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Review

Can ultrasound be used as an adjunct for tube thoracostomy? A systematic review of potential application to reduce procedure-related complications

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ABSTRACT

Background: chest tube insertions are commonly performed in various scenarios. Although frequent, these procedures result in a significant complication rate, especially in the acute care setting. Ultrasonography has been incorporated to interventional procedures aiming to reduce the incidence of complications. However, little is known about the applications of ultrasound in tube thoracostomies. The aim of this systematic review is to present the potential applications of ultrasonography as an adjunct to the procedure.

Methods: we searched Medline/Pubmed, EMBASE and Scopus databases. Out of 3012 articles, we selected 19 for further analysis. Thirteen of those were excluded because they did not meet the inclusion criteria. Ultimately, 6 articles were thoroughly evaluated and included in the review.

Results: The included articles show that ultrasound can be used to correctly identify a safe insertion site, to accurately find a vulnerable intercostal artery, and is reliable for timely diagnosis of drain malpositioning.

Conclusion: this systematic review highlights the potential benefits of incorporating ultrasonography in tube thoracostomies. No randomized clinical trials are available. However, it is reasonable to assume that proper use of ultrasound may reduce procedure-related complications.

1. Introduction

Despite being a common procedure, tube thoracostomy is associated with a significant rate of complications [1,2]. Some are very morbid and may be even lethal [3,4]. One of the reasons for such occurrences is the incorrect identification of the insertion site, which is currently based on anatomic landmarks. Even when this traditional technique is correctly used, anatomical variations and pathological changes can jeopardize the safety of the procedure [5,6].

Ultrasound is a diagnostic tool that has been increasingly used to guide procedures. The main contributions of the ultrasound-guided procedure are the real-time identification of anatomic structures and the potential to avoid iatrogenic injury. Ultrasound has improved safety and quality of vascular access, thoracocentesis, paracentesis and even percutaneous dilational tracheostomy (PDT), and the standardization of these techniques is well described [7–9].

However, ultrasound guidance is seldom applied for tube thoracostomies [4,10]. One of the reasons for that is the lack of a comprehensive analysis of the applicability of the ultrasound in such a scenario. Also, although there are descriptions of ultrasound-guided thoracic procedures [11], the specific technique for chest drainage has not yet been established.

The objective of this systematic review of the literature is to present current ultrasound techniques that may be used during a chest tube insertion in order to provide higher safety and quality for the procedure.

2. Methods

2.1. Search strategy

This systematic review is being reported following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) and the AMSTAR (Assessing the methodological quality of systematic reviews) guidelines, and it is registered in PROSPERO (CRD42018114500). No institutional review board approval was needed. We decided to perform a broad search because no complete description of an ultrasound-guided technique was available. We searched the literature (Medline/Pubmed, EMBASE and Scopus) using "(Chest Tube OR Chest Drainage OR Pleural Drainage OR Tube

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Thoracostomy) AND ultrasound". No language restrictions were used. The last search was performed in September 2017. According to commonly cited complications of chest drainage, we outlined four research questions to guide our review. Studies were included in the review if they answered at least one of the following questions:

a) Can ultrasound detect positioning (intrathoracic or subcutaneous) and orientation (inside the pleural cavity) of the chest tube?
b) Can ultrasound be used to avoid low drain insertions?
c) Can ultrasound be used to avoid iatrogenic injury to herniated abdominal viscera?
d) Can ultrasound detect vulnerable vascular structures in the intercostal space?

2.2. Eligibility criteria

We included randomized controlled trials, non-randomized controlled trials, cohort or case-series including a description of ultrasound techniques that could impact the chest drainage procedure. We excluded guidelines, reviews, case reports, and studies with no data about positioning and/or orientation of the chest tube, diaphragm visualization before intercostal incision, identification of a diaphragmatic hernia, or intercostal artery visualization.

2.3. Study selection

The identified articles underwent title and abstract screening by two independent reviewers. The next step was the appraisal of the full-text of the selected articles. A third reviewer was consulted in case of discordant opinions about study selection. We also evaluated their references to find additional articles. Studies with no reference to any of the research questions were not included.

2.4. Data extraction

We used a simple Excel spreadsheet to collect the main information about the selected articles for this review. Data included authorship, year of publication, study design, subjects evaluated, and sonographer's specialty and level of experience. They were further classified according to one of the four research questions, and the main findings were highlighted. Also, the principal limitations of each study were noted. Further details regarding the data were obtained by direct contact with the authors when necessary.

