Diagnostic accuracy of ultrasonography for the confirmation of endotracheal tube intubation: a systematic review and meta-analysis

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Abstract

Aim: Despite several studies and reviews reporting data accuracy of ultrasonography for confirmation of endotracheal intubation, there has been limited pooled evidence summarizing the diagnostic accuracy of this imaging modality, especially based on recent evidence. Hence, the current study reviews the recent literature and conducts a meta-analysis to compare the accuracy of ultrasonography for the confirmation of endotracheal tube placement. Material and methods: We conducted a systematic search for all studies reporting the diagnostic accuracy of ultrasonography in the databases of Medline, EMBASE, PubMed Central, ScienceDirect, Google Scholar & Cochrane library from inception till December 2021. Meta-analysis was performed using STATA software “midas” package. Results: Thirty-eight studies with 3,268 participants were included. The pooled sensitivity was 98% (95% CI, 97%-99%) and specificity was 95% (95% CI, 90%-98%), respectively. The AUC was 0.98 (95%CI: 0.96-1.00). The pooled DOR was 1090 (95% CI, 408-2910). Pooled LRP was 19 (95% CI, 9-39) and pooled LRN was 0.02 (0.01-0.03). There was significant heterogeneity found in the outcome with significant chi-square tests and I² statistics > 75%. Conclusion: Findings from our review demonstrate promise in the applicability of ultrasonography as a major diagnostic tool for confirming the endotracheal tube intubation.

Keywords: intubation; meta-analysis; ultrasonography; validation studies

Introduction

Endotracheal intubation of critically ill patients is a commonly performed intervention in the emergency setting. Directly visualizing the endotracheal tube passing through the cords is relied upon for the initial localization, followed by the confirmatory technique. Nonetheless, direct visualization of the passage of the endotracheal tube might be limited during certain situations such as difficult intubations, making approximately 4% of the emergency intubations esophageal [1].

Unrecognized esophageal intubation might lead to serious complications, contributing to a significant number of morbidity and deaths [2]. Traditional methods such as bilateral breath sounds or condensation in the endotracheal tube for the confirmation of appropriate placement of the endotracheal tube have not been found to be reliable enough for conclusively determining the location of the endotracheal tube [3]. Devices such as colorimetric capnography or end-tidal CO2 detection, requires at least five breaths for the confirmation. This can lead to a higher risk of aspiration or gastric distention, if the endotracheal tube is incorrectly placed in the esophagus. In addition, the application of capnography is not reliable in a certain group of patients, like those with recent ingestion of carbonated beverages, previous use of bag-valve-mask or when there is paucity in the production of carbon-di-oxide (i.e., cardiac arrest) [4,5]. The use of quantitative waveform capnography has been found to be only 65-68% sensitive in the accurate detection of loca-
tion of endotracheal tube during events such as cardiac arrest [6,7].

The above-mentioned limitations, in combination with the higher availability, comfort with the point-of-care ultrasound, have led to a large amount of research into the feasibility and use of ultrasonography for the confirmation of the placement of the endotracheal tube. Nonetheless, most of the studies had relatively smaller sample sizes, resulting in wide confidence intervals. Ultrasonography is a helpful adjunct for the confirmation of endotracheal tube placement, especially during serious events such as cardiac arrest or when the quantitative capnography is not readily available. However, before the routine implementation of ultrasonography, it is necessary to check the diagnostic characteristics of this imaging technique. Hence, we conducted this review to assess the diagnostic accuracy of ultrasonography for the confirmation of endotracheal tube placement.

Material and methods

Eligibility criteria

The eligibility criteria consist of studies investigating the accuracy of ultrasonography for the confirmation of endotracheal tube placement. There was no restriction in terms of study design or type of participants. Only full-text articles or abstracts were included while the unpublished data or studies were excluded.

Type of participants

We have included studies conducted among adult patients undergoing endotracheal intubation irrespective of the medical conditions suffered by the participants and the settings in which the study was conducted.

Index test

Studies that used ultrasonography for the confirmation of endotracheal tube placement were included.

Reference standards

Studies comparing ultrasonography with a standard endotracheal tube confirmatory test like end-tidal capnography, colorimetric capnography, fibreoptic bronchoscopy, direct visualization as the reference standard were also included.

