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Review

Use of end-tidal carbon dioxide detection to determine correct placement of nasogastric tube: A meta-analysis

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ABSTRACT

Objective: To review the diagnostic accuracy of end-tidal carbon dioxide detection in detecting inadvertent airway intubation and verifying correct placement of nasogastric tubes.
Design: We undertook a meta-analysis of diagnostic studies.
Study selection: All clinical trials that evaluated the diagnostic accuracy of the colorimetric capnometry or capnography in detecting inadvertent airway intubation and differentiating between respiratory and gastrointestinal tube placement in adults were included. Electronic databases including MEDLINE, CINAHL, EMBASE, All EBM Reviews, WanFang Data, China Journal Net, Chinese Medical Current Contents, and Index to Chinese Periodical Literature were searched from inception to July 2009.
Data extraction and quality assessment: Data were extracted using a form piloted prior to use. Two reviewers independently extracted data relating to purpose of the trial, sample, measurements used, index test results and reference standard. Methodological quality of eligible trials was assessed independently by two reviewers using a modified version of the Quality Assessment of Diagnostic Accuracy Studies for assessing studies of diagnostic accuracy. The accuracy of diagnostic tests is presented in terms of sensitivity, specificity, predictive values, and likelihood ratios.
Data synthesis: Nine clinical trials were eligible for inclusion in the meta-analysis. Eight trials were undertaken in intubated and mechanically ventilated patients and two trials also involved participants who were alert or awake. Eight involving a total of 456 nasogastric feeding tube placements investigated the diagnostic accuracy of either colorimetric capnometry or capnography to detect feeding tube placement. One trial involving 195 gastric tube insertions compared the diagnostic accuracy of simultaneous use of a colorimetric carbon dioxide detector and capnography to detect feeding tube placement. The use of colorimetric capnometry or capnography had a sensitivity ranging from 0.88 to 1.00, specificity 0.95 to 1.00, positive likelihood ratio 15.22 to 283.35, negative likelihood ratio 0.01 to 0.25. A summary receiver operator characteristics (SROC) curve was constructed and showed an area under the curve was 0.9959. Three trials reported significant cost savings using end-tidal carbon dioxide detectors.
Conclusions: There is evidence to support the use of capnography or colorimetric capnometry for the identification of nasogastric feeding tube placement in mechanically ventilated patients.

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What is already known about the topic?

- Inadvertent airway intubation during nasogastric tube insertion can be fatal.
- End-tidal carbon dioxide ($ETCO_2$) monitoring using colorimetric capnometry or capnography is sometimes used in mechanically ventilated patients to differentiate between respiratory and gastrointestinal placement of feeding tubes.
- There has been no systematic review on the effectiveness of $ETCO_2$ monitoring in determining correct placement of nasogastric tubes.

What this paper adds

- There is evidence to support the use of colorimetric capnometry or capnography for the identification of feeding tube placement in mechanically ventilated patients.
- Future trials should assess the potential beneficial impact of using $ETCO_2$ monitoring in clinical settings.
- More clinical trials are needed to determine the accuracy of $ETCO_2$ monitoring in non-intubated and non-mechanically ventilated patients.

1. Introduction

Nasogastric (NG) tubes are often used in the clinical management of patients requiring decompression, assessment, enteral feeding and medication administration. Respiratory (pulmonary aspiration) and tube-related (tube displacement/dislodgement, tube occlusion, nasopharyngeal trauma) complications are not uncommon (Leder and Suiter, 2008; Weinberg and Skewes, 2006; Wu et al., 2006).

Insertion of the NG tube requires skill and expertise. During initial tube insertion, misplacement includes brain, esophagus, peritoneum, intestine (Burns et al., 2001), and the respiratory tract (Sanaka et al., 2004). Inadvertent airway intubation during NG tube insertion can be fatal (Weinberg and Skewes, 2006). Displacement can occur with both large- and small-bore tubes, though small-bore tubes dislocate easily, often into the respiratory tract and with no external sign of displacement (Sanaka et al., 2004), and are prone to coiling (Swiech et al., 1994). Therefore, assessment of tube position is necessary to minimize the risks of tube-related complications and provide for optimal patient safety and comfort. A wide range of bedside methods such as observing for cough and choking, auscultation of air insufflated through the tube, aspiration of fluid (Rakel et al., 1994), visual inspection of the aspirates (Metheny et al., 1994), testing of aspirates for pH or concentrations of bilirubin, pepsin or trypsin (Metheny et al., 1997), observing for bubbling when the tip of the tube is held under water, testing the ability to speak, the use of magnetic detection (Tobin et al., 2000), spring gauge pressure manometer (Swiech et al., 1994), radiography, and end-tidal carbon dioxide ($ETCO_2$) monitoring using capnography or colorimetric capnometry (Howes et al., 2005; Kindopp et al., 2001) have been used to assess tube location. The objective of this systematic review was to investigate the diagnostic accuracy of $ETCO_2$ monitoring in detecting inadvertent airway intubation and verifying correct placement of NG tubes.

