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Review Article

# The Tracheal Accordion: A Review of Patient and Clinical Factors Affecting the Length of the Human Trachea

**Herway ST* and Benumof JL**

*Department of Anesthesiology, University of California San Diego, USA*

**Abstract**

The length of the human trachea in both awa-e and anesthetized and paralyzed patients is a critical consideration in preventing both endobronchial intubation and tracheal extubation. It is clear from the literature that with the dynamic clinical changes that occur under anesthesia, including the assumption of the supine position, head and nec- flexion and extension, pneumoperitoneum, and Trendelenburg positioning, the trachea acts as an accordion decreasing and increasing its length. -nowledge of the magnitude of the change in tracheal dimensions in response to these factors is an important clinical consideration.

***Corresponding author**

Seth Herway, Department of Anesthesiology, University of California San Diego, 200 West Arbor Drive MC 8770, San Diego CA 92103-8770, USA, Email: sherway@ucsd.edu

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- Head and nec- flexion
- Head and nec- extension

## INTRODUCTION

The length of the human trachea in both awa-e and anesthetized and paralyzed patients is a critical consideration in preventing both endobronchial intubation and tracheal extubation. Since tracheal length is expected to vary positively with patient height, *static patient factors* that are determinants of patient height such as race, gender and age, are also determinants of tracheal length. Furthermore, Croteau et al demonstrated in cadavers that intraluminal positive pressure increases tracheal volume and that longitudinal tension on the trachea increases tracheal length [1]. These findings suggest that the human trachea can act dynamically as an accordion and change in length and diameter in response to internal and external forces.

*Dynamic clinical factors* that have been studied that affect the dimensions of the trachea are head and nec- flexion and extension, pneumoperitoneum, and the Trendelenburg position.

## STATIC PATIENT FACTOR: RACE AND GENDER

Tracheal lengths in awa-e patients are typically based on radiographic studies that use anatomic landmar-s to identify approximate vocal cord location and thus measurements of exact vocal cord to carina (VC-CA) distances are not reported *(Table 1)* [2-4]. Under anesthesia, VC-CA distances can be directly measured with fiberoptic bronchoscopy and have been reported in several subsets of populations. A study in Caucasian males found a mean +/- SD VC-CA distance of 12.7 +/- 1.6 cm [5]. A study in the Thai population found a mean +/- SD VC-CA distance of 13.0 +/- 1.5 cm in males and 11.6 +/- 1.3 cm in females [6]. A mean +/- SD VC-CA distance of 13.1 +/- 1.6 cm in males and 11.2 +/- 1.5 cm was measured in a Taiwanese population [7]. A study in a Chinese population found a mean +/- SD VC-CA distance of 13.4 +/-1.3 cm in males and 12.0 +/- 1.2 cm in females [8]. In the Thai, Taiwanese, and Chinese populations studied, the difference between the average male and female tracheal length was 1.4, 1.9, and 1.4 cm, respectively (see Table 1). Across the four different male populations studied, average tracheal length varied 0.7 cm (12.7-13.4 cm). In the three female populations studied, tracheal length varied 0.8 cm (11.2-12.0 cm).

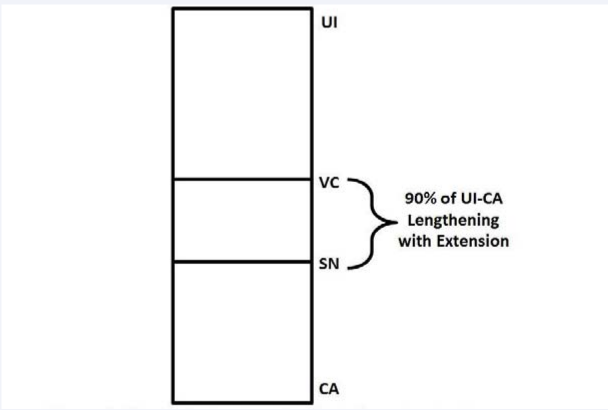


**Figure 1** Schematic drawing of various airway landmarks. Abbreviations: UI: Upper Incisors; VC: Vocal Cords; SN: Sternal Notch; CA: Carina

**Table 1:** Mean +/- SD vocal cord to carina (VC-CA) distances in four populations.

| | Vocal Cord to Carina Distances (mean +/- SD) | |
|---|---|---|
| **Population** | **Males** | **Females** |
| Caucasian | 12.7 +/- 4 1.6 | 4 |
| Thai | 13.0 +/- 4 1.5 | 11.6 +/- 4 1.3 |
| Taiwanese | 13.1 +/- 4 1.6 | 11.2 +/- 4 1.5 |
| Chinese | 13.4 +/- 4 1.3 | 12.0 +/- 4 1.2 |

