patients With Gastrointestinal Perforation

	Patients, No.		
	Traumatic	Nontraumatic	Total
Stomach	0	9	**9**
Duodenum	2	19	**21**
Small intestine	6	2	**8**
Large intestine	4	7	**11**
Rectum	2	3	**5**

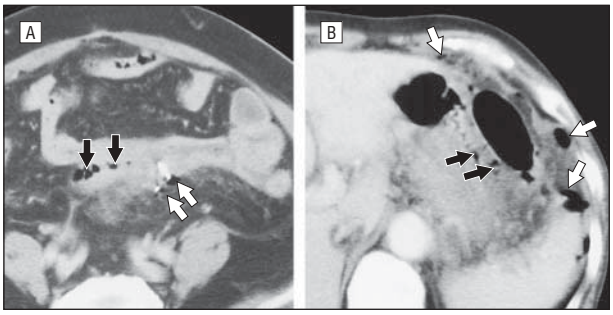

Figure 5. Computed tomography findings of the cases in which ultrasonography could not detect intraperitoneal free air (IPFA) because of small and few bubbles in a minor amount of fluid in the intermesenteric space (arrows in A) and because the IPFA did not appear in front of the liver surface (only in the left anterolateral abdomen) (arrows in B).

The IPFA was visualized by US in 46 of 54 patients with gastrointestinal perforation (85.2%). Of 8 patients in whom IPFA was not visualized by US, 3 did not show IPFA even by CT and 2 did not show IPFA in front of the liver surface but showed small and few bubbles in a minor amount of fluid in the intermesenteric space (**Figure 5**); in the other 3 patients, IPFA could not be visualized by US despite the presence of sufficient amounts for its detection. The IPFA was not visualized in patients without gastrointestinal perforation except in 1 patient whose symptoms mimicked those of intramuscular emphysema. In several other patients, however, high-echoic findings on the ventral surface of the liver mimicked IPFA, and a repeated and detailed examination lasting less than 1 minute or for 2 to 3 breath cycles was necessary to confirm the high-echoic finding as not being IPFA. The false IPFA signs were an overexpanded pleural cavity in the pneumothorax, high echogenicity (simple artifact) adjacent to the rib, and overriding of the colon or stomach on the liver (Figures 2-4).

Table 2. Gastrointestinal Perforation and IPFA by US in Patients With Chest-Abdominal-Pelvic Blunt Trauma or Severe Acute Abdominal Pain

	Patients, No.		
	With Gastrointestinal Perforation	Without Gastrointestinal Perforation	Total
Chest-abdominal-pelvic blunt trauma[a]			
IPFA by US (+)	12	1	13
IPFA by US (–)	2[b]	274	276
Subtotal	**14**	**275**	**289**
Severe acute abdominal pain[c]			
IPFA by US (+)	34	0	34
IPFA by US (–)	6[d]	155	161
Subtotal	**40**	**155**	**195**

Abbreviations: IPFA, intraperitoneal free air; US, ultrasonography.
[a] Sensitivity, 85.7%; specificity, 99.6%.
[b] The IPFA was not shown even by computed tomography.
[c] Sensitivity, 85.0%; specificity, 100.0%.
[d] The IPFA was not shown even by computed tomography in 1 of 6 patients.

In patients with blunt abdominal trauma, sensitivity for the diagnosis of gastrointestinal perforation by US was 85.7% and specificity was 99.6%; in patients with severe acute abdominal pain, sensitivity was 85.0% and specificity was 100.0% (**Table 2**). In contrast, 2 patients with blunt abdominal trauma, who were suspected of having gastrointestinal perforation due to the existence of IPFA-like images as shown by CT, were treated without laparotomy due to US findings showing no IPFA.

COMMENT

Gastrointestinal perforation is diagnosed by demonstrating intestinal content, air, or intestinal fluid in the peritoneal cavity. Air in the peritoneal cavity is indicated by the existence of IPFA. The diagnosis of IPFA is usually made using a plane radiograph (chest radiography in the standing position or abdominal radiography in the left lateral position) or CT,[22-24] which is thought to be the most sensitive method. The contamination of intestinal fluid in the peritoneal cavity is indicated by examination of the character of the intraperitoneal fluid, including its color, turbidity, smell, and increased levels of amylase or alkaline phosphatase. The diagnosis of contamination by intestinal fluid is made using a peritoneal tap and diagnostic peritoneal lavage; this method, however, has many problems, including difficulty in achieving retroperitoneal intestinal perforation and a high level of invasiveness for alert and hemodynamically stable patients.[4,25]

