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Evaluation of Endotracheal Tube Size Determination Using Thoracic Radiography in Dogs

흉부 방사선 촬영을 이용한 개의 기관내 튜브 크기 결정 방법의 평가

by

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ABSTRACT

The present study was conducted 1) to develop a method to select the optimal endotracheal tube size in dogs using thoracic radiography, 2) to determine how time affects intracuff pressure and air leak pressures after intubation with an appropriately sized endotracheal tube, and 3) to evaluate the reliability and usefulness of this novel method in clinical practice.

In chapter I, the internal tracheal diameter of a lateral thoracic radiographic image was measured at the thoracic inlet in Beagle dogs and was multiplied by 60,

70 and 80% to determine the endotracheal tube size. Considering the resistance felt during endotracheal tube insertion through the trachea and the ability to prevent aspiration by attaining a proper seal between the cuff and tracheal mucosa, it was determined that 70% of the internal tracheal diameter was suitable for choosing the appropriate endotracheal tube size in Beagle dogs.

In chapter II, changes in endotracheal tube intracuff pressures and air leak pressures over time were evaluated in anesthetized Beagle dogs. In part I, intracuff pressure measurements were recorded for 1 hour in eight endotracheal tubes studied in an *in vitro* setting under four treatments: room temperature without lubricant (RTWOL), room temperature with lubricant (RTWL), body temperature without lubricant (BTWOL), and body temperature with lubricant (BTWL). In part II, nine Beagle dogs were endotracheally intubated with an appropriately sized endotracheal tube and changes in intracuff pressures and air leak pressures were evaluated. In part I, intracuff pressure differed significantly between the RTWOL and RTWL treatments, and between the BTWOL and BTWL treatments. In part II, intracuff pressures significantly decreased over time in all dogs while air leak pressures significantly changed according to the individual. The decrease in intracuff pressures was attributed to the elastic properties of the cuff, the use of a lubricant, and muscle relaxation due to anesthesia.

In chapter III, the reliability and usefulness of using thoracic radiography to determine the appropriate endotracheal tube size was assessed in 51 client-owned dogs. When the correlation between individual tracheal diameters and endotracheal tube sizes was examined, significantly high correlations were found between

tracheal diameter and endotracheal tube size, and between tracheal diameter and cuff diameter.

Based on the results of the present studies, measuring the internal tracheal diameter of a thoracic radiographic image was a useful and reliable method to predict the optimal endotracheal tube size in dogs. It is expected that this method will allow for more accurate endotracheal tube size selection in small animal clinical practice. Furthermore, this method could be used for future studies to develop more objective recommendations and criteria for sizing endotracheal tubes in various situations.

Keywords: endotracheal tube size, thoracic radiography, intracuff pressure, air leak pressure, dog

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
BCS	Body condition score
BTWL	Body temperature with lubricant
BTWOL	Body temperature without lubricant
CD	Cuff diameter
Cd	Caudal
Cr	Cranial
$\mathbf{ET_{iso}}$	End-tidal concentration of isoflurane
ETS	Endotracheal tube size
HR	Heart rate
ID	Internal diameter
IM	Intramuscularly
IV	Intravenously
OD	Outer diameter
$\mathbf{P_{cuff}}$	Intracuff pressure
$\mathbf{P_{leak}}$	Air leak pressure
PVC	Polyvinyl chloride
RTWL	Room temperature with lubricant
RTWOL	Room temperature without lubricant
SD	Standard deviation
TD	Tracheal diameter

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GENERAL INTRODUCTION

Endotracheal intubation, which is a critical element of veterinary anesthesia, serves to provide a patent airway, deliver oxygen and volatile anesthetics, prevent fluid aspiration, and allow for effective positive pressure ventilation (Mosley, 2011; Briganti *et al*, 2012; Muir *et al*, 2013a). These functions are most effective when the optimal tube size is used. Endotracheal tubes that are too large in relation to the trachea may cause damage to the tracheal mucosa while tubes that are too small will be unable to attain an adequate seal between the cuff and trachea at recommended cuff pressures and will increase the work of breathing (Thomas and Lerche, 2011; Hughes, 2016).

After endotracheal intubation, the cuff should be appropriately inflated with air such that a proper seal can be achieved between the cuff and trachea without interrupting the tracheal mucosal blood flow (Stewart *et al*, 2003). Because the perfusion pressure of the tracheal mucosa ranges from 25–35 mmHg, it is generally recommended that intracuff pressures be maintained between 20–25 mmHg (Hartsfield, 2007). Within this range, the cuff should maintain a proper seal at airway pressures of 20–30 cmH_2O (Mosley, 2015). Overinflation of the cuff to pressures greater than 35 mmHg may result in ischemic damage to the trachea due to reduced capillary blood flow, while underinflation of the cuff to pressures less than 18 mmHg increases the risk of silent aspiration (Mosley, 2015).

Large individual variations in tracheal diameter exist in dogs due to differences associated with age, breed, bodyweight, and conformation (Thomas and Lerche, 2011; Hughes, 2016). As a result, it is difficult to find a single method that will provide the 'best fit' endotracheal tube size for all dogs. In clinical practice, the dogs' approximate lean bodyweight, the width of the nasal septum, as well as external palpation of the trachea are commonly used methods to select the optimal endotracheal tube size in dogs (Lish *et al*, 2008; Shelby and McKune, 2014; Hughes, 2016). However, these methods are subjective and only rely on physical parameters to select the 'best fit' endotracheal tube.

Therefore, this study was performed 1) to develop a new method to objectively determine the appropriate endotracheal tube size in dogs using thoracic radiography (Chapter I), 2) to determine the effect of time on intracuff pressures and air leak pressures when the appropriate tube size is used (Chapter II), and 3) to determine whether the new method for selecting tube sizes can be used for all breeds of dogs (Chapter III).

CHAPTER I.

Selection of Appropriate Endotracheal Tube Size Using Thoracic Radiography in Beagle Dogs

Abstract

This prospective, randomized, crossover experimental study was performed to determine the optimal endotracheal tube size in Beagle dogs using thoracic radiography.

