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Chest ultrasonography versus supine chest radiography for diagnosis of pneumothorax in trauma patients in the emergency department (Protocol)

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[Diagnostic Test Accuracy Protocol]

Chest ultrasonography versus supine chest radiography for diagnosis of pneumothorax in trauma patients in the emergency department

Kenneth K Chan[1], Daniel A Joo[1], Andrew D McRae[1], Yemisi Takwoingi[2], Zahra A Premji[3], Eddy Lang[1], Abel Wakai[4]

[1]Department of Emergency Medicine, University of Calgary, Calgary, Canada. [2]Institute of Applied Health Research, University of Birmingham, Birmingham, UK. [3]Libraries and Cultural Resources, University of Calgary, Calgary, Canada. [4]Emergency Care Research Unit (ECRU), Division of Population Health Sciences (PHS), Royal College of Surgeons in Ireland (RCSI), Dublin 2, Ireland

Contact address: Kenneth K Chan, Department of Emergency Medicine, University of Calgary, Foothills Medical Centre, Room C231, 1403 29th Street NW, Calgary, AB, T2N 2T9, Canada. kchan.med@gmail.com.

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ABSTRACT

This is a protocol for a Cochrane Review (Diagnostic test accuracy). The objectives are as follows:

To compare the diagnostic accuracy of chest ultrasonography (CUS) by frontline non-radiologist physicians versus supine chest X-ray (CXR) for diagnosis of pneumothorax in trauma patients in the emergency department.

BACKGROUND

Thoracic trauma can cause significant morbidity and mortality, directly accounting for 20% to 25% of deaths from trauma (Rosen 2014). Injury to any of several vital intrathoracic organs can result in immediate death. Traumatic pneumothorax is a common complication of thoracic trauma, occurring in 15% to 50% of patients with significant thoracic trauma (Khandhar 2007).

Target condition being diagnosed

Pneumothorax occurs when air collects between the parietal and visceral pleurae, causing the lung parenchyma to collapse. Traumatic pneumothorax commonly occurs when a fractured rib damages the pleural lining or lung laceration with resultant air leakage (ATLS 2012; Rosen 2014; Sharma 2008). Traumatic pneumothorax without rib fracture occurs when a traumatic force compresses the chest in a person with a closed glottis, suddenly increasing intrathoracic pressure and resulting in alveolar rupture (Rosen 2014). The size of the pneumothorax is quantified based on the proportion of the pleural cavity that is occupied by air, with 15% or less of the pleural cavity graded as small, 15% to 60% as moderate, and more than 60% as large (Rosen 2014). Occult pneumothoraces are those that are not initially detected by chest X-ray (CXR) but are found on computed tomography (CT).

Pneumothorax results in a ventilation/perfusion mismatch. Patients typically report dyspnoea and chest pain. Early detection of pneumothorax is important for determining management and disposition in trauma patients. Failure to detect and treat pneumothorax could lead to acute complications including hypoxia, tension pneumothorax, cardiopulmonary failure, or death. This is especially important in patients undergoing general anaesthesia and positive-pressure ventilation, and among those transported by air at high altitude, as the pneumothorax can quickly progress to a life-threatening tension pneumothorax (ATLS 2012). Long-term complications of untreated pneumothorax include the development of pneumomediastinum, re-expansion pulmonary oedema, empyema, or bronchopulmonary fistula (Rosen 2014). Identification and management of occult pneumothorax is currently a topic of discussion in the trauma literature owing to the risk of clinical deterioration in a patient with an unrecognized occult pneumothorax who undergoes positive-pressure ventilation (Mowery 2011). Clinical deterioration occurs as the result of an increase in the size of the pneumothorax, ultimately producing a tension pneumothorax, which causes shock by obstructing venous return to the heart. As such, early detection and decompression of significant pneumothorax is imperative.

Management of pneumothorax depends on the clinical status of the patient and the volume of air trapped in the pleural space. If the pneumothorax is considered clinically significant, treatment consists of a tube thoracostomy. However, studies have provided conflicting evidence regarding whether to treat or not treat occult pneumothorax before the patient undergoes positive-pressure ventilation (Enderson 1993; Kirkpatrick 2013). Emergency physicians and trauma surgeons perform this procedure at the bedside by inserting a tube into the pleural space for evacuation of collected air. The tube is typically attached to suction drainage to maintain a negative pressure within the pleural cavity while facilitating lung re-expansion. Tube thoracostomy is associated with a reported complication rate of 5% to 40%; complications include haemorrhage, organ injury, and infection (Filosso 2017; Kwaitt 2014). This highlights the clinical importance of a safer, more rapid, and more accurate method of diagnosing pneumothorax.

Index test(s)

Chest ultrasonography (CUS) may be a safer, more rapid, and more accurate modality for the diagnosis of pneumothorax in trauma patients. Studies have shown the high sensitivity and specificity of CUS in non-trauma settings, such as in the intensive care unit, or with postprocedure iatrogenic pneumothorax (Chung 2005; Lichtenstein 2005; Shostak 2013). The Advanced Trauma Life Support (ATLS) protocol currently recommends the use of ultrasonography (US) when Focused Assessment With Sonography for Trauma (FAST) is performed for assessment of intra-abdominal injuries (ATLS 2012). CUS can be completed in conjunction with the FAST scan at the bedside, without moving the patient out of the resuscitation bay, and can be an effective diagnostic tool for detecting thoracic injuries. Because US utilizes high-frequency sound waves, the patient encounters no ionizing radiation exposure.

Trauma patients are typically assessed in the supine position. Air collected in the pneumothorax rises up towards non-dependent areas within the thoracic cavity. CUS is completed in the longitudinal plane with the indicator pointing cephalad, and the probe is placed in the third or fourth intercostal space in the midclavicular line (Chan 2003; Husain 2012; Lichtenstein 2005). Although a microconvex probe is ideal, other transducers such as the convex or linear array probe may be used (Volpicelli 2012).