2. End-tidal carbon dioxide ($ETCO_2$) monitoring

End-tidal carbon dioxide ($ETCO_2$) monitoring using capnography or colorimetric capnometry is sometimes used in mechanically ventilated patients to differentiate between respiratory and gastrointestinal (GI) placement of feeding tubes (Frakes, 2001). Capnography comprises the continuous analysis and recording of carbon dioxide concentrations [CO_2] in respiratory gases. Capnographs use infrared technology to detect CO_2 and the result is expressed as partial pressure in millimetres of mercury. Flow waveform will also be displayed in capnographs showing the level of CO_2 detected. Although the terms capnography and capnometry are sometimes considered synonymous, capnometry suggests measurement without a continuous written record or waveform.

Colorimetric $ETCO_2$ devices use a phenol sulfonephthalein-impregnated pH-sensitive filter paper as an indicator and, in the presence of CO_2, will change from purple (indicating room air) to yellow (2–5% CO_2) (Jaffe, 2004; Nellcor Puritan Bennett, Inc., 2005).

2.1. Review questions

1. What is the diagnostic accuracy of $ETCO_2$ monitoring in correctly identifying tubes intentionally located in the airway?
2. What is the diagnostic accuracy of $ETCO_2$ monitoring in correctly differentiating between respiratory and GI tube placement?

2.2. PICO model

We used the PICO model to formulate the review question.

Population: All clinical trials that evaluated the diagnostic accuracy of the colorimetric capnometry or capnography in detecting inadvertent airway intubation and differentiating between respiratory and GI tube placement in adults.
Index tests: Colorimetric capnometry or capnography.
Comparison: Radiography, direct visualization or under direct endoscopic guidance, aspiration of stomach content, auscultation of air.
Outcome: The incidence of tube placement, the ability of the index test to identify correct placement of the NG tubes, the ability of the index test to identify respiratory placement of NG tubes.

3. Methods

3.1. Data sources and searches

Reports in English were considered in this review. Given that two of the reviewers were able to translate publications in the Chinese language, reports in Chinese were also considered. We electronically searched MEDLINE (1950 to July 2009), CINAHL (1982 to July 2009), EMBASE (1980 to July 2009), and All EBM Reviews (up to 2nd Quarter 2009) for publications in English. As each database has its own unique indexing terms, individual search strategies were developed for each database (Supplementary Data 1). During the development of the search strategy, consideration was given to the diverse terminology used and the spelling of keywords as this would influence the identification of relevant trials. The search terms used in both English and Chinese were intubation, gastrointestinal, feeding tubes, nasogastric, end tidal carbon dioxide, CO_2, capnometry, capnography, colorimetry. Chinese search terms were based on the terminology used in Taiwan and China (Supplementary Data 2).

No restrictions were placed on date of publications and each database was searched as far back as possible. We conducted a search of the following Chinese databases: WanFang Data (1998 to July 2009), China Journal Net (1994 to July 2009), Chinese Medical Current Contents (1994 to July 2009), Index to Chinese Periodical Literature (1970 to July 2009), and the Chinese Biomedical Literature Database (1980 to July 2009). The reference lists and bibliographies of retrieved articles were reviewed to identify any additional research. To complement the search strategies keyword searching of the World Wide Web was conducted.

3.2. Criteria for inclusion of publications in the review

Clinical trials that evaluated the diagnostic accuracy of the colorimetric capnometry or capnography in detecting inadvertent airway intubation and differentiating between respiratory and GI tube placement in adults were included. Publications that compared index tests with either radiography, direct visualization or under direct endoscopic guidance, aspiration of stomach content or auscultation of air were included. Publications that evaluated the incidence of tube placement, the ability of the index test to identify correct placement of the NG tubes, the ability of the index test to identify respiratory placement of NG tubes were included.

We included studies about diagnostic test accuracy that reported sufficient data to permit both sensitivity and specificity to be calculated. For those studies that reported insufficient data to permit both sensitivity and specificity to be calculated, qualitative summaries of the findings were presented. This review excluded descriptive reports, literature reviews, expert opinions and studies of other types of tubes such as nasointestinal feeding, gastrostomy and jejunostomy tubes.

