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Deep Needle Procedures: Improving Safety With Ultrasound Visualization

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Abstract: Promoting patient safety and increasing health care quality have dominated the health care landscape during the last 15 years. Health care regulators and payers are now tying patient safety outcomes and best practices to hospital reimbursement. Many health care leaders are searching for new technologies that not only make health care for patients safer but also reduce overall health care costs. New advances in ultrasonography have made this technology available to health care providers at the patient's bedside. Point-of-care ultrasound assistance now aids providers with real-time diagnosis and with visualization for procedural guidance. This is especially true for common deep needle procedures such as central venous catheter insertion, thoracentesis, and paracentesis.

There is now mounting evidence that clinician-performed point-of-care ultrasound improves patient safety, enhances health care quality, and reduces health care cost for deep needle procedures. Furthermore, the miniaturization, ease of use, and the evolving affordability of ultrasound have now made this technology widely available. The adoption of point-of-care ultrasonography has reached a tipping point and should be seriously considered the safety standard for all hospital-based deep needle procedures.

Key Words: point-of-care ultrasound, patient safety, quality improvement, cost reduction, central venous catheter, paracentesis, thoracentesis

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Primum non nocere—"First do no harm," is a central tenant of all practitioners in the modern era of medicine.[1] Alarmingly, the American Healthcare System has done harm, in large amounts. In 1995, the Centers for Disease Control and Prevention estimated that hospital-associated infections contributed to 99,000 patient deaths per year.[2] However, it was not until 1999, when the Institute of Medicine released its landmark report, *To Err is Human: Building a Safer Health System,* that the modern discipline of patient safety took on its current form.[3] The emphasis on analyzing, reporting, and preventing adverse health outcomes is now a regular part of the American Healthcare System's regulatory and payment structures.[4]

Many nonprofit regulatory agencies such as The Joint Commission use patient safety outcome measures as a major factor during their accreditation.[5] Health care purchasers have developed organizations such as the Leapfrog Group to use purchasing incentives to ensure greater health care quality and patient safety.[6] Now, large payers, such as the Centers for Medicare and Medicaid Services, are pressuring hospitals to develop more robust patient safety systems by denying the reimbursement of certain Patient Safety Indicators, such as iatrogenic pneumothorax and vascular catheter-associated infection.[7,8] Organizations, such as the National Quality Forum (NQF), have been created to help conduct this growing chorus of organizations to promote better and affordable health care, notably through evidence-based safe practices.[9]

The health care landscape will further change with the full implementation of the Patient Protection and Affordable Care Act of 2010 and the creation of Accountable Care Organizations—in which payments will be linked to quality improvements.[10] Currently, according to the Office of the Inspector General, costs related to unexpected adverse events have added $4.4 billion a year to the overall health care system and have contributed to an estimated 180,000 patient deaths per year.[11] In response, hospital governance structures are shifting to reflect a new emphasis on patient safety.[12] At no other time have hospital patient safety officer, chief medical officer, and chief executive officer duties been more focused on developing systems and acquiring new technologies that reduce cost and improve patient safety. One of these new technologies is bedside clinical ultrasound.

POINT-OF-CARE ULTRASONOGRAPHY

Ultrasonography has been used during the last 50 years to aid in diagnosis and guide procedures.[13] More recently, as ultrasound technology has improved and units are less expensive and more mobile, many different clinicians have incorporated ultrasound into their routine bedside practice.[14] Using nonionizing sound waves, point-of-care ultrasonography shows real-time images at the bedside without any radiation. This is particularly helpful in procedural guidance and can aid in the reduction of medical errors.[15,16] This patient-centered approach mirrors the recently described 5 Rights of Imaging framework, which promotes imaging technologies that have a clear favorable outcome for the patient.[17]

