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Original contribution

Prompt correction of endotracheal tube positioning after intubation prevents further inappropriate positions☆,☆☆,★

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Abstract
Study Objective: To determine whether the timely correction of endotracheal tube (ETT) positioning prevents further inappropriate positions.
Design: Prospective crossover study.
Setting: University-affiliated hospital.
Patients: 44 adult, ASA physical status 1, 2, and 3 patients undergoing open or laparoscopic abdominal procedures.
Interventions: ETT positioning was verified by both auscultation and fiberoptic bronchoscopy (FOB), after intubation, and before extubation. In laparoscopic procedures, two additional measurements were performed: after maximal abdominal gas insufflation and with head-down position. An ETT in the bronchus or at the carina was considered an inappropriate placement. An ETT ≤ one cm from the carina was considered a critical placement.
Measurements: The frequency of inappropriate and critical ETT positioning with both auscultation and FOB and the number of ETTs that remained in an incorrect position despite repositioning.
Main Results: FOB detected 5 inappropriately positioned ETTs, 4 of which were also detected by chest auscultation ($P = 0.99$). Critical positioning was detected by FOB in 6 patients, three of which were also detected by auscultation ($P = 0.24$). There were 15 other "out-of-desired range" positions (out of the

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3-5 cm range) – one placed too high and 14 placed too low, while 18 were placed within the range of positions. All patients with inappropriate ETT positioning were women ($P = 0.005$). Age, body mass index, Mallampati grade > 3, thyromental distance < 6 cm, or laryngoscopy grade ≥ 2 were not associated with either inappropriate or critical placement. No episodes of inappropriate or critical positioning were detected by FOB or auscultation at the end of surgery.

Conclusions: Early detection and prompt correction of inappropriate ETT positioning after intubation prevented further ETT migration into undesired positions.

1. Introduction

Accidental bronchial intubation is the most common critical incident associated with endotracheal intubation and arterial desaturation [1], responsible for 40% of the respiratory critical incidents that occur during anesthesia [2]. Accidental bronchial intubation may lead to serious complications [3]; thus, prompt diagnosis and correction of endotracheal tube (ETT) positioning is important.

Schwartz et al. [4] found an incidence as high as 15.5% of inappropriately placed ETTs, as verified by chest radiography. Confirmation of correct ETT positioning relies on direct visualization or indirect measures such as auscultation and capnography [5]. Lung auscultation is not always reliable in the diagnosis of accidental bronchial intubation [6]. Several methods have been used in detecting this event [7-9]; chest radiography and fiberoptic bronchoscopy (FOB) are considered the most reliable methods [4,10-13].

However, a chest radiograph may not be readily performed in all patients in the operating room (OR) suite. The more compelling reasons include time, cost, and radiation exposure, among others. Therefore, lung auscultation and FOB verification remain the most practical means in the detection of accidental bronchial intubation. It is uncertain whether early detection and correction of inappropriate ETT positioning prevents further ETT migration into an undesirable position throughout surgery. We investigated the hypothesis that timely correction of ETT positioning prevents further inappropriate positions.

2. Materials and methods

After approval from the Wolfson Medical Center Local and Ministry of Health Institutional Review Boards, and written, informed consent was obtained from all patients, this prospective crossover study of elective surgical patients undergoing general endotracheal anesthesia was conducted in 44 adult, ASA physical status 1, 2, and 3 patients (>18 yrs), undergoing elective open or laparoscopic abdominal surgery. All consecutive patients arriving at the holding area between 7 AM and 4 PM were included in the study. Pregnant patients, soldiers, and patients with psychiatric disorders were excluded from the study. Also excluded were patients with a history of surgery or pathology involving the trachea and bronchi.

2.1. Protocol

Premedication consisting of sublingual brotizolam 0.25 mg, given one hour before surgery, was given to all patients. Monitoring included electrocardiography (ECG), noninvasive blood pressure, capnography, pulse oximetry, core temperature, neuromuscular blockade, and peak airway pressure. Anesthesia was induced with midazolam, fentanyl, propofol, and rocuronium; it was maintained with isoflurane and aliquots of fentanyl and rocuronium, as deemed necessary.

