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An observational study to determine whether alignment of endotracheal tube indicator line with the vocal cords results in appropriate depth of intubation

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Abstract : *Background*: Inappropriate endotracheal tube placement depth may be associated with complications.
Objective : To determine whether the accurate alignment of the indicator ring on the endotracheal tube at the level of the vocal cords, results in its appropriate placement.
Design : Prospective observational study.
Patients : 98 adult patients scheduled for general anesthesia with orotracheal intubation. Interventions: The indicator band mark on the endotracheal tube was accurately placed at the vocal cords level under video-laryngoscope view. The tube length at the right upper incisor and the distance between its tip and the carina was measured using fibreoptic bronchoscope. Data to validate methods to predict insertion depth was collected and evaluated.
Main Outcome : To determine the distance between the tip of the endotracheal tube and the carina.
Results : The endotracheal tube tip depth was inappropriate in 46.94% cases and was <3 cm above the carina in 41.64% cases. This difference in this distance was similar (p = 0.246) in the two genders. A correlation was noted between topographic length and insertion depth in females only (r2 = 0.201 and p = 0.001). The mean tracheal length was 12.66 $\pm$ 1.35 cm in males and 12.04 $\pm$ 1.26 cm in females.
Conclusion : We found a high incidence of endotracheal tube tip malposition despite the accurate placement of the indicator band at the vocal cords level. We suggest that international endotracheal tube design standards be defined and endotracheal tube manufacturers modify the standard intratracheal length.

Keywords : endotracheal tube placement ; depth of endotracheal tube insertion ; oro-tracheal intubation ; vocal cords to carina distance.

Introduction

Inappropriate endotracheal tube (ETT) placement depth is a potential peril in general anesthesia and intensive care. ETT placement depth is a function of patient anatomy and surgical position. With a change in the head/neck position, upward or downward movement, of a malpositioned ETT within the airway, may result in complications such as endobronchial intubation, vocal cord trauma, vocal cord paralysis, atelectasis, tension pneumothorax, and accidental tracheal extubation (1-3). Radiographic verification studies have revealed a 15.5% incidence of inappropriate ETT placement, with a higher rate in women (4). The ETT's tip should be located 5 $\pm$ 2 cm above the carina, to prevent these complications (5).

Most manufacturers print indicator marks on the ETT to suggest the correct position at the vocal cords. This indicator mark is commonly used by anesthetists to decide the depth of ETT placement. We designed a prospective observational study to determine whether the accurate placement of the indicator ring on the ETT at the level of the vocal cords, results in appropriate ETT placement and whether this placement strategy is better than other methods described. We also analyzed whether there is a correlation between the depth of insertion and the patient's height and topographic length (mandibular length + mandible to sternum distance) as secondary objectives.

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Methods

This prospective observational study was conducted on 98 adult Indian patients, in American Society of Anesthesiologists (ASA) functional classification I-III, scheduled for elective surgery under general anesthesia with orotracheal intubation. The study period was one year, with a target of recruiting 100 patients with equal gender distribution. Ethical approval for this study (Ethical Committee No. TS/MSSH/Smart/IEC/Anaes/17-03) was provided by the Institutional Ethics Committee, Max Smart Super Speciality Hospital, Saket, Delhi, India (Chairperson Dr A.K. Agarwal) on 24 April, 2017. Written informed consent was taken from all participants. Exclusion criteria included: poor functional status; patients with anatomical upper airway, neck or chest distortion; a history of previous difficult tracheal intubation; and risk of pulmonary aspiration.

A routine preoperative evaluation was conducted. In addition, the mandibular length (distance from the angle of the mandible to a line tangential to the mandibular notch) and the span between the angle of the mandible and the sternal notch of all patients were measured (Fig. 1). The sum of these lengths was labelled as the topographical upper airway length.

