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Transtracheal ultrasound for confirmation of endotracheal tube placement in the intensive care unit: a systematic review and meta-analysis

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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.

Introduction

Patients in the Intensive Care Unit (ICU) require emergency tracheal intubation and mechanical ventilation. Intubation in these patients is often difficult and accidental esophageal intubation is uncommon[1,2]. Moreover, these conditions can have destructive consequences if not detected immediately[3,4]. Identifying the tracheal intubation site can be challenging for most ICU physicians[5,6]. Current guidelines recommend confirming endotracheal intubation (ETT) placement as soon as possible to minimize the disruption of other resuscitation efforts[7]. Although capnography is considered the gold standard for confirming ETT, it has few limitations. Because the detection of carbon dioxide tracings is dependent on adequate pulmonary blood flow, its accuracy is reduced in cases of cardiac arrest and massive pulmonary embolism[8]. In addition, capnography may provide false-negative results in cases of airway obstruction or those involving administration of epinephrine[9,10].

The integration of point-of-care ultrasound (POCUS) in airway management facilitates timely assessment of ETT placement in pre-hospital applications, emergency wards, intensive care units, and operation theatres. POCUS is easily portable, non-invasive, inexpensive, reproducible, widely available, and has a good safety record[6]. In recent years, several studies[11,12] have emphasized the role of ultrasound in ETT confirmation. Ultrasound confirmation is a potential alternative method when capnography is compromised or even as an adjunct to capnography. In recent years, an increasing number of original re-

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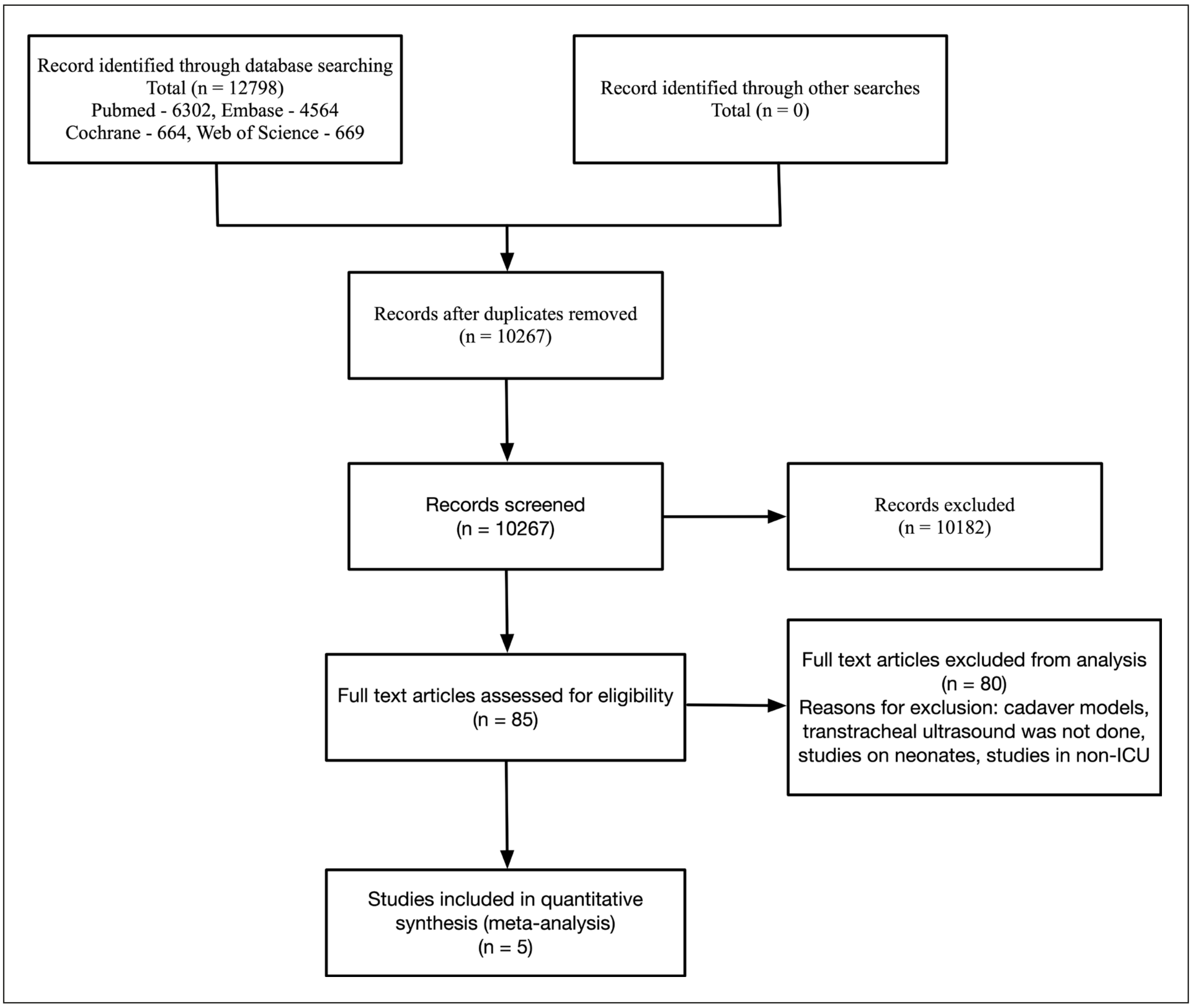