Endotracheal intubation was performed with a size #3 or #4 Macintosh blade. Portex ETTs with a Murphy eye (Smiths Medical, St. Paul, MN, USA), size 7 mm for women and 8 mm for men, were used for intubation. Tube fixation was done with a cotton tie tape. The ETT was placed orally and secured at the upper incisor teeth at the 23 cm mark in men and at the 21 cm mark in women [14,15]. Intubations were performed by anesthesia residents with over 12 months' experience with intubation. Two researchers performed the auscultations and two other researchers performed the FOB examinations. In each patient, auscultation was performed first, followed by FOB. The findings with either method were immediately recorded by the performer. The ETT was moved if necessary – only by the anesthesiologist who performed the patient's intubation – if it was placed too deeply or superficially.

Measurements were performed with the head and neck in the neutral position, at the beginning and at the end of surgery. In laparoscopic procedures, two additional measurements were recorded: after inclining the OR table in the head-down position and at maximal abdominal insufflation with CO_2.

All patients with accidental bronchial intubation that was found during the entire study had a chest radiograph taken in the Postanesthesia Care Unit.

A properly positioned ETT should have its tip placed 2.5 to 4 cm above the carina [16]. For safety purposes [17], we used a higher upper limit; we considered three to 5 cm as our desired ETT tip-carina distance. We were concerned that leaving the ETT at a distance less than 3 cm above the carina would increase the likelihood of accidental bronchial intubation on either inadvertent neck flexion or head-down positioning and abdominal insufflation with CO_2 during laparoscopy.

An ETT in the bronchus or at the carina was considered an inappropriate placement. An ETT ≤ one cm from the carina was considered a critical placement. Thus, all undesired ETT positions (range of three to 5 cm above the carina) were corrected at each time point to achieve an “ideal” distance of approximately 4 cm above the carina.

The primary endpoints of the study were the frequency of inappropriate and critical ETT positioning diagnosed by both chest auscultation and FOB and the number of ETTs that were in an incorrect position at the end of surgery despite repositioning.

2.2. Measurements

Demographic data, including age, gender, height, weight, body mass index (BMI), thyromental distance, Mallampati class, and laryngoscopy grade were recorded.

Tube positioning data included findings on chest auscultation and FOB following intubation and at the end of surgery, and two additional measurements in laparoscopic procedures: after inclining the table in the head-down position and at maximal abdominal insufflation with CO_2.

The number of patients with inappropriate and critical ETT positioning as diagnosed by FOB was recorded. In addition, the number of patients with less than ideal placement (out of the three to 5 cm range) was recorded.

Complications such as intraoperative episodes of oxygen saturation via pulse oximetry (SpO_2) < 95%, bronchospasm, and postoperative atelectasis also were recorded. Complications related to FOB may include major complications such as pneumothorax, pulmonary hemorrhage, and respiratory failure, and minor complications such as laryngospasm that resolved spontaneously, vomiting, bronchospasm, vasovagal syncope, and epistaxis [18,19].

2.3. Statistical analysis

2.3.1. Sample size

With 44 subjects, the present study had a confidence level of 95% and a confidence interval of 9.25% to estimate the prevalence of accidental bronchial intubation (incorrect ETT positioning), assuming an event rate of 10%.

2.3.2. Data analysis

Event rates were calculated using both FOB and chest auscultation. Association of measures by method was assessed using the McNemar test. Between-method agreement was evaluated by calculating diagnostics, including sensitivity, specificity, positive predictive value, and overall diagnostic accuracy. Negative predictive value could not be calculated due to a "zero" value for false-positives, holding FOB as the gold standard. Patient characteristics were compared across categories of ETT placement using one-way analysis of variance (ANOVA) or chi square test as appropriate. All tests were two-sided and considered significant at $P < 0.05$.

Table 1 Endotracheal tube positioning after intubation; between-test agreement

Variables	Auscultation	Fiberoptic bronchoscopy	*P*-value
Inappropriate position	4	5	0.99
Critical position	3	6	0.24

Data are expressed as numbers of cases.
Inappropriate position = at the carina or within the bronchus; Critical position = ≤ 1 cm above the carina.

