How Much Force Is Required to Dislodge an Alternate Airway?

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Abstract

Introduction. Endotracheal tube (ETT) dislodgment is a potentially catastrophic adverse event. Newer alternate airway devices—esophageal-tracheal Combitube (ETC), King laryngeal tube disposable airway (King LT), and laryngeal mask airway (LMA)—are easier to insert, but their relative extubating forces remain unknown. **Objective.** To examine the applied forces required to dislodge an ETC, King LT, LMA, and ETT. **Methods.** We used five recently deceased adult unembalmed cadavers. In random order, we sequentially inserted an ETC, King LT, LMA, and standard ETT. Because commercial tube holders are not designed for all alternate airways, we secured the devices with a standard adhesive tape method. Using a precision digital force measuring device, we measured the minimum manually applied axial force (lb) that dislodged each airway device at least 4 cm. We compared required dislodgment forces between airway devices using a mixed-effects regression model, adjusting for cadaver height, weight, neck circumference, and thyromental distance. **Results.** Characteristics of the cadavers were as follows (median, interquartile range [IQR]): height 172 cm (167–177), weight 98 kg (84–120), neck circumference 46.5 cm (41–52), and thyromental distance 7.5 cm (7.5–8). Required axial dislodgment forces for each airway device were as follows (median, IQR): ETC 28.3 lb (19.0–28.6), King LT 12.5 lb (11.7–13.3), LMA 18.3 lb (14.0–21.9), and ETT 14.4 lb (13.5-22.1). The ETC required twice as much dislodgment force as the ETT (adjusted difference 16.7 lb, 95% confidence interval [CI]: 8.3 to 25.1). The King LT and LMA dislodgment forces were similar to that of the ETT (King LT vs. ETT adjusted difference 5.9 lb, 95% CI: –2.4 to 14.2; LMA vs. ETT 8.1 lb, 95% CI: –0.2 to 16.5). **Conclusion.** In a cadaver model of unintended airway dislodgment, the ETC required the most force for dislodgment. The King LT and LMA performed similarly to a standard ETT. **Key words:** intubation; intratracheal; airway; dislodgment; force

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Introduction

Airway management is a core intervention in the resuscitation of out-of-hospital critically ill patients. While most advanced-level practitioners provide airway management using endotracheal intubation (ETI), many newer alternate airway devices provide alternatives to ETI; for example, the esophageal-tracheal Combitube (ETC; Kendall-Sheridan, Mansfield, MA), the laryngeal mask airway (LMA; LMA North America, San Diego, CA), and the King laryngeal tube airway (King LT; King Systems, Noblesville, IN). Rescuers may insert these devices in a rescue capacity when ETI efforts fail or in select cases as the primary airway device.[1]

A key task in ETI is securing the endotracheal tube (ETT) in place to prevent inadvertent airway dislodgment. Endotracheal tube dislodgment is a potentially catastrophic adverse event that may occur frequently in select settings.[2–5] Practitioners typically secure the ETT in place using adhesive tape or a commercial tube holder. In a prior effort we found that while one particular commercial tube holder required the largest extubation force, conventional taping performed comparably with other tube holders.[6]

Rescuers perceive alternate airways as requiring greater extubating force than ETTs. However, the relative alternate airway dislodgment forces—compared with each other as well as with a standard ETT—remain unknown. This knowledge is important because as with ETTs, alternate airway dislodgment could impair ventilatory efforts. The purpose of this study was to compare the forces required to dislodge an ETC, a King LT, an LMA, and an ETT.

Methods

Study Design

This study was approved by the University of Pittsburgh Committee on Research of the Newly Dead. We conducted a prospective trial evaluating airway device dislodgment from newly dead cadavers.

Study Protocol

We used five unembalmed, recently deceased (<24 hours) cadavers. We included adults who died during the course of hospital care. We excluded patients aged <18 years, those receiving surgical manipulation of the airway (cricothyroidotomy or tracheostomy), and those with craniofacial abnormalities.