Figure 1. PRISMA flow chart of the literature search and selection of studies that reported accuracy of ultrasonography for confirmation of endotracheal placement.

search publications[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)[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 placement 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, fibreoptic 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.

Quantitative Data Synthesis

Data synthesis was performed using methods recommended in the Cochrane Handbook for Systematic Reviews of Diagnostic Test Accuracy. A bivariate random effects model was used to analyze and pool the statistics of the diagnostic tests (sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, and diagnostic odds of ETT). The diagnostic test statistic refers to the ability of POCUS to detect the correct placement of an endotracheal ETT in our study.

Statistical Analysis

Heterogeneity statistics (Chi-square) X and inconsistency statistics (I^2) were calculated to assess the heterogeneity among studies. The *p*-value for Chi-square X <0.05 or I^2 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 Meta-DiSc software[19].

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[13-17]. 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 (Table II). 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 I. Characteristic of studies included in the meta-analysis.

Author	Year	Study Design	Country	Sample Size	Study Location	Sonographer Speciality	Mean Age	Male Patients (%)	Ultrasonic Technique	Transducer Type	Esophageal Intubation (%)	Gold Standard	Sensitivity	Specificity
Chen et al[17]	2020	Pros	China	118	ICU	CCM	71.5	60.2	Dynamic	Linear	10.2	DV+FB	0.75	1
Patil et al[14]	2019	Pros	India	91	ICU	CCM	NR	NR	Dynamic	Linear	2	CAP	0.97	1
Kabil et al[15]	2018	Pros	Saudi	40	ICU	CCM	55.7	65	Dynamic	Curvilinear	10	FB	0.97	1
Arya et al[16]	2018	Pros	US	75	ICU	CCM	63.4	55.3	Dynamic	Linear	16	CAP	0.83	1
Rahul et al[13]	2016	Pros	US	20	ICU	CCM	70.5	100	Static	Linear	0	CAP+A	1	1

A: auscultation; DV: direct visualization; FB: fiberoptic bronchoscopy; CAP: capnography.

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

Study	Risk of Bias				Applicability Concerns		
	Patient selection	Index test	Reference standard	Flow timing	Patient selection	Index test	Reference standard
Chen et al[17]	Low	Low	Low	Low	Low	Low	Low
Patil et al[14]	Low	Low	Low	Low	Low	Low	Low
Kabil et al[15]	Low	Low	Low	Low	Low	Low	Low
Arya et al[16]	Low	Low	Low	Low	Low	Unclear	Low
Rahul et al[13]	Low	Low	Low	Low	Low	Low	Low