3. Results

Data from 44 consecutive patients were analyzed. Following endotracheal intubation, FOB detected 5 episodes of inappropriate positioning, 4 of which were also detected by chest auscultation. Detection of inappropriate positioning did not differ by method ($P = 0.99$). Critical positioning was detected by FOB in 6 cases, three of which were also detected by auscultation; again, detection did not differ by method ($P = 0.24$) (Table 1).

Following intubation, there were 15 other "out-of-ideal" range positioning episodes (out of the 3-5 cm range) and 18 within the range ETT positionings. In 14 of the 15 patients in whom ETT were in "out-of-ideal" position, as defined by out of the 3-5 cm range, the ETT tip to carina distance was less than 3 cm (placed too far distally). In one case (a woman), the ETT tip was placed too proximally (ie, 6 cm from the carina). All of these out-of-range positions were corrected.

Auscultation is compared with FOB in Table 2. For both inappropriate and critical positions, specificity was 100% (95% CI 1.0-1.0), indicating that of all appropriate placements, auscultation accurately classified all as having appropriate placement. On the other hand, sensitivity to inappropriate placement was 80% (95% CI 0.45-1.15), meaning that of all inappropriate placements, auscultation correctly identified 80%. Moreover, sensitivity for critical placement was only 50% (95% CI 0.09-0.9), meaning that of all critical placements, auscultation only correctly classified half. Positive predictive value was 100% (95% CI 1.0-1.0) for both inappropriate and critical placements, meaning that

Table 2 Prediction statistics for inappropriate and critical endotracheal tube positions comparing auscultation with fiberoptic bronchoscopy as the gold standard

	Inappropriate position	Critical position
Sensitivity	0.8 (0.45-1.15)	0.5 (0.09-0.9)
Specificity	1.0 (1.0-1.0)	1.0 (1.0-1.0)
Positive predictive value	1.0 (1.0-1.0)	1.0 (1.0-1.0)
Accuracy	0.98 (0.93-1.02)	0.93 (0.86-1.0)

Data are presented as point estimates (95% CI).
Inappropriate position = at the carina or within the bronchus; Critical position = ≤ one cm above the carina.

Table 3 Patient characteristics by endotracheal tube position as detected by fiberoptic bronchoscopy after intubation

Endotracheal tube position:	Inappropriate position (n = 5)	Critical position (n = 6)	Other "out-of-ideal" range [a] (n = 15)	In range (n = 18)	*P*
Age (yrs)	56.7 ± 8.2	52.3 ± 18.9	55.7 ± 14.7	61.7 ± 3.4	0.56
Gender (% female)	5 (100)	2 (33.3)	13 (86.7)	7 (38.9)	0.005
Body mass index (kg/m^2)	28.9 ± 2.7	27.7 ± 3.1	28.0 ± 4.9	26.7 ± 4.1	0.7
Height (cm)	162.8 ± 5.4	164.8 ± 6.9	162.5 ± 7.4	166.9 ± 4.9	0.2
Weight (kg)	76.4 ± 6.3	77.0 ± 9.4	75.1 ± 15.6	74.8 ± 14.6	0.9
Thyromental distance < 6 cm	2 (40)	5 (83.3)	7 (46.7)	12 (66.7)	0.2
Mallampati grade 3 or 4	1 (20)	2 (33.3)	4 (26.7)	2 (11.1)	0.6
Laryngoscopy grade ≥ 2	4 (80)	4 (67.7)	11 (73.4)	13 (73.2)	0.9

Results are expressed as means ± SD and absolute numbers (percentages).

[a] 'Ideal' range = 3-5 cm above the carina; Inappropriate position = at the carina or within the bronchus; Critical position = ≤ one cm above the carina.

when auscultation detected one of these inappropriate placements, it was correct 100% of the time. Overall accuracy was high, 98% for inappropriate placement, and 93% for critical placement.