3.3. Study selection

Each citation was assessed against the inclusion/exclusion criteria independently by two reviewers and the full text of studies deemed relevant was obtained. For studies with unclear titles and abstracts, the full text was obtained. Decisions to include a publication in the review were made independently by two reviewers following evaluation of the full text of all retrieved papers. Any disagreement was resolved by consensus with close attention to the inclusion/exclusion criteria.

3.4. Quality assessment and data extraction

Methodological quality of eligible trials was assessed independently by two reviewers using a modified version of the Quality Assessment of Diagnostic Accuracy Studies (QUADAS) for assessing studies of diagnostic accuracy (Whiting et al., 2003). An item in the original version of QUADAS, "were the same clinical data available when test results were interpreted as would be available when the test is used in practice?", was omitted as the interpretation of the index test in this review involved no interpretation of other clinical data (Whiting et al., 2003). The minimum score obtainable using the amended scale thus was zero and the maximum score was 13. All studies scored above the threshold level which was calculated using the formula "Mean-1 SD" (Sutton et al., 1998) and were hence included in the review.

Data were extracted using a form piloted prior to use. Two reviewers independently extracted data relating to purpose of the trial, sample, measurements used, index test results and reference standard. If any data were missing from the trial report, attempts were made to obtain them by contacting the authors.

3.5. Data synthesis and statistical analysis

All calculations were made using SPSS-PC version 16.0 (SPSS Inc., Chicago, IL, USA), and Meta-DiSc version 1.4 (Zamora et al., 2006). The accuracy of diagnostic tests is presented in terms of sensitivity and specificity (Sackett et al., 2000). In this review, sensitivity refers to the ability of the index tests to identify placement of the NG tube in the airway and specificity refers to the ability of the index tests to identify placement of tubes not in the airway.

The positive predictive value (the proportion of those who tested positive who were true positives) and negative predictive value (the proportion of those who tested negative who were true negatives) were also used to assess the performance of these tests (Portney and Watkins, 2000). In addition, the positive likelihood ratio (LR+) (sensitivity/(1 − specificity)) and negative likelihood ratio (LR−) ((1 − sensitivity)/specificity) (Simel et al., 1991), were also calculated and presented to provide information about the likelihood that a given test result would be expected when the target condition is really present compared with the likelihood that the same result would be expected when the condition is really absent (Sackett et al., 2000).

Not all trials reported true positive (TP), true negative (TN), false positive (FP) and false negative (FN) rates, therefore these rates were calculated based on the data in the published papers. A two by two truth table was reconstructed for each study, and sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), LR+ and LR− were calculated for each study. If the numbers were not sufficient for such a calculation, the results were not pooled in the meta-analysis. The heterogeneity of sensitivities and specificities were tested using I-squared tests (Higgins et al., 2003). In the absence of heterogeneity a fixed effects model was used ($p > 0.05$). A summary receiver operator characteristics (SROC) curve was constructed to determine the relationship between sensitivity and specificity and the area under the SROC curve which measured the usefulness of a test was calculated. For those studies that reported insufficient data to permit both sensitivity and specificity to be calculated, narrative summaries of the findings are presented.

4. Results

A total of 352 publications (188 in English and 164 in Chinese) were identified from the databases. A review of the reference lists and bibliographies of the retrieved articles identified an additional clinical trial in English relevant to the topic. All 164 publications in Chinese were excluded: 161 because they did not meet the inclusion criteria, one because it was a translation of an article published in English, and the other two did not meet the required methodological quality criteria. These two trials did not offer sufficient detail to be able to determine issues such as the validity of the index tests, accuracy, and information essential to assess the rigour of these trials. Of the 188 English publications, 32 were duplicates. Of the remaining 156, the majority were excluded as they did not meet the inclusion criteria, leaving nine for the review, which are detailed in Supplementary Data 3.

4.1. Methodological quality of included trials

The methodological quality of the nine publications included in the review ranged from 7 to 13. Incomplete details of sample selection and inclusion/exclusion criteria were the main reasons for low scores. Sensitivity and specificity of the diagnostic tests should be reported in diagnostic studies to enable the readers to make clinical decisions, but, only six (Araujo-Preza et al., 2002; Elpern et al., 2007; Howes et al., 2005; Kindopp et al., 2001; Meyer et al., 2009; Thomas and Falcone, 1998) of the nine clinical trials reported these and compared them with reference standards such as radiography, direct visualization or under direct endoscopic guidance.