Lateral thoracic radiographs were used to measure the internal tracheal diameter at the thoracic inlet in eight healthy Beagle dogs. This measurement was multiplied by 60, 70 and 80% to determine the outer diameter of the endotracheal tube for each dog. In each treatment, medetomidine (5 μg kg^{-1}) was administered intravenously (IV) for premedication. Anesthesia was induced with alfaxalone (2 mg kg^{-1}) IV and maintained with isoflurane. After induction of anesthesia, the resistance to passage of the endotracheal tube through the trachea was scored by a single anesthesiologist. Air leak pressures (P_{leak}) were measured at intracuff pressures (P_{cuff}) of 20 and 25 mmHg (27 and 34 cmH_2O). The results were analyzed using Friedman tests and repeated measures ANOVA.

There were statistically significant increases in resistance as the endotracheal tube size increased ($p = 0.003$). When P_{cuff} was 20 mmHg, mean P_{leak} for the 60, 70

and 80% treatments were 9.7 ± 6.7, 16.2 ± 4.2 and 17.4 ± 3.9 cmH_2O, respectively, but no significant differences were found. When P_{cuff} was 25 mmHg, mean P_{leak} for the 60, 70 and 80% treatments were 10.6 ± 8.5, 19.7 ± 4.9 and 20.8 ± 3.6 cmH_2O, respectively, and statistically significant increases were found between treatments 60 and 70% (p = 0.011) and between treatments 60 and 80% (p = 0.020). Three dogs in the 80% treatment had bloody mucus on the endotracheal tube cuff after extubation.

Results based on resistance to insertion of the endotracheal tube and the ability to achieve an air-tight seal suggested that an appropriately sized endotracheal tube for Beagle dogs is 70% of the internal tracheal diameter measured on a thoracic radiograph.

Introduction

Endotracheal intubation is a crucial element of small animal anesthesia that serves many purposes, such as maintaining a patient airway, ensuring efficient delivery of volatile anesthetics and oxygen, facilitating positive pressure ventilation, preventing aspiration of fluids, and limiting environmental contamination with waste anesthetic gases (Mosley, 2011; Briganti *et al*, 2012; Muir *et al*, 2013a), all of which are most effective when an appropriate tube size is used. Intubation with a tube having a diameter that is too small may fail to provide an effective seal, increasing the risk of aspiration and environmental pollution, probably resulting in inadequate anesthetic depth, whereas a tube that is too large can result in tracheal mucosal damage, causing tracheal necrosis or rupture (Thomas and Lerche, 2011).

The perfusion pressure of the tracheal mucosa is 25–35 mmHg; therefore, an endotracheal tube cuff pressure of approximately 20–25 mmHg exerted on the tracheal wall should not interfere with the tracheal mucosal blood flow (Hartsfield, 2007). Cuff pressures >35 mmHg may impede capillary blood flow and result in ischemic damage of the tracheal wall, whereas pressures <18 mmHg can increase the risk of aspiration (Mosley, 2015). Therefore, it is generally recommended that the pressure exerted by the cuff be maintained at 18–25 mmHg (Hartsfield, 2007). At this pressure range, the cuff should be able to prevent an air leak at airway pressures of 20–30 cmH_2O (15–22 mmHg) (Mosley, 2015).

Breed, conformation, age and bodyweight influence the tracheal diameter in dogs (Thomas and Lerche, 2011; Hughes, 2016). Consequently, it is difficult to determine a single technique that will provide an accurate endotracheal tube size for every dog. Several methods are used to determine the appropriate endotracheal tube size in dogs in clinical practice. Basing the determination on the approximate lean bodyweight of the dog (Hughes, 2016) is dependent on the experience of the anesthetist and is difficult in obese and cachexic patients. Another method is to externally palpate the trachea immediately cranial to the thoracic inlet and assume that the outer diameter (OD) of the trachea approximates the appropriate endotracheal tube size (Lish *et al*, 2008; Shelby and McKune, 2014). The third method is to measure the width of the nasal septum and select an endotracheal tube with an OD of that width (Lish *et al*, 2008; Shelby and McKune 2014). Selecting an endotracheal tube based on tracheal palpation had only 46% accuracy and using the nasal septum width had 21% accuracy (Lish *et al*, 2008), suggesting the need for a more accurate method to select appropriately sized endotracheal tubes.

The aim of this study was to develop a method to determine the appropriate 'best fit' endotracheal tube size in dogs by measuring the internal tracheal diameter of a lateral thoracic radiographic image. Several factors were considered for this study: 1) the magnification factor involved with the use of radiographs; 2) the resistance of endotracheal tube passage through the trachea; and 3) the ability of the endotracheal tube to attain an adequate seal when the cuff is properly inflated. The hypothesis was that using larger percentages of the measured internal tracheal diameter would result in an endotracheal tube that is too large (creating a high resistance to insertion), while smaller percentages would result in an endotracheal tube that is too small (an inadequate seal between the trachea and cuff); therefore, the percentage of the internal tracheal diameter that best represents the appropriate 'best fit' endotracheal tube size could be determined.

Materials and Methods

1. Animals

The experimental protocol was approved by the Institutional Animal Care and Use Committee of Seoul National University (SNU-170223-3). Five male and three female Beagle dogs with mean ± standard deviation (SD) age of 3.0 ± 1.0 years were studied. They were determined to be clinically healthy based on complete physical examination, blood tests (complete blood cell count and serum chemistry analysis) and thoracic and abdominal radiographs. Body condition score was evaluated on a 9-point scale (Mawby *et al*, 2004).

2. Radiographic technique and endotracheal tube size selection

Thoracic radiographs (Comet EVA-HF525; United Radiology Systems Inc., IL, USA) were taken at maximum inspiration with the dog in right lateral recumbency using manual restraint without sedation or anesthesia. The neck was placed in an anatomically neutral position and the thoracic limbs were pulled cranially to minimize superimposition with the cranial thorax. Images were obtained within 1–2 minutes of recumbency. The magnification factor, which was measured by palpating the trachea at the thoracic inlet and placing a 25 mm calibration ball (Digital X-ray Calibration Ball 25 mm; Jorgensen Labs Inc., CO, USA) at the level of the trachea of all dogs, was determined to the 9%. Radiographs were saved as DICOM-files and were viewed using a commercially available diagnostic image viewing system (INFINITT PACS, INFINITT Healthcare Co., Ltd, Korea). The internal tracheal diameter was measured at the thoracic inlet by an investigator (CWS) using a previously described method (Harvey and Fink, 1982; Hayward *et al*, 2008). A line denoting the boundary of the thoracic inlet was drawn from the ventral aspect of the vertebral column at the center of the most cranial rib to the dorsal aspect of the manubrium at its point of minimal thickness (Fig. 1). The trachea diameter was then measured between the inner tracheal margins angled perpendicularly to the long axis of the trachea at the point where the thoracic inlet line intersected the center of the tracheal lumen (Hayward *et al*, 2008). A total of three measurements were taken for each dog, and the mean value was used as the internal tracheal diameter.