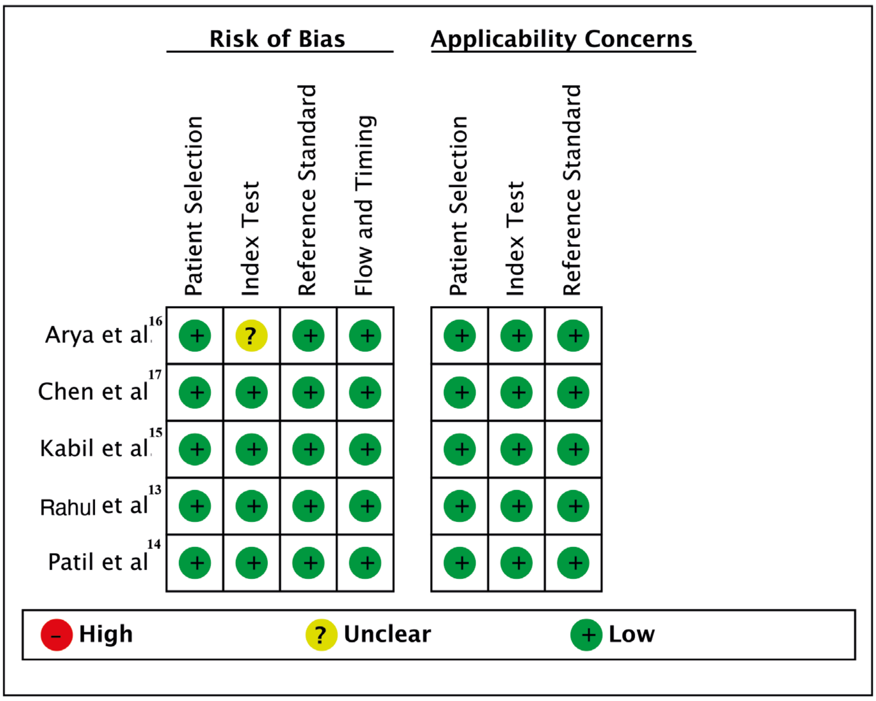

Figure 2. Risk of bias and applicability concerns summary.

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-analysis[20] 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-

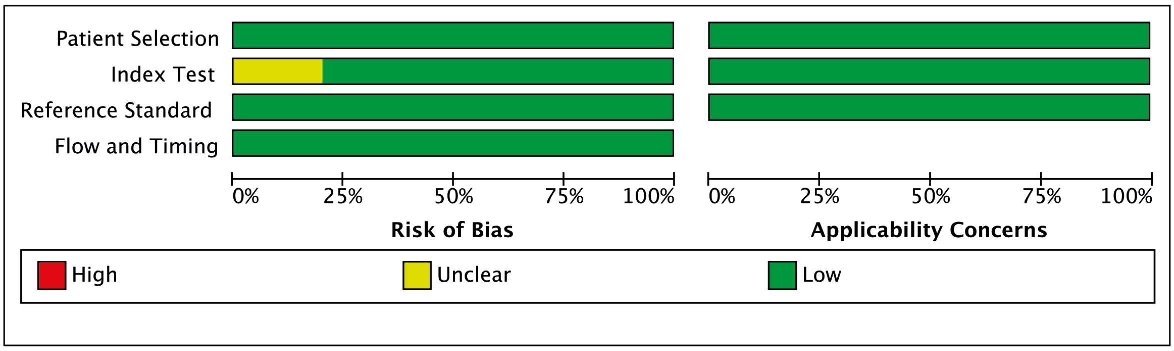

Figure 3. Graph of risk of bias and applicability concerns.

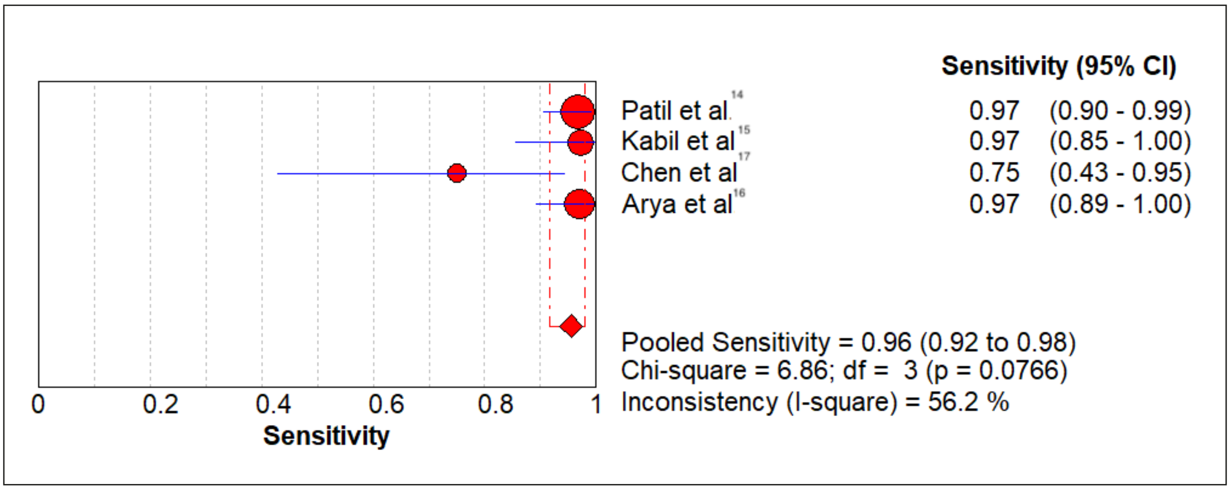

Figure 4. Forest plots of the sensitivity of ultrasonography for ETT tube placement.