Four sonographic findings are associated with pneumothorax on CUS: absence of lung sliding; absence of B-lines or comet-tail artefact; presence of lung point; and absence of lung pulse (Volpicelli 2012). Normal lungs are attached to the visceral pleura and slide along the parietal pleura in a rhythmical pattern with the respiratory cycle. Via M-mode, a visual representation of lung sliding over time can be generated, known as the "seashore sign" (Alrajhi 2012; Lichtenstein 2005; Husain 2012). In pneumothorax, air trapped in the pleural space disrupts this rhythmical sliding, and M-mode would demonstrate the "barcode sign" or "stratosphere sign" (Husain 2012; Lichtenstein 2005). Comet-tail artefacts, or B-lines, are bright hyperechoic vertical rays produced by reverberation artefacts (Alrajhi 2012; Husain 2012). These B-lines originate from the visceral pleura and move synchronously with lung sliding (Chan 2003; Husain 2012). Absence of B-lines suggests the presence of a pneumothorax. The lung point is the point at which the visceral pleura of the lung begins to separate from the parietal pleura of the chest wall at the margin of a pneumothorax; this is visible on CUS (Lichtenstein 2005). Finally, lung pulse comprises the subtle rhythmical movements of the pleura due to cardiac oscillations (Volpicelli 2011; Volpicelli 2012).

ATLS guidelines recommend use of CXR as an adjunct to the primary survey in the initial trauma assessment (ATLS 2012). This diagnostic tool is commonly used to identify many thoracic injuries such as haemothorax, pneumomediastinum, pulmonary contusion, or rib fracture. However, previous literature has shown that it is not a sensitive test for detecting pneumothorax (Wilkerson 2010). For many reasons, the trauma patient is usually kept supine during acute resuscitation until a full assessment to identify injuries is completed. Performing supine CXR requires time, resources, and equipment and may further delay the diagnosis and management of a pneumothorax. A film cassette or a flat panel detector must be placed underneath the supine patient, and the X-ray tube brought in over the top of the patient. Positioning the cassette or detector may require rolling the patient, risking further injury, and prolonging resuscitation of the patient. To protect healthcare providers from radiation exposure, all personnel within the vicinity must wear lead-shielded personal protective gear or must vacate the area, leaving the patient unattended. CXR exposes the patient to a small dose of radiation, estimated at 0.1 millisievert (mSv), or the equivalent of exposure to natural background radiation for 10 days (Chung 2014). The X-ray must be positioned correctly and must be timed to synchronize with the patient's inspiration. The entire process of completing supine CXR therefore can be very disruptive and may delay resuscitation of the trauma patient.

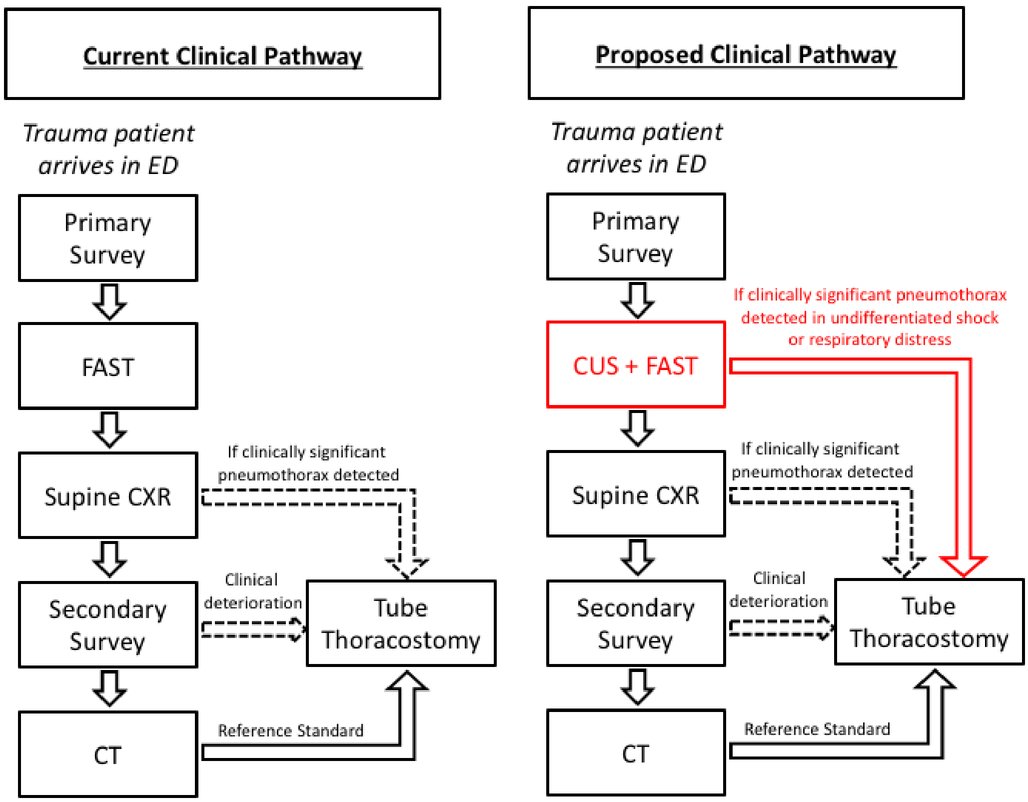
Clinical pathway

Trauma patients in the emergency department are initially assessed clinically for immediate life-threatening conditions. Resuscitative measures such as administration of intravenous fluids or blood products, airway intubation, or tube thoracostomy may be required. Many emergency physicians and trauma surgeons consider the use of US for FAST scans as standard-of-care, as it can be used to identify intra-abdominal injuries that may require immediate operative management. Supine CXR is used as an adjunct to the primary survey to identify intrathoracic injuries but "should be used judiciously, and should not delay patient resuscitation" (ATLS 2012).