**Table 2:** A list of dynamic clinical factors during anesthesia and paralysis that affect tracheal length and the tracheal accordion.

| Dynamic Clinical Factors During Anesthesia and Paralysis | Mechanism of Action Affecting Tracheal Length and the Tracheal Accordion |
|---|---|
| **1. Assumption of the Supine Position** | 1. Abdominal Contents Push |
| | Diaphragm Cephalad -> |
| | Mediastinal Shortening |
| **2. Paralysis of Diaphragm** | 2. Abdominal Contents Push |
| | Diaphragm Cephalad -> |
| | Mediastinal Shortening |
| **3. Paralysis of Head and Neck Extensors** | 3. Head and Neck Become More Flexed |
| **4. Trendelenburg Position** | 4. Abdominal Contents Push |
| | Diaphragm Cephalad -> |
| | Mediastinal Shortening |
| **5. Pneumoperitoneum** | 5. Increased Abdominal Pressure |
| | Pushes Diaphragm Cephalad -> |
| | Mediastinal Shortening |

## STATIC PATIENT FACTOR: AGE

Croteau's cadaver study showed that there were significant decreases in tracheal and bronchial compliance and linear elasticity with advancing age [2]. As expected, Griscom et al found that tracheal length and diameter increase with increasing age [9]. However, no measurements of age -related changes in tracheal compliance and elasticity exist in vivo.

## STATIC PATIENT FACTOR: HEIGHT

It is intuitively obvious that over wide ranges of height in adult patients, tracheal length correlates with patient height. Accordingly, two studies have attempted to correlate appropriate depth of endotracheal tube (ETT) placement with patient height [7,10]. One study recommends a formula of "(Height in cm/5) – 13" to determine the depth of ETT placement in centimeters at the right corner of the mouth [7]. Another study in an Indian population recommend a depth of ETT placement equal to "(Height in cm/7) – 2.5" cm [10].

Dynamic Clinical Factor: Head and Nec- Flexion and Extension Changes in head and nec- position are well documented to result in displacement of ETTs with head and nec- flexion and extension resulting in caudad and cephalad ETT migration, respectively [11-16]. The reported magnitude of shortening in distance between the ETT tip and the carina (ETT-CA) with head and nec- flexion in adults ranges from a mean of 0.6 cm (13) to a mean of 1.5 cm [11]. The increase in ETT-CA distance in adults with head and nec- extension has been reported to range from a mean of 0.6 cm [13] to a mean of 1.7 cm [14]. Head rotation has been shown to have bidirectional and minimal effects on ETT-CA [13,14].

Saito et al found that double lumen tubes also migrate within the trachea and mainstem bronchi during nec- flexion and extension [17]. They report that from full nec- flexion to full nec- extension and vice versa, the proximal and distal tube tips migrate caudad and cephalad a mean +/- SD distance of 2.8 +/- 0.6 cm (range 1.0-3.5 cm) and 2.7 +/- 0.6 cm (range 1.5-3.5 cm) respectively.

Wong et al [15] have demonstrated that the increase in ETT-CA in going from head and nec- flexion in the supine position caused by a 10 cm head pillow to head and nec- extension in the supine position with no head pillow is primarily due to elongation of the trachea. Their study specifically investigated the distances

between the upper incisors and vocal cords (UI-VC), the vocal cords and the sternal notch (VC-SN), the sternal notch and the carina (SN-CA), the upper incisors and carina (UI-CA), and the vocal cords and carina (VC-CA) as the head is extended (see Figure 1). They found that with change from head and nec- flexion on the 10 cm head pillow to head and nec- extension with no head pillow, the VC-CA and UI-CA distances increased significantly [1.6 +/-0.7 cm and 2.0 +/-0.70 cm (mean +/- SD), respectively]. Their results show that VC-SN comprises 40% of the VC-CA distance but accounts for 90% of the lengthening of the UI-CA distance when going from head and nec- flexion to head and nec- extension. Since the VC-SN segment is entirely within the nec-, it is the only segment of the trachea exposed to the action of the nec- muscles and to have flexion, extension, lateral and rotary mobility. We hypothesize that the reason the VC-SN segment of the trachea is responsible for 90% of tracheal lengthening on head and nec- extension is due to the mobility of the VC-SN tracheal segment. Furthermore, we agree with Wong et al [13] that with the proximal end of the ETT anchored at the mouth and with the VC-SN segment lengthening and shortening during nec- extension and flexion, respectively, it is a logical consequence for the ETT to ascend and descend and move away and towards, respectively, the carina-im et al investigated the effect of head and nec- extension in children [16]. They found that the average tracheal length of 8.0 +/-0.9 cm (mean +/- SD) with the head and nec- in a neutral position increased by 1.0 +/- 0.4 cm (mean +/- SD) with full head and nec- extension.

