The Role of Ultrasound in Patients with Possible Penetrating Cardiac Wounds: A Prospective Multicenter Study

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Background: Ultrasound is quickly becoming part of the trauma surgeon's practice, but its role in the patient with a penetrating truncal injury is not well defined. The purpose of this study was to evaluate the accuracy of emergency ultrasound as it was introduced into five Level I trauma centers for the diagnosis of acute hemopericardium.

Methods: Surgeons or cardiologists (four centers) and technicians (one center) performed pericardial ultrasound examinations on patients with penetrating truncal wounds. By protocol, patients with positive examinations underwent immediate operation. Vital signs, base deficit, time from examination to operation, operative findings, treatment, and outcome were recorded.

Results: Pericardial ultrasound examinations were performed in 261 patients. There were 225 (86.2%) true-negative, 29 (11.1%) true-positive, 2 false-negative, and 7 (2.7%) false-positive examinations, resulting in sensitivity of 100%, specificity of 96.9%, and accuracy of 97.3%. The mean time from ultrasound to operation was 12.1 ± 5 minutes.

Conclusion: Ultrasound should be the initial modality for the evaluation of patients with penetrating truncal wounds because it is accurate and rapid.

Prompt detection and treatment are critical factors in saving the lives of patients with cardiac or major thoracic vascular injuries, but the unreliability of physical examination alone in assessing severity may delay operative management. Furthermore, because of the advancements in prehospital transport systems, some patients may arrive in the emergency department with potentially life-threatening thoracic wounds and yet be relatively asymptomatic.

Regardless of the cause or the patient's presentation, the diagnosis of cardiac tamponade should be made rapidly and accurately so that operation is not delayed. Pulsus paradoxus or Beck's triad (venous pressure elevation, decline in arterial pressure, and muffled heart tones) may be associated with cardiac tamponade, but neither is consistently present. Although the subxiphoid pericardial window accurately detects cardiac injury, it is an invasive procedure and may not be indicated in patients in whom there is a low suspicion for a cardiac wound. As a noninvasive and sensitive modality, ultrasound can rapidly detect pericardial effusion and therefore, is an attractive alternative to invasive procedures for the detection of hemopericardium in injured patients.

We hypothesized that ultrasound was an accurate method to detect hemopericardium in high-risk patients with penetrating truncal injuries and that the results of the studies could be used in the clinical management of these patients. The purpose of this prospective multicenter study was to evaluate the accuracy of emergency ultrasound for the diagnosis of acute hemopericardium.

Patients and Methods

During a 27-month period, ultrasound was prospectively evaluated for the detection of hemopericardium at five Level I trauma centers. To be entered into the study, patients had to have a precordial (Fig. 1) or transthoracic wound with a suspicion for a cardiac injury, a physical examination, and the need for a diagnostic modality or test for complete assessment. Hypotension was defined as an admission systolic blood pressure of less than 100 mm Hg. Patients who presented in extremis (blood pressure unobtainable) with an indication for an emergent median sternotomy or thoracotomy were excluded from the study. Pericardial ultrasound examinations were performed and interpreted by sonographers (three centers), cardiologists or surgeons (one center), and surgeons and technicians initially but later reviewed by radiologists (one center).

Ultrasound Performed and Interpreted by Surgeons

Attending trauma surgeons, fellows, and surgical residents from three centers (Emory University School of Medicine, Washington Hospital Center, and Memorial Medical Center) completed an ultrasound training course conducted by experienced surgeons-sonographers. The course content included didactics, videotapes, and sample pericardial ultrasound images with normal and abnormal findings. The
practical session entailed the observation and performance of the ultrasound examinations on volunteer students and on patients with benign pericardial effusions.

Ultrasound examinations were performed with the Panther Ultrasound Scanner Type 2002 (B&K Medical, North Billerica, Mass) and the Ultramark IV (Advanced Technology Laboratories, Bothell, Wash) located in the trauma resuscitation areas. Variable-frequency (3.5–5.0 MHz) sector transducers were used for the studies. Although most of the examinations were performed using a 3.5-MHz frequency setting, occasionally the 5.0-MHz transducer was needed to decrease the penetration of the ultrasound wave and provide better resolution of the heart in a pediatric patient. The subcostal sagittal or longitudinal axis view of the heart was obtained, and the pericardial region was examined for blood. After a good-quality view was acquired, the automatically timed and dated ultrasound image was printed and attached to a data form.