Point-of-care ultrasound guidance during procedures is used by multiple specialties and includes central and peripheral vascular access, thoracentesis, arthrocentesis, paracentesis, abscess incision and drainage, nerve blocks, arterial cannulation, pericardiocentesis, and other procedures.[13,18] Point-of-care ultrasound is especially important during deep-needle procedures such as central line insertion because the provider can visualize the needle in a dynamic, real-time fashion. Such technology has enabled health care providers to achieve a high degree of first-pass success and has decreased complications when compared with traditional, landmark-based approaches.[19,20]

The use of point-of-care ultrasonography during deep-needle procedures, specifically during central venous catheter (CVC) insertion, paracentesis, and thoracentesis, increases quality of care, decreases costs, and improves patient safety. Point-of-care ultrasonography is becoming the standard of care for deep-needle procedures, and leaders of hospital quality and safety departments should consider promoting its universal adoption.

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Ultrasound Probe Disinfection

Ultrasound-guided deep needle procedures are performed under maximal barrier precautions, which include a commercially available full-length ultrasound probe cover.[21] Robust evidence for disinfection and sterilization does not exist. A recent review article on ultrasound probe contamination shows that wiping ultrasound probes with an alcohol-soaked paper towel can almost completely eliminate bacteria.[22] Ultraviolet C disinfection and germicidal wipe disinfection after removing debris with a dry and wet towel have also been shown to eliminate most contaminants.[23,24] Endocavitary probes continue to need high-level disinfection.[25,26] Current practice with ultrasound-guided deep needle procedures uses low-level disinfection (removing debris with a towel, using a germicidal wipe) and then applying a long full-length, sterile probe cover before initiating the procedure.

CVC INSERTION

Description of Procedure

Central venous catheter insertion is a common procedure. More than 48% of intensive care unit (ICU) patients have CVCs placed, accounting for 15 million catheter-days per year.[27] These procedures are not just confined to the ICU but are performed in a wide range of locations within the hospital and on multiple locations on the body. Reasons for CVC placement range from hemodynamic monitoring and delivery of blood products and vasoactive medications to total parenteral nutrition administration, among others. Traditionally, CVCs have been placed using surface landmark-based techniques. The internal jugular approach, which has been shown as a site with fewer central line–associated bloodstream infections, has classically been performed by using the sternal and clavicular head of the sternocleidomastoid muscle as a landmark for venipuncture.[28–30] Unfortunately, common anomalies in anatomy may cause the operator to pass the needle in an inappropriate direction such as toward the carotid or the lung pleura. In contrast, with the use of point-of-care ultrasound, the operator can perform the procedure with continuous, dynamic observation toward the intended target[31] (Fig. 1).

Patient Safety

The use of point-of-care ultrasound to guide central access has shown a reduction in procedural failure rate, a decrease in the number of attempts, and a decrease in the complication rate as compared with the landmark technique.[20,32,33] The major mechanical complications associated with CVC insertion range from arterial puncture, hemothorax, and pneumothorax. Ultrasound guidance during CVC insertion can virtually eliminate these mechanical complications. Used along with the recommendations from the NQF to prevent central line–associated bloodstream infections, point-of-care ultrasonography can be used under sterile conditions to avoid infection and mechanical complications.[9]

In 1 prospective, randomized trial, comparing CVC catheterization of the internal jugular vein in critical care patients with the landmark technique, operators using ultrasound had a complete elimination of iatrogenic pneumothorax. Furthermore, the incidence of other mechanical complications was negligible.[31] This study confirmed previous conclusions from 2 large meta-analyses.[19,20] This evidence led the Agency for Healthcare Research and Quality to list the "use of real-time ultrasound guidance during central line insertion to prevent complications" as one of the most highly rated patient safety practices.[15] In tandem, in October 2012, the Centers for Medicare and Medicaid Services added iatrogenic pneumothorax associated with venous catheterization to the hospital-acquired condition list and will no longer reimburse hospitals to cover the cost of this condition.[34] Ultrasound visualization can eliminate iatrogenic pneumothorax from CVC insertion and is thus an important technology for health systems in terms of patient safety and reimbursement.