Search strategy

A systematic search in the databases such as Medline, EMBASE, PubMed Central, ScienceDirect, Google Scholar & Cochrane library was conducted. We used both the “medical subject headings (MeSH)” & “free-text words” while performing the search. The terms used in our search strategy were as follows: “Endotracheal Intubation”, “Validation Studies”, “Intubation”, “Ultrasonography”, “Ultrasound” “Diagnostic Imaging”, “Sensitivity”, “Specificity”, “Adults”, “Ultrasound Imaging”, and “Diagnostic Accuracy Studies”. We restricted the search from inception of databases to December 2021 and the language restriction to English only. References in the full-text articles retrieved during the search process were hand-searched for the identification of any relevant studies missed during the search of databases. The detailed search strategy is provided in Supplementary file 1.

Study selection process

It involved three stages:

Stage 1: Two independent investigators (XL and VH) have screened title, abstract and keywords by following the search strategy. Full-texts were retrieved for the original research articles based on the inclusion criteria.

Stage 2: Retrieved studies were fully screened by the same two investigators (XL and VH) and evaluated against inclusion criteria. Studies that fully satisfy the criteria were included.

Stage 3: Disagreements and differences during the selection process were resolved with the help of the corresponding author (MK) and a final consensus was reached.

Data extraction and management

Data was extracted by the primary investigator (XL) using a pre-defined form. The following information were obtained: author, publication year, study design, sample size, study setting, index test information, type of reference standard, study participants, quality related information, and accuracy parameters. Data entry process and management was double-checked by the set of secondary investigators (VH, MK).

Risk of bias assessment in included studies

Two independent authors (XL and VH) examined the bias risk using the “Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2)” tool [8]. The following keywords were used: “patient selection, index test, reference standard, and flow and timing of assessments”. Based on these keywords, grading was assessed as high, low and unclear for potential sources of bias.

Statistical analysis

Bivariate meta-analysis method was utilized to obtain the pooled sensitivity, specificity, positive likelihood ratio (LRP), negative likelihood ratio (LRN) and diagnostic odds ratio (DOR) for Ultrasonography. Summary Receiver Operator Characteristic curves (sROC) were constructed to produce the area under the curve (AUC). Diagnostic value can be considered to be better when the AUC value is closer to 1. The Fagan plot was utilized to determine how much the findings on PET/CT change the probability that a suspected patient has a correct endotracheal tube placement. Heterogeneity was identified through a bivariate box plot graphically, using the chi-square test for identifying statistical heterogeneity. We also calculated the $I^2$ statistics to quantify the level of
inconsistency [9]. Publication bias was checked through a funnel plot and the Deek’s test. The analysis was completed using STATA 14.2 (StataCorp, College Station, TX, USA).

**Results**

**Study selection process**

In total, 896 records were identified through the literature search and 123 of them were relevant to our review question and their full-texts were obtained. An additional two full-texts were gained through the hand-search of references in the retrieved full-texts. In the final stage of screening, 38 studies with 3,268 participants were included as per the eligibility criteria of the review (fig 1) [10-47].

**Study characteristics**

All the included studies were prospective in nature. The majority of the studies were conducted in Asian and Middle Eastern countries such as India, China, Korea, Iran and Turkey. The average age of the patients varied between 38.9 and 71.5 years. We utilized data from 3,268 patients in our review to understand the accuracy of ultrasonography (samples sizes varied between 19 and 150 patients). The majority of the studies used capnography as the gold standard criterion followed by auscultation and direct visualization (Table I).

**Risk of bias assessment**

First, with respect to patient selection, 25 out of the 38 studies had a low bias risk. Regarding the index test standards, 22 studies had a low risk of bias in its conduct & interpretation, while 22 studies had a low bias risk with respect to patient flow and interval. Finally, 32 studies had a lower bias risk with respect to the conduct & interpretation of the reference standard. Overall, 27 out of 38 studies had a lower bias risk as per QUADAS results (figure 2).

**Diagnostic accuracy of ultrasonography**

The utility of ultrasonography for the confirmation of endotracheal tube intubation was reported in 38 studies. The pooled sensitivity was 98% (95% CI, 97%-99%) and specificity was 95% (95% CI, 90%-98%), respectively (fig 3). The AUC was 0.98 (95%CI: 0.96-1.00) (fig 4). The pooled DOR was 1090 (95%CI, 408-2910). Pooled LRP was 19 (95% CI, 9-39) and pooled LRN was 0.02 (0.01-0.03). LR scattergram revealed that both the likelihood measures (LRP and LRN) occupied the left upper quadrant (fig 5). Fagan's nomogram revealed significantly higher utility of PET/CT scan in the mediastinal nodal metastasis of NSCLC (Positive=99; Negative=10%) differing significantly from the pre-test probability (86%) (fig 6). Wide heterogeneity was found with a significant chi-square test (p<0.001) and very high I² statistic (>75%). This was graphically depicted through a bivariate box plot, which further confirmed the between-study variability (Supplementary fig 1). The funnel plot indicates the possibility for the publication bias. It was also statistically confirmed by the significant Deek’s test (p=0.02) (Supplementary fig 2).