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[20].

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[21]. Tests in

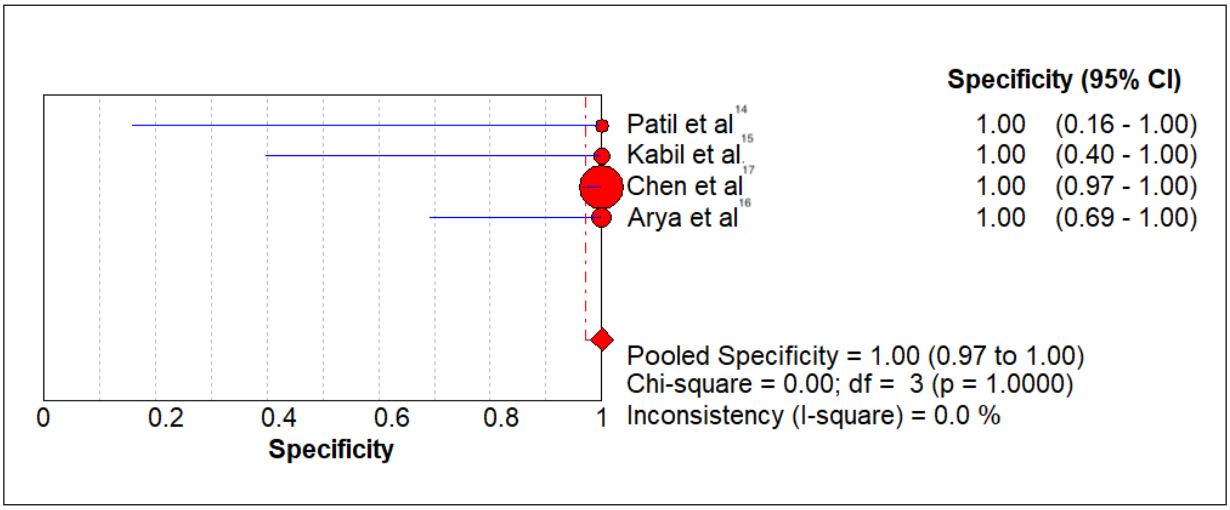

Figure 5. Forest plots of the specificity of ultrasonography for ETT tube placement.

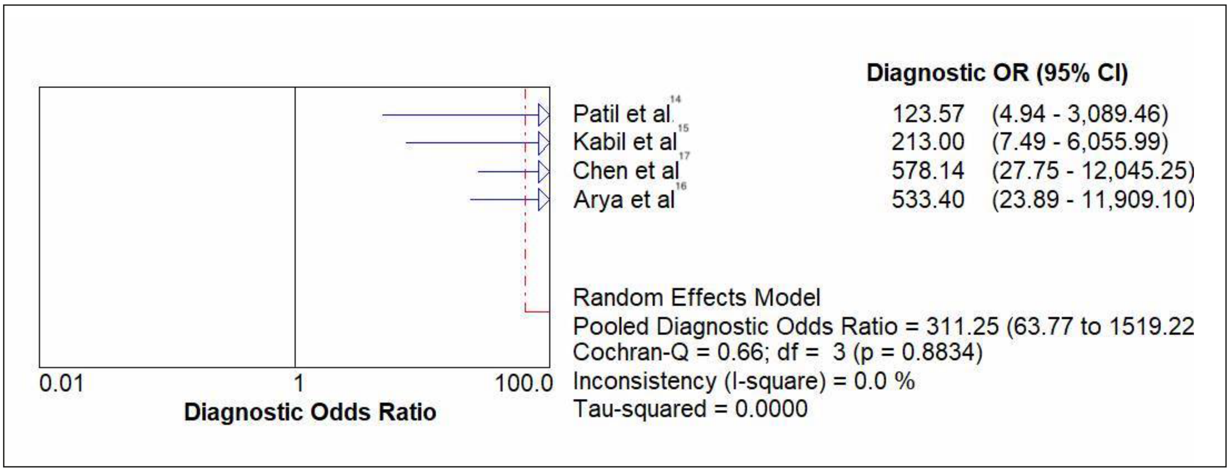

Figure 6. Forest plots of the diagnostic odds ratio of ultrasonography for ETT tube placement.