4.2. Description of studies

Eight trials involving a total of 456 NG feeding tube placements investigated the diagnostic accuracy of $ETCO_2$ detection in detecting inadvertent airway intubation and differentiating respiratory and GI placement of the feeding tubes. $ETCO_2$ detection was undertaken using either colorimetric capnometry (Araujo-Preza et al., 2002; Elpern et al., 2007; Howes et al., 2005; Meyer et al., 2009; Thomas and Falcone, 1998) or capnography (Burns et al., 2001; D'Souza et al., 1994; Kindopp et al., 2001). One trial (Burns et al., 2006) involving a total of 195 gastric tube insertions in 130 patients compared the diagnostic accuracy of the simultaneous use of a colorimetric CO_2 detector and capnography to detect feeding tube placement.

4.3. Reference standards

The accuracy of tube placement was confirmed by a two-step chest roentgenogram (Araujo-Preza et al., 2002; Howes et al., 2005; Kindopp et al., 2001; Meyer et al., 2009) or a post-insertion radiograph (Elpern et al., 2007; Thomas and Falcone, 1998). In a trial comparing index test results (capnography) against the reference standard (D'Souza et al., 1994), the feeding tube was placed into the trachea and pharynx under direct visualization or under direct endoscopic guidance. For those feeding tubes inserted into the stomach, aspiration of stomach content was used to confirm gastric placement (D'Souza et al., 1994). Another trial (Burns et al., 2001) compared the index test results with the reference standard adopted in their setting. For small bore feeding (SBF) tubes, confirmation of gastric placement was by auscultation of air and an abdominal radiograph, and for Salem Sump (SS) tube placement, only by auscultation (Burns et al., 2001). Supplementary Data 4 presents a description of the included studies including the inclusion/exclusion criteria, population, setting, index test examined, type of nasogastric tubes used, and methods of verification of tube placement.

4.4. Outcomes

4.4.1. Sensitivity and specificity of colorimetric capnometry or capnography in correctly identifying tubes intentionally located in the airway

4.4.1.1. Colorimetric capnometry. Four trials (Araujo-Preza et al., 2002; Howes et al., 2005; Meyer et al., 2009; Thomas and Falcone, 1998) evaluated the diagnostic accuracy of the colorimetric capnometry to detect feeding tube placement in the airway in 140 mechanically ventilated patients. All feeding tubes were intentionally inserted into the already placed endotracheal tubes with the colorimetric CO_2 detector attached to obtain gas samples. Two models of the colorimetric CO_2 detectors were used (EasyCap and EasyCap II, Nellcor Puritan Bennett, Pleasanton, CA, USA). Tracheal intubation was confirmed if the colour changed from purple to yellow indicating the presence of CO_2. In all four studies colorimetric capnometry was able to detect 100% of the feeding tubes (sensitivity = 1.00) placed in the trachea (Supplementary Data 5).

4.4.1.2. Capnography. Two trials (Burns et al., 2001; D'Souza et al., 1994) with a total of 25 observations reported the use of capnography to verify tubes that were intentionally placed in the endotracheal or tracheostomy tubes in patients admitted to a critical care unit. A capnography was attached to the feeding tube to obtain gas samples. Both studies demonstrated 100% accuracy (sensitivity = 1.00) in detecting tubes located in the airway.

4.4.2. Sensitivity and specificity of colorimetric capnometry or capnography in correctly differentiating between respiratory and GI tube placement

Nine trials assessed the sensitivity and specificity of colorimetric capnometry or capnography in correctly differentiating between respiratory and GI tube placement; however data from only seven trials could be pooled in a meta-analysis. The data from the remaining two trials (Elpern et al., 2007; Thomas and Falcone, 1998) could not be pooled as they had no confirmed lung placement thus no false negative results could be determined.

The pooled results for sensitivity, specificity, positive and negative likelihood ratios were 0.99, 0.99, 57.30 and 0.05 respectively (Figs. 1–5). The use of colorimetric capnometry or capnography had a sensitivity ranging from 0.88 to 1.00, specificity 0.95 to 1.00, positive likelihood ratio 15.22 to 283.35, negative likelihood ratio 0.01 to 0.25. A summary ROC curve was constructed and showed an area under the curve was 0.9959. These results indicate that the use of capnography or colorimetric capnometry is an effective method in differentiating between respiratory and GI tube placement for adult patients. The results also suggest that these two methods have a satisfactory agreement with the reference standard.