Ultrasound Performed and Interpreted by Surgeons or Sonographers

Chief and senior surgical residents (University of California, San Francisco) completed an ultrasound training course conducted by an experienced surgeon-sonographer and the cardiologist coinvestigator. The course content included didactics, videotapes, and sample pericardial ultrasound images with normal and abnormal findings. The practical session consisted of the observation and performance of the ultrasound examinations on volunteer residents.

The ultrasound examinations were performed with the Aloka SSD-500 using a 3.5-MHz transducer or the Aloka SSD-1700 using a 2.5- to 5.0-MHz variable-frequency transducer (Aloka, Wallingford, Conn). The machines were located in the trauma resuscitation room, and the examinations were performed by the experienced surgeon-sonographer alone, the senior or chief surgical resident under the supervision of the experienced surgeon-sonographer, or the senior or chief surgical resident under the supervision of a cardiologist attending or fellow. Subcostal and parasternal views were obtained on each patient. All examinations were videotaped and then reviewed by the surgeon-sonographer and the cardiologist coinvestigator.

Ultrasound Performed by the Technician and Interpreted by Surgeons and Technicians

Although there was no formal training in ultrasound for these surgeons (University of California, San Diego), they were present during the performance of the studies and learned to interpret them along with the registered diagnostic medical sonographers. The ultrasound examinations were performed with either an Acuson 128-XP (Acuson Computed Sonography, Mountain View, Calif) or an Advanced Technologies Laboratory HDI 3000 (Advanced Technology Laboratories, Bothell, Wash) with a 3.5-MHz sector transducer. Occasionally, when better visualization or resolution was needed, a 2.25- or 5.0-MHz sector transducer or 5.0-MHz curved array transducer was used. The standard examination for the detection of pericardial effusion was performed and included the long-axis and short-axis subcostal, apical, and parasternal (right and left) views with attention toward (1) separation of the pericardial layers with an anechoic area; (2) a decrease in the motion of the parietal pericardium; and (3) identification of a swinging motion of the heart within the pericardial sac. Although a preliminary interpretation of the study was made by the sonographer and the surgeon, the recorded images were reviewed and interpreted by radiologists at a later time.

Protocol

All ultrasound examinations were performed with the patient in the supine position during the "secondary survey," as taught in the American College of Surgeons' Advanced Trauma Life Support Course. Using the machine's annotation keys, the medical record number was entered so that the image was appropriately labeled. With the thoracoabdominal area adequately exposed, hypoallergenic water-soluble ultrasound transmission gel was applied to the pericardial region, and the examination was conducted according to the study protocol.

According to the principles of ultrasound physics, blood or fluid is visualized as an anechoic or echoluent, dark area on the ultrasound image. In contrast, structures with higher density, such as the pericardium, appear echogenic or as a bright reflecting surface on the ultrasound image. In the normal heart, the visceral (epicardium) and parietal layers of the pericardium show as a single echogenic line on the ultrasound image (Fig. 2A). When blood accumulates between the pericardial layers, each layer is visualized as a distinct echogenic line with an echoluent zone (blood) between them, consistent with hemopericardium (Fig. 2B).

All ultrasound images were reviewed by the investigators at each institution, who noted the quality of the image and the accuracy of the reading. A good-quality image was defined as one that showed the correct sections of the heart with adequate visualization of the pericardium to determine the presence or absence of hemopericardium.

The following protocol was followed for the evaluation of patients in this study (Fig. 3). If the ultrasound examination...
Pericardial Ultrasound in Penetrating Traumatic Injury

was negative for hemopericardium, the asymptomatic patient was admitted for observation and a repeat physical examination was performed every 12 hours. Patients were followed for a minimum of 23 hours of inpatient observation, through discharge, and as outpatients in the clinic or the surgeon’s office. Patients with positive ultrasound examinations underwent immediate operative intervention, and findings were recorded. If the ultrasound examination performed by the surgeon-sonographers was equivocal or a good-quality image was unobtainable, a subxiphoid pericardial window was performed by the members of the trauma team. Admission blood pressure, admission base deficit, operative findings (graded according to the American Association for the Surgery of Trauma’s Organ Injury Scale guidelines), treatment, and outcome were recorded. Results of the pericardial ultrasound examinations were categorized as true positive, true negative, false positive, and false negative (Table 1). This study was approved by the institutional review board of each participating center, but informed consent was not required. Data were analyzed by Student’s t test and reported as two times the SEM.