The secondary survey allows for a more thorough clinical examination as well as specialized diagnostic tests such as X-rays of specific areas like the spine or wrist, CT, or angiography. These specialized diagnostic tests typically require transporting the patient out of the resuscitation bay and into the diagnostic imaging department, which typically is ill-equipped for resuscitative interventions. Unfortunately, if no pneumothorax is suspected on clinical examination or CXR, the clinician may opt to not do a CT scan of the chest and may miss a clinically significant pneumothorax. CT scans of the cervical spine in trauma patients have detected occult pneumothoraces that were previously missed on supine CXR, or when patients did not receive a CT of their chest (Ball 2012). Depending on the clinical status of the patient, the extent of injury, and the capability of the hospital, the patient will be further treated by a trauma surgery service or will be transferred to a centre with trauma care expertise.

CUS may have a role in the primary survey for rapidly diagnosing clinically significant traumatic pneumothorax as the source of instability in a critically ill trauma patient. Traumatic pneumothorax identified with CUS may provide an accurate and rapid diagnosis, leading to immediate management with tube thoracostomy (Figure 1). However, because of potential thoracic injuries other than pneumothorax that can be revealed by CXR, CXR will continue to play an important role in the initial diagnostic evaluation and management of trauma.

Figure 1. Current and proposed clinical pathway - CUS may provide a faster and more accurate diagnosis of traumatic pneumothorax, leading to immediate tube thoracostomy in an unstable trauma patient. Supine CXR is a useful diagnostic tool for identification of other traumatic pathologies, such as rib fractures, mediastinal injuries, etc.



Once a pneumothorax has been identified, clinicians will determine whether tube thoracostomy is clinically warranted. Generally speaking, it is accepted practice that a tube thoracostomy is indicated when a pneumothorax is identified in a hypotensive trauma patient (ATLS 2012). In our clinical context, producing a true positive (TP) equates to finding a pneumothorax, which may lead to a clinically appropriate tube thoracostomy, and a false positive (FP) suggests that a pneumothorax has been found when there is none, potentially leading to a clinically unnecessary tube thoracostomy. A true negative (TN) would successfully rule out a pneumothorax, leading to an appropriate decision to not perform tube thoracostomy; whereas a false negative (FN) would mean that a pneumothorax that may have required a clinically necessary tube thoracostomy might be missed.

Many hospitals and healthcare systems do not have in-hospital trauma specialists, intensivists, or radiologists to perform CUS or tube thoracostomy. In most emergency departments, the frontline physician assessing and treating trauma patients is an emergency physician or a trauma surgeon. Hence, these physicians play a key role in the initial diagnosis and management of traumatic pneumothorax. Once a patient's condition has been stabilized, and the patient has been resuscitated, the frontline physician arranges for the patient to be transferred to a designated trauma centre for further assessment and management, if clinically warranted.

Alternative test(s)

Clinical examination for pneumothorax may reveal hyper-resonance on percussion, subcutaneous emphysema on palpation, and decreased or absent breath sounds on auscultation (Rosen 2014). These findings are not reliable for a small pneumothorax (Noppen 2008). Unfortunately, the accuracy and utility of these physical exam manoeuvres are extremely limited in the noisy and chaotic resuscitation bay.

CT is considered the reference standard for detection of thoracic injuries including pneumothorax (Alrajhi 2012; Chung 2014;

Wilkerson 2010). CT technology has drastically improved over the years, allowing for greater image resolution and improved sensitivity in detecting pathology. CT reveals the diagnosis of pathology with the perspective of its relation to the rest of the thorax. However, CT has limitations. Transporting a potentially unstable patient away from the resuscitation bay to the diagnostic imaging department has its inherent risks due to lack of equipment, space, and personnel to help with resuscitation should the patient decompensate. CT exposes the patient to ionizing radiation estimated at 7 mSv or the equivalent of exposure to two years of natural background radiation (Chung 2014). Allergic reactions to CT contrast dye present additional risk.

Depending on the patient's condition, tube thoracostomy may be performed emergently at any point of trauma resuscitation. Upon insertion of the chest tube into the pleural space, a rush of air or bubbling in the chest drain confirms the diagnosis of pneumothorax. This has been accepted in the trauma literature as an alternative reference standard (Alrajhi 2012; Wilkerson 2010).

Rationale

US technology has progressively improved over the years and has become more accessible and portable in the emergency department (Husain 2012). Image generation has become easier and more reliable with new hardware and software. Recognizing the importance of bedside US, many healthcare systems, hospitals, and specialty training programmes have incorporated US training for their non-radiologist physicians. Emergency physicians and trauma surgeons have already been using bedside US for FAST scans in trauma patients. Rapid detection of traumatic pneumothorax with CUS will lead to more efficient management with tube thoracostomy, reducing the incidence of pneumothorax-related complications, and thus improving outcomes in trauma patients.

Systematic reviews on the diagnostic accuracy of CUS have been published, but these reviews have significant heterogeneity for patient population, etiology of pneumothorax, operator medical background (radiologists, intensivists, respirologists, etc), methodological quality of included studies, and poor data analysis methods (Alrajhi 2012; Alrajab 2013; Ding 2011; Ebrahimi 2014). The etiology of pneumothorax is important to consider, as trauma patients lie supine for the CUS and CXR, whereas if the cause of pneumothorax was spontaneous or iatrogenic from a biopsy, from a central line insertion, or post surgery, the patient may not have been lying supine, significantly altering the test characteristics of both CUS and CXR.