As shown in Table 3, age, BMI, Mallampati grade > 3, thyromental distance < 6 cm, and laryngoscopy grade ≥ 2 were not associated with either inappropriate or critical placement. A significant difference in distribution of gender across placement categories was detected; all inappropriate placements occurred in women ($P = 0.005$). No episodes of inappropriate or critical positions were detected by either FOB or auscultation during the two types of laparoscopic manipulations and at the end of surgery. No episodes of SpO_2 < 95% and no other intraoperative or postoperative complications were encountered.

4. Discussion

Proper placement of an ETT in the airway assures airway protection and facilitates mechanical ventilation [20]. Several methods have been suggested to verify proper positioning within the airway, including direct visualization of the tracheal rings between the cords, observation and palpation of chest movements, measuring ETT depth from the incisors by referring to the marks on the tube, capnography, chest radiography, and by FOB [14,15,21].

Chest auscultation, although the most common method used, has relatively low accuracy due to referred sounds or noisy environments [22]. Failure to diagnose mainstem intubation by auscultation may result from using ETTs with a Murphy eye (as with those ETTs used in the present study) [23]. In a study by Verghese et al. [6], chest auscultation was compared with fluoroscopy in pediatric patients. The authors emphasized that failure to diagnose mainstem intubation by auscultation alone may be related to the use of ETTs with a Murphy eye. The Murphy eye was designed to allow ventilation of the lung when the bevel of the ETT was occluded. The Murphy eye also permits bilateral breath sound auscultation, even with accidental bronchial intubation, thus reducing the reliability of chest auscultation in detecting endobronchial intubation. They found that, on fluoroscopy, the ETT tip was seen in the right mainstem bronchus in 18 patients (11.8%) despite normal auscultation of the lungs. We also used ETTs with a Murphy eye and found that chest auscultation detected only 4 accidental bronchial intubations while FOB detected 5 of these events.

Furthermore, critical position (one cm or less distance from ETT tip to carina) was detected by auscultation in only three of the 6 cases that were detected by FOB.

In a previous study [24], we showed that use of a topographic measurement method that calculates the required ETT insertion length reduced the risk of accidental bronchial intubation. However, this method possibly assures a correct ETT position only immediately after intubation. Operating table repositioning or patient movement, as well as abdominal insufflation with CO_2 that is performed in laparoscopic procedures, may further move the ETT [25,26], eventually relocating with its tip into the bronchus.

In the present study, all patients with accidental bronchial intubation were women. We have to consider whether this finding was the result of choosing 21 cm as the point at which the ETT was secured in this patient group. Chong et al. [27] found that patient height (<167.5 cm) was a risk factor for accidental bronchial intubation, which may explain why short-statured women are at higher risk of this event. The fact that, in our study, the only case whose ETT was placed too high was a woman, may suggest that patient height and tracheal length [27], not female gender per se, is the reason for the accidental bronchial intubation. Chong et al. noted that many of the commonly used ETTs were placed close to or beyond the carina when the black intubation guide mark was at the level of the vocal cords, which may signify that the 21-23 cm insertion technique carries no higher danger for accidental bronchial intubation than other non-fail safe (besides FOB and chest radiography) ETT positioning methods.

Short stature [27] and short neck [28], especially in patients undergoing laparoscopic surgeries, may represent an indication for ETT position checking and correction with the aid of a FOB. Additional studies in subgroups of high-risk patients are warranted.

In our study, 4 of the 5 inappropriate ETT positionings were diagnosed by auscultation. However, critical positioning was diagnosed by auscultation in only 50% of patients (three of 6 pts) compared with 100% of patients by FOB. Though a 100% relative increase in detecting critical positioning using FOB versus auscultation was observed, this difference in detection rate was not statistically significant ($P = 0.24$). The present study clearly was underpowered to detect this individual endpoint. As noted in the statistical analysis, the study included 44 subjects, which conferred a confidence level of 95% and a CI of 9.25% to estimate the prevalence of accidental bronchial intubation (incorrect ETT positioning), assuming an event rate of 10%.

We conclude that prompt detection and correction of an inadequately or incorrectly positioned ETT appears to reduce the frequency of further ETT migration and thus the likelihood of accidental endobronchial intubation or undesirable extubation.

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