RESULTS

Emergency ultrasound examinations of the pericardial region were performed in 261 patients (175 with stab wounds, 83 with gunshot wounds, 3 with shotgun wounds) during a 27-month period. Most of the patients were males (86.1%) with a mean age of 30.7 ± 0.3 years (range, 10–76 years) and a mean Injury Severity Score of 10.73 ± 10.5. There were 225 (86.2%) true-negative, 29 (11.1%) true-positive, 0 false-negative, and 7 (2.7%) false-positive examinations, yielding 100% sensitivity, 96.9% specificity, and 97.3% accuracy. The mean Injury Severity Score for the 29 patients with true-positive examinations was 22.3 ± 12.7 (range, 9–75), and the mean time from the performance of the ultrasound examination to the start of the operation was 12.1 ± 5.9 minutes. Operative findings for all 29 patients included wounds to the following: left ventricle (5 patients), right ventricle (18 patients), right atrium (1 patient), multiple cardiac chambers (2 patients), and multiple cardiac chambers with a major thoracic vessel (1 patient) and ascending aorta (2 patients). Twenty-eight of the 29 patients (96.5%) survived.

<table>
<thead>
<tr>
<th>TABLE 1. Result categories: definitions</th>
</tr>
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<tbody>
<tr>
<td>Category</td>
</tr>
<tr>
<td>-----------------------------------</td>
</tr>
<tr>
<td>True positive</td>
</tr>
<tr>
<td>True negative</td>
</tr>
<tr>
<td>False positive</td>
</tr>
<tr>
<td>False negative</td>
</tr>
</tbody>
</table>

Operations

Penetrating Chest Wound

US

POS

Equivocal

NEG

Pericardial window

Observation and Discharge

FIG. 3. Algorithm representing the protocol for patients in this study.
of hemopericardium, 12 of the patients had subxiphoid pericardial window, all patients who had a positive ultrasound examination underwent immediate operation. Despite the documentation of hemopericardium, 12 of the patients had subxiphoid pericardial window performed before the thoracic incision was made.

For those studies performed by the surgeons, the films were interpreted by experienced surgeon-sonographers or surgeon-sonographers with cardiologists who agreed with the interpretations of all the studies. The surgeons were unable to obtain adequate pericardial ultrasound examinations in seven patients (3.5%). Three of these patients had echocardiographic examinations performed by a cardiologist and four underwent subxiphoid pericardial window, according to the protocol for this study. All seven examinations showed normal findings.

Seven patients (four with gunshot wounds, three with stab wounds) had false-positive pericardial ultrasound examinations (Table 2). Five of these patients had abdominal or thoracic operations for associated injuries, and the subxiphoid pericardial window was performed during those procedures.

One patient underwent a median sternotomy and was found to have a partial transection of the innominate vein and the pulmonary hilar vessel but no presence of hemopericardium. Although six of the seven patients had associated hemothorax, none had a massive hemothorax as defined by the American College of Surgeons' Advanced Trauma Life Support Student Course Manual.18

Cardiologists/Technicians/Radiologists (Emory University School of Medicine, University of California, San Francisco, University of California, San Diego)

Twenty-three pericardial ultrasound examinations were performed by cardiologists or technicians, and the radiologists' interpretations agreed with those of the technicians in all of the studies. There were 19 (82.6%) true-negative, 4 (17.4%) true-positive, and no false-negative or false-positive examinations, yielding 100% sensitivity, 100% specificity, and 100% accuracy. Three of the four patients with true-positive ultrasound examinations underwent subxiphoid pericardial window before the median sternotomies were performed, probably because the modality was new to the trauma team members. Admission base deficits for the four patients with true-positive ultrasound examinations ranged from -8.1 to 0.8 with a mean of -5.8 ± 2.2, which is statistically significantly lower (p = 0.02) than the base deficits of patients with true-positive results whose examinations were performed by surgeons.

**DISCUSSION**

As a noninvasive and sensitive diagnostic modality, ultrasound is quickly becoming an integral part of the surgeon's practice,10-13,17,21-29 particularly in patients with blunt truncal trauma. Recent studies have supported its important role in the evaluation of patients with penetrating injuries as well.10-13,24,30 Because it is rapid and easily repeatable, ultrasound is especially useful for the assessment of patients with thoracic wounds, not only to establish the presence or absence of hemopericardium, but also to reevaluate a patient who suddenly becomes hypotensive.