A magnification factor of 0.91 was obtained; thus, the internal tracheal diameter was multiplied by 90% to represent the true internal tracheal diameter. Then, three polyvinylchloride (PVC) endotracheal tubes (RUSCH super safety clear; Teleflex Medical, NC, USA) were chosen for each dog with ODs based on 60, 70 and 80% of the measured internal tracheal diameter. The endotracheal tubes selected for testing were tube OD sizes that were closest to the desired OD. If the desired OD was between the available tube sizes, then the endotracheal tube with the larger OD was chosen. Using a random crossover model, each dog was intubated with each of the three endotracheal tube sizes (treatments 60, 70 and 80%) under the same experimental conditions, with 1-week interval between each treatment. The order was chosen randomly by drawing lots. The endotracheal tube type (PVC) was consistent across all dogs and all intubations. Newly opened endotracheal tubes were used for each trial because reuse after sterilization can affect the compliance and tensile strength of the endotracheal tube cuffs (Yoon *et al*, 2007).

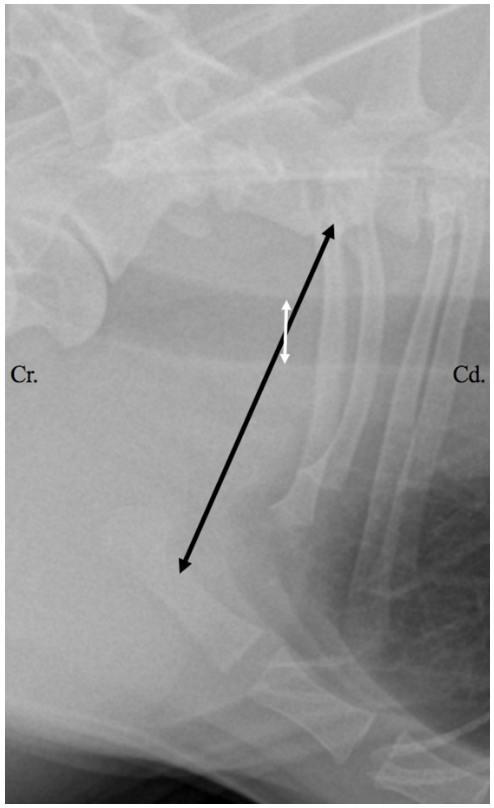


Fig. 1. Right lateral thoracic radiograph demonstrating the technique for measuring the internal tracheal diameter at the thoracic inlet. The boundary of the thoracic inlet (black arrow) is drawn from the ventral aspect of the vertebral column at the center of the most cranial rib to the dorsal aspect of the manubrium at its point of minimal thickness. The tracheal diameter (white arrow) is then measured between the inner tracheal margins angled perpendicularly to the long axis of the trachea at the point where the thoracic inlet line intersects the center of the tracheal lumen. Cr, cranial; Cd, caudal. (Adapted from: Hayward *et al*, 2008).

3. Anesthetic protocol and measurement of resistance

Food was withheld for 12 hours prior to anesthesia but water was available *ad libitum*. Prior to anesthesia, all endotracheal tubes were checked for leaks by inflating the cuff and observing for decreases in cuff volume. A 22 gauge over-the-needle catheter (Sewoon Medical Co. Ltd, Korea) was aseptically placed in the cephalic vein, and the dog was premedicated with 5 μg/kg medetomidine (Domitor; Zoetis, NJ, USA) administered intravenously (IV). Anesthesia was induced with 2 mg/kg alfaxalone (Alfaxan; Jurox Pty Ltd, Australia) IV. Intubation was performed using a laryngoscope with a Miller blade and the dog in sternal recumbency by an experienced investigator (HK) who was blinded to the chosen treatment. The resistance of endotracheal tube passage through the trachea was scored and recorded as 0, no resistance; 1, mild resistance; 2, moderate resistance; and 3, severe resistance.

4. Measurement of air leak pressure

Immediately after intubation, the dog was positioned in dorsal recumbency and the endotracheal tube was securely tied to the mandible to prevent movement within the trachea. A ventrodorsal fluoroscopic image of the thorax was used to identify the position of the distal tip of the endotracheal tube. If the endotracheal tube was not long enough to reach the first rib, the tube was untied from the mandible and carefully inserted as far caudally as possible into the trachea. Anesthesia was maintained with isoflurane (Ifrane; Hana Pharm., Korea) using a vaporizer setting of 2.5% and an oxygen flow of 2 L/minute delivered through a circle system (Multiplus MEVD Anesthesia Machine; Royal Medical, Korea). Although spontaneous respiration was maintained, the high inspired isoflurane concentration was employed to diminish respiratory efforts during the air leak pressure tests. Hartmann's solution (H/S; Daihan Pharmaceutical Co. Ltd, Korea) was administered at 10 mL/kg/hr IV throughout the experiment. Heart rate (HR), arterial oxygen saturation by pulse oximetry, respiratory rate, inspiratory and expiratory tidal volume, oscillometric arterial blood pressure, and end-tidal carbon dioxide tension by capnography were continuously monitored using a multiparameter monitor (FI/Carescape Monitor B650; GE Healthcare, Finland).

The pilot balloon of the endotracheal tube was connected via a three-way stopcock to a pressure transducer (Transpac IV Monitoring Kit; ICU Medical Inc., CA, USA) as previously described (Gopalakrishnan *et al*, 2013; Krishna *et al*, 2014). The transducer was connected to a monitor (Datex-Ohmeda S/5; GE

Healthcare, Finland) for continuous measurement of the intracuff pressure (P_{cuff}). The transducer was zeroed to room pressure before P_{cuff} measurements were recorded. A 5 mL syringe was connected to this pressure monitoring device stopcock which was opened so that air could be injected into the cuff to the desired pressure.