Quality Improvement

Ultrasound-based CVC insertion also shows a clear benefit in health care quality. There is a lower technical failure rate (overall and first attempt), and ultrasound-guided CVC insertion is more efficient when compared with traditional techniques.[35] In fact, a study in the emergency department showed a 54% reduction in the mean number of attempts and a 78% reduction in the length of procedure time with ultrasound guidance compared with the landmark-based approach.[36] A similar study showed a mean access time of 17.1 (16.5) seconds when using ultrasound compared with 44 (95) seconds ($P < 0.001$) when using the traditional landmark-based technique for CVC insertion.[31] Decreasing the number of attempts and becoming more efficient reduce the possibility of risk to the patient and also ensure that they are less likely to undergo a prolonged and uncomfortable procedure.[19] In addition, a recent meta-analysis concludes that real-time ultrasound use is associated with decreased risk for cannulation failure, arterial puncture, hematoma, and hemothorax, confirming previous single-study hypothesis.[37]

Cost Reduction

Complications from iatrogenic pneumothorax during CVC insertion attribute to a significant amount of charges and increase

FIGURE 1. Ultrasound-guided CVC insertion. A, A clinical provider performing real-time ultrasound guidance using a high-frequency linear transducer (13-6 MHz) during the insertion of a right internal jugular CVC with the patient in Trendelenburg. B, Transverse view of the right internal jugular vein and the right carotid artery. The clinician can confirm venous puncture using ultrasound, avoiding arterial puncture and iatrogenic pneumothorax.

length of stay. An analysis using the Agency for Healthcare Research and Quality Patient Safety Indicators identified medical injuries in 7.45 million hospital discharge abstracts across 28 states and showed an occurrence of 3919 iatrogenic pneumothoraces during CVC insertion. These complications accounted for an excess charge of $17,312 ($24,168 in 2013 when adjusted for health care cost inflation factors) on average per complication and accounted for 4.38 days in excess length of stay.[38] Similarly, in the United Kingdom, economic modeling indicates that using point-of-care ultrasonography during CVC insertion was likely to save $3249 of National Health Services resources for every 1000 procedures.[39] Using ultrasound at the bedside during nonemergent CVC catheter insertion can eliminate these nonreimbursed costs.

The use of point-of-care ultrasound increases patient safety and health care quality while reducing hospital cost and lengths of stay, and its use is now endorsed by many health-professional societies and governmental agencies.[40–47]

THORACENTESIS

Description of Procedure

A thoracentesis is a deep needle procedure used to drain fluid from the pleural space. It is an essential procedure in the diagnostic evaluation of pleural effusions and can provide therapeutic effects to patients with respiratory distress. Traditionally, this procedure is performed with the patient sitting upright. The site of puncture should be 1 to 2 intercostal spaces below the highest level of effusion in the midscapular or posterior axillary line. The physician then clinically locates the effusion by percussion and a decrease in tactile fremitus.[48] In contrast, point-of-care ultrasound can identify the pleural effusion accurately and in real time, improving previous clinical techniques[49,50] (Fig. 2).

Patient Safety

Thoracentesis has many mechanical complications. Punctures at inappropriate sites can lead to dry punctures; patient discomfort; and procedure-related complications, such as pneumothorax.[51,52] Indeed, complications are not uncommon. Pneumothorax has been reported to occur in 2% to 30% of diagnostic thoracenteses, and 15% to 50% of those have required tube thoracostomy as treatment.[53,54] In a retrospective clinical study, the use of point-of-care ultrasound guidance showed a 52% decrease in the occurrence of an iatrogenic pneumothorax when compared with performing the procedure without ultrasound guidance.[55] Indeed, a recent comprehensive review of the available literature shows a reported pneumothorax complication rate to range as low as 0% to 9.1% when the provider used ultrasound guidance.[56] Unlike the CVC insertion literature, there are no robust, prospective randomized controlled trials to prove the benefit of point-of-care ultrasound during thoracentesis; however, recent reviews and guidelines are advocating for the use of ultrasound as a best practice technique given the correlation between the use of ultrasound and the reduction of complications such as pneumothorax.[57] Furthermore, real-time visualization of pleural fluid with ultrasound can eliminate wrong-site thoracentesis, an NQF Safe Practice for Better Healthcare.[9,58]