**Discussion**

We assessed the accuracy of ultrasonography for confirmation of endotracheal tube intubation. Following the
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<th>Esophageal intubation (%)</th>
<th>Ultrasonic technique</th>
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literature search, we found 38 prospective studies reporting the accuracy of ultrasonography. We discovered that ultrasonography had a high level of sensitivity (98%) and specificity (95%) for confirmation of endotracheal tube intubation. This indicates that this imaging technique can be used for both confirmation and exclusion of intubation among adult patients. This was further confirmed by the findings in the LR scattergram, as both the likelihood measures (LRN & LRP) were placed in the left upper quadrant. The utility for clinical practice was significantly better as the Fagan’s nomogram showed that there was a significant increase in the post-imaging probability compared to the pre-imaging probability.

Based on the literature available till date, it is possible to recommend ultrasonography as even the first line tool for confirmation of endotracheal tube intubation compared to gold standard techniques such as end-tidal capnography, colorimetric capnography, fibreoptic bronchoscopy, direct visualization. Previous meta-analysis assessing the accuracy of ultrasonography revealed similar accuracy parameters compared to our review [48-52]. This shows that ultrasonography has a high amount of applicability in the clinical practice, as it has excellent performance with a very high specificity.

However, the application of ultrasonography or any other alternate method as the sole technique for the detection of esophageal intubation or confirmation of endotracheal tube placement is not recommended. This is mainly because of the grave consequences of malposition in the endotracheal tube [52]. The confirmation of the placement of endotracheal tube during intubation can be made either by directly scanning the anterior neck during the endotracheal tube intubation, or by indirectly looking...
activity with suboptimal specificity, especially among the patients having a cardiac arrest or the low level of pulmonary blood flow [54,55]. However, ultrasonography has three main advantages for the airway assessment and confirmation of endotracheal tube placement. First, the use of ultrasonography can be done in real time, as the endotracheal tube is passed via either the trachea or esophagus. The mistakes during intubation can be easily identified even before any ventilation begins. The second advantage is that ultrasonography has a very high specificity for confirming the placement of endotracheal tube. Hence, it can be used when the capnography results are equivocal. This can reduce the unnecessary attempts for intubation amongst the critically ill patients. Finally, the ultrasonography can be performed even during the cardiopulmonary resuscitation (CPR) without interrupting the chest compressions [56].

However, future research is required to identify the best non-invasive imaging modality that can improve the assessment of endotracheal tube intubation and rule out the esophageal intubation. Till all the longitudinal research studies demonstrate a high amount of accuracy (both sensitivity and specificity) for evaluating an intubation attempt on a consistent basis, it can never replace the AHA guidelines and become the gold standard technique. However, use of this imaging modality has been evolving and expanding across multiple clinical facets and might soon be integrated into a routine examination across various areas of clinical practice.

Our review has certain strengths. Though a similar review exists, we included a greater number of studies and performed an updated meta-analysis with the most recent evidence, making it the most up to date review in the field. The majority of the studies had a lower risk of bias, adding to the credibility of the evidence. However, the review has certain limitations. First, significant heterogeneity found in our analysis might limit the ability to infer the obtained pooled results. Secondly, the accuracy of ultrasonography depends on several factors such as the experience and skill of the clinicians, and the severity of the condition and risk factors associated with the patients. But, the influence of these factors cannot be assessed.

Despite these limitations, our review provides important information and valuable implications for the evaluation of endotracheal tube intubation amongst adult patients and informs that ultrasonography has the ability to be used as an important tool in ruling out esophageal intubation especially in resource constrained settings. The use of this imaging modality can aid patients by reducing significantly the time and money spent during these procedures. Another important implication is that the early assessment of suspected patients can help in engaging
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the diagnosed patients early in the effective therapeutic management. Further large-scale research, that have specific and longitudinal settings in nature are necessary to ascertain it as a useful non-invasive modality and its applicability in the standard protocol for endotracheal intubation.

Conflict of interest: none

References