After administration of 1-2 $\mu g.kg^{-1}$ fentanyl intravenous (IV), general anesthesia was induced with 2 $mg.kg^{-1}$ propofol IV. Atracurium (0.6 $mg.kg^{-1}$) was administered to facilitate tracheal intubation. The trachea of all patients was intubated with a plain cuffed polyvinyl chloride ETT of the same manufacturer (Portex, Smith Healthcare Manufacturing SA de C.V., Baja California, Mexico). C-MAC (C-MAC PM Set, Karl Storz GmbH & Co, Tuttlingen, Germany) or a UEscope (UEscope VL400, Zhejiang UE Medical Corp., Zhejiang, China) video-laryngoscope facilitated tracheal intubation and the black indicator band printed above the ETT cuff was placed at the level of vocal cords under clear vision. The ETT length mark at the level of the right upper incisor was noted and after that, the ETT secured with tape at the right corner of the mouth. After fixing the ETT, the ETT tip to carina length was measured, under fibreoptic bronchoscope vision (the distance the bronchoscope moved on withdrawal from the level of the carina to the level of the tip of the ETT). The vocal cords were not visualized through the bronchoscope. All measurements were made with the head in the neutral position. The following parameters were noted (Fig. 2):

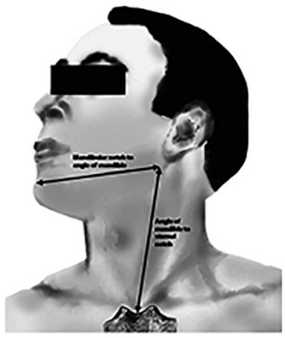

Fig. 1. — Topographic length measurement.

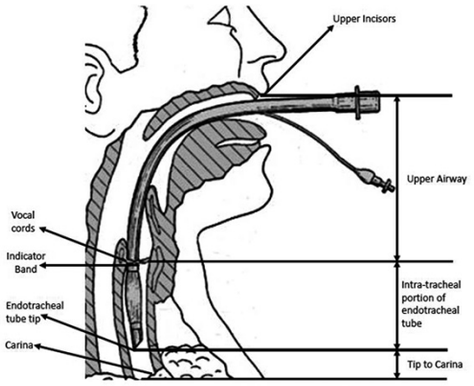

Fig. 2. — Parameters recorded after endotracheal tube insertion.

– length from the indicator band to the ETT tip (intra-tracheal length of the ETT) ;
– distance from vocal cords to the carina (tracheal length, i.e. intra-tracheal length + ETT tip to carina length) ;
– distance from incisors to the vocal cords (upper airway length) ;
– sum of the upper airway length and the intra-tracheal ETT length (Insertion Depth) ;
– sum of the upper airway length and the tracheal length (airway length).

Anesthesia was maintained as per institutional protocol and standard ASA recommended monitoring done. On completion of the surgery, all patients were weaned off anesthesia and their trachea extubated, after ensuring a full recovery.

Statistical analysis

The data was analyzed using SPSS version 20.0. Correlation–regression analysis was done for correlating various distances and patient factors using standard tests of significance. P-value < 0.05 was considered a statistically significant correlation.

Results

A total of 100 subjects were recruited and studied to determine the airway dimension characteristics. All tracheal intubations were performed by experienced anesthetists (MCK, SG, AP) and measurements with the bronchoscope were performed in less than 2 min. An experienced anesthetist supervised the bronchoscopic measurements. Data of 50 males and 48 females were taken for analysis (there was data recording error in two female subjects). The mean height of the male subjects was 167.67 ± 11.05 cm and of female subjects 156.36 ± 7.84 cm; and their mean weight was 75.89 ± 14.54 kg and 65.99 ± 11.42 kg respectively. The intra-tracheal length of the Portex ETT used was noted as 9.5 cm for 8.0 and 8.5 mm ID size ETT; and is 9.0 cm for 7.0 and 7.5 mm ID size ETT.

The ETT tip to carina length data is presented as Table 1. In 46.94% of cases, the ETT tip was at an inappropriate depth, with the distance between the ETT tip and the carina < 3 cm in 41.84% cases and >5 cm above the carina in 5.1% cases. In 47.92% of cases, the ETT was too deep in females vis-à-vis 36% in males (Fig. 3). When the depth of intubation was analyzed based on ETT size, in 51.28% of cases with ETT 7.5 mm ID and 46.67% of cases with ETT 7.0 mm ID, the length between the ETT tip and the carina was <3 cm (Table 1). The difference in the ETT tip to carina length was not statistically significant (p = 0.246) between the two genders. However, the difference in the ETT tip to carina length was statistically very significant, when compared by ETT size (p=0.001).