4.4.3. Sub group analysis

4.4.3.1. Colorimetric capnometry. Five trials (Araujo-Preza et al., 2002; Elpern et al., 2007; Howes et al., 2005; Meyer et al., 2009; Thomas and Falcone, 1998) evaluated the diagnostic accuracy of the colorimetric capnometry to differentiate between respiratory and GI placement of 316 NG feeding tube placements (Supplementary Data 6). A colorimetric $ETCO_2$ detector was attached to the feeding

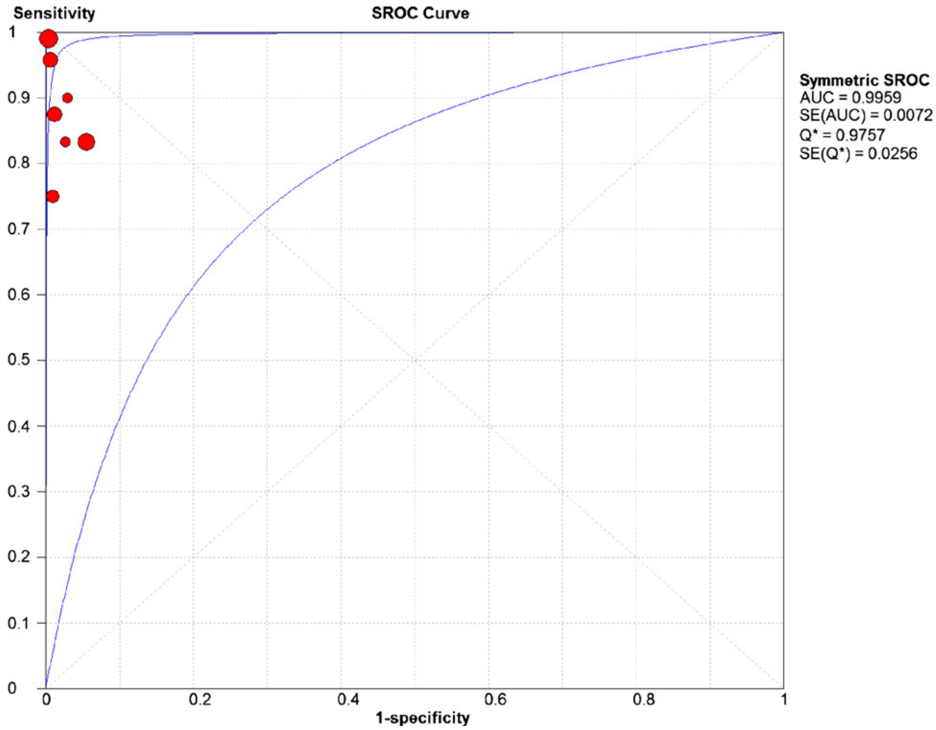

Fig. 1. SROC curve from test accuracy studies of colorimetric capnometry or capnography in the verification of tube placement.

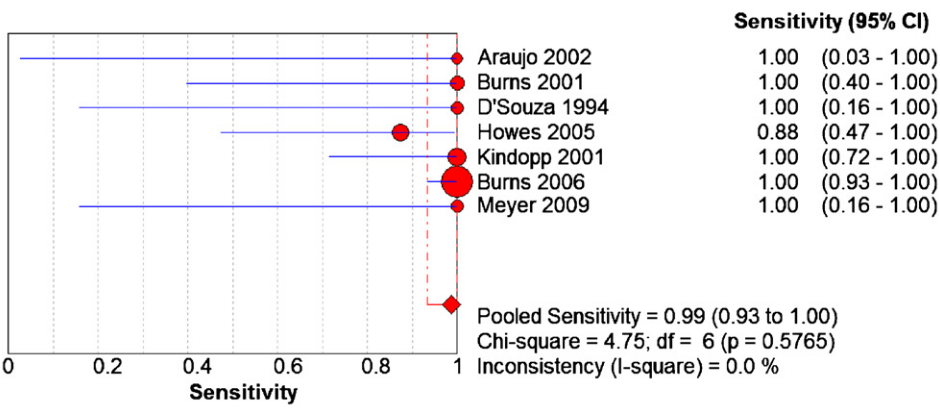

Fig. 2. Forest plot of sensitivities from test accuracy studies of colorimetric capnometry or capnography in the verification of tube placement.

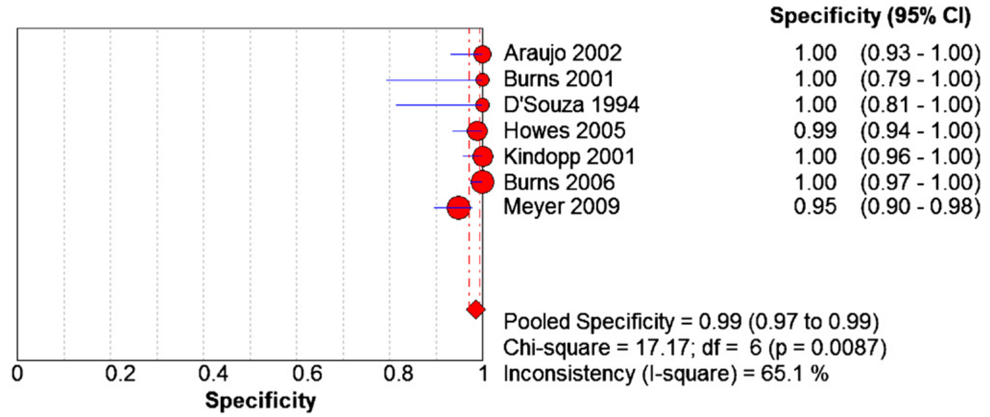

Fig. 3. Forest plot of specificities from test accuracy studies of colorimetric capnometry or capnography in the verification of tube placement.