2.5. Risk of bias assessment

Each study was individually assessed by two authors independently. In case of disagreement, a third was consulted. The quality of prospective randomized trials was assessed using the Cochrane Risk of Bias Assessment Tool [12]. The National Heart, Lung, and Blood Institute (NHLBI) Quality Assessment Tool for Before-After (Pre-Post) Studies with no Control Group was used for both prospective non-randomized and case-series studies. This checklist is easy to use and abides by recent guidelines of reporting studies in systematic reviews [13].

3. Results

The flowchart of this systematic review can be appraised in Fig. 1. We ultimately included 6 articles. Table 1 exhibits general information about each study. Individual assessment of the risk of bias is presented in Tables 2 and 3.

Among the 13 studies initially considered eligible, 9 did not meet the study inclusion criteria. Of the other 4 studies, one analyzed thoracocentesis and not chest drainage, and one evaluated chest tube positioning but did not use ultrasound. The other two mentioned diaphragmatic visualization as part of their study protocol but did not evaluate that feature specifically nor provided further details of that assessment.

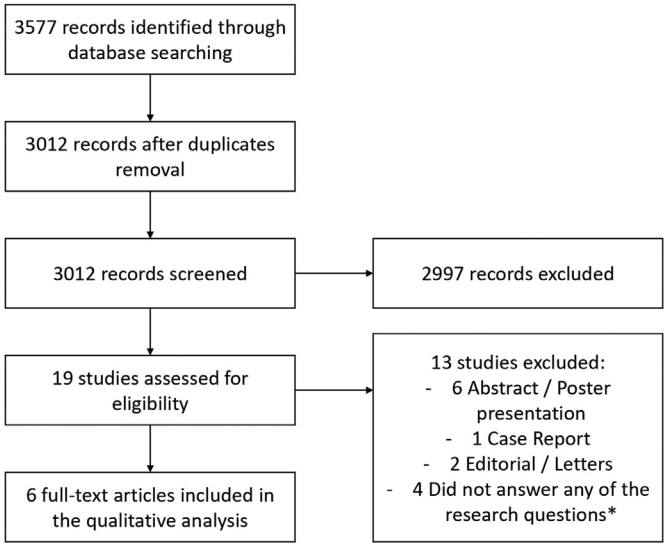

Fig. 1. PRISMA flowchart.

3.1. Description of included studies

3.1.1. Position and orientation of the chest tube

We included 3 articles describing the ultrasound evaluation of the drain's position, whether intrathoracic or subcutaneous. None of the articles selected for this review assessed the orientation of the drain inside the pleura, whether apical, basal or medial.

There were two prospective experimental trials using cadavers. Both randomized the drain's position, whether intrathoracic or subcutaneous, and examiners were blinded to that information. Together they yielded 188 chest tubes evaluations. Nakitende et al. [14] observed a sensitivity of 100% and a specificity of 96%. Three exams yielded false-negative (sonographic examination suggested an extrathoracic drain when it was placed properly). Their exams took less than 16 s. Salz et al. [15] reported sensitivity and specificity of 100%, and less than 1 min to complete each evaluation. The authors were contacted to provide detailed results. By combining the data from both studies, we calculated an overall sensitivity of 100% and specificity of 96,8%.

The remaining was a prospective study including 17 patients whose drains were already placed [16]. Tube positioning was confirmed by chest radiography after the procedure, and the sonographers were not aware of the results. Sonographic evaluation correctly identified an intrathoracic drain in all cases using both linear and curved transducer. Sonographers favored the use of the former due to its better definition of superficial planes.

3.1.2. Avoidance of low insertion sites

We included 1 study reporting the use of ultrasound to identify the diaphragm, thus avoiding low insertions [6]. This was a prospective non-randomized trial including both hemithoraces of 31 young and healthy volunteers, yielding 62 ultrasound evaluations. The study aimed to compare ultrasound and anatomical landmarks in terms of finding a safe intercostal space to insert the drain. Skin marks were placed according to anatomical landmarks for chest drainage using international guidelines (Advanced Trauma Life Support – ATLS, European Trauma Course – ETC, and British Thoracic Society – BTS) and the traditional palpation method from the second costal cartilage. Then, the fifth intercostal space, considered a safe insertion site, was assessed by ultrasound. The skin marks were compared with the sonographic

Table 1
Characteristics of the studies which met the inclusion criteria for this systematic review.