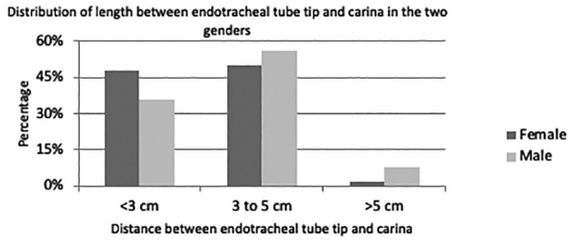

Fig. 3. — Bar diagram displaying distribution of distance between endotracheal tube tip and carina in the two genders.

The tracheal length was found to vary between 10 and 14.8 cm. Regression analysis to determine the correlation between patient height and tracheal/airway length (Table 2) revealed a very significant statistical correlation of airway length

Table 1

Free tracheal length: distribution based on gender and endotracheal tube size

	n	Endotracheal tube tip to carina length			Chi Square Value	p value
		<3 cm n (%)	3-5 cm n (%)	>5 cm n (%)		
All cases	98	41 (41.84%)	52 (53.06%)	5 (5.10%)		
Female	48	23 (47.92%)	24 (50%)	1 (2.08%)	2.678	0.246
Male	50	18 (36.00%)	28 (56.00%)	4 (8.00%)		
Endotracheal tube 7.0 mm ID	15	7 (46.67%)	8 (53.33%)	0	22.715	0.001
Endotracheal tube7.5 mm ID	39	20 (51.28%)	18 (46.15%)	1 (2.56%)		
Endotracheal tube 8.0 mm ID	30	9 (30.00%)	21 (70.00%)	0		
Endotracheal tube 8.5 mm ID	14	5 (35.71%)	5 (35.71%)	4 (28.57%)		

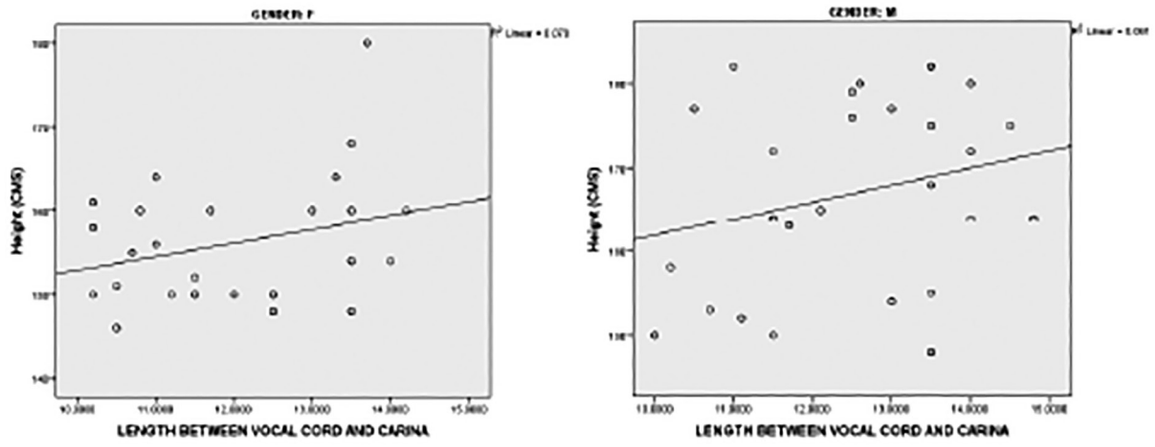

Fig. 4. — Scatter plots displaying correlation between patient height and tracheal length in females but not in males. males.