Quality Improvement

The use of point-of-care ultrasound increases the accuracy of thoracentesis. In a prospective study, ultrasound guidance increased the rate of accurate puncture sites by 26% and prevented possible accidental organ puncture in 10% of all cases within the study.[59] The rates of dry punctures and number of attempts were also shown to decrease, which may decrease patient discomfort.[59]

Cost Reduction

Iatrogenic pneumothorax complications from thoracentesis also have a financial impact. A recent abstract used data collected from the Premier Perspective automated hospital database to assess the costs associated with pneumothorax associated with thoracentesis. For the 61,261 patients who underwent a thoracentesis procedure, 2.7% had an associated pneumothorax. These patients had an increased total cost of their hospitalization by $2752 ($2854 in 2013 adjusted for health care cost inflation factors) and an increased length of stay by 1.4 days.[60] Thus, there is a 20% reduction in hospitalization costs when a thoracentesis is performed without complications.[61]

PARACENTESIS

Description of Procedure

Paracentesis is a deep needle procedure that has both diagnostic and therapeutic indications. The procedure can help identify the presence of infection or the cause of new-onset ascites.[62] Furthermore, it can be used to relieve the cardiorespiratory and gastrointestinal manifestations of tense ascites by draining large volumes of fluid from the abdominal cavity.[63,64] Traditionally, the procedure is performed in the supine position, and the clinician

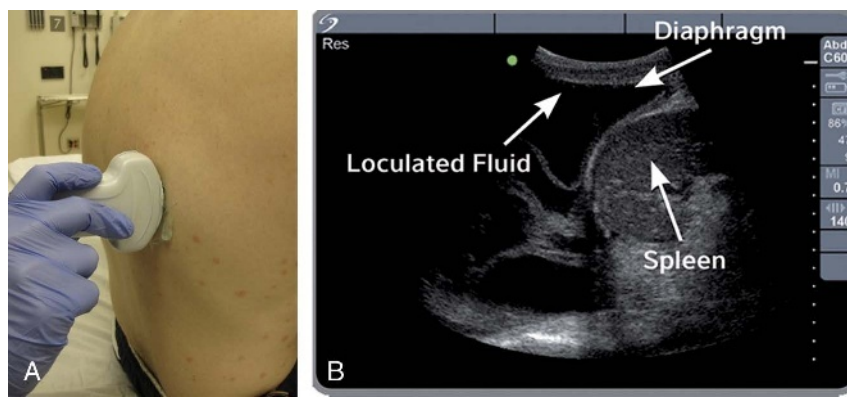

FIGURE 2. Ultrasound-guided thoracentesis. A, A clinician performing real-time ultrasound guidance using a phased array transducer (5-2 MHz) during a thoracentesis with the patient in seated position. B, Ultrasound view of target for thoracentesis. The clinician can safely sample loculated fluid for analysis, with a large decrease in rate of iatrogenic pneumothorax.