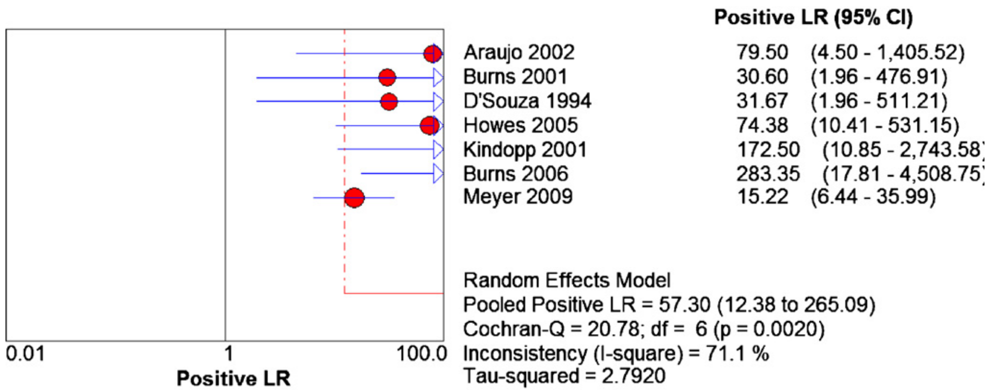

Fig. 4. Forest plot of positive likelihood ratio from test accuracy studies of colorimetric capnometry or capnography in the verification of tube placement.

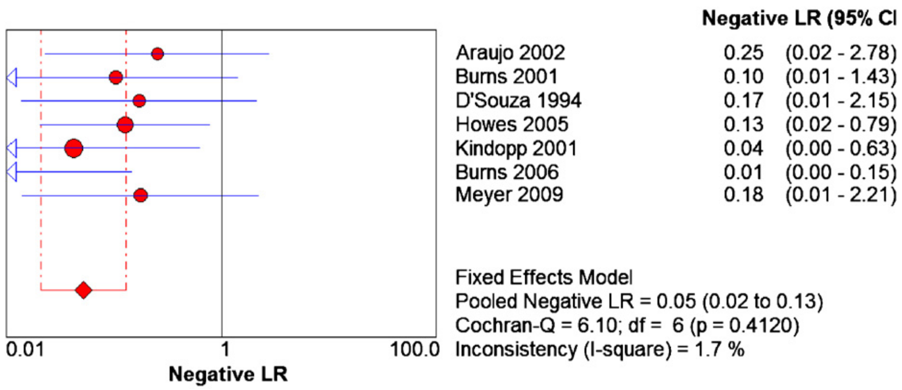

Fig. 5. Forest plot of negative likelihood ratio from test accuracy studies of colorimetric capnometry or capnography in the verification of tube placement.

tube to detect CO_2 and to verify ventilation or correct tube placement. The test results ($ETCO_2$) were obtained after the feeding tubes had been inserted to approximately 30 cm (Araujo-Preza et al., 2002; Howes et al., 2005; Thomas and Falcone, 1998). One study (Elpern et al., 2007), obtained the test results ($ETCO_2$) after the feeding tubes had been inserted into the stomach. An EasyCap II was connected for the two steps for all 69 NG tube insertion (total 138 measurements). The first measurement of $ETCO_2$ was performed when the NG tube was inserted 30 cm from the nostril, and the second measurement was performed after the insertion was completed to a total distance of 50 cm (Meyer et al., 2009). Two trials (Araujo-Preza et al., 2002; Meyer et al., 2009) reported high sensitivity and specificity of the colorimetric capnometry in detecting airway intubation and high agreement with the reference standard radiological technique (sensitivity 1.00, specificity 0.95–1.00). One study (Howes et al., 2005) demonstrated a less than 1.00 sensitivity and specificity and recommended using a new colorimeter for each test of tube placement to improve its accuracy. Another study (Elpern et al., 2007) demonstrated a specificity of 0.84 and suggested false positive results could be related to contamination of the capnometer due to reflux gastric contents.