Table 2

Regression Analysis to determine correlation between patient height with airway length and tracheal length : distribution based on patient gender

	n	Mean ± SD	r	r^2	t value	p value
Airway length in females (cm)	48	22.47±1.95	0.599	0.359	5.075	0.0001
Height (cm)		156.23±7.81				
Airway length in males (cm)	50	24.29±1.63	0.169	0.029	1.188	0.2410
Height (cm)		167.30±11.24				
Tracheal length in females (cm)	48	12.04±1.26	0.264	0.070	1.858	0.070
Height (cm)		156.23±7.81				
Tracheal length in males (cm)	50	12.66±1.35	0.246	0.061	1.758	0.085
Height (cm)		167.30±11.24				

Table 3

Regression Analysis to determine correlation between topographic length and insertion depth: distribution based on gender

	n	Mean±SD	r	r^2	t value	p value
Insertion Depth in females (cm)	48	19.48±1.32	0.448	0.201	3.403	0.001
Topographic length in females (cm)		21.39±2.50				
Insertion Depth in males (cm)	50	21.05±1.22	0.242	0.058	1.726	0.091
Topographic length in males (cm)		24.38±3.15				

Table 4

Relation of patient height with endotracheal tube insertion depth, tracheal length and total airway length

Height range (cm)	n	Insertion depth (cm)		Tracheal length (cm)		Airway length (cm)		Suggested insertion depth (cm)
		mean ±SD	Range	mean ± SD	Range	mean ± SD	Range	
141-150	24	18.92±1.1	18-20	11.98±1.15	10-13.5	22.1±1.81	19.5-25.5	18
151-160	27	19.85±1.54	18-24	11.91±1.36	10.2-14.2	22.61±1.72	19.8-25.6	19
161-170	22	21.0± 0.87	19-22	12.65± 1.51	10.2-14.8	24.33±1.87	21.6-27.3	20
171-180	20	21.08± 0.86	20-23	12.93± 1.12	10.5-14.5	24.61±1.59	21-27.2	21
181-190	8	21.40± 0.89	21-23	13.0± 1.12	11-13.5	24.9±0.22	24.5-25	21

with height in females (r^2 = 0.359 and p = 0.0001) but not in males (Fig. 4). However, the tracheal length did not correlate statistically with height in both genders. Regression analysis to determine the relationship between topographic length and insertion depth (Table 3) found a very significant statistical correlation in females (r^2 = 0.201 and p = 0.001) but not in males. The difference between the topographical length and the insertion depth was about 2 cm in females and about 3 cm in males.

We attempted to correlate the height range of the two genders with insertion depth (Table 4). The tracheal length was not very different between the height groups. The airway length was similar for height between 141 cm to 170 cm and height between 171 cm and 180 cm. The airway length was, however, more in those with a height between 181 cm and 190 cm, indicating a more significant contribution of the upper airway in determining the airway length in taller patients.

Discussion

The standard method used to guide ETT insertion depth is an approximation of the indicator mark on the ETT to the vocal cords (6-8). However, this mark may be inappropriate as it is placed arbitrarily by manufacturers and does not cater for patients of all physical characteristics. The mark may also be inappropriate because the distance between the ETT tip and the carina cannot be predicted (9). Definitive methods to confirm ETT placement are chest radiograph and fibreoptic bronchoscopy examination, but they involve additional costs and intervention (10, 11).

Our protocol was designed to study the intubation depth with the indicator band aligned to the vocal cords. Conventional laryngoscopy does not permit good visualization of the indicator band in patients with grade III and IV laryngoscope views (8, 12). We performed tracheal intubation

with a video-laryngoscope to ensure clear vision and thereby accurate alignment of the vocal cords with the indicator band. We used two different video laryngoscopes, based on availability in the operating rooms, as the study was not designed to assess the laryngoscopes. The mean insertion depth in our study (in neutral head) position) was 19.51 $\pm$ 1.32 cm in females (range 18 to 21 cm) and 21.11 $\pm$ 1.15 cm in males (range 19 to 24 cm), with the indicator line at the level of the vocal cords. In 51.85% of our female subjects, the ETT tip position was inappropriate (< 3 cm away from carina in 47.92% or > 5 cm away from carina in 2.08%), while it was inappropriate in 44% of the male subjects (< 3 cm away from carina in 36% and > 5 cm away from the carina in 8%).