Therefore, we aim to assess the diagnostic accuracy of CUS compared with supine CXR in the detection of pneumothorax in emergency department trauma patients. The findings of this review may provide evidence for the incorporation of CUS into trauma (e.g. ATLS) protocols and algorithms in future medical training programs, and may potentially change routine management of trauma.

O B J E C T I V E S

To compare the diagnostic accuracy of chest ultrasonography (CUS) by frontline non-radiologist physicians versus supine chest X-ray (CXR) for diagnosis of pneumothorax in trauma patients in the emergency department.

Secondary objectives

To determine the diagnostic accuracy of individual CUS findings such as absence of lung sliding, absence of B-lines or comet-tail artefact, presence of lung point, and absence of lung pulse.

To investigate the effects of potential sources of heterogeneity such as type of CUS operator (frontline non-radiologist physicians), type of trauma (blunt vs penetrating), and type of US probe on test accuracy.

M E T H O D S

Criteria for considering studies for this review

Types of studies

We will include prospective, paired comparative accuracy studies. In paired comparative studies, patients suspected of having pneumothorax undergo both CUS by frontline non-radiologist physicians and CXR as index tests, as well as CT of the chest or tube thoracostomy as the reference standard. We will exclude studies involving participants with already diagnosed pneumothorax (i.e. case control studies) and participants with non-traumatic pneumothorax; studies involving participants who have already been treated with tube thoracostomy; and studies in which a frontline non-radiologist physician did not perform CUS.

Participants

We will include trauma patients in the emergency department setting, irrespective of age and gender.

Index tests

The two main index tests are CUS completed by a frontline non-radiologist physician and CXR done in the supine position. If studies report data on specific CUS findings (such as absence of lung sliding, absence of B-lines or comet-tail artefact, presence of lung point, and absence of lung pulse), we will also estimate the diagnostic accuracy of these individual CUS findings.

Target conditions

The target condition is traumatic pneumothorax of any severity.

Reference standards

We define a pneumothorax identified on CT scan of the chest or via clinical findings of a rush of air or bubbling in chest drain after tube thoracostomy as the reference standard.

Search methods for identification of studies

Electronic searches

We will search PROSPERO and the Cochrane Library for related reviews. We will develop and carry out systematic searches in the following electronic databases: MEDLINE (1946 to present), Embase (1974 to present), Cumulative Index to Nursing and Allied Health Literature (CINAHL) Plus (1937 to present), Database of Abstracts of Reviews of Effects (1991 to 2015), Web of Science (1900 to present), Clinicaltrials.gov, and the Cochrane Library. We will use sensitive search strategies as recommended in Chapter 7 of the*Cochrane Handbook for Systematic Reviews of Diagnostic Test Accuracy* (De Vet 2013). Our search strategy will include subject headings and free text terms. We will apply no language restrictions or additional filters in the searches. We will translate the MEDLINE search strategy (Appendix 1) for use in the other electronic databases.

Searching other resources

We will handsearch reference lists of relevant articles and reviews, retrieved via electronic searching, for eligible studies missed in the electronic database searches. We will also carry out forward citation searching of relevant articles in Google Scholar and will look at the "Related articles" on PubMed. We will carry out a search on Google to identify any unpublished studies or relevant grey literature.

Data collection and analysis

Selection of studies

Two review authors (KC and DJ) will screen titles and abstracts and will exclude irrelevant citations. We will obtain the full text of articles that potentially meet the inclusion criteria based on initial screening. Two review authors (KC and DJ) will independently screen these articles for inclusion. We (KC and DJ) will resolve any discrepancies through discussion; if disagreements arise, a third review author (AM) will arbitrate.

Data extraction and management

Two review authors (KC and DJ) will independently extract data using a standardized data collection form (Appendix 2). A third review author (AM) will evaluate any discrepant judgements. When necessary, we will contact study authors for clarification or additional data.

We will collect the following information.

- General characteristics: title, journal, year, institution, country where the study was performed, study period, study design, sample size, units of analysis (per patient or per lung field), type of CUS operator (frontline non-radiologist physicians).
- Population characteristics: age, gender, type of trauma, inclusion/exclusion criteria used in study, sampling used in study.
- Accuracy data for CUS, CXR, and individual US findings (absence of lung sliding, absence of B-lines or comet-tail artefact, presence of lung point, and absence of lung pulse): two-by-two tables of the numbers of true positives, false positives, false negatives, and true negatives, or summary statistics that will enable derivation of the tables.
- Time to CUS, CXR, and CT.
- Type of US probe (curvilinear, high-frequency linear, etc) and transducer.
- Definitions of test positivity for each index test and reference standard (CT).
- Reference standard: characteristics of CT or tube thoracostomy.

Assessment of methodological quality

We will use the QUADAS-2 tool to assess risk of bias and the applicability of each included study. This tool assesses risk of bias in four domains: patient selection; index tests; reference standard; and flow and timing. In addition, we will examine concerns about applicability in the first three domains (Whiting 2011). We have tailored the tool to our review question, as shown in Appendix 3. One of the signalling questions in the patient selection domain is not applicable because we will exclude case control studies. Therefore, we deleted this question from the tool. Two review authors (KC and DJ) will perform the assessments independently. They will discuss discrepancies and will resolve disagreements that remain through consultation with a third review author (AM).

Statistical analysis and data synthesis

The unit of analysis (per patient or per lung field) may differ between studies. Our primary analyses will be per patient. Data permitting, we will also consider lung fields in secondary analyses. For preliminary analyses of CUS, CXR, and each of the four US findings, we will use Review Manager (RevMan 2014) to plot estimates of sensitivity and specificity from studies in receiver operating characteristics (ROC) space and on forest plots.