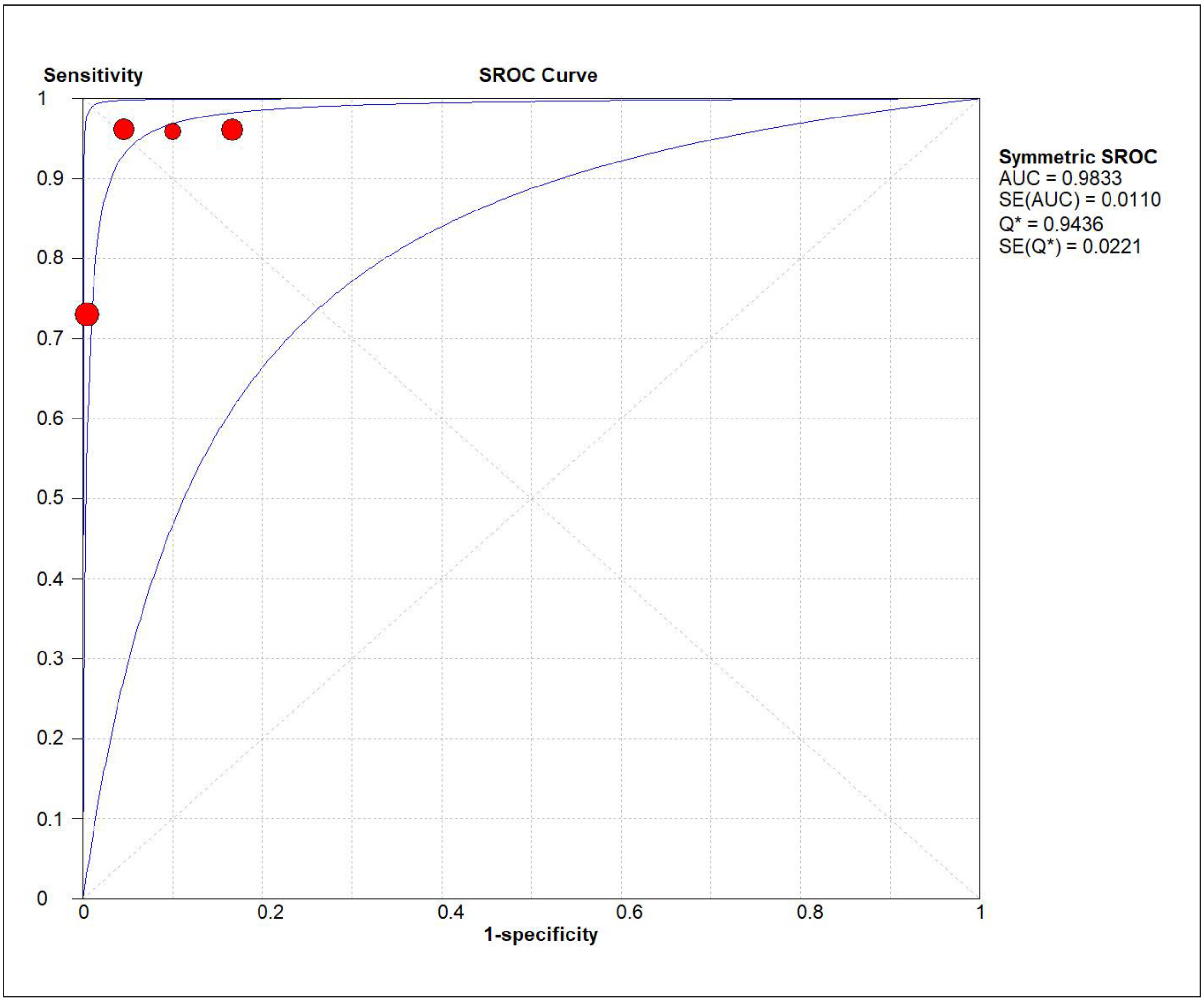

Figure 7. Summary plots of five studies investigating the diagnostic ability of ultrasonography to detect ETT tube position.

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[22]. 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 significantly 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.

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