By convention, the depth of ETT insertion is evaluated by auscultation for bilateral breath sounds and symmetric chest expansion, but they fall woefully short of being referred to as benchmarks, as high or low placement of the ETT won't be detected by them. Flexion of the neck from full extension may result in a 3-5 cm (mean 3.8 cm) caudal movement of the ETT toward the carina, while an extension of the neck may result mean 1.9 cm movement of the tip of ETT away from the carina (on manoeuvre of the head from neutral position to full extension)(9, 10). To prevent ETT misplacement and main-stem bronchial intubation during head movement, the tip of the ETT should thus be located at least 3 cm cephalad to the carina and the proximal end of the ETT cuff should be at least 2 cm below the vocal cords to avoid cuff impingement on the vocal cords (1, 13, 14). A difference of 4 cm between the ETT tip and the carina has been described as the 'best-fit' distance (10). The insertion depth for our population subset was calculated by reducing a value of 4 cm from the airway length. It was estimated to be 18 cm for patients with height 141-150 cm; 19 cm for height 151-160 cm; 20 cm for height 161-170 cm; and 21 cm for height >171 cm (Table 4). A study on Colombian subjects has proposed similar insertion depths (15).

Several methods to determine the appropriate depth of ETT insertion are described in contemporary literature, but none are universally accepted. Attempts to validate methods to determine oro-tracheal ETT insertion depth have been frustrated by variability in patient height, weight, gender, race, build and airway anatomy. Simple formulae, landmarks, and estimations to determine the adequate depth of ETT insertion, have been suggested but need validation in different population groups (6, 13, 14, and 16). Some studies have recommended ETT insertion depth based on gender (1), while others suggest that it be as per topographic measurements and height of the individual patient (17). Most physicians place the ETT at a predetermined depth, based on gender. Although gender difference in ETT insertion depth is recognized, ETTs do not have gender-specific manufacture design.

Most clinicians follow the 21/23 cm rule (21 cm and 23 cm mark at the incisor level in women and men respectively) to decide ETT insertion depth, but 59% incidence of ETT malposition is associated with it (18). Evron et al. reported that 58.5% of ETTs were positioned <3 cm above the carina with the 21/23 cm insertion depth method and thus recommended a 20/22 cm rule for normal-sized women and men instead (17). They also reported that the tip-carina distance was significantly shorter in women vis-à-vis men. Flazone et al. also cautioned against acceptance of depths other than 20 cm in women and 22 cm in men (19).

Other authors however, felt that predetermined distances are not good predictors for appropriate placement of ETT and their use may increase patient risk (10). Evron et al. found good correlation between topographically measured length of airway and insertion depth (17). Manger et al., however, reported a 47% malposition rate using the same topographical method (10). We used the same anatomical structures but found that the difference between the measured topographical length and insertion depth varied by a large range (-2.0 cm to +9 cm). The insertion depth correlated with topographical length on regression analysis in females ($p = 0.001$, $r^2 = 0.201$) but not in male patients ($p = 0.091$, $r^2 = 0.058$).

Owen and Cheney (1) reported that the adult tracheal length (vocal cord to carina distance) ranges between 10 and 15 cm and that it correlates with patient height, but Evron et al. (17) could not validate this correlation. There was no correlation between tracheal length and patient height in both females and males in our study ($p = 0.070$, $r^2 = 0.070$ and $p = 0.085$, $r^2 = 0.061$, respectively).

We found the tracheal length to be 12.66 $\pm$ 1.35 cm in males and 12.04 $\pm$ 1.26 cm in females, which was similar to earlier reports. Pang et al. measured the tracheal length in Caucasians, using fibreoptic bronchoscopy, and reported it to be 13.6 $\pm$ 1.4 cm in males and 11.8 $\pm$ 1.3 cm in females (20). Tracheal length was reported as a mean of 12.8 cm (range 11-14 cm) in males and 11.9 cm (range 9.8-14 cm) in females in a study on British subjects (21). Tracheal length has been reported to be similar in western and oriental population (13). Our findings

