A comparison of endotracheal tube cuff pressures using estimation techniques and direct intracuff measurement

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Cuffed endotracheal tubes are one aspect of airway management designed to ensure safety, yet patients can be at risk for injury from underinflated and overinflated endotracheal cuffs. Tracheal pressures exceeding approximately 48 cm H_2O impede capillary blood flow, potentially causing tracheal damage, and pressures below approximately 18 mm Hg may increase the risk of aspiration. There is no standard identified in the literature describing the method of cuff inflation, and nurse anesthetists use various cuff inflation techniques.

The purpose of this study was to compare endotracheal cuff pressures obtained by estimation techniques with direct endotracheal cuff pressure measurements. A convenience sample of 40 anesthesia providers (nurse anesthesia students, Certified Registered Nurse Anesthetists, and anesthesiologists) inflated the endotracheal tube cuff using their usual inflation technique. The endotracheal tube cuff pressure was measured with a noninvasive manometer connected to the pilot balloon. Pressures obtained by estimation techniques ranged from 6 to 60 cm H_2O (mean = 44.5; SD = 13.07). Analysis revealed that fewer than one third of the anesthesia providers inflated the cuff within an ideal range. No differences were found between level of anesthesia provider and cuff inflation pressures. We conclude that estimation techniques for cuff inflation are inadequate and suggest that direct measurements be used.

Key words: **Endotracheal cuff pressures, estimation techniques.**

Management of cuffed endotracheal tubes is routine practice for anesthetists. Although various cuff inflation techniques are used, there is no standard identified in the literature addressing the method of cuff inflation or intracuff pressure maintenance in anesthetic practice.

The goal in using cuffed endotracheal tubes is to achieve a seal between the cuff and trachea with a pressure great enough to prevent aspiration but not so high that tracheal blood flow will be impeded. Table 1 provides ideal, high, and low intracuff pressures in both centimeters of water and millimeters of mercury. While there is no single number, the consensus regarding an acceptable maximum cuff pressure ranges from 25 to 40 cm H_2O.[1-4] This pressure limit is determined in part by the capillary blood pressure supplying the trachea, which is approximately 48 cm H_2O.[1,2] Ischemia and stenosis of the tracheal mucosa occur when pressure against the tracheal wall from the hyperinflated cuff exceeds the pressures in the capillary blood supply. An intracuff pressure greater than 34 cm H_2O can result in decreased perfusion to the trachea,[4] whereas total obstruction of tracheal blood flow occurs at approximately 50 cm H_2O.[2] Pressures less than 34 cm H_2O are associated with a decreased incidence and severity of tracheal injury with the use of high-volume, low-pressure cuffs.[3] Even at 27 cm H_2O, tracheal blood flow is reduced by 75% at the cuff site.[1]

Pathologic changes resulting from overinflation of the cuff include ischemia, inflammation, ulceration, granulation, and stenosis at the site of contact between the cuff and trachea.[1] Endoscopic studies show a correlation between elevated cuff pressures and tracheal lesions ($r = 0.62$; $P = .001$).[5] Moreover, there is an association with postoperative sore throat in cases in which the endotracheal cuff pressure is elevated.[6]

Patients also can be at risk if the cuff pressure is too low. The minimum occlusive intracuff pressure required for positive pressure ventilation, to prevent aspiration, is approximately 27 cm H_2O.[1] Aspiration has been shown to occur with intracuff pressures of approximately 20 cm H_2O.[7] Thus, there is a narrow range of cuff pressures

Table 1. Intracuff pressures

Pressure	cm H_2O	mm Hg
Ideal	25-40	18-30
High	>40	30
Low	<25	18

required to maintain a functionally safe seal while not exceeding capillary blood pressure.

Several factors influence the amount of pressure the cuff exerts against the tracheal wall. Factors such as the volume of the gas or liquid used to inflate the cuff, tracheal diameter, and pressure changes within the thorax influence cuff pressure.[1] The type of anesthetic agent used also can influence intracuff pressures. For example, nitrous oxide has been shown to increase cuff pressures intraoperatively by diffusing into the cuff.[3,5] This is especially problematic if, following intubation, the cuff is initially overinflated. Overinflation of the endotracheal tube cuff from diffusion of nitrous oxide potentially can place the patient at risk for tracheal injury ranging from a sore throat to tracheal lesions.[5,6] How do anesthetists achieve and maintain endotracheal cuff pressures?

• *Inflation methods.* An important factor in determining the amount of cuff pressure is the technique used to determine the adequacy of cuff pressure. Presently, there is no consensus for the method of cuff inflation maintenance in anesthetic practice. There are, however, several methods in current anesthetic practice used to determine cuff pressure.

