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Diagnostic accuracy of a novel software technology for detecting pneumothorax in a porcine model

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ABSTRACT

Introduction: Our objective was to measure the diagnostic accuracy of a novel software technology to detect pneumothorax on Brightness (B) mode and Motion (M) mode ultrasonography.

Methods: Ultrasonography fellowship-trained emergency physicians performed thoracic ultrasonography at baseline and after surgically creating a pneumothorax in eight intubated, spontaneously breathing porcine subjects. Prior to pneumothorax induction, we captured sagittal M-mode still images and B-mode videos of each intercostal space with a linear array transducer at 4 cm of depth. After collection of baseline images, we placed a chest tube, injected air into the pleural space in 250 mL increments, and repeated the ultrasonography for pneumothorax volumes of 250 mL, 500 mL, 750 mL, and 1000 mL. We confirmed pneumothorax with intrapleural digital manometry and ultrasound by expert sonographers. We exported collected images for interpretation by the software. We treated each individual scan as a single test for interpretation by the software.

Results: Excluding indeterminate results, we collected 338 M-mode images for which the software demonstrated a sensitivity of 98% (95% confidence interval [CI] 92–99%), specificity of 95% (95% CI 86–99), positive likelihood ratio (LR+) of 21.6 (95% CI 7.1–65), and negative likelihood ratio (LR−) of 0.02 (95% CI 0.008–0.046). Among 364 B-mode videos, the software demonstrated a sensitivity of 86% (95% CI 81–90%), specificity of 85% (81–91%), LR+ of 5.7 (95% CI 3.2–10.2), and LR− of 0.17 (95% CI 0.12–0.22).

Conclusions: This novel technology has potential as a useful adjunct to diagnose pneumothorax on thoracic ultrasonography.

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1. Introduction

1.1. Background

Bedside thoracic ultrasonography is a valuable tool for the diagnosis of pneumothorax but is prone to operator error [1]. Ultrasonography demonstrates higher diagnostic accuracy for pneumothorax when compared to physical examination and supine chest radiography [2,3]. However, skilled operators may not be routinely available to provide training and quality assurance. There is potential for computer technology to aid in the diagnosis of this potentially life threatening condition in the absence of expert sonographers such as the prehospital setting.

To assist the novice ultrasonographer, biomedical engineers developed the Intelligent Focused Assessment with Sonography in Trauma (iFAST) software algorithm [4]. The iFAST is a computerized diagnostic assistant designed to automatically detect pneumothorax on standard ultrasonography imagery. This software systematically analyzes Brightness (B) mode video clips and Motion (M) mode still images for the presence of sliding lung and seashore signs, respectively [5]. In a recent study, the iFAST demonstrated a sensitivity of 79% and a specificity of 87% to detect pneumothorax as compared to expert physician sonographers [6]. Limitations of this study included retrospective design and lack of definitive reference standard for diagnosis.

1.2. Study objectives

The primary objective of this investigation was to estimate the diagnostic accuracy of the iFAST computer algorithm to detect pneumothorax

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on M-mode and B-mode ultrasonography imagery. The secondary objective was to assess the association between algorithm sensitivity and pneumothorax volume.

2. Methods

2.1. Study design and setting

We conducted an experimental study assessing the accuracy of computerized interpretation of thorax ultrasound in a porcine pneumothorax model. We conducted the study as part of a parallel investigation of chest seal placement in an animal vivarium. We complied with the regulations and guidelines of the Animal Welfare Act and the American Association for Accreditation of Laboratory Animal Care. The Institutional Animal Care and Use Committee approved the investigation.

2.2. Animal subjects

The veterinary service prepared eight female crossbred Yorkshire swine (*Sus scrofa*) in similar fashion to a prior study evaluating chest seals in pneumothorax [7]. Swine weighing 35 to 45 kg underwent sedation with a mixture of intramuscular ketamine, tiletamine-zolazepam, and midazolam. After induction with 2–3% isoflurane in 30% oxygen, technicians intubated the animals with a cuffed 7.5 mm endotracheal tube and set the ventilator to assist-control mode, tidal volume (Vt) 8 mL/kg, respiratory rate (RR) 12 to 16 breaths/min, and fraction of inspired oxygen (FiO2) 21 to 30%.

Veterinary technicians then established carotid and femoral arterial lines (Millar Instruments, Houston, TX) and an internal jugular vein Swan Ganz catheter (Edwards Lifesciences, Irvine, CA) for continuous hemodynamic monitoring as part of the parallel investigation. We delivered isotonic crystalloid at a maintenance rate and titrated to urine output. After instrumentation, we discontinued the isoflurane and provided sedation and analgesia with propofol at 3–6 mg/kg/h and buprenorphine at 2–8 μg/kg/h. The animals were supine and spontaneously breathing (transitioned to pressure support ventilation) for all ultrasonography examinations.