After a stabilization period of 15 minutes, P_{cuff} was set to 20 mmHg. Then, the air leak pressure (P_{leak}) was determined by closing the expiratory relief valve on the circle system and increasing the oxygen inflow to 5 L/minute. The peak inspiratory pressure was measured in cmH_2O from the pressure gauge on the circle system. The P_{leak} was recorded as the circle pressure at which an audible air leak was heard by auscultation with a stethoscope just cranial to the thoracic inlet. As soon as inspiratory pressures increased to 25 cmH_2O, the expiratory valve was opened, and the circle pressure decreased to zero. If an audible leak was not detected when peak inspiratory pressure reached 25 cmH_2O, P_{leak} was recorded as 25 cmH_2O. A total of three measurements were taken at each P_{cuff} with 5 minutes between measurements, and the mean P_{leak} was recorded. The procedure was repeated with a P_{cuff} of 25 mmHg.

5. Statistical analyses

Statistical analysis was performed using the SPSS 22 statistical program (SPSS Inc., IL, USA). All tests used a p value < 0.05 to determine statistical significance. Data on P_{leak} were presented as mean ± SD. Data on resistance to endotracheal tube passage through the trachea were presented as median (range). The data were evaluated for normal distribution using the Shapiro-Wilk method. When the descriptive data did not show normal distribution, a Friedman repeated measures analysis of variance (ANOVA) on ranks was used. A one-way ANOVA with repeated measures was used to analyze descriptive data that were normally distributed. *Post hoc* analysis was performed using the Wilcoxon signed ranks test and a sequentially rejective Bonferroni-Holm method. The p-values of multiple comparisons were arranged in an ascending order, and the Bonferroni-Holm rejective criteria were 0.0167, 0.0250 and 0.0500 (significance of 5%).

Results

A total of eight Beagle dogs were included in this study. The mean ± SD bodyweight was 11.6 ± 0.9 kg, and the median body condition score was 5 (range, 4–6). The results for measured internal tracheal diameter, corrected tracheal diameter calculated using a magnification factor of 0.91, desired and actual OD of endotracheal tubes, and endotracheal tube internal diameter (ID) were presented in Table 1. The smallest endotracheal tube ID that was used for the study was 3.5 mm and the largest endotracheal tube ID was 8.5 mm. The trachea, as judged by the thoracic radiographs, was normal for all dogs.

There was a statistically significant difference in resistance between all treatments (p = 0.003; Table 2). When P_{cuff} was set to 20 mmHg, there was no statistical difference in P_{leak} between treatments (p = 0.107; Table 2). When P_{cuff} was increased the 25 mmHg, there was a statistically significant difference in P_{leak} between treatments 60 and 70% (p = 0.011), and between treatments 60 and 80% (p = 0.020), but not between treatments 70 and 80% (p = 1.000). Comparison of P_{leak} within each treatment showed a statistically significant difference in the 80% treatment (p = 0.028), but not in the 70 and 60% treatments (p = 0.075 and p = 0.398, respectively).

In the 60% treatment, the endotracheal tube of one dog could only be intubated to the sixth cervical vertebra. In the 80% treatment, bloody mucous was observed on the endotracheal tube cuff after extubation in three of the eight dogs

(37.5%). One dog showed severe sinus bradycardia in all treatments, with HR of approximately 40 beats/minute when inspiratory pressure reached 25 cmH_2O. No complications were observed after completion of the experiment.

Table 1. Data for the internal tracheal diameter measured from a radiograph, the corrected tracheal diameter calculated using a magnification factor of 0.91, and the outer and internal diameters (OD and ID, respectively) of the endotracheal tubes

Dog number	Tracheal diameter		Treatment	Endotracheal tubes		
	Measured (mm)	×0.91 (mm)		Desired OD	Tested OD	Tested ID
1	9.3	8.5	80	7.5	7.3	5.5
			70	6.5	6.7	5.0
			60	5.6	5.3	3.5
2	11.4	10.4	80	9.1	9.3	7.0
			70	8.0	8.0	6.0
			60	6.9	6.7	5.0
3	10.9	9.9	80	8.7	8.7	6.5
			70	7.6	7.3	5.5
			60	6.5	6.7	5.0
4	13.9	12.6	80	11.1	11.3	8.5
			70	9.7	10.0	7.5
			60	8.3	8.0	6.0
5	14.4	13.1	80	11.5	11.3	8.5
			70	10.1	10.0	7.5
			60	8.6	8.7	6.5
6	12.3	11.2	80	9.9	10.0	7.5
			70	8.6	8.7	6.5
			60	7.4	7.3	5.5
7	14.0	12.8	80	11.2	11.3	8.5
			70	9.8	10.0	7.5
			60	8.4	8.7	6.5
8	13.4	12.2	80	10.7	10.7	8.0
			70	9.4	9.3	7.0
			60	8.1	8.0	6.0

Table 2. Resistance to insertion of endotracheal tubes into the trachea and values for peak inspiratory pressures (cmH_2O) when an air leak was noted at intracuff pressures (P_{cuff}) of 20 or 25 mmHg (27 or 34 cmH_2O)

Treatment	Resistance	Peak inspiratory pressure	
		P_{cuff} = 20 mmHg	P_{cuff} = 25 mmHg
60%	0 (0-1)	9.7 ± 6.7	10.6 ± 8.5
70%	1 (0-2)*	16.2 ± 4.2	19.7 ± 4.9*
80%	3 (0-3)*†	17.4 ± 3.9	20.8 ± 3.6*

Resistance was scored as 0, no resistance; 1, mild resistance; 2, moderate resistance; 3, severe resistance. *Significant difference from treatment 60% ($p < 0.05$). †Significant difference from treatment 70% ($p < 0.05$).

Discussion

When considering both resistance to placement and the ability to create a proper seal between the endotracheal tube cuff and trachea, the results of the present study indicate that using 70% of the internal tracheal diameter measured on thoracic radiography may be suitable for selecting an endotracheal tube of optimal size in Beagle dogs.

Appropriate selection of endotracheal tube size is essential for administering inhalant anesthesia in veterinary medicine. Thoracic radiography may provide a more accurate method to determine the endotracheal tube size because it provides a visual image of the trachea, whereas other methods rely on approximate estimations of tracheal size based on physical parameters. Moreover, preoperative thoracic radiographs may help discover unsuspected pathology which, if undetected, might increase the risk of anesthetic complications. However, the risk of radiation exposure to both the patient and employees of the hospital as well as the additional cost for the client must also be considered. Therefore, the benefits should be weighed against the risks associated with the procedure. Patients with underlying comorbidities or patients with anticipated difficult tracheal intubation may benefit from preoperative thoracic radiographs not only to help confirm the presence or progression of a suspected illness, but also to help select the appropriate endotracheal tube size.