• *Minimal occlusive volume technique.* A volume of air is injected into the cuff that eliminates an audible end-inspiratory leak with positive pressure ventilation.[8] This technique has been shown to be inadequate. In one study in which this technique was used, 12 of 15 patients were considered at risk for aspiration from cuff pressures too low, 1 was considered at risk for ischemia from cuff pressures too high, and only 2 were considered in an ideal range compared with the direct measurement technique.[3]

• *Minimum leak technique.* This technique is described as air being injected into the cuff allowing only a "small" leak to be auscultated at end-inspiration.[8] *Small* is not defined specifically; thus, variations in results would be expected. Compared with the minimal occlusive technique, this method is associated with an increased risk of silent aspiration.[8]

• *Predetermined volume technique.* A randomly selected predetermined volume of air is used to inflate the endotracheal cuff.[3] This technique does not take into account the tracheal diameter, thoracic pressure, or the type of anesthetic agent used. One study of this method in 20 patients found that 5 (25%) were at risk for aspiration, 12 (60%) were at risk for ischemic damage, and only 3 (15%) were in an ideal range.[3] This technique has been shown to be inaccurate and has been criticized as a method to inflate the endotracheal cuff.[9]

• *Palpation technique (finger estimation).* The endotracheal cuff is inflated with air, and the pilot balloon is palpated as a gross indication of intracuff pressure.[1] For practical reasons, this is one of the most used techniques in the clinical setting.[9] This technique, however, is reported to be unreliable for determining the adequacy of cuff pressure and is considered an unacceptable technique by some authors.[1] One study of 9 patients found that 2 were at risk for aspiration from low cuff pressures, 4 at risk for ischemia from high cuff pressures, and only 3 in an ideal range compared with the direct measurement technique.[3] Factors such as the physical differences among endotracheal tubes and variability among observers were cited as reasons for the low accuracy of this technique.[9]

• *Direct intracuff pressure measurement technique.* A manometer is used to directly assess the intracuff pressure via the pilot balloon.[4,10] Because a specialized tool, a manometer, is required, this technique requires a cost outlay and is less convenient and is, therefore, not performed commonly by anesthetists. It is, however, recommended as an effective technique to prevent overinflation and underinflation of endotracheal tubes.[3,9,10]

While there are several methods from which anesthesia providers can choose to inflate endotracheal tube cuffs, all but the direct intracuff pressure measurement technique provide only an estimation of appropriate cuff pressures. Estimating cuff pressures may be inadequate because of the narrow range of cuff pressures required to create a functionally safe seal while preventing tracheal damage. Few studies actually compared techniques used to estimate cuff pressures with using the direct measurement method.

Purpose of the study

The purpose of this study was to compare endotracheal cuff pressures obtained by the palpation estimation technique with direct endotracheal cuff pressure measurement.

• *Research questions*

1. What are the direct endotracheal tube cuff pressures obtained using estimation techniques?
2. Is there a difference in the ability of anesthesia providers to estimate endotracheal tube cuff pressures?

Materials and methods

• *Subjects.* A convenience sample of anesthesia providers from the operating room of a level I trauma medical center in a metropolitan city in the southeastern United States was recruited for this study. All anesthesia providers who administered anesthesia to patients meeting the following inclusion criteria were invited to participate: (1) men or women, 18 to 65 years old; (2) ASA patient classification I through III; (3) orally intubated with a No. 7 or No. 8 high-volume, low-pressure endotracheal tube; (4) operative procedures that allow access to the endotracheal tube pilot balloon; (5) operative procedures not requiring hypothermia; and (6) operative procedures not involving the thoracic cavity. The operative schedule was reviewed, and all providers administering anesthesia to patients meeting the selection criteria during the study period were selected for this study.

• *Protection of human subjects.* Permission to conduct the study was obtained from the university and hospital institutional review boards.

Consents were not required because the patients continued to receive the usual and customary care; data collected did not involve techniques that normally would require consent outside the research context. The inflation technique used was at the discretion of the anesthesia provider, and no alteration in the anesthetic plan was required for this study. No personal identifying information regarding the patient or anesthesia provider was obtained, and, therefore, patient and provider anonymity was maintained.

• *Instruments.* Two data collection tools were used. The first tool was a demographic data record that included level of the anesthesia provider, months or years in anesthesia practice, endotracheal tube size, endotracheal tube cuff inflation technique, and anesthetized patient age, sex, and ASA status. In addition, a direct intracuff measurement was recorded after the anesthesia provider determined adequacy of intracuff pressure using an estimation technique.