4.4.3.2. Capnography. Three trials (Burns et al., 2001; D'Souza et al., 1994; Kindopp et al., 2001), with a total of 140 observations, determined the sensitivity and specificity of capnography in correctly differentiating between respiratory and GI tube placement (Supplementary Data 6). Feeding tubes were inserted into the GI tract with a capnograph attached to obtain gas samples. The $ETCO_2$ reading and/or waveform were observed at various time intervals. In one trial (D'Souza et al., 1994), the feeding tube was placed into the pharynx under direct visualization or under direct endoscopic guidance. The placement of the tube within the airway was defined as the detection of a capnogram (presence of a waveform) with $ETCO_2$ levels exceeding 15 mmHg (Swiech et al., 1994), or the presence of a capnogram (D'Souza et al., 1994).

In the trial by Burns et al. (2001), four out of 13 feeding tubes were placed into the airway on initial placement and were detected by the presence of CO_2 waveforms. Upon reinsertion of feeding tubes into these four patients, CO_2 was not detected and auscultation and aspiration of stomach contents confirmed gastric placement.

In the second trial ($n = 20$), the capnogram curve disappeared in all patients when the feeding tubes were introduced into the esophagus (D'Souza et al., 1994). However the capnogram continued to be displayed in two subjects despite advancement of the tube up to the esophageal mark, direct visualization confirming the tube had curled in the pharynx. The authors also indicated that the tube had to be purged of secretions before obtaining the capnogram for three patients.

The third trial (Kindopp et al., 2001) reported a 1.00 sensitivity and specificity in using capnography to verify tube placement. Of the 100 tubes inserted, 11 were placed in the bronchus, 86 were in the esophagus and three were intra-oral placements. The capnographs clearly detected the locations of the tubes that were placed in the bronchus which were confirmed by radiography. Capnography was also able to identify tubes located in the esophagus and in the oral cavity but was unable to differentiate between the two. The authors therefore recommended obtaining one radiograph after tube placement to ascertain final position prior to feeding.

4.4.3.3. Capnography versus colorimetric capnometry in verifying tube placement. One trial (Burns et al., 2006) compared the use of a portable capnograph in detecting inadvertent respiratory intubation among 130 mechanically ventilated adult patients (195 gastric tube insertions) in the intensive care unit. Insertion failures with detection of CO_2 occurred in 27% of instances. $ETCO_2$ was successfully detected with the colorimetric indicator (within seconds) for all insertions. The results demonstrated a sensitivity: 1.00 (95% CI 0.93–1.00), specificity: 1.00 (95% CI 0.97–1.00), PPV: 1.00, NPV: 1.00, positive likelihood ratio: 283.35 (95% CI 17.81–4508.75) and negative likelihood ratio: 0.01 (95% CI 0.00–0.15). The authors concluded a colorimetric device was as accurate as capnography for detecting CO_2 during placement of NG tubes.

4.5. Costs

Three trials (Howes et al., 2005; Meyer et al., 2009; Thomas and Falcone, 1998) investigated the costs associated with checking feeding tube placement using colorimetric CO_2 detectors and chest X-ray. All three trials reported that there were significant cost savings using CO_2 detectors compared to chest X-rays. The costs of the devices for $ETCO_2$ monitoring were reported to be USD $14.5 (Thomas and Falcone, 1998), CAD $13.14 (Howes et al., 2005), EUR $16.47 (Meyer et al., 2009) when compared to the costs of a single chest X-ray which was USD $60.45 (Thomas and Falcone, 1998), CAD $75 (Howes et al., 2005), EUR $ 33.96 (Meyer et al., 2009). These costs reported excluded nurses and physician time. One trial (Kindopp et al., 2001) reported an average of 72.5 min for using capnography alone and 169.4 min for a two-step radiographic approach to verify tube placement and this time difference was statistically significant.

5. Discussion

This meta-analysis was undertaken to summarize and present the best available evidence relating to the use of $ETCO_2$ in verifying tube position for use in clinical decision making. A systematic search of the literature resulted in nine published trials that were eligible for inclusion in this review. Eight trials (Araujo-Preza et al., 2002; Burns et al., 2001, 2006; D'Souza et al., 1994; Elpern et al., 2007; Howes et al., 2005; Meyer et al., 2009; Thomas and Falcone, 1998) using either colorimetric capnometry or capnography were evaluated in intubated and ventilated patients and two (D'Souza et al., 1994; Elpern et al., 2007) of these trials also involved participants who were alert or awake. One trial (Kindopp et al., 2001) did not mention whether patients were awake, intubated or mechanically ventilated.

The results of this review indicate that the use of colorimetric capnometry or capnography is an effective method in differentiating between respiratory and GI tube placement for adult patients. The evidence also suggests that these two methods have a satisfactory agreement with the reference standard. A colorimetric device was found in one study (Burns et al., 2006) to be as accurate as capnography for detecting CO_2 during the placement of gastric tubes.