	Study Design	Study Subjects	Who Performed the Exam?	Research Question	Main Findings
Salamonsen 2013	Prospective Non-randomized, no control group, observational	50 patients with suspected parenchymal or mediastinal disease	Radiologist and Respiratory Physician	Identification of vulnerable intercostal artery	- Sensitivity of 95%, specificity pf 97%, and negative predictive value of 96% (CT scan as the gold-standard).
Salamonsen 2012	Prospective Non-randomized, no control group, observational	22 patients undergoing thoracocentesis	Radiologist and Respiratory Physician	Identification of vulnerable intercostal artery	- ICA was visualized in 84% of the cases. - ICA are less often visualized in the lateral positions. - ICA are less often visualized in patients with higher BMI and chest wall thickness.
Bowness 2015	Prospective Non-randomized, no control group, observational	31 healthy volunteers	Emergency Medicine Physician	Diaphragmatic identification and incision guidance	- Up to 25% of the marks were below the 5th intercostal space.
Jenkins 2012	Prospective Non-randomized, no control group, observational	17 patients with chest drains in place	Emergency Medicine Senior Residents, Certified Sonographers, and Emergency Ultrasound Fellow.	Positioning and Orientation	- All sonographic exams were able to correctly identify the intrathoracic tube placement. - The "black-out sign" was created by observing the behaviour of the drain on M-Mode.
Nakitende 2017	Prospective Randomized Double-blinded	Cadaver model	Emergency Medicine Residents with low experience in ultrasound	Positioning and orientation	- Quick assessments (mean 16s) - sensitivity of 100% and specificity of 96% to assess the tube position.
Salz 2010	Prospective Randomized Double-blinded	Cadaver model	Emergency Physicians, Emergency Sonographer and Senior Emergency Medicine Resident	Positioning and orientation	- Quick assessment (less than 1 min) - Sensitivity and specificity of 100% to evaluate the tube position.

results. The authors concluded that the latter may lead to up to 25% of low insertions (i.e. risking iatrogenic visceral injuries), and that female patients are at higher risk of dangerous site selection.

3.1.3. Diaphragmatic hernia identification

None of the studies screened for this review addressed this question. Therefore, we could not analyze the role of ultrasound in detecting diaphragmatic hernia, thus potentially preventing iatrogenic visceral injuries.

3.1.4. Identification of the intercostal artery

We included 2 prospective studies reporting the use of ultrasound to detect the intercostal artery (ICA) [17,18]. In the first, Salamonsen et al. examined four commonly used positions (three in the back, and one in the mid-axillary line) for pleural procedures in 22 patients, yielding 88 exams [17]. They report that the ICA was readily seen with the Doppler scan in 74 patients (84%) using a linear probe. Of note, the visualization of the ICA was more difficult in the lateral position, comprising 57% of the non-visualized ICA. Moreover, the authors state that this finding did not correlate with age or body mass index (BMI).

In 2013, the same authors recruited volunteers who were undergoing chest computerized tomography (CT). The primary goal of the study was to compare the accuracy of Doppler ultrasound in identifying the ICA compared to CT scan (gold-standard). They scanned three positions (two in the back and one in the posterior axillary line) with a linear probe. Out of 133 positions analyzed, ultrasound was able to identify the ICA in 114 (85.7%) and CT scan, in 96.2%. The results of this study show that ultrasound can visualize a vulnerable intercostal artery within the intercostal space with a sensitivity of 95%, specificity of 97%, and negative predictive value of 96%.

We could not perform a meta-analysis due to the heterogeneity of the included studies. Only two studies were randomized trials. However, both were experimental studies that randomized the position of the chest drain using cadaver models [14,15].

4. Discussion

This systematic review highlights the increasing interest in using ultrasound to address technical complications of chest tube insertions over the last decade. The studies included demonstrate that ultrasound can be used throughout the procedure, potentially making it safer. However, no complete and comprehensive description of an ultrasound-guided chest drainage using these data was found during the search period.

The use of ultrasound for pleural drainages is not a novelty. There are reports showing the benefits of sonographic guidance for the drainage of localized collections or pleural effusion analysis [19–21]. However, these reports most commonly focus on the efficacy of the procedure, rather than the potential to reduce complications related to it.

Chest tube complications in the emergency setting are cumbersome. Their incidence is variable but may be as high as 26,5% [1,3,22–24]. Although some may represent minor complications, others might be very morbid and even lethal [4,25]. By further analyzing these complications, it is reasonable to assume that some might be avoided by performing an ultrasound-guided technique [26].