**True Negatives**

Most (86.2%) of the patients in this study had true-negative ultrasound examinations, a finding similar to the results of other studies that included large numbers of patients with penetrating thoracic wounds.14,31-35 When the ultrasound examination result is negative and the patient is hemodynamically stable, time in the resuscitation area is used more efficiently and patients undergo triage more effectively.12 If a pericardial ultrasound excludes hemopericardium (pericardial effusion) by showing normal findings in the hemodynamically unstable patient, then the surgeon's efforts can be directed toward other potential causes of hypotension.10-13,21,24 In the case of a hypotensive patient who suffers a thoracoabdominal gunshot wound, ultrasound can quickly scan the pericardium, thorax, and abdomen for blood, thus allowing the surgeon to prioritize the injuries that need repair.10-13,21,24 Ultrasound is valued, therefore, not only for the detection of the presence of hemopericardium but also for the documentation of its absence.

**True Positives**

Twenty-eight of the 29 patients who had true-positive ultrasound examinations (hemopericardium) survived. The patient who died suffered a shotgun wound to the chest with injuries

<table>
<thead>
<tr>
<th>Patient</th>
<th>Cause</th>
<th>BP (mm Hg)</th>
<th>Base Deficit</th>
<th>Injuries (AAST Organ Injury Scale)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SW</td>
<td>98</td>
<td>-6.0</td>
<td>Lung (II), kidney (II), bilateral pneumothoraces, left hemothorax, SPW: (during celiotomy) benign effusion</td>
</tr>
<tr>
<td>2</td>
<td>SW</td>
<td>148</td>
<td>ND</td>
<td>Left pneumothorax, SPW: benign effusion</td>
</tr>
<tr>
<td>3</td>
<td>GSW</td>
<td>110</td>
<td>-12.9</td>
<td>Celiotomy: diaphragm (II), spleen (V), stomach (II), colon (II); right hemopneumothorax, SPW (during celiotomy); benign effusion</td>
</tr>
<tr>
<td>4</td>
<td>GSW</td>
<td>110</td>
<td>ND</td>
<td>Right hemopneumothorax; median sternotomy: lung (V) and thoracic vessel (II)</td>
</tr>
<tr>
<td>5</td>
<td>GSW</td>
<td>104</td>
<td>-7.0</td>
<td>SPW: benign effusion; left thoracotomy: lung (V)</td>
</tr>
<tr>
<td>6</td>
<td>GSW</td>
<td>122</td>
<td>-7.0</td>
<td>Left hemopneumothorax: 750 mL; SPW: benign effusion; left thoracotomy: lung (V)</td>
</tr>
<tr>
<td>7</td>
<td>SW</td>
<td>122</td>
<td>-17.9</td>
<td>SPW: benign effusion; left thoracotomy: lung (V); thoracic vessel (IV)</td>
</tr>
</tbody>
</table>

SW, stab wound; GSW, gunshot wound; BP, admission systolic blood pressure; SPW, subxiphoid pericardial window; ND, not done; AAST, American Association for the Surgery of Trauma.
to the right ventricle (grade IV), the lung (grade IV), and the axillary vein.

On admission, 16 of the 29 patients had systolic blood pressure ≥ 100 mm Hg, and 9 patients had blood pressure ≥ 120 mm Hg. It is in this subset of patients (who appear to be almost hemodynamically stable yet have life-threatening wounds) that ultrasound has its greatest value as an accurate screening modality for hemopericardium. Despite the mechanism of injury and the location of wounds within the "cardiac box," these modestly symptomatic patients may not have undergone early subxiphoid pericardial window or the insertion of central venous lines for monitoring of central venous pressure. Although these patients will eventually become symptomatic, avoidance of shock by early diagnosis and treatment is advantageous and may decrease associated morbidity.12,36

Using ultrasound to make an early diagnosis of hemopericardium is even more important in patients who are hypotensive because when it is positive, the source of hypotension is rapidly identified and the time interval from diagnosis to operation is markedly reduced.12 Decreasing delays to the operating room for symptomatic patients with penetrating truncal wounds has been advocated by many authors2,12,18,37,38 and can be achieved with ultrasound through its unique quality of real-time imaging. This property of ultrasound produces instantaneous results of the examination and, therefore, enables the clinician to make earlier decisions regarding patient management. In this study, 3 of the 29 patients with true-positive examinations had multiple penetrating truncal wounds and were hypotensive on admission. Although several potential sources of blood loss were identified, ultrasound rapidly detected hemopericardium and the cardiac injuries were repaired.