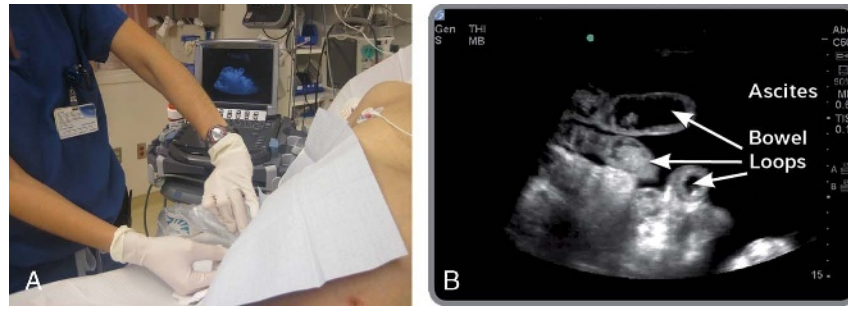

FIGURE 3. Ultrasound-guided paracentesis. A, A clinician performing bedside ultrasound guidance using an abdominal transducer (5-1 MHz) during a paracentesis, with the patient in supine position and the head of bed at 30 degrees. B, Ultrasound view of ascitic fluid. The clinician can safely identify the target for paracentesis, reducing intraperitoneal hemorrhage and bowel perforation.

confirms the presence of intra-abdominal fluid by percussion. A needle is then inserted approximately 2 cm below the umbilicus in the midline, where the rectus muscles join to form the thin, avascular linea alba, or in either of the lower quadrants, approximately 4 to 5 cm above and medial to the anterior superior iliac spine.[65] Fortunately, point-of-care ultrasound is a very sensitive tool for identification of fluid within the peritoneal cavity and can also distinguish structural impediments to the safe introduction of a paracentesis needle, such as the bladder, bowel, solid organs, and pregnant uterus[66,68] (Fig. 3).

Patient Safety

The mechanical complications of a paracentesis are relatively rare, but when they occur, they can have significant morbidity and mortality. Intraperitoneal hemorrhage, abdominal wall hematomas, bowel perforation, and bladder perforation have been reported with the traditional procedure.[69,70] Furthermore, many of these patients have an underlying coagulopathy or thrombocytopenia, making blind needle insertion more dangerous. Point-of-care visualization with ultrasound allows the user to avoid these serious complications. Ultrasound assistance displays the largest pocket of readily accessible fluid and will identify the presence of fluid mimics, such as a cystic mass or ventral hernia. Furthermore, in a prospective, randomized study comparing point-of-care ultrasound guidance with the traditional technique, operators increased their success rate from 65% to 95% when using ultrasound assistance.[71] Recently, data from the Premier Perspective database, which covers 20% of American hospital discharges, show that patients undergoing a paracentesis with ultrasound guidance had a 68% reduction in bleeding complications.[71] Point-of-care ultrasound assistance increases the success rate and decreases complications when performing a paracentesis.

Quality Improvement

Published data on the effectiveness of point-of-care ultrasonography as it relates to quality improvement are sparse. Nazeer et al[71] measured the operator's speed and the number of procedural attempts when comparing ultrasound-assisted paracentesis with the traditional technique. The use of ultrasound did not show a statistical difference in these outcome variables. However, ultrasound was used as a "rescue" technique in 15 of 100 patients because the traditional technique had failed and these patients went on to have successful procedures. The authors concluded that point-of-care ultrasound is more likely to be used in patients in whom the provider feels the procedure will be difficult to complete.

Cost Reduction

Although the bleeding complications from paracentesis are rare (approximately 0.8%), the subsequent care for these medical errors is very costly. For those patients with a bleeding complication, their hospital costs were nearly $30,000 (2013 cost), approximately triple the cost for patients without a complication ($9476). Furthermore, patients with a complication had an increased length of stay of 4.3 days compared with those who did not have a complication.[61] This model showed that just a single complication would pay for an ultrasound device. The use of point-of-care ultrasound enables the provider to avoid these costly complications, especially when the procedure is deemed difficult.[71]

CONCLUSIONS

Point-of-care ultrasonography used during deep needle procedures makes patient care safer, increases health care quality, and reduces health care costs. These procedures are performed throughout the hospital, from clinical areas such as the emergency department and ICUs to the medical/surgical wards and operating suites. Health care leaders and administrators should seriously consider creating hospital-wide policies that require bedside ultrasound guidance for all deep needle procedures.

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