The use of thoracic radiography to select the endotracheal tube size has been studied in pediatric anesthesia. A study comparing a radiograph-based formula with standard age-based formulas to select appropriately sized uncuffed endotracheal tubes in children aged 3–6 years revealed that the radiograph-based formula had a greater success rate than the standard age-based formulas (Park *et al*, 2013). This suggests that thoracic radiography may be useful for predicting the optimal endotracheal tube size.

An appropriately sized endotracheal tube should be able to pass easily through the narrowest part of the airway without causing trauma to the trachea (Hughes, 2016) while effectively sealing the trachea when the cuff is inflated (Thomas and Lerche, 2011). Generally, the cuff should be able to prevent an air leak at airway pressures of 20–30 cmH_2O (Clarke *et al*, 2014a; Mosley, 2015). Therefore, in the present study, two criteria were used to determine the optimal endotracheal tube size: minimal resistance of endotracheal tube passage through the trachea and the ability to prevent an air leak at inspiratory pressures of 20–25 cmH_2O. This study was performed with the dogs in dorsal recumbency because it is one of the most commonly used surgical positions in veterinary medicine. Moreover, because changing the position of the head and neck can affect the position of the endotracheal tube within the trachea (Quandt *et al*, 1993), the depth of tube placement was assessed after the dogs were placed in dorsal recumbency.

In the current study, the resistance of endotracheal tube passage through the trachea significantly increased as the endotracheal tube size increased. This suggests that using 80% of the internal tracheal diameter measured on the lateral thoracic radiographic image would result in an oversized endotracheal tube. Previous studies have found that the mucosa and submucosal structures of the trachea are vulnerable to endotracheal tube compression injury (Schwartz *et al*, 1993) and that tight-fitting endotracheal tubes can result in subglottic stenosis (Fine and Borland, 2004). In addition, laryngeal and tracheal edema and inflammation, which can predispose patients to upper airway obstruction once extubated (Muir *et al*, 2013a), can result in tracheal necrosis or tracheal rupture (Thomas and Lerche, 2011). Furthermore, the cuff of an oversized endotracheal tube will have more invaginations when inflated to occlusion, thereby increasing the risk of aspiration of fluids along these folds (Dorsch and Dorsch, 2008; Hwang *et al*, 2011). In the present study, bloody mucous was observed on the endotracheal tube cuff after extubation in three of the eight dogs (37.5%) in the 80% treatment, suggesting evidence of tracheal mucosal damage. Therefore, it can be concluded that using ≥ 80% of the internal tracheal diameter to determine endotracheal tube size is not suitable.

When properly inflated, the cuff on the endotracheal tube provides an adequate seal for positive pressure ventilation, prevents leakage of anesthetic gases, protects the airway from gastric and oral secretions and provides optimal positioning of the endotracheal tube in the trachea to prevent mucosal injury caused by the tip of the endotracheal tube (Thomas and Lerche, 2011; Volsko *et al*, 2016). It is generally recommended that the intracuff pressure be maintained between 18 and 25 mmHg (Hartsfield, 2007). In the present study, P_{cuff} was set to 20 and 25 mmHg, and the inspiratory pressures at which audible air leaks were detected using a stethoscope were recorded for each treatment. When P_{cuff} was set to 20 mmHg, all treatments had mean P_{leak} of < 20 cmH_2O, suggesting that P_{cuff} of 20 mmHg may be inadequate to prevent air leaks in different sized endotracheal tubes when inspiratory pressures reach 20 cmH_2O. When P_{cuff} was increased to 25 mmHg, leaks did not occur in the 70 and 80% treatments until airway pressure increased to 20 cmH_2O; however, tubes in the 60% treatment leaked at airway pressures < 20 cmH_2O. Therefore, endotracheal tubes selected using 60% of the internal tracheal diameter would most likely result in an inability to create an effective seal within the trachea, leading to difficulty in keeping the patient anesthetized, environmental pollution caused by gas leakage and aspiration of fluids (Thomas and Lerche, 2011; Muir *et al*, 2013a; Hughes, 2016). Moreover, a narrow tube increases resistance to breathing, and overinflation of the cuff to maintain a seal will result in high pressures on the tracheal mucosa, increasing the risk of tracheal necrosis (Alderson *et al*, 2006; Dugdale, 2010; Wylie *et al*, 2015). Therefore, it can be concluded that using values ≤ 60% of the internal tracheal diameter to determine the endotracheal tube size is not suitable.

When P_{leak} at different P_{cuff} were compared within each treatment, there was a statistically significant increase in P_{leak} in the 80% treatment, but no significant differences were found in the 70 and 60% treatments. This suggests that increasing the P_{cuff} by 5 mmHg may not have a significant effect on increasing P_{leak}.

In the current study, optimal endotracheal tube size was evaluated on the basis of both resistance and the ability to create an adequate seal between the cuff and trachea. Among the treatments, the 70% treatment prevented air leaks at the recommended cuff pressures with only a mild resistance to endotracheal tube insertion. This suggests that 70% of the internal tracheal diameter measured on the thoracic radiographic image is suitable for selecting an appropriately sized endotracheal tube. However, it must be noted that, even in the 70% treatment, there were instances where moderate resistance was felt during intubation (three out of eight dogs) and where P_{leak} were inadequate ($P_{leak} < 20$ cmH_2O in three out of eight dogs). Because no method of selecting the correct endotracheal tube size is foolproof, it is recommended that several endotracheal tube sizes be prepared (the size believed to fit, one size smaller, and one size larger) prior to induction of anesthesia.

