Abstract. – OBJECTIVE: The major objective of this review was to compare the diagnostic accuracy of ultrasound in confirming tracheal intubation to the standard methods of confirmation in the intensive care unit (ICU).

MATERIALS AND METHODS: This systematic review and meta-analysis of observational studies was conducted from inception to July 2022. We included studies that compared the diagnostic accuracy of ultrasound-detected tracheal intubation to that of the gold standard diagnostic technique performed in adult patients who underwent tracheal intubation as part of any procedure. We searched the following electronic databases for published studies: PubMed, EMBASE, Cochrane Central, and Web of Science. Risk of bias was assessed using a standard procedure based on the Quality Assessment of Diagnostic Accuracy Studies-2 criteria. The results were analyzed using the RevMan or Meta-Disc software to determine the adequacy and conclusiveness of the available evidence.

RESULTS: Five studies that included 344 patients met the inclusion criteria. Pooled sensitivity was 0.96 (95% confidence interval (CI) 0.92-0.98) and 1.00 (95% CI: 0.97-1.00), respectively. Furthermore, the diagnostic odds ratio of ultrasonography was 311.25 (95% CI: 63.77-1,519.22), which was confirmed by a summary receiver operating characteristic curve with an area under the curve of 0.98.

CONCLUSIONS: Ultrasonography has high sensitivity and specificity, is a valuable adjunct for confirming tracheal intubation in the ICU and should be performed when capnography is unavailable or unreliable.

Key Words: Ultrasound, Endotracheal tube, Capnography.
search publications\textsuperscript{13-17} has evaluated the accuracy of ultrasound in confirming ETT intubation and reported the high sensitivity and specificity of this technology in the ICU. The primary objective of this review was to compare the diagnostic accuracy of ultrasound in confirming ETT with that of standard confirmation methods in the ICU.

**Materials and Methods**

**Data Sources and Searches**

We performed a systematic review and meta-analysis of published research using the methods outlined in the Cochrane Handbook for Reviews of Diagnostic Test Accuracy and by the Preferred Reporting Go to Items for a Systematic Review and Meta-analysis of Diagnostic Test Accuracy Studies (PRISMA-DTA)\textsuperscript{18}. From their inception to July 2022, databases, including PubMed, EMBASE, Cochrane Central, and Web of Science, were searched in the English language. The systematic search was performed using the Medical Subject Headings (MeSH) terms: “ultrasound” and “intubation”. In this regard, for ultrasonography we used “sono”, “sonography”, “ultrasonography”, “ultrasound”, “ETT”, “esophageal intubation”, and “intubation”.

**Selection Criteria**

Study selection was performed by two independent investigators (Tang and Ye). We included studies that assessed and compared the diagnostic accuracy of transtracheal (POCUS) ETT place-
ment confirmation with that of the gold standard ETT confirmation methods, including capnography or fiber optic bronchoscopy, with or without clinical examination, in adult patients aged 18 y. Case reports, case series, retrospective studies, and studies conducted in cadavers, manikins, and pediatric populations (<18) were excluded. The study site was in the ICU. Disagreements between reviewers were resolved by a third reviewer (Wang).

**Data Abstraction and Quality Assessment**

The collected data included study characteristics (authors, study design, and study sample size), participant characteristics [mean age, sex (% men)], the type of transducer used (linear or curvilinear), method of tube confirmation (capnography, direct visualization, auscultation, fiberoptic bronchoscopy, aspiration of ETT), sensitivity, and specificity. The data retrieved or extracted were the percentage of esophageal intubation and diagnostic validity/accuracy statistics for correct tracheal intubation. One reviewer extracted the data (Liu), and the other reviewer (Jiang) independently verified the data to construct a 2 × 2 contingency table, including TP = correct endotracheal tube placement and correct visualization by ultrasonography; FP = incorrect endotracheal tube placement but not visualized by ultrasonography; FN = correct endotracheal tube placement but not visualized by ultrasonography; TN = incorrect endotracheal tube placement and correct visualization by ultrasonography. The methodological quality of the studies was assessed using the quality assessment of diagnostic accuracy studies (QUADAS-2) tool. Two authors (Tang and Ye) performed the quality assessments, and the disagreements were resolved by consensus in the presence of a third reviewer (Chen). We intended to explore reporting bias using funnel plots but did not proceed due to the lack of sufficient number of studies.

**Statistical Analysis**

Heterogeneity statistics (Chi-square) $X$ and inconsistency statistics ($F$) were calculated to assess the heterogeneity among studies. The $p$-value for Chi-square $X < 0.05$ or $F$ value $> 50\%$ was considered as significant heterogeneity. A hierarchical summary receiver operating curve (HSROC) analysis was performed, and the area under the curve $> 0.9$ was considered highly accurate in assessing the summary accuracy of ultrasound. All analyses were performed using the Review Manager 5.3 (Review Manager Web, The Cochrane collaboration, Copenhagen, Denmark) or MetaDiSc software.

**Results**

**Search Results and Study Characteristics**

The literature search flow diagram is summarized in the PRISMA format (Figure 1). We identified 12,798 studies during the preliminary search. After removing 2,531 duplicates, abstracts of the remaining 10,263 studies were assessed by two independent reviewers (Tang and Ye). The eligibility criteria were applied to the full texts of 85 articles and 80 articles were rejected based on the exclusion criteria. Ultimately, 5 articles with 344 patients were included in our meta-analysis.