The diaphragm may be injured during chest drainage [3,27]. Several conditions such as atelectasis, intraabdominal hypertension, and neurological dysfunctions may result in an elevation of the diaphragm [25,28]. As such, the traditional approach based on anatomical landmarks may result in iatrogenic injuries or intrabdominal insertion of drains, especially when using a trocar. Only one study specifically addressed the ability of ultrasound to avoid a low insertion site for the chest tube [6]. The authors found that women were the population at higher risk for such occurrences. However, this study has several limitations. First, the position of the arm varied across the methods used

Table 2
Risk of bias assessment using the checklist from the National Heart, Lung, and Blood Institute (NHLBI) Quality Assessment Tool for Before-After (Pre-Post) Studies with no Control Group.

	Salamonsen 2013	Salamonsen 2012	Bowness 2015	Jenkins 2012
Study Design				
1. Was the study question or objective clearly stated?	YES	YES	YES	YES
2. Were eligibility/selection criteria for the study population prespecified and clearly described?	YES	YES	YES	YES
Selection				
3. Were the participants in the study representative of those who would be eligible for the test/service/intervention in the general or clinical population of interest?	YES	YES	NO	YES
4. Were all eligible participants that met the prespecified entry criteria enrolled?	CD	YES	YES	NO
5. Was the sample size sufficiently large to provide confidence in the findings?	CD	CD	CD	CD
Intervention and Outcome				
6. Was the test/service/intervention clearly described and delivered consistently across the study population?	YES	YES	YES	YES
7. Were the outcome measures prespecified, clearly defined, valid, reliable, and assessed consistently across all study participants?	YES	YES	YES	YES
8. Were the people assessing the outcomes blinded to the participants' exposures/interventions?	YES	NO	NO	YES
9. Was the loss to follow-up after baseline 20% or less? Were those lost to follow-up accounted for in the analysis?	N/A	N/A	N/A	N/A
Statystical Analysis and Measurements				
10. Did the statistical methods examine changes in outcome measures from before to after the intervention? Were statistical tests done that provided p values for the pre-to-post changes?	YES	YES	YES	NO
11. Were outcome measures of interest taken multiple times before the intervention and multiple times after the intervention (i.e., did they use an interrupted time-series design)?	N/A	N/A	N/A	N/A
12. If the intervention was conducted at a group level (e.g., a whole hospital, a community, etc.) did the statistical analysis take into account the use of individual-level data to determine effects at the group level?	N/A	N/A	N/A	N/A

Table 3
Risk of bias assessment using the Cochrane Risk of Bias Assessment Tool.

Domain	Nakitende 2015	Salz 2010
Selection Bias - Random sequence generation	Low Risk	Low Risk
Selection Bias - Allocation Concealment	Low Risk	Low Risk
Reporting Bias - Selective Reporting	Low Risk	Low Risk
Performance Bias - Blinding (Participants and personnel)	Low Risk	Low Risk
Detection Bias - Outcome Assessment	Low Risk	Low Risk
Attrition Bias - Incomplete Outcome Data	Low Risk	Low Risk
Other Bias	Low risk	Low Risk
Overall Quality	*Good*	*Good*

(landmarks vs. ultrasound). Second, volunteers were in their 20's and had no comorbidities. Third, there is no mention of the level of experience of the sonographer. Fourth, the ultrasound assessment was performed while the patient was in a semirecumbent position (45°). Fifth, the 62 examinations were obtained from 31 volunteers, which may be considered a small sample size. Lastly and most importantly, the subjects were not submitted to the procedure but were rather used as models for simulation. Since the digital exploration may confirm that the pleural cavity was accessed, this study may prove more important for pigtail insertions or chest tubes using the trocar technique.

Complications related to tube positioning vary from 1.1% to 30% [25,29,30]. Traditionally, the position of the drain is assessed by chest radiography or computerized tomography. However, the former lacks accuracy [30,31], while the latter is associated with higher radiation and costs, and the need to transport the patient outside the emergency department [14,15]. Patients undergoing emergency pleural drainage, especially in the trauma room, benefit from timely and optimal interventions. The unrecognized malpositioning of a chest drain may result in worse outcomes in those patients. This review underlines that ultrasound is a reliable tool for rapid assessment of the drain's position. The three studies included show high sensitivity and specificity for the detection of intrapleural or subcutaneous drains [14–16]. However, some limitations may undermine the generalization of the results. Two of those studies were performed in cadavers, and the ultrasound assessment was done by physicians with extensive experience with sonography [14,15]. Moreover, the subject's BMI, which may potentially jeopardize this evaluation, is stated in only one of the reports [14]. That particular study was conducted using 2 cadavers, being one obese, and the other, overweight. There were three false-positives, meaning an extrathoracic chest tube considered to be intrapleural. However, since there were no other subjects for comparison, we could not draw any conclusions regarding the association between BMI and a successful exam. The only study performed in real patients was limited by the absence of incorrect placements, the late sonographic assessment (between 15 min and 2 days after the procedure), and no registry of the BMI of the patients [16]. None of the studies specifically addressed the intrapleural orientation of the drain. Indeed, the interposition of gas and the air-filled lungs make the intrapleural identification of the drain very difficult. Conversely, when draining a pleural effusion, one might be able to follow the intrapleural position of the tube, which is facilitated by the fluid interface.