Table 5

Suggested length between black ring on endotracheal tube and its tip

	n	Endotracheal tube tip to carina length(cm)	Tracheal length (cm)	Intra-tracheal tube length (cm)	Suggested intra-tracheal tube length (cm)	Suggested dimensions of segments (cm)		
						line to cuff	cuff	cuff to tip
Endotracheal tube 7.0mm ID	15	3.04 ± 1.1	12.07 ± 1.13	9.0	8.0	2.0	3.5	2.5
Endotracheal tube 7.5mm ID	39	2.87 ± 1.33	11.87 ± 1.33	9.0	8.0	2.0	3.5	2.5
Endotracheal tube 8.0mm ID	30	3.0 ± 1.0	13.0 ± 1.0	9.5	8.5	2.0	3.5	3.0
Endotracheal tube 8.5mm ID	14	3.52 ± 1.67	13.02 ± 1.67	9.5	8.5	2.0	3.5	3.0

showed that the tracheal length in our ethnic group was similar to that in the western population and standard anatomy texts. A study in our ethnic group had earlier noted a mean tracheal length in males to be 9.83 cm and 9.27 cm in females in a study from India, which is much shorter than that reported in most studies (22). The study design of this study was depended on extra-tracheal glow of a light source inside trachea, which can be erroneous as light disperses during its passage through the layers of the skin (21).

In a study based on computed tomography, Eagle (13) did not find a correlation between patient height, tracheal length or insertion depth. However, a recent study found a positive correlation and proposed a height based ETT insertion depth (23). We found lack of correlation between the morphological lengths in males and similar results have been reported by other studies using body morphology-based predictors (13, 17).

The indicator band on the ETT should be the preferred method to guide insertion depth as it derived from the tracheal length. The indicator mark method is valid for both oro- and naso-tracheal intubation. Despite ensuring accurate placement of the indicator band at the vocal cords, we found inappropriate ETT insertion depth in nearly half the subjects. Analysis of tracheal length data suggests that there is a need to have a universal guideline for the design of the intra-tracheal part of the tube and define manufacturing standards for the intra-tracheal length of ETT with dimensions of these segments defined as per ETT size.

The intra-tracheal portion of the 7 mm and 7.5 mm ID Portex ETTs (length distal to the indicator band) is 9 cm long while in the 8 mm and 8.5 mm ID ETTs it is 9.5 cm long. The tracheal length (distance between the vocal cords and the carina) in subjects with 7 mm and 7.5 mm ID ETTs was about 12 cm and was about 13 cm in those with 8 mm and 8.5 mm ID ETTs. All studies on tracheal length have reported mean adult tracheal length as between 10-12 cm. Considering the median distance to be maintained between the tube tip and carina to be 4 cm (cited above), the intra-tracheal length of the ETT must be restricted to 8 cm in 7 mm and 7.5 mm ID ETTs and 9 cm in 8 mm and 8.5 mm ID ETTs (Table 5).

No universal ETT manufacturing standards exist for the length of ETT, their cuff size or indicative marks placement (tube length below the glottic opening). Some standard adult ETT manufacturers print a circumferential band to indicate the suggested ETT level at the vocal cords while others print two rings with recommendations that the vocal cords are between the two circles. Some pediatric ETTs have black bands indicating the segment kept below the vocal cords. Several studies have estimated the dimension of the adult airway and tried to correlate it to body morphology, but none has made recommendations about the designing of ETT based on their estimates. We recommend designing of ETTs of standard adult sizes with a definition of the length of the sub-segments (indicator line to upper margin of the cuff; cuff; and lower margin of the cuff to the distal tip) as shown in Table 5.

The limitations of our study were that our study population was generally shorter than 180 cm in height; thus, data of taller people was limited. A study with a more extensive set of subjects may not be advocated as the distance between the tube tip and the carina was far too significantly short to justify a larger sample. The tracheal length measured was similar to that seen in the western studies and thus the results will have international ramifications.

To conclude, we studied the ETT insertion depth in adult patients but found a high incidence of ETT tip malposition despite ensuring accurate alignment of the indicator mark to the vocal cords, under video-laryngoscope vision. ETT malposition

can result in endobronchial intubation on changing the neck position after endotracheal tube fixation. The analysis of the data suggests that the issue can be resolved by changing the dimensions of the ETT between the indicator line and the tube. It is also recommended that international design standards for manufacture of ETT be defined.

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