Since the results of CXR and CUS are binary (i.e. pneumothorax present or absent), we will perform meta-analysis by using a bivariate model to estimate summary sensitivities and specificities (Chu 2006; Reitsma 2005). For the comparative meta-analysis of CUS and CXR, we will add test type as a covariate to a bivariate model (Macaskill 2013; Takwoingi 2015a). This comparative meta-analysis is a direct comparison of the accuracy of the two tests because we plan to include only comparative studies of CUS and CXR in the review. Comparative studies are generally scarce (Takwoingi 2013); if a meta-analysis includes few studies, we will simplify the bivariate model to univariate random-effects logistic regression models for sensitivity and specificity. If a random-effects meta-analysis of sensitivity (or specificity) failed to converge, and if we observed minimal or no variability in sensitivity (or specificity) between studies on a summary receiver operating characteristic (SROC) plot, and on a forest plot, we will use fixed-effect logistic regression models (Takwoingi 2015b). We will use likelihood ratio tests to assess the statistical significance of differences in sensitivity, and specificity. We will fit bivariate and univariate logistic regression models using the meqrlogit command in Stata version 15 (Stata 2017).

Investigations of heterogeneity

We will graphically explore heterogeneity by using forest plots and SROC plots. Data permitting, we will use meta-regression to formally investigate the effect of each potential source of heterogeneity on sensitivity and specificity of CUS and CXR by adding covariate terms for type of trauma (blunt vs penetrating) to a bivariate model. For CUS, we will also investigate the effect of type of CUS operator (frontline non-radiologist physicians) and the type of US probe (curvilinear, high-frequency linear, or phased array probes). We will investigate only one covariate at a time in the model for each test. If possible, we will investigate the effect of type of trauma on the relative accuracy of CUS and CXR. If data permit, we will examine the effects of different combinations of CUS findings (absence of lung sliding, absence of B-lines or comet-tail artefact, presence of lung point, and absence of lung pulse) used to define a positive CUS test for pneumothorax.

Sensitivity analyses

We will perform a sensitivity analysis to examine the impact of blinding by excluding studies in which the same frontline non-radiologist physician who performed the CUS interpreted the CXR.

Assessment of reporting bias

We do not plan to assess reporting bias, as methods are not well developed.

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REFERENCES

Additional references

Alrajab 2013
Alrajab S, Youssef AM, Akkus NI, Caldito G. Pleural ultrasonography versus chest radiography for the diagnosis of pneumothorax: review of the literature and meta-analysis. *Critical Care* 2013;**17**:R208. DOI: 10.1186/cc13016; PUBMED: 24060427

Alrajhi 2012
Alrajhi K, Woo MY, Vaillancourt C. Test characteristics of ultrasonography for the detection of pneumothorax: a systematic review and meta-analysis. *Chest* 2012;**141**(3):703–8. DOI: 10.1378/chest.11-0131; PUBMED: 21868468

ATLS 2012
ATLS Committee. *Advanced Trauma Life Support® Student Course Manual*. 9th Edition. Chicago: American College of Surgeons, 2012. [ISBN 13: 978–1–880696–02–6]

Ball 2012
Ball CG, Roberts DJ, Kirkpatrick AW, Feliciano DV, Kortbeek JB, Datta I, et al. Can cervical spine computed tomography assist in detecting occult pneumothoraces?. *Injury* 2012;**43**(1):51–4. DOI: 10.1016/j.injury.2011.09.019; PUBMED: 21999936

Chan 2003
Chan SS. Emergency bedside ultrasound to detect pneumothorax. *Academic Emergency Medicine* 2003;**10**(1):91–4. [PUBMED: 12511323]

Chu 2006
Chu H, Cole SR. Bivariate meta-analysis of sensitivity and specificity with sparse data: a generalized linear mixed model approach. Journal of Clinical Epidemiology 2006; Vol. 59, issue 12:1331-2; author reply 1332-3. [PUBMED: 17098577]

Chung 2005
Chung MJ, Goo JM, Im JG, Cho JM, Cho SB, Kim SJ. Value of high-resolution ultrasound in detecting a pneumothorax. *European Radiology* 2005;**15**(5):930–5. DOI: 10.1007/s00330-004-2518-7; PUBMED: 15609058

Chung 2014
Chung JH, Cox CW, Mohammed TH, Kirsch J, Brown K, Dyer DS, et al. ACR appropriateness criteria blunt chest trauma. *Journal of the American College of Radiology* 2014;**11**(4):345–51. DOI: 10.1016/j.jacr.2013.12.019; PUBMED: 24603073

De Vet 2013
de Vet HCW, Eisinga A, Riphagen II, Aertgeerts B, Pewsner D. Chapter 7: Searching for studies. In: Deeks JJ, Bossuyt PM, Gatsonis C, editor(s). Cochrane Handbook for Systematic Reviews of Diagnostic Test Accuracy. Version 1.0.0. Cochrane Collaboration, 2013. Available from srdta.cochrane.org.