Examination of the base deficits from the patients with true-positive results showed that the physiologic derangement was greater (base deficit was more negative) for patients who had examinations performed by the surgeons. This may imply that only a select group of patients will be hemodynamically stable enough to wait for the technician to be paged, come to the resuscitation area, and perform the detailed echocardiographic examination. This emphasizes that for ultrasound to be an effective diagnostic test for most patients with these wounds, it must be immediately available in the resuscitation area and be performed and interpreted by surgeons.

**False Positives**

Seven patients had false-positive ultrasound examinations, all of which were performed by the surgeons who examined only the subcostal view. Six of these patients underwent subxiphoid pericardial window that showed moderate benign pericardial effusions, two of which were performed during celiotomies for associated injuries. Considering the mechanisms of injury and the documentation of pericardial effusion, surgery was appropriate in all seven patients.

**False Negatives**

Although there were no false-negative ultrasound examinations in this study, other authors have expressed concern about the accuracy of echocardiography for the detection of hemopericardium.12,39-41 In the study by Bolton et al., subxiphoid pericardial window was more accurate than echocardiography for the detection of intrapericardial injuries.39 More recently, Meyer and colleagues cautioned that a false-negative ultrasound reading may occur in patients with large hemothoraces that obscure small amounts of hemopericardium.40 The experience of two of the authors (G.S.R. and M.G.O.) has shown that a massive hemothorax may surround the pericardium and produce a false-positive result or the hemopericardium may decompress into the thoracic cavity and yield a false-negative result. Although more data need to be accrued based on this experience, a repeat pericardial ultrasound examination or the performance of a subxiphoid pericardial window should be considered after tube thoracostomy is performed for the evacuation of a large hemothorax.

Other factors that may potentially improve the sensitivity and specificity of pericardial ultrasound include (1) expansion of the focused examination to include not only the subcostal view but also the parasternal and the apical views (the other views provide more information about the amount of pericardial fluid present),14,19 which is especially useful because a small effusion may be detected only in certain areas of the pericardium; and (2) routine videotaping of the ultrasound examination to give the sonographer the benefit of reviewing the entire study in the dynamic, real-time mode. Because more information can be gleaned with the recorded view than with the hard-copy image alone, the confidence level associated with the reading of each examination is increased.42 Although advantageous, remembering to routinely videotape the examination was difficult for the trauma team, especially when hemopericardium was diagnosed, because the tendency was to quickly move that patient to the operating room. Although these issues are worth discussing, they more appropriately apply to decreasing the incidence of false-negative ultrasound examinations, of which there were none in this study. Furthermore, clinicians should understand that ultrasound is a diagnostic adjunct for the evaluation of injured patients and that sound clinical judgment should be applied when using it to avoid unnecessary adverse outcomes.

**Potential Deficiencies**

Potential deficiencies in this study included the following: (1) patients were not prospectively randomized to undergo pericardial ultrasound examination or subxiphoid pericardial window; (2) with the exception of one institution (Washington Hospital Center), the study population was not a consecutive sample; and (3) not all patients received follow-up after they were discharged.

A comparison of ultrasound examination results with subxiphoid pericardial window results was not done because all of the investigators had considerable experience with the use of ultrasound in this setting,10-12,17,23,24,27-29,43-45 and these invasive procedures would have been unnecessary in most of the patients. Other parameters, such as the presence of jugular venous distention, cardiac murmurs, electrocardiographic changes, and other signs, were recorded in the patient's phys-
Although the patients in this study were for the most part a nonconsecutive sample, the data may be biased; overall, however, they are representative of the mechanisms of injury and the trauma patient populations at all five centers. Another deficiency of this study was the lack of follow-up of all patients after they were discharged. Considering that the patients in this study were observed for a minimum of 23 hours, it was likely that any adverse events would be detected during that time. Furthermore, the investigators reported that patients who were treated at their institutions for penetrating thoracic wounds would most commonly return if a complication developed. To our knowledge, no injury was missed.