We first measured key anatomic dimensions potentially related to airway placement or dislodgment, including height, weight, neck circumference, and thyromental distance.[7] Pathology staff determined cadaver height and weight through standard measurements. We measured neck circumference (cm) at the level of the thyroid cartilage.[8] We measured thyromental distance (cm) as the distance from the lower border of the mandibular mentum to the thyroid notch with the mouth closed and head in full extension.[7]

In each cadaver we sequentially inserted and attempted dislodgment of four airway devices: ETT, ETC, King LT, and LMA. We placed a size 8-0 ETT using direct laryngoscopy to a depth of 23 cm at the lip for male cadavers and 21 cm at the lip for the female cadaver.[9] We confirmed placement by direct visualization of the ETT between the vocal cords.[10] We inflated the ETT cuff to 20–25 cmH_20.[11]

For the ETC, we selected a size 41F device. We inserted the airway using standard technique, advancing the airway to the proper position with depth marks at the incisors. As recommended by the manufacturer, we inflated the proximal and distal cuffs with 80 and 10 mL of air, respectively.[12,13] The ETC manufacturer recommended volume-guided rather than pressure-guided inflation. We verified esophageal placement of the ETC by direct laryngoscopy.

We used the disposable LMA Unique model of the LMA, selecting a size 5 device per manufacturer guidelines for patients weighing 70–100 kg.[14] We inserted the LMA in the supraglottic position using standard recommended technique. We inflated the cuff to a pressure of 60 cmH_2O. For the King LT, we used the size 4 disposable LT-D model per manufacturer recommendations for patients 155–180 cm in height. We inserted the device using standard technique, advancing the device until the base of the connector aligned with the teeth. We inflated the cuffs to 60 cmH_2O.[15] We verified cuff pressures using the manufacturer's pressure gauge.

We secured each airway device to the cadaver using Curasilk cloth adhesive tape (Kendall, Mansfield, MA). While numerous commercial tube holders are available for securing an ETT, there are no commercial tube holders recommended for the tested alternate airways. In pilot manikin efforts, we observed that common commercial tube holders would not fit or securely hold the alternate airways in place. Furthermore, in our prior study, we found that tape was superior to many other commercial tube holders for holding an ETT in place.[6] Therefore, we elected to use only adhesive tape in this study.

FIGURE 1. The esophageal-tracheal Combitube secured to a manikin using the Lillehei technique.[10]

We applied the adhesive tape to the airway devices using the Lillehei method[10] (Figs. 1–3). This technique places tape circumferentially around the head, with the free ends divided in half. One free end wraps around the airway while the other adheres to the lip of the patient. The same investigator placed and secured all devices in all cadavers. We used each cadaver for a single insertion of each of the four devices. To simulate normal oral secretions, we sprayed the distal end of each airway device with a saliva substitute (Roxane Laboratories Inc., Columbus, OH).

To facilitate airway dislodgment, we applied manual traction to the end of the airway device. One researcher pulled the airway device vertically while another held the head and thorax of the cadaver in place. We measured the maximum applied vertical force (lb) using a digital force measuring device (CER 100000, Com-Ten Industries, Pinellas Park, FL) attached to the exposed end of each airway.

Prior studies indicate that ETT dislodgment occurs with as little as 2 cm of vertical movement.[16] There are no data describing the vertical displacement compromising alternate airway function. Therefore, based on pilot manikin efforts, we defined airway device dislodgment as 4 cm of vertical movement. We determined vertical displacement by observing the depth marks on each airway device during extraction.