Ding 2011
Ding W, Shen Y, Yang J, He X, Zhang M. Diagnosis of pneumothorax by radiography and ultrasonography. *Chest* 2011;**140**(4):859–66. DOI: 10.1378/chest.10-2946; PUBMED: 21546439

Ebrahimi 2014
Ebrahimi A, Yousefifard M, Kazemi HM, Rasouli HR, Asady H, Jafari AM, et al. Diagnostic accuracy of chest ultrasonography versus chest radiography for identification of pneumothorax: a systematic review and meta-analysis. *Tanaffos* 2014;**13**(4):29–40. [PUBMED: 25852759]

Enderson 1993
Enderson BL, Abdalla R, Frame SB, Casey MT, Gould H, Maull KI. Tube thoracostomy for occult pneumothorax: a prospective randomized study of its use. *Journal of Trauma* 1993;**35**(5):726–30. DOI: 10.1097/00005373-199311000-00013; PUBMED: 8230337

Filosso 2017
Filosso PL, Guerrera F, Sandri A, Roffinella M, Solidoro P, Ruffini E, et al. Errors and complications in chest tube placement. *Thoracic Surgery Clinics* 2017;**27**(1):57–67. DOI: 10.1016/j.thorsurg.2016.08.009; PUBMED: 27865328

Husain 2012
Husain LF, Hagopian L, Wayman D, Baker WE, Carmody KA. Sonographic diagnosis of pneumothorax. *Journal of Emergencies, Trauma, and Shock* 2012;**5**(1):76–81. DOI: 10.4103/0974-2700.93116; PUBMED: 22416161

Khandhar 2007
Khandhar SJ, Johnson SB, Calhoon JH. Overview of thoracic trauma in the United States. *Thoracic Surgery Clinics* 2007;**17**(1):1–9. DOI: 10.1016/j.thorsurg.2007.02.004; PUBMED: 17650692

Kirkpatrick 2013
Kirkpatrick AW, Rizoli S, Ouellet JF, Roberts DJ, Sirois M, Ball CG, et al. Occult pneumothoraces in critical care: a prospective multicenter randomized controlled trial of pleural drainage for mechanically ventilated trauma patients with occult pneumothoraces. *Journal of Trauma and Acute Care Surgery* 2013;**74**(3):747–54. DOI: 10.1097/TA.0b013e3182827158; PUBMED: 23425731

Kwaitt 2014
Kwaitt M, Tarbox A, Seamon MJ, Swaroop M, Cipolla J, Allen C, et al. Thoracostomy tubes: a comprehensive review of complications and related topics. *International Journal of Critical Illness and Injury Science* 2014;**4**(2):143–55. DOI: 10.4103/2229-5151.134182; PUBMED: 25024942

Lichtenstein 2005
Lichtenstein DA, Mezière G, Lascols N, Biderman P, Courret J, Gepner A, et al. Ultrasound diagnosis of occult pneumothorax. *Critical Care Medicine* 2005;**33**(6):1231–8. [PUBMED: 15942336]

Macaskill 2013
Macaskill P, Gatsonis C, Deeks JJ, Harbord RM, Takwoingi Y. Chapter 10: Analysing and presenting results. In: Deeks JJ, Bossuyt PM, Gatsonis C, editor(s). Cochrane Handbook for Systematic Reviews of Diagnostic Test Accuracy. Version 1.0.0. Cochrane Collaboration, 2013. Available from srdta.cochrane.org.

Mowery 2011
Mowery NT, Gunter OL, Collier BR, Diaz JJ, Haut E, Hildreth A, et al. Practice management guidelines for management of hemothorax and occult pneumothorax. *Journal of Trauma: Injury, Infection, and Critical Care* 2011;**70**(2):510–8. DOI: 10.1097/TA.0b013e31820b5c31; PUBMED: 21307755

Noppen 2008
Noppen M, De Keukeleire T. Pneumothorax. *Respiration* 2008;**76**(2):121–7. DOI: 10.1159/000135932; PUBMED: 18708734

Reitsma 2005
Reitsma JB, Glas AS, Rutjes AW, Scholten RJ, Bossuyt PM, Zwinderman AH. Bivariate analysis of sensitivity and specificity produces informative summary measures in diagnostic reviews [Review]. *Journal of Clinical Epidemiology* 2005;**58**(10):982–90. [PUBMED: 16168343]

RevMan 2014 [Computer program]
The Nordic Cochrane Centre, The Cochrane Collaboration. Review Manager (RevMan). Version 5.3.5. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014.

Rosen 2014
Eckstein M, Henderson SO. Thoracic trauma. In: Marx JA editor(s). *Rosen's Emergency Medicine: Concepts and Clinical Practice*. 8th Edition. Vol. **1**, Philadelphia: Saunders, 2014: 431–58.

Sharma 2008
Sharma A, Jindal P. Principles of diagnosis and management of traumatic pneumothorax. *Journal of Emergencies, Trauma, and Shock* 2008;**1**(1):34–41. DOI: 10.4103/0974-2700.41789; PUBMED: 19561940

Shostak 2013
Shostak E, Brylka D, Krepp J, Pua B, Sanders A. Bedside sonography for detection of postprocedure pneumothorax. *Journal of Ultrasound in Medicine* 2013;**32**(6):1003–9. DOI: 10.7863/ultra.32.6.1003; PUBMED: 23716522

Stata 2017 [Computer program]
StataCorp LLC. Stata Statistical Software (Stata). Version 15. College Station, TX: StataCorp LLC, 2017.

Takwoingi 2013
Takwoingi Y, Leeflang MM, Deeks JJ. Empirical evidence of the importance of comparative studies of diagnostic test accuracy. *Annals of Internal Medicine* 2013;**158**(7):544–54. [PUBMED: 23546566]

Takwoingi 2015a
Takwoingi Y, Riley DD, Deeks JJ. Meta-analysis of diagnostic accuracy studies in mental health. *Evidence-Based Mental Health* 2015;**18**(4):103–9. DOI: 10.1136/eb-2015-102228; PUBMED: 26446042

Takwoingi 2015b
Takwoingi Y, Guo B, Riley RD, Deeks JJ. Performance of methods for meta-analysis of diagnostic test accuracy with few studies or sparse data. *Statistical Methods in Medical Research* 2015;**26**(4):1896–911. [PUBMED: 26116616]

Volpicelli 2011
Volpicelli G. Sonographic diagnosis of pneumothorax. *Intensive Care Medicine* 2011;**37**:224–32. DOI: 10.1007/s00134-010-2079-y; PUBMED: 21103861