The second tool was an endotracheal tube cuff manometer designed exclusively to obtain direct intracuff pressure measurements from the endotracheal tube cuff. The SIMS Portex Cuff Pressure Indicator (Portex Limited, Kent, United Kingdom), shipped new from the manufacturer, was used to obtain intracuff pressure readings from the endotracheal tube cuff pilot balloon. The units of measurement for the manometer range from 0 to 60 cm H_2O. Calibration of this device to zero was performed by the manufacturer before shipment.

• *Methods.* After receiving approval to conduct research from the university and from the hospital, the study began. All anesthesia providers administering anesthesia to patients meeting the selection criteria during the study period participated. Usual and customary care for the patients began with the induction of general anesthesia. Inhalation agents administered following induction included nitrous oxide, isoflurane, and sevoflurane.

Following induction of anesthesia, orotracheal intubation was performed using a Mallinckrodt Hi-Lo endotracheal tube (A. Mallinckrodt, Juarez, Mexico). After verification of tube placement, the anesthesia providers inflated the endotracheal tube cuff and established intracuff volume using their usual inflation technique. Anesthesia providers were asked to determine the adequacy of intracuff pressure using an inflation technique at their discretion. A single intracuff pressure measurement was obtained in centimeters of water from the endotracheal tube pilot balloon using the SIMS Portex Cuff Pressure Indicator.

If the case had already begun, the measurement was performed after the anesthesia provider was asked to determine the adequacy of cuff pressure by using his or her usual inflation technique. The pressure measurement was recorded. This reading was provided to the anesthesia providers, who, at their discretion, could make appropriate adjustments. Data collection ended after a single reading was obtained, recorded, and provided to the anesthesia provider. The timing of the direct intracuff measurements was irrelevant to this study because the providers were requested to verify the pressure immediately before the measurements. It was the relationship of the providers' estimation of pressure to the direct pressure that was under study.

Results

To answer the research questions, frequencies, percentages, means, medians, SDs, and ranges were computed. The objective of the data analysis was to compare endotracheal cuff pressure obtained by estimation technique used by anesthesia providers with the direct endotracheal tube cuff pressure measurement.

• *Description of the sample.* The subjects consisted of the first 40 anesthesia providers who administered general anesthesia to patients meeting the criteria for inclusion in the study. Table 2 describes the anesthesia provider sample (n = 40). Length of practice ranged from 6 to 264 months (22 years; mean = 57.35 months; SD = 71.4 months). The techniques used to estimate endotracheal tube cuff pressure are shown in Table 3.

Table 4 lists the demographic data for the patient sample (n = 40). Their ages ranged from 18 to 65 years (mean = 45.93 years; SD = 14.51 years). The ASA classification of patients was limited to ASA class I through III for this study. The distribution of patients by ASA status also is shown in Table 4, as are endotracheal tube sizes.

• *Research question.* The first research question was: "What are the direct endotracheal tube cuff pressures obtained using estimation techniques?" A direct cuff measurement range of 25 to 40 cm H_2O was used as a reference for ideal intracuff pressure. Three estimation techniques were used by providers in this study to

Table 2. Demographic data: Anesthesia providers

Variables	Frequency	Percentage
Nurse anesthesia student		
First year	14	35
Second year	9	22
Certified Registered Nurse Anesthetist	13	32
Anesthesiologist	4	10
Male	23	58
Female	17	42
Total providers	40	100

Table 3. Estimation techniques

Technique	Frequency	Percentage
Palpation	35	88
Minimal leak	4	10
Predetermined volume	1	2
Total	40	100

Table 4. Demographic data: Patient sample

Variables	Frequency	Percentage
Male	15	38
Female	25	62
ASA class I	7	18
ASA class II	18	45
ASA class III	15	38
Endotracheal tube size		
No. 7	26	65
No. 8	14	35
Total	40	100

determine the adequacy of endotracheal tube cuff pressure, although the majority (35/40 [88%]) used the palpation technique. Pressures obtained by estimation techniques ranged from 6 to 60 cm H_2O (mean = 44.5 cm H_2O; SD = 13.07 cm H_2O). As shown in Table 5, the majority of the 40 providers using estimation techniques achieved pressures higher than 40 cm H_2O, fewer than one third achieved pressures within the 25- to 40-cm H_2O range, and 2 achieved pressures less than 25 cm H_2O.