FIGURE 2. The King LT-D airway secured to a manikin using the Lillehei technique.[10]

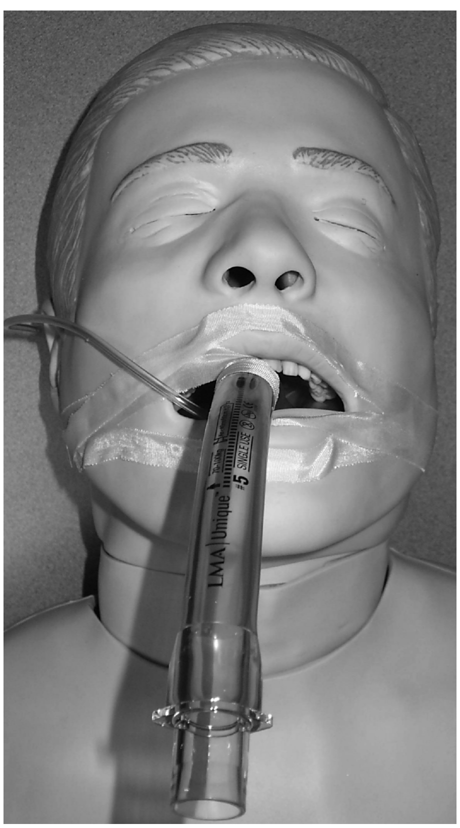

FIGURE 3. The LMA Unique secured to a manikin using the Lillehei technique.[10]

Data Analysis

Because each cadaver was used in four sequential trials, and in order to adjust for anatomic variations, we analyzed the data using mixed-model regression (xtmixed; StataCorp LP, College Station, TX). We fit a mixed model defining dislodgment force as the dependent variable and each airway device as independent variables, defining ETT as the referent category and modeling each cadaver as a random effect. Because anatomic variation may plausibly affect tube dislodgment force, we fit a second model with additional adjustment for height, weight, neck circumference, and thyromental distance. We carried out all analyses using Stata 10.0 (StataCorp LP).

RESULTS

The five cadavers included four males and one female. The cadavers were similarly sized (Table 1). The applied vertical forces needed to displace the King LT and LMA were similar to that for the ETT (Table 2). The applied vertical force needed to displace the ETC was greater than that for the ETT (Fig. 4; Table 2). We observed similar results when additionally adjusting for height, weight, and neck circumference. The regression model excluded thyromental distance because of colinearity.

DISCUSSION

Dislodgment of an ETT is a potentially catastrophic event. Dislodgment of an alternate airway device may similarly complicate resuscitative efforts. In this study we found that the applied vertical forces needed to dislodge the King LT and the LMA were similar to that needed to dislodge an ETT. In contrast, ETC dislodgment required twice as much applied force as that for the ETT.

Our observations have important implications for clinical practice. Despite manufacturer recommendations, many practitioners do not secure alternate airways in place. However, we showed that the required dislodgment forces for the taped King LT and LMA were similar to that for the ETT. We surmise that the required dislodgment forces for untaped airways would have been even lower. These observations are

TABLE 1. Characteristics of the Five Cadavers Used in the Study

Characteristic	Minimum	Maximum	Median (IQR)
Height (cm)	165	179	172 (167–177)
Weight (kg)	79	132	98 (84–120)
Neck circumference (cm)	40	55	47 (41–52)
Thyromental distance (cm)	7.0	10.5	7.5 (7.5–8.0)

IQR = interquartile range.

TABLE 2. Airway Dislodgment Force

Device	Force, lb (IQR) Median Dislodgment	Relative Dislodgment Force Compared with ETT, lb (95% CI)	Relative Dislodgment Force Compared with ETT, Adjusted for Anatomic Dimensions, lb (95% CI)
Endotracheal tube	14.4 (13.5–22.1)	*Referent*	*Referent*
King LT airway	12.5 (11.7–13.3)	3.1 (–4.6, 10.9)	5.9 (–2.5, 14.2)
Laryngeal mask airway	18.3 (14.0–21.9)	4.7 (–3.1, 12.5)	8.1 (–0.2, 16.5)
Esophageal-tracheal Combitube	28.3 (19.0–28.6)	12.6 (4.9, 20.4)	16.7 (8.3, 25.1)

Relative dislodgment forces were determined through a mixed-effects model. The second model additionally adjusted for height, weight, and neck circumference. CI = confidence interval; ETT = endotracheal tube; IQR = interquartile range.

particularly important as primary King LT and LMA use may broaden in the out-of-hospital treatment of cardiac arrest.[17] In contrast, the ETC required almost twice as much applied vertical force as the ETT to cause dislodgment. While this observation does not obviate the need to tape the ETC in place, it does verify the ETC's superior ability to maintain proper position.

