Safety of Ultrasound-Guided Thoracentesis in Patients Receiving Mechanical Ventilation*

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Objective: To determine the safety of ultrasound-guided thoracentesis (UST) performed by critical care physicians on patients receiving mechanical ventilation.

Design: Prospective and observational.

Setting: ICUs in a teaching hospital.

Patients: Two hundred eleven serial patients receiving mechanical ventilation with pleural effusion requiring diagnostic or therapeutic thoracentesis.

Interventions: Two hundred thirty-two separate USTs were performed by critical care physicians without radiology support. Anteroposterior chest radiographs were reviewed for possible postprocedure pneumothorax.

Results: Pneumothorax occurred in 3 of 232 USTs (1.3%). The procedure was well tolerated in this critically ill population.

Conclusions: UST performed in patients receiving mechanical ventilation without radiology support results in an acceptable rate of pneumothorax.

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Key words: pleural effusion; thoracentesis; ultrasonography

Abbreviations: PEEP = positive end-expiratory pressure; UST = ultrasound-guided thoracentesis

Pleural effusion is a common problem occurring in 62% of patients in the ICU.1 Thoracentesis is clinically useful in 56% of ICU patients with pleural effusion.2 Pneumothorax is a complication of thoracentesis. Tension pneumothorax is a dangerous risk of thoracentesis in patients requiring mechanical ventilation. The purpose of this study is to examine the safety of ultrasound-guided thoracentesis (UST) performed on patients receiving mechanical ventilation by critical care physicians.

Materials and Methods

Between August 1995 and December 1998, we prospectively collected data on 232 consecutive thoracenteses performed under ultrasound guidance on patients requiring mechanical ventilation in the medical ICUs of Beth Israel Medical Center, New York City. All patients were tracheally intubated and receiving mechanical ventilation (Puritan Bennett 7290; Puritan Bennett; Carlsbad, CA) at the time of the procedure. The decision to perform the thoracentesis was made on clinical grounds alone and was not protocol driven. Two critical care attendings were assigned the task of becoming proficient in ultrasound localization of pleural fluid by ultrasonography. All USTs were performed under the direct supervision of one of these attendings, with actual needle insertion performed by medical housestaff. All USTs were performed using a ultrasound machine with a 3.5-MHz probe (UF 4500; Fukuda Denshi; Tokyo, Japan). No radiologist was involved in the ultrasound training of personnel or the performance of the thoracenteses. This project was approved by the Committee on Scientific Activities of Beth Israel Medical Center.

Ultrasoundography and Thoracentesis

Pleural effusion typically appears as an echo-free space on sonography.3 Occasionally, internal echoes may be present in the fluid. The echogenicity may be homogenous as occurs with proteinaceous or highly cellular effusions, or heterogeneous as in septate effusions or macroscopic pleural metastasis. The positive identification of pleural fluid requires the demonstration of dynamic signs such as a change in shape of the echo-free space during the respiratory cycle,4 atelectic or compressed lung, and...
swirling motion in the echo-free space. In difficult cases, additional evidence of pleural effusion includes color Doppler sonographic signal within the echo-free space.

The position of the patient during the procedure was at the discretion of the sonographer but was usually supine allowing scanning of the lateral hemithorax. The feasibility of thoracentesis required the demonstration of a sonographic window to the fluid persisting throughout the respiratory cycle. There was no formal lower limit of effusion size beneath which thoracentesis was not attempted, but generally a visceral to parietal pleural distance of at least 10 mm was required. Incursions of lung or diaphragm during the respiratory cycle into the sonographic window were considered contraindications to thoracentesis. Positive identification of the diaphragm plus liver or spleen was also required to avoid puncture of these organs. If no safe sonographic window was identified, we made no effort at thoracentesis.

After identification of a suitable sonographic window, the angle of the sonoprobe was noted, the required depth of penetration measured from the sonographic image, and the skin was marked. Site preparation and thoracentesis immediately followed ultrasound with care not to alter patient position. The angle of the sonoprobe was duplicated by the needle inserter during the procedure, but needle insertion was not directly visualized by sonography. The sonographic image permitted insertion of the needle along a safe axis of penetration. Therefore, the procedure is properly designated as ultrasound guided. This does not imply the need for direct real-time visualization of needle insertion.

All patients were deeply sedated, and on occasion paralyzed, to minimize movement during the procedure. Positive end-expiratory pressure (PEEP) settings were not altered for the procedure. The ventilator was set to continuous mandatory ventilation mode. Small-volume thoracentesis was performed with a 21-gauge needle and syringe. High-volume therapeutic thoracentesis was carried out using various commercially available catheter drainage systems designed for pleural drainage. Complex loculated effusions were drained using a cavity drainage catheter (Cook; Reading, PA) or standard chest tube. These larger chest drainage devices were inserted using the same sonographic guidance methods as for UST; the best site for insertion was determined by sonographic examination of the loculated effusion. Following each UST, the patient had an anteroposterior chest radiograph that was interpreted by a radiologist without knowledge of the data collection.

Results

In total, 232 separate thoracenteses were performed on 211 patients. Three thoracenteses yielded no fluid (1.3%). Results are reported as mean ± SD.