There were several limitations to this study. The first limitation was related to the small sample size. Using more animals would have provided greater statistical significance and more precise and reliable results. The second limitation was that only one breed and one type of endotracheal tube were studied. The percentage of the internal tracheal diameter (measured on the lateral thoracic radiographic image) required to select the optimal endotracheal tube size may be different between small, medium and large breed dogs, as well as between different types of endotracheal tubes (silicone *versus* PVC) and cuffs. Further investigations are required to determine whether the results of this study can be extrapolated to other breeds of dogs and endotracheal tubes. A third limitation was that measuring the internal tracheal diameter at the thoracic inlet cannot be used in patients with tracheal collapse where the tracheal diameter is narrowed at the thoracic inlet. Further studies are required to determine whether other points along the length of the trachea can be used to select appropriately sized endotracheal tubes in a dog with a collapsing trachea. Another limitation was the reliability of thoracic radiographs for accurate measurement of the tracheal diameter. A previous study comparing the tracheal diameter obtained from radiography and computed tomography in canine cadavers revealed that tracheal diameter measurements obtained from computed tomography were on average 1.03 mm larger than those obtained from radiographs (Montgomery *et al*, 2015). Although this difference may be clinically significant for selecting the tracheal stent size, it is most likely clinically insignificant when determining the appropriate endotracheal tube size. In addition, although the tracheal diameter does not change significantly between inspiration and expiration in normal dogs and cats, mild physiological changes may occur during respiration, and extension of the head and neck can result in compression and narrowing of the tracheal lumen (Hayward *et al*, 2008; Ettinger, 2010). To minimize the impact of these factors, all radiographs were obtained in this study during the maximum inspiratory phase with the head and neck in neutral position. A further limitation was that the thoracic radiographs were taken in only one radiographic view. Measuring the internal tracheal diameter of ventrodorsal, dorsoventral and left lateral thoracic radiographic images may have provided differing measurements. Right lateral radiographs were selected for this study because the tracheal margins on ventrodorsal and dorsoventral views are difficult to accurately measure owing to superimposition of the trachea over the vertebrae and sternebrae. In addition, because the trachea normally deviates slightly to the right at the thoracic inlet in dogs, measuring the internal tracheal diameter of left lateral views may give higher measurements due to a larger magnification factor. Nonetheless, future studies comparing measurements across different radiographic views are necessary to determine whether any view can be used to select appropriate endotracheal tube sizes.

Conclusions

In conclusion, after considering both resistance to insertion and the ability to create an adequate seal between the cuff and trachea, using 70% of the internal tracheal diameter measured on the thoracic radiographic image was suitable for selecting an optimal endotracheal tube size in Beagle dogs. The use of this method may be beneficial for patients where thoracic radiography is a part of the preoperative examination. Moreover, this study may serve as a preliminary study for future studies to create more objective recommendations for endotracheal tube size.

CHAPTER II.

Changes in Endotracheal Tube Intracuff Pressure and Air Leak Pressure over Time in Anesthetized Beagle Dogs

Abstract

This study was performed to evaluate endotracheal tube intracuff pressure (P_{cuff}) changes over time and the effect of these changes on air leak pressure (P_{leak}).

In part I, *in vitro* measurements of P_{cuff} were recorded for 1 hour in eight endotracheal tubes subjected to four treatments: room temperature without lubricant (RTWOL), room temperature with lubricant (RTWL), body temperature without lubricant (BTWOL), and body temperature with lubricant (BTWL). In part II, nine healthy adult Beagle dogs were endotracheally intubated and P_{leak} was evaluated at P_{cuff} of 25 mmHg. Subsequently, P_{cuff} was reset to 25 mmHg (baseline) and P_{cuff} measurements were recorded every 5 minutes for 1 hour. Afterwards, a second P_{leak} measurement was recorded at the current P_{cuff}. The data were analyzed using Wilcoxon signed ranks test, repeated measures ANOVA and Mann-Whitney U test.

In part I, there were significant differences in P_{cuff} between the RTWOL and RTWL treatments at 5–60 minutes, and between the BTWOL and BTWL treatments at 5–35, 55 and 60 minutes ($p < 0.05$). In part II, compared with

baseline pressures, mean P_{cuff} decreased to <18 mmHg at 10 minutes and significant decreases were observed from 15–60 minutes, during which minimum and maximum P_{cuff} were 10.0 ± 4.9 and 13.4 ± 6.3 mmHg, respectively. Significant differences were observed between the first and second P_{leak} measurements ($p = 0.034$). Air leak pressure decreased in six of nine dogs, was not changed in two dogs, and increased in one dog.

Significant decreases in P_{cuff} can be expected over time. P_{leak} may decrease during anesthesia and increase the risk for silent pulmonary aspiration. This study supports the need for additional P_{cuff} and P_{leak} monitoring, especially 10 minutes after the onset of anesthesia.

Introduction

Endotracheal intubation is a crucial element of anesthesia, critical care, and emergency medicine in both human and veterinary medicine. Intubation with a cuffed endotracheal tube is regularly performed during small animal anesthesia in order to maintain a patent airway, deliver volatile anesthetics and oxygen, enable positive pressure ventilation, protect the airway from aspiration of fluids, and prevent exposure to waste anesthetic gases (Mosley, 2011; Briganti *et al*, 2012; Muir *et al*, 2013a). After intubation, the cuff should be properly inflated so that an airtight seal can be achieved between the cuff and trachea without impeding tracheal blood flow (Stewart *et al*, 2003). Because the tracheal mucosal perfusion pressure ranges from 25–35 mmHg, intracuff pressures of 20–25 mmHg will generally not impede blood flow through the tracheal mucosa (Hartsfield, 2007). Within this pressure range, the cuff should be able to maintain an airtight seal at airway pressures of 20–30 cmH_2O (15–22 mmHg) (Mosley, 2015). Cuff pressures <18 mmHg increase the risk for aspiration while pressures >35 mmHg compromise capillary blood flow, which may lead to various perioperative complications such as inflammation of the tracheal wall, ischemia/necrosis of the tracheal mucosa, or, in extreme cases, tracheal rupture (Dugdale, 2010; Thomas and Lerche, 2011; Muir *et al*, 2013a; Mosley, 2015).

Although intracuff pressures may be checked initially after cuff inflation following endotracheal intubation, the pressure within the cuff is a dynamic process that can be affected by alterations in the shape and size of the trachea, body temperature, variations in head and neck position, and the anesthetic gas mixture (Kako *et al*, 2015). Several studies in human medicine revealed that intracuff pressures decrease over time in critically ill patients intubated for prolonged periods (Sole *et al*, 2009; Nseir *et al*, 2009; Sole *et al*, 2011). In veterinary medicine, it has been recommended that cuff inflation be checked again after 15 or 30 minutes of anesthesia because the tracheal diameter may change due to muscle relaxation (Thomas and Lerche, 2011). However, no objective standard exists for cuff pressure monitoring.

The aim of this study was to evaluate changes in intracuff pressures over time, to determine which factors influence cuff pressures, and whether these changes affect the endotracheal tube's ability to maintain an airtight seal. The hypothesis was that intracuff pressures would decrease over time. In addition, the authors hypothesized that this decrease in intracuff pressures would result in an inadequate seal between the cuff and trachea.