The second research question was: "Is there a difference in the ability of anesthesia providers to estimate endotracheal tube cuff pressures?" Because of the unequal groups, for statistical purposes, the anesthesia provider level values were collapsed to yield 2 groups: a nonexperienced group, which included first and second year nurse anesthesia students (n = 23), and an experienced group, which included Certified Registered Nurse Anesthetists (CRNAs) and anesthesiologists (n = 17). Pressures for the nonexperienced group (mean = 44.57 cm H_2O; SD = 12.43 cm H_2O) and the experienced group (mean = 44.59 cm H_2O; SD = 14.27 cm H_2O) showed no differences in estimated cuff pressures ($t = -0.005$; $P = .996$).

Table 5. Categorization of direct intracuff pressure

Direct measurement	Frequency	Percentage
Pressure > 40 cm H_2O	26	65
Pressures 25-40 cm H_2O	12	30
Pressures < 25 cm H_2O	2	5
Total	40	100

Discussion

This study examined the estimation techniques used by 40 anesthesia providers to determine the adequacy of cuff pressure. In addition, the study examined differences among level of anesthesia providers in their ability to estimate endotracheal tube cuff pressures. Estimation techniques resulted in 28 pressures (70%) being too high or too low, while only 12 (30%) were within an ideal range. The manometer was not able to measure pressures exceeding 60 cm H_2O, so there was a ceiling effect in measuring high pressures. In other words, it was not known how high the pressures that reached 60 cm H_2O actually were. Moreover, the *t* test revealed no difference between nonexperienced providers (nurse anesthesia students) and experienced providers (CRNAs and anesthesiologists) in ability to estimate endotracheal tube cuff pressures.

Estimation techniques used by the providers in this study included predetermined volume, minimal leak technique, and palpation (finger estimation) technique; the latter was most common. The results of this study suggest that estimation techniques used by anesthesia providers to assess the adequacy of intracuff pressure are not accurate and, therefore, not adequate. Estimation techniques used by 40 providers in this study resulted in 12 pressures 30% within an ideal range of 25 to 40 cm H_2O, whereas 28 (70%) were outside the ideal range. In other words, fewer than one third were within an ideal range.

The results of this study also suggest that there is no difference among level of anesthesia providers in the ability to estimate endotracheal tube cuff pressures. This is not a surprising finding because this is a skill taught by experienced providers to inexperienced providers. If the "teacher's" estimation is incorrect, the student's will be also. Interestingly, after adjusting the intracuff pressure to an acceptable range, a majority of the providers palpated the pilot balloon to feel what a "normal" pressure range felt like. Most were surprised at how the pilot balloon felt in an ideal range. For many providers, this was the first time that a manometer had been used to demonstrate ideal cuff pressures.

• *Delimitations and limitations.* The study was limited by the following: (1 data collection in 1 level I trauma hospital in a southeastern city in the United States; (2) a convenience sample; and (3) a manometer that would record pressures only up to 60 cm H_2O.

• *Implications for anesthesia education.* There was no standard found in the anesthesia literature that addresses endotracheal tube cuff inflation techniques, although various estimation techniques are in use. This study and the limited data in the literature suggest that estimation techniques are inadequate for determining cuff pressures. The providers in this study neither possessed nor had access to a manometer with which to directly assess cuff pressure. This was noteworthy in that data were collected in an institution in which training of anesthesia providers occurred. The use of manometers in anesthesia education and in practice is strongly recommended.

There is no standard identified addressing endotracheal tube cuff inflation techniques or maintenance of cuff pressure during surgery, even though estimation techniques have the potential to harm the patient. The literature clearly delineates the morbidity associated with endotracheal tube cuffs that are underinflated or overinflated. Pressure and time are the variables that have the most significant effects. Much effort is made to ensure that nursing practice techniques result in the best care for patients while reducing the chance of harm. Based on the findings of this study, it seems prudent to use a manometer to establish and maintain intracuff pressure. This is particularly important during longer operative procedures.

This study provides support for future studies regarding the issue of estimation techniques to establish cuff pressure. Once trained with a manometer, estimation techniques could then be assessed.

Summary

This study focused on estimation techniques used to assess the adequacy of endotracheal tube cuff pressure by anesthesia providers. The results of this study suggest that estimation techniques are not adequate and that there is not a difference in the ability to estimate endotracheal tube cuff pressure among the levels of anesthesia providers. There is not an identified standard in anesthesia addressing estimation techniques used to inflate endotracheal tube cuffs. The findings of this study can be used to establish standards in anesthesia practice and add to the body of information to support practice guidelines in all areas of nursing. The findings of this study also can be used to guide future studies.

The limitations of this study and the implications for standards, training, and research were identified. This study provides support that estimation techniques are inadequate and changes in standards of practice and future research are warranted.

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