An important issue that has been raised by this study is the utility of repeat ultrasound examinations. Present recommendations regarding repeat ultrasound studies refer to the evaluation of the abdomen in the injured patient.11,13,47-49 To our knowledge, no conclusive recommendations have been made regarding the repeat evaluation of the pericardium in patients with penetrating thoracic wounds. In this study, only two patients underwent repeat pericardial ultrasound examinations; these were performed within about 12 hours of admission and showed normal findings. The trauma team performed the repeat studies because there was a high index of suspicion of a cardiac wound; however, according to the protocol, these patients should have undergone subxiphoid pericardial window. It is conceivable that there may be a role for repeat pericardial ultrasound examinations in select patients, such as those with unexplained base deficit,20,51 persistent tachycardia, or large hemorthorax.40 Repeat examinations may also be applicable considering reports on delayed cardiac tamponade52-56 and injuries to low-pressure chambers (a small atrial laceration) that may initially show normal findings on the ultrasound study. Until more data are acquired that define the indications for, the interval for, and the utility of repeat pericardial ultrasound examinations, emphasis should still be placed on the performance of repeat physical examinations and the observation of other physiologic parameters so that decisions regarding patient management are based on the entire clinical picture rather than on the result of the ultrasound examination alone.

**The Learning Process**

In other studies that examined the use of ultrasound as performed by surgeons in the trauma setting, the learning curve has had an impact on the sensitivity and specificity of the data.10,11,37,58 In this study, however, its impact on the results was less severe. First, the hard-copy ultrasound images were deemed to be of good quality, and second, the ultrasound training courses focused on the difficulties of imaging for surgeons in the clinical setting. For example, the surgeons learned to accurately perform and interpret positive examinations in patients with small as well as large pericardial effusions so that differences in the spectrum of positive studies could be appreciated. Additionally, the surgeon-sonographers were instructed that visualization of the echogenic pericardium was an essential component of the examination.

When a good-quality ultrasound image was obtainable, the team followed the protocol to perform a subxiphoid pericardial window or to obtain an echocardiographic examination by the cardiologist. The essential cardiac images are usually not difficult to obtain, although a severe chest-wall injury, a very narrow subcostal area, subcutaneous emphysema, or morbid obesity can prevent a satisfactory examination.10,42 Both of the latter conditions are associated with poor imaging because air and fat reflect the sound beam too strongly and prevent penetration of the ultrasound wave into the target organ.16 Consequently, there is very little reflection of the wave back to the transducer and a poor image is formed. In this study, the reasons that the pericardial view was unobtainable included morbid obesity (five patients), subcutaneous emphysema (one patient), and unknown (one patient) Although the use of a lower-frequency transducer, transesophageal echocardiography,41,58 thoracoscopy,40,61 or, in some cases, laparoscopy43 may have improved cardiac imaging, these are not indicated in the majority of patients with precordial or transthoracic wounds.

Surgeons did not perform all ultrasound examinations in our study, but they were always involved in the process. First-hand observations were made about the unique qualities of ultrasound, including minimal patient preparation and the fact that the procedure is painless, noninvasive, rapid, portable, and repeatable. Additionally, surgeons gained familiarity with the instrumentation and basic principles of ultrasound physics.42,44 Like the development of surgical skills, each technique or principle learned reinforces the surgeon’s knowledge of ultrasound, encourages rapid learning of new ultrasound techniques, and extends the surgeon’s diagnostic tools.

To develop surgeon-performed ultrasound in their institutions, investigators in this study worked closely with physicians and technicians who routinely use ultrasound in their practices. This resourceful strategy provides practical ultrasound instruction to surgeons who have limited resources, including the lack of availability of ultrasound equipment and competent instructors.44 Even when the ultrasound equipment is owned by surgeons (University of California, San Francisco), working with the cardiologists not only improves the surgeon’s skills in ultrasound but also serves to decrease political pressures from the radiologists. Alternative educational approaches include the use of an interactive multimedia computer version of the ultrasound examinations or the use of the UltraSim simulation technology (MEDSIM, Advanced Medical Simulation, Fort Lauderdale, Fla). Also, surgeons now understand that practice domains have blurred43 that no medical specialty has ownership of ultrasound technology,49 and that properly trained surgeons should use ultrasound in their practices.17 Although radiologists may be willing to provide around-the-clock in-hospital service, having the surgeon perform the ultrasound examination has distinct advantages because it becomes part of the surgeon’s diagnostic skills, i.e., essentially a part of the physical examination. By performing and interpreting ultrasound, therefore, the surgeon has immediate additional information for the evaluation of the patient without the enduring delays related to the
arrival of an ultrasound technician, the time of the examination, and the radiologist’s interpretation of the study.