Materials and Methods

1. *In vitro* measurements of intracuff pressures

Using a crossover model, eight newly opened 7.5 mm internal diameter polyvinyl chloride endotracheal tubes (RUSCH super safety clear 112482; Teleflex Medical, NC, USA) were studied under four treatment conditions: 1) room temperature (20–25°C) without lubricant (RTWOL), 2) room temperature with lubricant (RTWL), 3) body temperature (37.3–39°C) without lubricant (BWTOL), and 4) body temperature with lubricant (BTWL). After each experiment, the tube was washed with water to remove lubricant and air dried. All eight tubes underwent each of the four treatments with a 3-day interval between each treatment. The order of the treatments was randomly chosen by writing the treatment names on pieces of paper and blindly drawing lots. The endotracheal tube cuff was fully deflated and the tube was inserted into a 10 mL syringe barrel (Kovax-syringe 10 mL; Korea Vaccine Co. Ltd., Korea) with an inner diameter of 14.5 mm and intracuff pressure was continuously measured for 1 hour. Prior to each treatment, the endotracheal tube was checked for leaks caused by defective products by inflating the cuff with air (17–18 mL) for 5 minutes followed by deflation. If the same amount of air was removed, it was judged that the cuff was intact. Room temperature (20–25°C) was continuously monitored and recorded every 5 minutes using two devices: 1) a mercury thermometer and 2) the temperature probe from the multi-parameter monitor (Datex-Ohmeda S/5; GE Healthcare, Finland) that were placed vertically near the endotracheal tube. Body temperature (37.3–39°C) was achieved and maintained by placing the outlet of a warm air device (Bair hugger, 3M, MN, USA) into a 50 L plastic bag and measuring the temperature with a mercury thermometer and the temperature probe of the multi-parameter monitor. The mercury thermometer and temperature probe were placed vertically through a small hole and with the tip placed inside the plastic bag containing the endotracheal tube temperature was continuously monitored and recorded every 5 minutes. For the lubricant treatments, 2 mL of water-soluble gel lubricant containing chlorhexidine (Silgreen Cream; Firson Co., Ltd., Korea) was generously applied to the cuff before inserting the endotracheal tube into the syringe barrel. Prior to starting the continuous intracuff pressure measurements, each endotracheal tube was acclimatized to the selected temperature (room or body temperature) for 5 minutes.

Using a previously described and validated technique to continuously measure intracuff pressure, the pilot balloon of the endotracheal tube was connected to a standard direct pressure monitoring setup (Transpac IV Monitoring Kit; ICU Medical Inc., CA, USA) via a 3-way stopcock (Gopalakrishnan *et al*, 2013; Krishna *et al*, 2014). The pressure transducer was connected to a multi-parameter monitor (Datex-Ohmeda S/5; GE Healthcare, Finland) and was zeroed to room pressure before intracuff pressure was measured. Air was injected through the pilot balloon to increase the intracuff pressure to 25 mmHg using a syringe that was connected to the 3-way stopcock. After a stabilization period of 2 minutes, baseline intracuff pressure was set to 25 mmHg and intracuff pressure measurements were recorded every 5 minutes for 1 hour.

2. Animals

This study was approved by the Institutional Animal Care and Use Committee of Seoul National University (SNU-170529-1). Nine adult male Beagle dogs (mean ± standard deviation (SD) age 4.0 ± 1.0 years) were included in this study. All dogs were considered to be clinically healthy based on physical examination, complete blood count, serum chemistry analysis, and thoracic and abdominal radiographs. Body condition score was assessed using a 9-point scoring system (Laflamme, 1997).

3. Anesthetic protocol and measurement of resistance/air leak pressure

Food was withheld for 12 hours before anesthesia, but water was available *ad libitum*. All dogs were aseptically catheterized in a cephalic vein using a 22 gauge over-the-needle catheter (Sewoon Medical Co. Ltd., Korea). Medetomidine (5 μg/kg; Domitor; Zoetis, NJ, USA) was administered intravenously (IV) for premedication and anesthesia was induced with alfaxalone (2 mg/kg; Alfaxan; Jurox Pty Ltd, Australia) administered IV. Hartmann's solution (H/S; Daihan Pharmaceutical Co. Ltd., Korea) was administered at a rate of 10 mL/kg/hr throughout the experiment. Anesthesia was maintained with isoflurane (Ifrane; Hana Pharm., Korea) in >95% oxygen using a rebreathing system (Multiplus MEVD Anesthesia Machine; Royal Medical, Korea). The oxygen flowmeter was set at 2 L/minute and the vaporizer at 2.0%. The dogs breathed spontaneously during the procedure. Electrocardiogram, respiratory rate, arterial hemoglobin oxygen saturation by pulse oximetry, oscillometric arterial blood pressure, and end-tidal carbon dioxide tension by capnometry were monitored throughout the experiment (FI/Carescape Monitor B650; GE Healthcare, Finland). Normothermia (37.3–39.0°C) was maintained using a warm water blanket (HTP-1500 Heat Therapy Pump; Adroit Medical Systems, TN, USA).

Endotracheal tube size was determined using a previously described method of measuring the internal tracheal diameter of a right lateral thoracic radiographic image (Shin *et al*, 2018). Newly opened endotracheal tubes were used for every dog and all tubes were checked for leaks and lubricated using the same product as in the *in vitro* experiment prior to intubation. Dogs were endotracheally intubated in sternal recumbency by one experienced investigator (HK) who scored the resistance of endotracheal tube passage through the trachea (0, no resistance; 1, mild resistance; 2, moderate resistance; 3, severe resistance). If moderate resistance was noted during intubation, the endotracheal tube was exchanged for one that was 0.5 mm smaller. After intubation, the dogs were positioned in dorsal recumbency and a ventrodorsal fluoroscopic image of the thorax was taken (Spinel 3G Mobile Surgical Fluoroscopic X-ray System; GEMSS Medical, Korea). The endotracheal tube was deemed to be in the correct position if the distal tip was located at the cranial border of the thoracic inlet.