2.3. Study procedures

Two ultrasonography fellowship-trained emergency physicians prospectively collected sagittal thoracic ultrasonography images using a Sonosite M-Turbo (Bothell, WA) equipped with a linear array transducer (5 to 10 MHz). We collected images at baseline and after surgically creating a pneumothorax in eight intubated, spontaneously breathing porcine subjects. We induced only one pneumothorax in each subject to avoid hemodynamic compromise. We arbitrarily chose the left chest in all subjects to maintain consistency. We recorded one M-mode still image along with a six second B-mode video clip of each intercostal space of the left chest, all in the sagittal plane, beginning with the second intercostal space in the mid-clavicular line and continuing in an inferior-lateral direction until we visualized the diaphragm. If we visualized the heart or lung pulse, we moved the probe laterally until these findings were no longer present. There were no instances in which we were unable to capture these measurements in each intercostal space.

After we obtained baseline images, a research physiologist inserted a 14-gauge pleural catheter into the left sixth intercostal space in the mid-axillary line. We then attached this catheter to a three-way stopcock connected to a digital manometer (NETECH, Digimano, Farmingdale, NY), injected 250 mL of air in the pleural space, and confirmed a non-negative resting intrapleural pressure to establish the presence of pneumothorax. We always confirmed presence of pneumothorax through identification (by one of the two ultrasonography fellowship-trained emergency physicians) of absent lung sliding, barcode sign, and lung point. The lung point location varied according to pneumothorax volume; we visualized the lung point at higher intercostal spaces with lower pneumothorax volumes. Following confirmation of pneumothorax, we repeated the left-sided ultrasonography examinations beginning with the second intercostal space and continuing in an inferior-lateral direction until visualization of the lung point. Because the sonographic lung point defines the terminal edge of the pneumothorax, we did not collect images at intercostal spaces below this level [5].

We continued with 250 mL incremental injections of air into the pleural space and repeated the ultrasonography examinations for pneumothorax volumes of 500 mL, 750 mL, and 1000 mL. Finally, we exported all images from the ultrasonography machine and arranged them in random order on a compact disc for iFAST interpretation. The biomedical engineer, blinded to the diagnosis and the timing of the ultrasonography examinations, applied the iFAST alogorithm to each image and recorded the software interpretation on a standardized data collection instrument. For each image, the iFAST rendered an interpretation of positive, negative, or indeterminate for pneumothorax.

We have described the iFAST computer algorithm in detail previously [4,6]. Briefly, in M-mode the iFAST identifies the pleural line as the most hyperechoic horizontal line on the image and then analyzes below that line for pixel granularity or “bar code” pattern (Fig. 1). The iFAST will report negative for pneumothorax if there is a significant proportion of sub-pleural speckling in M-mode resembling a “sandy beach.” In B-mode, the iFAST first identifies the rib shadows to locate the pleural line. Once identified, the iFAST dynamically scans video clips at 30 frames per second for pixel movement along the pleural line as well reverberation artifacts extending below (Fig. 2). The iFAST reports negative for pneumothorax if it identifies the presence of sliding lung. When the iFAST is unable to identify a pleural line, it reports an indeterminate result. The algorithm remained fixed during this study.

2.4. Outcomes

The primary outcome was the diagnostic accuracy of the iFAST computer algorithm interpretation of M-mode and B-mode scans, considered independently. As we did not have access to computed tomography, the reference standard was presence of surgically-induced pneumothorax as confirmed by intrapleural pressure monitor [7-9]. One of the two ultrasonography fellowship-trained emergency physicians also confirmed presence of pneumothorax by identification of all three of the following: absent lung sliding, barcode sign, and lung point.

2.5. Analysis

We analyzed the data using non-parametric descriptive statistics to report intrapleural pressure measurements stratified by lung volume (Fig. A.1). We calculated iFAST diagnostic test characteristics separately for M-mode and B-mode. Characteristics calculated included sensitivity, specificity, positive likelihood ratio (LR+) and negative likelihood ratio (LR−). We further stratified these calculations by pneumothorax volume. We excluded indeterminate results from these calculations. We also repeated these calculations assuming all indeterminate results were inaccurate to generate conservative estimates of the algorithm's diagnostic accuracy [10]. We calculated confidence intervals using jackknife resampling methods [11].

3. Results

3.1. Main results

We collected 343 M-mode and 364 B-mode thoracic ultrasonography images for interpretation by the iFAST (Table 1). We excluded three (0.9%) M-mode images and two (0.5%) B-mode images which were irretrievable from the Sonosite hard drive. The iFAST was indeterminate for 2 (0.6%) M-mode images and 14 (3.8%) B-mode, leaving