Iatrogenic injury of the ICA is a rare event. Nonetheless, these patients commonly require invasive procedures, resulting in high morbidity [3,32]. These injuries may be related to a vulnerable ICA (not protected by the ribs) in the intercostal space. Unprotected ICA are not common at lateral positions on the chest, although they may occur especially in the elderly [17,33]. The identification of a vulnerable ICA prior to chest tube insertion is likely to limit iatrogenic injuries. The studies included in this review, both by the same author, highlight the excellent performance of Doppler scanning to detect vulnerable ICA [17,18]. However, in their first study, the author included a small number of patients [17]. Also, when the ICA was not visualized, it was impossible to discern whether the ICA was protected, or the sonographer did not find it. Moreover, the lack of spectral Doppler analysis may have resulted in misinterpretation of the correct vessel. In the following year, the same authors did a similar study and overcame these limitations by adding more study subjects, comparing ultrasound and CT scan in identifying the ICA, and using spectral Doppler [18].

We do acknowledge the lack of high-quality evidence supporting the ultrasound uses described in this systematic review. Although being

non-randomized prospective studies, the sample sizes were small. Only two studies were double-blinded. Both were experimental, performed in cadavers. Nevertheless, we perceive this as an opportunity for further research. Indeed, the adjunct use of sonography in chest tube insertions is a promising area for investigation. It may prove to be more useful for less experienced practitioners and procedures using the trocar technique. Furthermore, it may potentially develop into a novel approach to standard tube thoracostomies with fewer complications, mimicking the higher safety profile of other ultrasound-guided procedures [7–9]. This systematic review is the first to provide the best available evidence on the subject. Thus, it may be regarded as a starting point for guiding future studies.

Chest tube insertions have been done for years using the same basic techniques. Although considered a relatively safe procedure, the risk of complications during the procedures must be highlighted. There are some reports of using an ultrasound-guided technique to perform tube thoracostomies showing good result in terms of complications. However, they lack uniformity and a clear specification of how the ultrasound was actually used [20,34,35]. We believe that ultrasound is seldom studied as an adjunct for tube thoracostomies due to insufficient knowledge of the potential application of the tool, and the lack of a standardized ultrasound-guided technique. This systematic review aims to fill the knowledge gap. Based on the complication rate of tube thoracostomies, especially in the emergency setting, and the potential uses of ultrasound during the procedure as outlined in this review, our group developed a description of a step-by-step ultrasound-guided technique [26]. Since it is a novel approach, no prospective trials compared the standard technique with the ultrasound-guided in terms of complications. Although it is reasonable to assume that the latter might result in less visceral and vascular injuries, and faster malpositioning diagnosis, such benefits should be confirmed by further randomized trials.

5. Conclusion

This systematic review provides the available data regarding the potential benefits of adding ultrasound assessment to chest drainages. The studies were searched based on clinical questions that might reduce the incidence of frequently reported complications. The reports focused on feasibility and diagnostic performance of the sonographic exams. Although heterogeneous and limited by several aspects, these studies outline the potential benefits of an ultrasound-guided chest drainage. Future studies should compare the ultrasound-guided technique and the conventional one, in terms of procedural complications and feasibility in different clinical scenarios.

Ethical approval

N/A (review article).

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Author contribution

- Carlos Augusto M Menegozzo: conceptualization, data curation, formal analysis, investigation, methodology, writing original draft
- Everson LA Artifon: methodology, review & editing of the manuscript
- Adriano R Meyer-Pflug: data curation, formal analysis
- Marcelo C Rocha: data curation, formal analysis
- Edivaldo M Utiyama: methodology, review & editing of the manuscript, supervision

Conflicts of interest

No conflicts of interest to be stated.

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Provenance and peer review

Not commissioned, externally peer-reviewed.

Data statement

Since this is a review article, the data used in this study is publicly available in the original reports.

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Appendix A. Supplementary data

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