Volpicelli 2012
Volpicelli G, Elbarbary M, Blaivas M, Lichtenstein DA, Mathis G, Kirkpatrick AW, et al. International evidence-based recommendations for point-of-care lung ultrasound. *Intensive Care Medicine* 2012;**38**(4):577–91. DOI: 10.1007/s00134-012-2513-4; PUBMED: 22392031

Whiting 2011
Whiting PF, Rutjes AW, Westwood ME, Mallett S, Deeks JJ, Reitsma JB, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. *Annals of Internal Medicine* 2011;**155**(8):529–36. DOI: 10.7326/0003-4819-155-8-201110180-00009; PUBMED: 22007046

Wilkerson 2010
Wilkerson RG, Stone MB. Sensitivity of bedside ultrasound and supine anteroposterior chest radiographs for the identification of pneumothorax after blunt trauma. *Academic Emergency Medicine* 2010;**17**(1):11–7. DOI: 10.1111/j.1553-2712.2009.00628.x; PUBMED: 20078434

* *Indicates the major publication for the study*

A P P E N D I C E S

Appendix 1. MEDLINE search strategy

Database: Ovid MEDLINE(R) Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) Daily, and Ovid MEDLINE(R) <1946 to Present>
Search strategy:
----
1. Pneumothorax/
2. pneumothora*.tw,kf.
3. PTX.tw,kf.
4. 1 or 2 or 3
5. Radiography/
6. Radiography, Thoracic/
7. radiograph*.tw,kf.
8. roentgen*.tw,kf.
9. radiogram*.tw,kf.
10. radiology.tw,kf.
11. chest film*.tw,kf.
12. CXR.tw,kf.
13. x-ray*.tw,kf.
14. x ray*.tw,kf.
15. xray.tw,kf.
16. 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15

17. Ultrasonography/
18. ultrasound*.tw,kf.
19. sonogra*.tw,kf.
20. ultrasonogra*.tw,kf.
21. CUS.tw,kf.
22. ultrasonic.tw,kf.
23. echotomograph*.tw,kf.
24. echograph*.tw,kf.
25. 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24
26. 4 and 16 and 25
27. 26 not (Animals/ not (Animals/ and Humans/))
****

Appendix 2. Data extraction form

General characteristics	
Title:	
Authors:	
Journal:	
Institution/Country where study was performed:	
Study period:	
Study design:	
Sample size:	
Sampling used:	
Units of analysis (per patient or per lung field):	
Type of US probe (curvilinear, high frequency linear, etc.):	
Specialty of CUS operator:	
Definition of test positivity by CUS:	
Definition of test positivity by CXR:	
Definition of test positivity by CT or tube thoracostomy:	

Population characteristics	
Age (years):	
Male gender (%):	
Blunt trauma (%):	
Inclusion criteria:	
Exclusion criteria:	

Diagnostic accuracy data for CUS			
	CT/Thoracostomy positive	CT/Thoracostomy negative	Total
CUS positive			
CUS negative			
Total			
Sensitivity (%):			
Specificity (%):			
Absence of lung sliding			
Sensitivity (%):			
Specificity (%):			
Absence of B-lines or comet-tail artefact			
Sensitivity (%):			
Specificity (%):			
Presence of lung point			
Sensitivity (%):			
Specificity (%):			
Absence of lung pulse			

(*Continued*)

Sensitivity (%):	
Specificity (%):	

Diagnostic accuracy data for CXR			
	CT/Thoracostomy positive	CT/Thoracostomy negative	Total
CXR positive			
CXR negative			
Total			
Sensitivity (%):			
Specificity (%):			

Time to diagnostic imaging	
Time to CUS (min)	
Time to CXR (min)	
Time to CT/Thoracostomy (min)	

Notes:
CUS = Chest ultrasonography
CXR = Chest X-ray
CT = Computed tomography

Appendix 3. QUADAS-2 tool for assessing methodological quality of included studies

Domain	Signaling question	Signaling question	Risk of bias	Concerns about applicability
Domain 1: Patient selection				

(*Continued*)

Patient selection	Was a consecutive or random sample of patients enrolled?	Did the study avoid inappropriate exclusions?	Could the selection of patients have introduced bias?	Is there concern that the included patients do not match the review question?
	Yes: if all consecutive or random samples of trauma patients were enrolled No: if convenience or selected samples of trauma patients were enrolled Unclear: if this was not clear from the report	Yes: if the study avoided inappropriate exclusions No: if patients were excluded inappropriately (e.g. age, gender, ethnicity) Unclear: if this was not clear from the report	Low: if "Yes" for all signalling questions High: if "No" was reported for at least 1 signalling question Unclear: if "Unclear" was reported for at least 1 signalling question	Low: if the included population consists of trauma patients in the emergency department setting, irrespective of age and gender, and if inappropriate exclusions were avoided High: if study authors used inappropriate exclusions Unclear: if insufficient information was available to make a judgement
Domain 2: Index tests				
Index test - CUS	Were CUS results interpreted without knowledge of the results of CT or tube thoracostomy?	Did the authors prespecify the criteria for a positive CUS finding?	Could the conduct or interpretation of the index test have introduced bias?	Is there concern that the index test, its conduct, or interpretation differ from the review question?
	Yes: if CUS results were interpreted without knowledge of the results of CT No: if CUS results were interpreted with knowledge of the results of CT Unclear: if this was not clear from the report	Yes: if criteria for positive CUS findings were prespecified No: if the criteria for positive CUS findings were not prespecified Unclear: if this was not clear from the report	Low: if "Yes" for all signalling questions High: if "No" was reported for at least 1 signalling question Unclear: if "Unclear" was reported for at least 1 signalling question	Low: if CUS was performed by frontline physicians (emergency physicians or trauma surgeons) in the emergency department High: if CUS was performed by someone other than emergency physicians or trauma surgeons outside of the emergency department setting Unclear: if insufficient information was available to make a judgement
Index test - CXR	Were CXR results interpreted without knowl-		Could the conduct or interpretation of the in-	Is there concern that the index test, its conduct,