The most useful features of US are its mobility and the ease of examination it provides.[8,9] These characteristics make US particularly desirable in remote locations, at emergency scenes, in ambulances, in the absence of immediate support by radiographic technical engineers in a hospital, and for hemodynamically unstable patients unable to travel to a radiographic examination area. Patients with severe chest-abdominal-pelvic blunt trauma or severe acute abdominal pain with shock are often too unstable to be transferred to a radiographic examination area or to another bed, so US is becoming the initial imaging study of choice for these patients in our center. In particular, the high sensitivity of US for documenting intraperitoneal free fluid is well known.

Detection of IPFA and gastrointestinal perforation by means of US has also been sporadically reported,[10,11,15] but there have been few studies concerning the usefulness of US in detecting IPFA.[16-21] Classically, Muradali et al[14] showed the usefulness of US for diagnosing IPFA by means of an animal experiment. Grassi et al[26] reported that US examination could help confirm intestinal paresis and obtain evidence of intraperitoneal free fluid if IPFA has not been detected. Some researchers[16-19] have reported high sensitivity (92%-94%) and specificity (53%-100%) for US for diagnosing hollow-organ perforation, demonstrating that US has improved its sensitivity and accuracy and provided a similar level of specificity as plain radiography in patients with severe acute abdominal pain. There also have been few studies concerning a systematized and relatively easy US technique for detecting the reappearance of IPFA. In addition, there have been no reliable studies concerning the diagnostic superiority of US in patients with trauma.[22,27]

The most important issue concerning US examination is technique, ie, the difficulty of repeat imaging of the same location and features.[8,9,27] Therefore, the most important issue in any study involving US, including the present study, is not the accuracy of the statistical analysis but the accuracy of the interpretation of the US findings, which is based on the examiner's impression of the findings only and not on a systematic method of analysis. Regardless, the present study shows the usefulness of US for detecting IPFA. The reason for the present good results may be related to the training system for US. We learned US under nonemergency conditions involving the elective examination of medical or surgical patients, which has allowed us to study the technique repeatedly and slowly until full understanding has been obtained as a result of good communication between the trainee and the patient, which results in a high level of technique.[8,9]

There are several key technical points regarding abdominal US, particularly regarding the technique for differentiating IPFA from high-echoic findings other than IPFA, that deserve mention.[11,15] First, it is important to confirm the image of the sliding of the lung over the liver, which can differentiate the line of the peritoneum from the line of the parietal pleura in the US image and IPFA from air in the lung. Second, it is important to place the probe on the anterior (not the lateral) wall of the abdomen vertically (not obliquely) in relation to the abdominal wall, and the probe should be moved slowly to maintain the anterior and vertical placement and, thus, to avoid misdiagnosis. Therefore, detection of IPFA by means of US is not suitable for FAST in traumatology, in which the duration of the procedure is most important; instead, it should be performed after obtaining a guarantee of survival in the secondary systemic survey.

Another issue in the present study is that it is well known that there are many patients with traumatized intestinal perforation who do not show IPFA in the early phase after injury. Hasegawa et al[24] showed that free air can scarcely be detected using CT within 4 hours of small-bowel injury in blunt abdominal trauma but can be detected more than 4 hours after injury. Other researchers have indicated the same phenomenon.[26] The number of traumatized intestinal perforation cases in the present study was not sufficient for a reliable analysis. We cannot judge based on the present knowledge whether the absence of IPFA is always indicative of gastrointestinal perforation. Further examination and analysis is, therefore, necessary.

Of course, the technique of CT is superior to that of US for correct diagnosis of many conditions, including IPFA, and the accuracy of diagnosis of IPFA using CT is also superior to that of US. The merits of US, including its mobility and ease of examination, are not surpassed by any other imaging instrument, including CT. However, it is well known that CT, particularly the high-speed type, often shows IPFA-like images adjacent to the diaphragm.[28,29] In 2 patients in the present study, CT showed false IPFA and US showed no IPFA. We can eliminate unnecessary laparotomy for patients with false IPFA by evaluating the abdominal condition of the patient using the instrument (including US) by hand and by close observation.

Ultrasonography is useful for the diagnosis of IPFA indicating gastrointestinal perforation in patients with severe chest-abdominal-pelvic blunt trauma or severe acute abdominal pain. However, it cannot be used to make a diagnosis of gastrointestinal perforation without IPFA.

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