## DYNAMIC CLINICAL FACTOR: PNEUMOPERITONEUM AND TRENDELENBURG POSITION

Trendelenburg position was first reported to decrease the ETT-CA distance and tracheal length in anesthetized patients in The Lancet in 1969 [18]. Subsequent studies that have found that between 10 and 30 degrees of Trendelenburg positioning, as an independent variable, results in an average shortening in the ETT- CA distance of 0.3-0.6 cm [13,19-22]. No studies have been performed comparing the VC-CA distance in the upright versus the supine position in the same patient.

Several studies have documented a decrease in the ETT-CA distance during abdominal insufflation [19,22-25]. One study found a statistically significant decrease in the ETT-CA distance of 0.7 +/-1.4 cm (mean +/- SD) in the supine position with abdominal insufflation of CO2 to a pressure of 15 cm H2O resulting in endobronchial intubation in 8 of the 30 patients studied [19]. A Japanese study of 10 patients found an average decrease in the ETT-CA distance of 1.1 +/-0.4 cm (mean +/- SD) with 10 mm Hg CO2 abdominal insufflation [25]. A 1996 investigation found an average initial ETT-CA distance of 3.4 +/- 0.6 cm decreased significantly to 2.6 +/-0.9 cm after initiation of 10 mm Hg $CO_2$ insufflation (mean +/- SD) [22].

Some studies have looked at the combined effect of both pneumoperitoneum and the Trendelenburg position on tracheal dimensions. One study found that 12-14 mm Hg $CO_2$ pneumoperitoneum and 15 degrees of Trendelenburg positioning in 23 patients undergoing laparoscopic gynecologic surgery caused an average decrease in the ETT-CA distance of 0.9 +/-0.3 cm and a decrease in the VC-CA distance of 0.4 +/- 0.2 cm (mean +/- SD) [26]. The change in VC-CA accounted for 50% of the decrease in the ETT-CA distance. Another found that both ETT-CA and VC-CA distance decreased significantly both with pneumoperitoneum alone and pneumoperitoneum with Trendelenburg positioning [20]. Finally, a study investigating 12-15 mm Hg $CO_2$ insufflation combined with 10 degrees of Trendelenburg in 30 patients undergoing laparoscopic hernia repair found no significant change in ETT-CA distance after these interventions; the ETT-CA distance was 4.0 +/-0.13 cm before and 3.9 +/- 0.1 cm after the test interventions (mean +/- SD) [27].

A study that examined the effect of pneumoperitoneum (12-14 cm $H_2O$) and Trendelenburg position (15 degrees) on ETT-CA distance with time in 50 patients found an initial average ETT-CA distance of 3.0 +/-1.4 cm decreased to 2.0 +/-1.5 cm after 5 minutes and then to 1.7 +/-1.6 cm after 25 minutes (mean +/-SD) [21].

## DYNAMIC CLINICAL FACTOR: ANESTHESIA AND MUSCLE RELAXATION

Although measurements of tracheal length have been performed in radiographic studies in awa-e patients and with fiberoptic techniques in anesthetized patients, no study has examined tracheal dimensions in the same patient in both the awake and the anesthetized and paralyzed states (2-8). Based on what we -now, we thin- the tracheal length will be significantly shorter in the supine or Trendelenburg position in the anesthetized and paralyzed state compared to the semi-upright position in the awake state in the same patient. We predict that paralytics will cause relaxation of head extensors (necessary for the sniff position) resulting in some head flexion and relaxation of the diaphgragm allowing abdominal contents to push the mediastinal contents cephalad (as occurs with pneumoperitoneum). Therefore, both relaxation of head extensors and the diaphragm will result in shortening of the trachea.

## THE TRACHEAL ACCORDION AND CLINICAL IMPLICATIONS

It is clear from the literature that with the dynamic clinical changes that occur under anesthesia, including the assumption of the supine position, head and neck flexion and extension, pneumoperitoneum, and Trendelenburg positioning, the trachea acts as an accordion decreasing and increasing its length (Table 2). The magnitude of the change in tracheal dimensions in response to these factors is an important clinical consideration. Anesthesiologists frequently are required to induce anesthesia and muscle relaxation in patients who are awake and in the upright position with an appropriately positioned ETT in the ICU. The induction of anesthesia and paralysis will most likely involve a change in position from upright to supine or Trendelenburg position resulting in increased pressure of the abdominal contents against the diaphragm (as occurs with a pneumoperitoneum) and may involve some neck flexion as neck extensor muscles relax. All of these changes will cause the tracheal accordion to shorten. Thus endobronchial intubation may very well be an underappreciated mechanism of hypoxemia with the induction of anesthesia and paralysis in previously appropriately intubated, awake patients.

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