(*Continued*)

	edge of the results of CT or tube thoracostomy?		dex test have introduced bias?	or its interpretation differ from the review question?
	Yes: if CXR results were interpreted without knowledge of the results of CT No: if CXR results were interpreted with knowledge of the results of CT Unclear: if this was not clear from the report		Low: if "Yes" for all signalling questions High: if "No" was reported for at least 1 signalling question Unclear: if "Unclear" was reported for at least 1 signalling question	Low: if CXR was performed in the supine fashion in the emergency department High: if CXR was not performed in the supine fashion or outside of the emergency department setting Unclear: if insufficient information was available to make a judgement
Domain 3: Reference standard				
Reference standard - CT or tube thoracostomy	Is the reference standard likely to correctly classify the target condition?	Were the reference standard results interpreted without knowledge of the results of the index tests?	Could the reference standard, its conduct, or its interpretation have introduced bias?	Is there concern that the target condition as defined by the reference standard does not match the review question?
	Yes: if an acceptable reference standard, such as CT or tube thoracostomy findings, was used No: if trauma patients did not undergo an acceptable reference standard Unclear: if this was not clear from the report	Yes: if CT results were interpreted without knowledge of results of the index tests (Note: Tube thoracostomy after CUS and CXR but before CT suggests clinical deterioration and was required for patient safety) No: if CT or tube thoracostomy results were interpreted with knowledge of results of the index tests Unclear: if this was not clear from the report	Low: if "Yes" for all signalling questions High: if "No" was reported for at least 1 signalling question Unclear: if "Unclear" was reported for at least 1 signalling question	Low: if an acceptable reference standard, such as CT or tube thoracostomy findings, was used, and if CT results were interpreted without knowledge of the index tests High: if an acceptable reference standard was not used or if CT or tube thoracostomy results were interpreted with knowledge of results of the index tests Unclear: if insufficient information was available to make a judgement
Domain 4: Flow and timing				

(*Continued*)

Flow and timing	Was there an appropriate interval between CUS, CXR, and CT/tube thoracostomy?	Did all patients receive a reference standard?	Were all patients included in the analysis?	Could patient flow have introduced bias?
	Yes: if CUS, CXR, and CT/tube thoracostomy was sequentially performed within 2 hours No: if CUS, CXR, and CT/tube thoracostomy was not sequentially performed within 2 hours Unclear: if this was not clear from the report	Yes: if all patients received a CT scan or tube thoracostomy No: if some patients did not receive a CT scan or tube thoracostomy Unclear: if this was not clear from the report	Yes: if all patients were included in the final analysis No: if all patients were not included in the final analysis Unclear: if this was not clear from the report	Low: if "Yes" for all signalling questions High: if "No" was reported for at least 1 signalling question Unclear: if "Unclear" was reported for at least 1 signalling question

Notes:
CT = Computed tomography.
CUS = Chest ultrasonography.
CXR = Chest X-ray.

WHAT'S NEW

Date	Event	Description
4 October 2018	Amended	Acknowledgement section amended to include Co-ordinating Editor

CONTRIBUTIONS OF AUTHORS

Kenneth K Chan (KC), Daniel A Joo (DJ), Andrew D McRae (AM), Yemisi Takwoingi (YT), Zahra Premji (ZP), Eddy Lang (EL), Abel Wakai (AW).

Conceiving the review: KC.

Co-ordinating the review: KC.

Undertaking manual searches: KC, ZP.

Screening search results: KC, DJ, AM.

Organizing retrieval of papers: KC, ZP.

Screening retrieved papers against inclusion criteria: KC, DJ, AM.

Appraising quality of papers: KC, DJ.

Abstracting data from papers: KC, DJ.

Writing to authors of papers for additional information: KC, ZP.

Providing additional data about papers: KC, DJ.

Obtaining and screening data on unpublished studies: KC, DJ.

Managing data for the review: KC.

Entering data into Review Manager: KC.

Interpreting RevMan statistical data: KC, YT.

Performing other statistical analysis not using RevMan: YT.

Interpreting data: KC, YT.

Making statistical inferences: KC, YT.

Writing the review: KC, DJ, AM, YT, ZP, EL, AW.

Securing funding for the review: N/A.

Performing previous work that was the foundation of the present study: KC.

Serving as guarantor for the review (one review author): KC.

Taking responsibility for reading and checking the review before submission: KC.

DECLARATIONS OF INTEREST

Kenneth K Chan is a Resident Physician with the University of Calgary and Alberta Health Services. He has no conflicts of interest to declare.

Daniel A Joo is an Attending Emergency Physician with the University of Calgary and Alberta Health Services. He has no conflicts of interest to declare.

Andrew D McRae is the Emergency Department Research Director with the University of Calgary and Alberta Health Services. His institution has been awarded Research grants and consulting fees on cardiac biomarkers from Roche Diagnostics Canada.

Yemisi Takwoingi is a Senior Research Fellow in Biostatistics, University of Birmingham, UK. She has no conflicts of interest to declare.

Zahra A Premji is a Research and Learning Librarian with the University of Calgary and Alberta Health Services. She has no conflicts of interest to declare.

Eddy Lang is the Department Head of Emergency Medicine and a Clinician Scientist with the University of Calgary and Alberta Health Services. He has no conflicts of interest to declare.

Abel Wakai is the Director of Emergency Care Research Unit, Division of Population Health Sciences, Royal College of Surgeons, in Ireland. He has no conflicts of interest to declare.