Furthermore, the use of pericardial ultrasound by the surgeon is well suited to the trauma setting because it is potentially cost-effective. The exact institutional savings are difficult to determine because of multiple variables and fixed costs, but expenses and patient morbidity can be decreased if unnecessary invasive procedures, such as the insertion of a central venous line for monitoring of central venous pressure, are performed less frequently or even eliminated (Table 3). Indirectly, revenue is gained because resources are conserved when resuscitation time is minimized. For example, no further studies were needed to exclude hemopericardium in the 225 patients whose examinations were negative, and the time interval from a positive ultrasound examination to operation was only 12.1 ± 5.9 minutes.

**SUMMARY**

Although ultrasound is rapidly becoming an accepted practice in many trauma centers in North America, its importance as a diagnostic modality as used by the surgeon will ultimately depend on the areas in which it has the greatest impact on the assessment and management of patients. Our acquired experience with ultrasound has convinced us of its advantages and has significantly influenced this facet of our approach to the injured patient. Examination of data on large numbers of patients, such as those in this study, has provided essential information that continues to clarify the role of ultrasound in the traumatized patient. Confident in these results and in those from our previous studies,10–13,23,24,29,44 we now routinely use ultrasound initially and almost exclusively for the evaluation of patients with penetrating injuries to the precordial or transthoracic region. Consequently, our indications for the performance of subxiphoid pericardial window have narrowed substantially.

In our study, the high survival rate (96.5%) in patients with the diagnosis of pericardial tamponade and the absence of false-negative examination results underscores the fact that ultrasound is a rapid and accurate diagnostic modality for the detection of hemopericardium from penetrating thoracic trauma.10–14 Also, this study illustrated several practical alternative approaches by which surgeons can learn the principles of ultrasound.

The following conclusions have been reached from an analysis of emergency pericardial ultrasound examinations in 261 patients who were considered to be at high risk for cardiac injury from penetrating precordial or transthoracic wounds: (1) ultrasound should be the initial diagnostic modality for the evaluation of patients with precordial wounds because it is rapid, accurate, and augments the surgeon’s diagnostic capabilities; (2) delay times from admission to the operating room are minimized by using ultrasound to evaluate patients with penetrating cardiac wounds; and (3) because of the high sensitivity and specificity of ultrasound when used for the evaluation of patients with precordial or transthoracic wounds, immediate operative intervention is justified when those patients have positive ultrasound examinations.

Based on the data in this study, we recommend that pericardial ultrasound should replace monitoring of central venous pressure for the assessment of patients for the detection of hemopericardium. To that end, the accuracy of surgeon-performed ultrasound in this study strongly supports educational efforts in this technique for both residents and practicing surgeons. We encourage surgeons to become proficient in using this specific ultrasound technique and strongly suggest that program directors in general surgery incorporate focused ultrasound instruction into the training of residents.

**ACKNOWLEDGMENTS**

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59. Goldberg SP, Karalis DG, Ross JJ Jr, et al. Severe right or, David H. Wisner (Sacramento, California): Based on both our own experience as well as the results of this study and Dr. Rozycki’s previous work, it seems fairly convincingly that interrogating the pericardial space with ultrasound for the presence of hemopericardium is both a rapid and sensitive means of detecting penetrating cardiac injury. Watching Dr. Ledgerwood’s body language over the last several hours has successfully intimidated me into keeping this short, but I nonetheless have several questions.

The time between a positive ultrasound and a trip to the operating room was a laudable 12 minutes on average. What would be more interesting, however, is the average interval between patient arrival in the emergency department and the subsequent trip to the operating room. I’d also be interested to know if there were significant differences in that interval, i.e., the interval between arrival in the emergency department and the trip to the operating room, if the study was done by someone in house or by someone who had to be called in from home.

I’m also wondering about the patients who underwent subxiphoid pericardial windows after a positive ultrasound exam. It may have been that all of those windows were done in patients with equivocal studies, but I’d appreciate a little bit more comment from the authors on that point.