We attribute our observations to the different cuff designs of the three devices. The stiff upper balloon of the ETC fills the entire oropharynx, effectively resisting vertical movement. The King LT has cuffs that are smaller and more pliable than the ETC, presenting less vertical resistance. The single cuff of the LMA seals the perilaryngeal structures but offers limited vertical resistance.

Based on our observations, the balloon with the largest volume (ETC 80 mL) required the largest force for dislodgment. We hypothesize that future alternate airway devices with similar large oropharyngeal balloons may better resist dislodgment. However, higher volumes can also lead to higher mucosal pressures, potentially injuring oral mucosa.[18] Future modifications must account for these competing considerations.

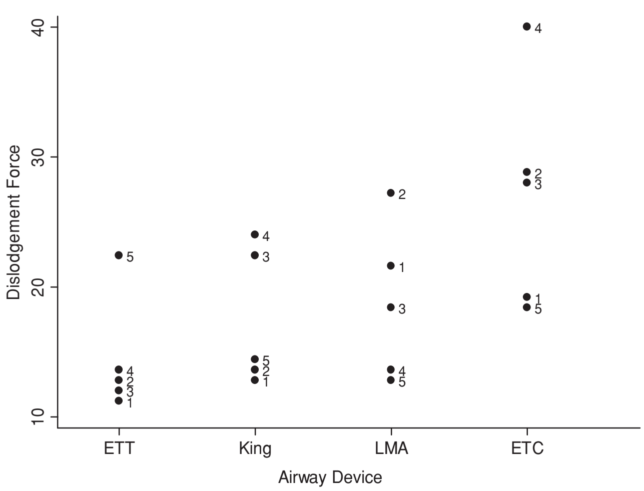

FIGURE 4. Applied vertical force (lb) required to dislodge each airway device. Numbers correspond to individual cadavers. ETC = esophageal-tracheal Combitube; ETT = endotracheal tube; King = King laryngeal tracheal airway; LMA = laryngeal mask airway.

Limitations

Our study has important limitations. We evaluated tube taping using only the Lillehei method.[10] Other taping methods exist such as taping without splitting the tape or splitting the tape ends into three pieces.[19] Additional approaches include the use of twill tape, bite blocks, or modified Velcro tape.[20] We focused on the most common technique in order to avoid multiple comparisons. We evaluated applied vertical force only. However, in clinical practice, dislodgment may occur from flexion, rotation, or horizontally applied force. The relative dislodgment forces of these different vectors have not been systematically evaluated.

We studied only five cadavers because of institutional limitations in the number of available unembalmed anatomic cadavers. Replication using a larger series is needed to confirm our observations. While we used a cadaver model in order to enhance our focus on the mechanics of airway dislodgment, our observations merit independent confirmation in the clinical setting. There are presently no published reports of clinical out-of-hospital alternate airway dislodgment.

In this study we used adhesive tape to secure the airway devices in place. Previous studies have suggested the superiority of the Thomas ETT holder in holding an ETT in place.[6] However, in pilot efforts we confirmed that the shapes of this and other common commercial tube holders could not accommodate the larger diameters of alternate airways. If modified for alternate airways, commercial tube holders could demonstrate equivalent or superior performance. Whereas we applied a saliva stimulant, in emergency situations copious secretions, blood, and vomitus could potentially interfere with adhesive tape application and traction. In these situations, a properly designed commercial tube holder could potentially demonstrate better performance.

CONCLUSION

In this model of unintended airway dislodgment, the ETC required the most force for dislodgment. The King LT and LMA performed similarly to a standard ETT.

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