It should be noted that while both techniques can be used to differentiate respiratory and GI tube placement, they cannot differentiate between esophageal, gastric or intestinal and, therefore, additional methods to verify correct placement are needed. Reuse of the colorimeter for multiple patients can result in malfunction (Howes et al., 2005), therefore given the high sensitivity of the colorimetric capnometry, the use of a new colorimeter at each test is recommended.

The presence of an $ETCO_2$ exceeding 15 mmHg and/or a respiratory waveform (Burns et al., 2001), and a normal capnogram (D'Souza et al., 1994; Kindopp et al., 2001) were employed to denote respiratory placement of feeding tubes. Caution needs to be taken while relying on capnography in determining GI placement as the results of one study (Kindopp et al., 2001) indicated a lack of normal trace in capnographs in three intra-oral placements. The tubes were curled in the patients' mouth and this might be mistaken as esophageal placement.

It should be noted that different protocols were applied in these studies with regard to when to obtain the $ETCO_2$ measurement, of which most of the test results ($ETCO_2$) were obtained after the feeding tubes had been inserted to approximately 30 cm and some trials obtained the test results ($ETCO_2$) after the feeding tubes had been inserted to the stomach. Two recent trials (Elpern et al., 2007; Meyer et al., 2009) determining the use of colorimetric capnometry to ensure correct NG tube placement reported false positive results possibly due to the contamination of the capnometer by refluxed gastric contents either during patient's coughing or after intubation. The optimal timing of measurement remains to be determined.

With regard to air sampling, one trial (Kindopp et al., 2001) used a syringe to push 30 ml of air through the tube to clear any secretions to avoid interference with gas aspiration by the capnograph. Low wall suction was applied to the opposite end of the EasyCap II for approximately five seconds in order to ensure gas sampling and to minimize the waiting time for the CO_2 to pass from the tube to the detector (Howes et al., 2005). 1 min was allowed for the EasyCap to detect CO_2 in order to avoid confusion resulting from the ingestion of carbonated beverages (Araujo-Preza et al., 2002). However, these techniques have not been employed in other studies and more trials to determine whether these techniques help with gas sampling are needed.

Three studies (Howes et al., 2005; Meyer et al., 2009; Thomas and Falcone, 1998), one undertaken in the USA, one in France, and the other in Canada provided cost data and reported significant cost savings associated with the use of colorimetric CO_2 detectors compared to chest X-rays. This finding has significant implications for health services. However further research needs to be undertaken in order to generalize the health economic results to settings in other countries. Economic modeling is therefore vital to inform decision making. Although capnography is an emerging diagnostic test for locating feeding tubes, only one trial (Kindopp et al., 2001) provided information on the time taken to undertake this test.

This meta-analysis had several limitations. The first limitation concerns the use of different index tests to assess the adequate placement of the NG tube in these studies. Another limitation is that the majority of the studies included in the review were undertaken in patients who required mechanical ventilation, thereby systematically excluding a potentially vulnerable population. Furthermore, the people performing the diagnostic test, particularly capnography and capnometry, were often not reported. Therefore, the ideal personnel to perform those tests is unknown. A final limitation is that we only consider trials published in English and Chinese which could lead to language bias.

6. Implications for practice

Nurses are often responsible for placement of NG tubes in hospitalised patients, and there is a risk of inadvertent pulmonary intubations. Traditional bedside methods of detecting pulmonary placement have lacked precision, and nurses are increasingly advised to base their clinical practice on the best available evidence. This review has demonstrated that the use of capnography or colorimetric capnometry is a safe method for verifying proper feeding tube placement in mechanically ventilated patients. In light of its accuracy, and significant time savings, colorimetric CO_2 detection should be considered for the routine practice of confirming NG feeding tube placement. However prior to implementation nursing practice issues such as education and training relating to, colorimetric CO_2 measurement must be addressed.

7. Implications for research

This meta-analysis provides a guide to future priorities for research. More clinical trials are needed to determine the accuracy of using colorimetric capnometry or capnography in non-intubated and non-mechanically ventilated patients. Given the costs associated with development and delivery of newer technology of diagnostic tests, further research efforts should be directed towards evaluating the potential beneficial impact of using capnography or colorimetric capnometry on decreasing the use of chest X-ray to confirm NG tube placement. The outcomes include radiation exposure, costs, or mobilization of personnel.

8. Conclusions

In summary, based on the trials undertaken to date, there is evidence to support the use of capnography or colorimetric capnometry for the identification of feeding tube placement in mechanically ventilated patients.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ijnurstu.2010.12.004.

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