The survival rate for patients with true-positive studies was remarkably high in the study population. One possible explanation is that the rapid diagnosis via ultrasound improved survival, and I’m inclined to believe that that’s the case. An alternative explanation, however, is that there was a significant selection bias in the study.

I’m therefore interested if the authors could tell us, for comparison, how many total patients during the course of the study were treated at the centers for penetrating injuries to the heart. In other words, how many patients with penetrating cardiac injuries underwent surgical intervention without a prior ultrasound exam? Along the same lines, it would also be interesting to know if the introduction of ultrasound for the diagnosis of penetrating cardiac injuries has significantly impacted the overall survival rate for this class of patients.

Finally, I have a question about the patients with a negative study. A 100% sensitivity in a large group of patients such as this suggests that patients with a negative study might be safely discharged to home from the emergency department. Are the authors ready to recommend emergency department discharge for such patients, or should they all be admitted for a while just to play it safe? It was a pleasure to review this paper, and I thank the Association for the privilege of the floor.

Dr. Juan A. Asensio (Los Angeles, California): I rise to congratulate Dr. Rozycki on a very nice study. It certainly confirms our biases at L.A. County/USC. Grace, your basic population was very hemodynamically stable. My question is very simple. Why did you choose such hemodynamically stable patients? I think that you could extend this study to the patients that are arriving in extremis. I think that’s where the average value of ultrasound is really found. It takes such a very short time in your very capable hands.

We strongly believe at L.A. County that it is that critical patient, particularly those that come in with multiple injuries, gunshot wounds, thoracoabdominal injuries, in which ultrasound is of great value, and we have certainly supported it’s value in our prospective experience with 105 penetrating cardiac injuries. Thank you and congratulations.

Dr. Ronald I. Gross (Bridgeport, Connecticut): Once again, Dr. Rozycki’s presented an elegant study. My only question is in the time that it took to perform the ultrasound. In your previous studies your total ultrasound time for the FAST has been about 2.5 minutes, and here it’s 1.4 plus or minus. Was there a learning curve for those who were new to this procedure, and did you indeed perform a FAST in addition or concurrently with the pericardial study? Thank you.

Dr. Michael L. Hawkins (Augusta, Georgia): Did any of these patients get a repeat study, and if so, were any of the true positives picked up on the secondary ultrasound? Dr. Brad M. Cushing (Portland, Maine): Grace, do you repeat all negative ultrasounds? How many times do you actually have somebody who was initially negative who subsequently develops a tamponade or refusion? Dr. William B. Long (Portland, Oregon): How many of these studies were technically inadequate and for what reason? In other words, how many people had subcutaneous or mediastinal emphysema that precluded this being a valid test? Dr. Joseph P. Minei (Dallas, Texas): I’d be curious to know about patients with hemothorax. In the study that came out of our institution by Dan Meyer and presented here a couple of years ago, there were a couple of false negatives in patients with left hemothorax.

Dr. Joseph C. Young (Pittsburgh, Pennsylvania) I think that the issue about the left chest space having blood in it has been discussed in the past, and I’d like to have her comment about whether that is a compounding variable relative to interpretation.

Dr. Grace S. Rozycki (closing): I would like thank the discussants for their very insightful comments. We selected this patient population so that surgeons as well as technicians...
and radiologists could be involved in the study. Drs. Hoyt and Knudson worked closely with technicians, radiologists, and cardiologists to show alternate ways to introduce ultrasound into surgeons' hands. Those patients who presented in extremis were excluded from the study because they rarely need a diagnostic modality to diagnose cardiac tamponade.

We also wanted to show where ultrasound has its greatest impact in the management of patients with penetrating thoracic wounds. Several of these patients were very hemodynamically stable and hemopericardium was not suspected.

There were two patients who had repeat examinations, both of which showed negative results. Although the role for a repeat ultrasound examination in this setting has yet to be defined, it is safer to perform a subxiphoid pericardial window if the ultrasound examination is equivocal and there is a strong suspicion for a cardiac wound.

As per the studies of Drs. Bolton and Meyer, we were concerned about false-positive and negative results in the presence of a massive hemothorax. Seven patients had associated hemothoraces, none of which were massive.

Data regarding the timing of the ultrasound examinations were difficult to analyze because the institutions had different systems in place for the evaluation of these patients. This would provide an interesting question for a future study. I would like to thank the Association for the privilege of presenting our research.