Of the 232 thoracenteses, 222 thoracenteses (95.6%) were performed with patients receiving PEEP at 6.8 ± 2 cm H2O and 148 thoracenteses (63%) with vasopressor therapy. The Pao2/fraction of inspired oxygen was 178 ± 38. We performed 90 thoracenteses (38.8%) whose primary purpose was diagnostic, removing 90 ± 31 mL of fluid. We performed 142 thoracenteses (61.2%) whose primary purpose was therapeutic, removing 800 ± 255 mL of fluid in 139 successful attempts. Of 229 successful thoracenteses, 140 thoracenteses (61%) yielded a transudate by standard criteria. One patient had unexpected malignant cytology. Fourteen patients had complex loculated effusions, of which eight were empyemata by standard criteria. Regarding the unsuccessful thoracenteses, all three patients were massively obese and edematous with chest wall thickness > 15 cm. We suspect that needle length was inadequate in these cases.

Pneumothorax occurred in three cases (1.3%; 95% confidence interval, 0 to 3.7%). One of these occurred after leaving a stopcock open following complete drainage of the pleural cavity and before the catheter was removed. No pneumothorax was under tension, and no pneumothorax occurred in the three procedures that yielded no fluid. All were treated successfully with chest tube insertion followed by full lung expansion without air leak. We did not establish formal objective criteria to measure other complications of thoracentesis in this series, such as bleeding or hemodynamic compromise. Subjectively, UST resulted in no adverse hemodynamic consequence nor bleeding complication.

Discussion

Our study demonstrates that UST results in a low and acceptable rate of pneumothorax based on the objective data presented. The safety of thoracentesis in patients receiving mechanical ventilation has been investigated previously. Gervais et al9 reported a case series including 92 patients receiving mechanical ventilation who underwent UST, resulting in pneumothorax in 6 patients (6.5%). The procedures were performed in a radiology suite by radiologists. Our pneumothorax rate of 1.3% compares favorably with this report. Petersen et al10 reported a series of thoracenteses using ultrasound guidance that included 83 procedures on patients receiving mechanical ventilation. The pneumothorax rate for the entire series of 338 thoracenteses was 1.2%, although what percentage occurred in the subset receiving mechanical ventilation was not reported. In Lichtenstein et al,4 a study comparable to ours, intensivists performed 45 sonoguided thoracenteses in patients receiving mechanical ventilation with a pneumothorax rate of 0%. Other studies have dealt with the question of thoracentesis in patients receiving mechanical ventilatory support. Godwin and Sahn11 reported two pneumothoraces in a series of 32 thoracenteses (6.25%), McCartney et al12 reported three pneumothoraces in 31 thoracenteses (9.7%), and Fartoukh et al2 observed five pneumothoraces in 68 procedures (7.3%) in patients who underwent thoracentesis while receiving mechanical ventilation. Jones et al13 reported 941 USTs performed by interventional radiologists in nonintubated patients with 24 pneumothoraces (2.7%), a rate similar to ours.

One of our pneumothoraces resulted from three-
way stopcock malposition; the other two (0.8%) resulted either from lung puncture, lung entrapment, or entrainment of air through the catheter-needle assembly. None of them had consequential clinical effect, although all resulted in insertion of a chest tube. Massive osteitis prevented successful thoracentesis in 3 of 232 patients (1.3%). Many of the patients were receiving PEEP and vasopressor medications, suggesting that critical illness does not preclude indicated thoracentesis.

The training of ultrasonographers was task specific and aimed at the positive identification of pleural fluid and surrounding organs, as well as the demonstration of unobstructed access to the fluid. These simple and well-defined skills were readily acquired by medical intensivists without any training from radiologists. We did not prescribe patient position during thoracentesis or the type of equipment used. All levels of medical housestaff were involved in the drainage procedure at the discretion of the intensivist sonographer. However, the sonographer was solely responsible for determination of needle insertion site, angle of needle insertion, and depth of penetration. We believe that meticulous adherence to sonographic criteria and avoidance of patient movement between sonographic examination and fluid accession were the key factors responsible for the low pneumothorax rate in our series. Obviously, the presence of a trained sonographer at the bedside during every procedure performed was a critical factor. Direct real-time visualization of needle insertion was unnecessary, as has been demonstrated in a large study of sonoguided pericardiocenteses. The 232 procedures were performed over a period of >2 years. The extended period of observation documents the sustainability of a high degree of safety in routine clinical practice over time.

This study is observational and has limitations. We did not perform screening sonography on all patients in the ICUs during the study period, and therefore cannot report the proportion of total pleural effusions that were sampled by UST. Likewise, we are not able to compare the safety of UST performed by study personnel with thoracentesis performed in patients receiving mechanical ventilation using alternative guidance strategy such as physical examination, chest radiograph, or CT. We cannot compare our performance against radiologists in our hospital during the time of the study. We also cannot answer the question of what caused us to suspect the presence of a pleural effusion in a patient leading to the decision to perform UST.

An important question is what type of training is required for performance of UST by nonradiologists. This study did not address this issue; but, for clinicians who have interest in the technique, we can report on our own personal experience. One of us had background in abdominal sonography. Intra-abdominal fluid collection is a common feature of abdominal sonography, as is sonographically guided paracentesis. The identification of pleural fluid is a straightforward extension of abdominal sonographic technique. In this context, UST required no formal training for this attending. The first study attending, following satisfactory UST results, trained the second study attending. They personally supervised all 232 USTs reported in this study. We received no training from radiologists. As the safety of UST became evident, we have since trained all the attendings in our department in the performance of UST, as well as incorporating it into our fellowship training program. We have not established an absolute number of UST required to establish competence for independent function. This will need further consideration. We believe that UST is particularly suited to the specialty of pulmonary/critical care medicine, as the specialists in this field are familiar with the radiographic anatomy of the thorax. For this group, the transition to sonographic imaging of the thorax is straightforward. In our opinion, the performance of UST depends on physician competence and should not be limited to any particular type of hospital. The present study documents the safety of UST performed in patients receiving mechanical ventilation by intensivists.

References