**Characteristics of Included Studies**

The characteristics of the five included studies (sensitivity and specificity of each study) are summarized in Table I. The studies were conducted between 2016 and 2020 and included sample sizes from 20 to 118 patients.

**Quality Assessment**

Quality assessment of the included studies was performed using the QUADAS-2 tool. The overall risk of bias for the included studies was low for most parameters (Figure 2 and Figure 3).

**Quantitative Data Synthesis Results**

The pooled sensitivity and specificity of correct ETT placement detected by ultrasound were 0.96 (95% confidence interval (CI) (0.92-0.98) and 1.00 (95% CI: 0.97-1.00), respectively (Figure 4 and Figure 5). Furthermore, the diagnostic odds ratio of ultrasonography was 311.25 (95% CI: 63.77-1,519.22) (Figure 6). The area under the summary receiver operating characteristic curve (SROC) revealed an appropriate accuracy of 0.98 (Figure 7).
### Table 1. Characteristic of studies included in the meta-analysis.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Study Design</th>
<th>Country</th>
<th>Sample Size</th>
<th>Study Location</th>
<th>Sonographer Speciality</th>
<th>Mean Age</th>
<th>Male Patients (%)</th>
<th>Ultrasound Technique</th>
<th>Transducer Type</th>
<th>Esophageal Intubation (%)</th>
<th>Gold Standard</th>
<th>Sensitivity</th>
<th>Specificity</th>
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<td>China</td>
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<td>Linear</td>
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<td>Patil et al14</td>
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<td>CCM</td>
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<tr>
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<td>CCM</td>
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<td>70.5</td>
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<td>Linear</td>
<td>0</td>
<td>CAP+A</td>
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</table>

Table II. Quality assessment of the included studies using QUADAS-2 tool.

<table>
<thead>
<tr>
<th>Study</th>
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<th></th>
<th>Applicability Concerns</th>
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<td>Reference standard</td>
<td>Flow timing</td>
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<tr>
<td>Rahul et al15</td>
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</table>
Discussion

This systematic review and meta-analysis of 344 ICU patients revealed that ultrasonography performed well in confirming ETT placement, with an overall pooled sensitivity of 0.96 (95% CI 0.92-0.98) and specificity of 1.00 (95% CI 0.97-1.00). The diagnostic odds ratio of ultrasonography was 311.25, and the area under the SROC curve revealed an appropriate accuracy of 0.98. Our findings confirm the effectiveness of ultrasound as an adjunct to assess ETT position during intubation. Moreover, these results are important because capnography has revealed low levels of accuracy, especially in patients with critical conditions.

A meta-analysis20 of 30 studies and 2,534 intubations reported that the pooled sensitivity and specificity of ultrasounds were 98.2% (95% CI 97.1-98.8) and 95.7% (90.1% CI 98.2-99), re-
spectively. Compared with our study, this reported difference in accuracy may be because of the different populations included in the literature. Tracheal ultrasonography can identify esophageal intubation by identifying esophageal dilatation and dual-track signs in the adjacent trachea. Compared with traditional methods of confirming the ETT position, tracheal ultrasonography is simple, convenient, and can guide clinical decision-making in real-time. Clinically, if real-time tracheal ultrasonography is used to detect esophageal intubation, the operator can make appropriate decisions immediately without waiting for confirmation using other methods. The other advantages over other confirmation methods are that it is faster, more accessible, non-invasive, and does not require multiple ventilations to confirm its location. The integration of POCUS has proven useful in all the phases of rapid sequential intubation, that is, the pre-oxygen generation, tracheal intubation, and ETT confirmation phase.

The ETT position must be identified quickly and accurately during the ICU rescue. Several methods exist for the clinical confirmation of ETT locations, and capnography is considered the gold standard for confirming ETT. However, this technique has few major limitations. End-tidal carbon dioxide monitoring revealed false negative and positive results, with an accuracy rate of only 67.9% in patients with respiratory arrest. Tests in
Transtracheal ultrasound for confirmation of endotracheal tube placement in ICU

**Figure 6.** Forest plots of the diagnostic odds ratio of ultrasonography for ETT tube placement.

**Figure 7.** Summary plots of five studies investigating the diagnostic ability of ultrasonography to detect ETT tube position.
patients without cardiac arrest reveal a 93% sensitivity and 97% specificity, whereas, in cases of low pulmonary blood flow, such as cardiac arrest, the accuracy is even lower\(^2\). This review showed a comparable sensitivity and specificity of ultrasound, despite the small sample size reviewed in this study.

**Limitations**

This review had several methodological limitations. The total sample size for emergency intubation in the ICU was small, consisting of five studies with 344 emergency intubations. The number of esophageal intubations was significant lower than that of ETT intubations due to the low morbidity.

**Conclusions**

This review found that transtracheal ultrasound is a new technique with acceptable accuracy that allows confirmation of endotracheal ETT placement in a reasonably rapid time without the need for ventilation. Ultrasonography is a valuable auxiliary tool for confirming ETT, with superior sensitivity and specificity in the ICU. However, this technique should be considered when capnography is unavailable or unreliable.

**Conflict of Interest**

The authors declare that they have no competing interests.

**Funding**

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**References**