Intracuff pressure was continuously measured as in the *in vitro* experiment. Using a 5-mL syringe that was connected to the 3-way stopcock, air was added to the cuff through the pilot balloon to obtain an intracuff pressure of 25 mmHg. Subsequently, an air leak pressure measurement was performed within 5 minutes of intubation by increasing the oxygen flowmeter to 5 L/minute and closing the adjustable pressure limiting valve. As pressure within the circle system increased, the peak inspiratory pressure at which an air leak was audible was recorded by one experienced investigator (HK) who placed a stethoscope just cranial to the thoracic inlet and listened for leaks around the cuff. The adjustable pressure limiting valve was opened once airways pressures reached 25 cmH_2O (18.4 mmHg) to prevent pulmonary barotrauma. If no audible leak was detected at airway pressures of 25 cmH_2O, air leak pressure was recorded as >25 cmH_2O. If air leak pressure <20

cmH_2O, the animal was extubated and re-intubated with an endotracheal tube that was 0.5 mm larger. After air leak pressure was measured, a stabilization period of 2 minutes was allowed before continuous intracuff pressure measurements were taken.

4. Continuous measurement of intracuff pressure

Baseline intracuff pressure was set to 25 mmHg and intracuff pressure measurements were taken every 5 minutes for 1 hour. Subsequently, a second air leak pressure measurement was taken at the current intracuff pressure before the vaporizer was turned off and the dog was allowed to recover from anesthesia.

5. Statistical analyses

The data were analyzed using the SPSS 22 statistical program (SPSS Inc., IL, USA). Data on intracuff pressure and air leak pressure were presented as mean ± SD. The Wilcoxon signed ranks test was used to evaluate differences in intracuff pressures between the *in vitro* treatments. One-way analysis of variance (ANOVA) with repeated measures was used to evaluate changes in intracuff pressure over time and *post hoc* analysis was performed using the Bonferroni-Holm method. Differences in intracuff pressures between the BTWL treatment and *in vivo* group were evaluated using the Mann-Whitney U test. The change in air leak pressure before and after the 1 hour of anesthesia was analyzed using the Wilcoxon signed ranks test. A p-value < 0.05 was considered to be statistically significant.

Results

In vitro study

Intracuff pressure measurements obtained at each time point for all treatment groups were shown in Fig. 2. There were significant differences in intracuff pressures between the RTWOL and RTWL treatments at all time points except for the baseline measurement ($p < 0.05$). Significant differences in intracuff pressures between the BTWOL and BTWL treatments were observed at 5–35, 55, and 60 minutes ($p < 0.05$). No significant difference in intracuff pressures were noted between the RTWOL and BTWOL, as well as the RTWL and BTWL treatments at all time points ($p > 0.05$). In all treatments, significant decreases in intracuff pressures were observed at 5–60 minutes compared to the baseline measurement ($p < 0.05$).

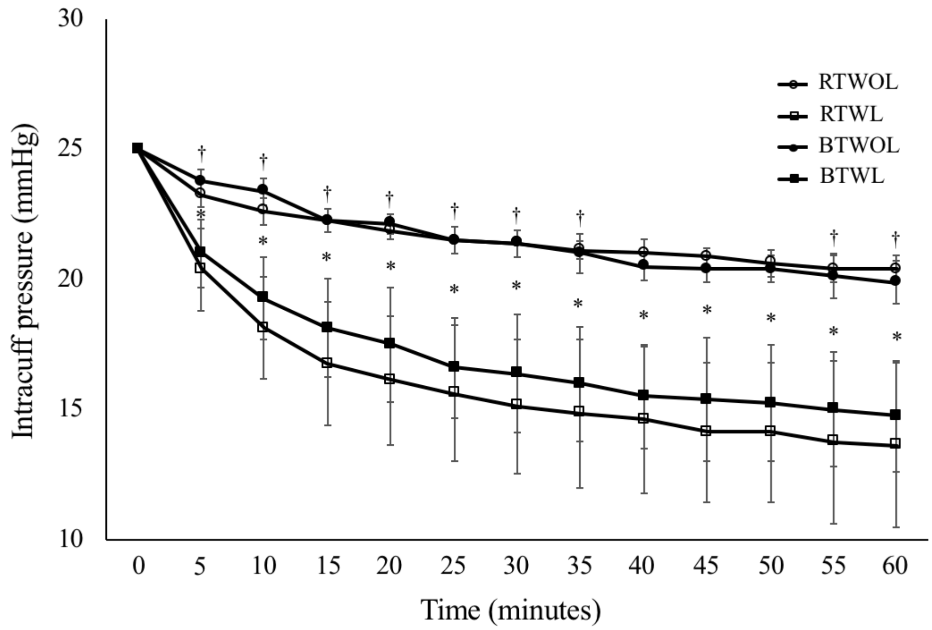


Fig. 2. Change in intracuff pressures (mean ± SD) over 1 hour following insertion of a 7.5 mm internal diameter endotracheal tube into a 10-mL syringe barrel. RTWOL, room temperature without lubricant; RTWL, room temperature with lubricant; BTWOL, body temperature without lubricant; BTWL, body temperature with lubricant. *Significant difference between the RTWOL and RTWL groups ($p < 0.05$). †Significant difference between the BTWOL and BTWL groups ($p < 0.05$).

***In vivo* study**

The mean ± SD body weight was 11.0 ± 1.2 kg, and the median body condition score was 4 (range, 4–6). All tracheas were determined to be normal based on thoracic radiographs.

Intracuff pressure measurements obtained at each time point were shown in Fig. 3. All dogs showed a decrease in intracuff pressure over time. Relative to the baseline measurement, intracuff pressure decreased significantly at 15–60 minutes ($p < 0.05$). No significant differences in intracuff pressures were observed between the BTWL treatment and the *in vivo* group at all time points ($p > 0.05$).

Air leak pressures and the corresponding intracuff pressure measurements obtained after endotracheal intubation (T_0) and after 1 hour of intracuff pressure measurements (T_{60}) were shown in Table 3. Relative to the baseline measurement, significant differences in air leak pressure were observed after 60 minutes ($p = 0.034$). Air leak pressure decreased in six out of nine (66.6%) dogs, increased in one (11.1%) dog, and did not change in two out of nine (22.2%). Moderate resistance to endotracheal tube insertion was noted in one dog and air leak pressure was <20 cmH_2O in one dog; therefore, a 0.5 mm smaller and larger endotracheal tubes were used for re-intubation, respectively. Mild hypotension (mean arterial blood pressure 54–59 mmHg) was observed in four dogs but recovered within 15 minutes. No adverse complications of the hypotensive episodes or from endotracheal intubation were observed. All dogs recovered in the same condition in which they started.

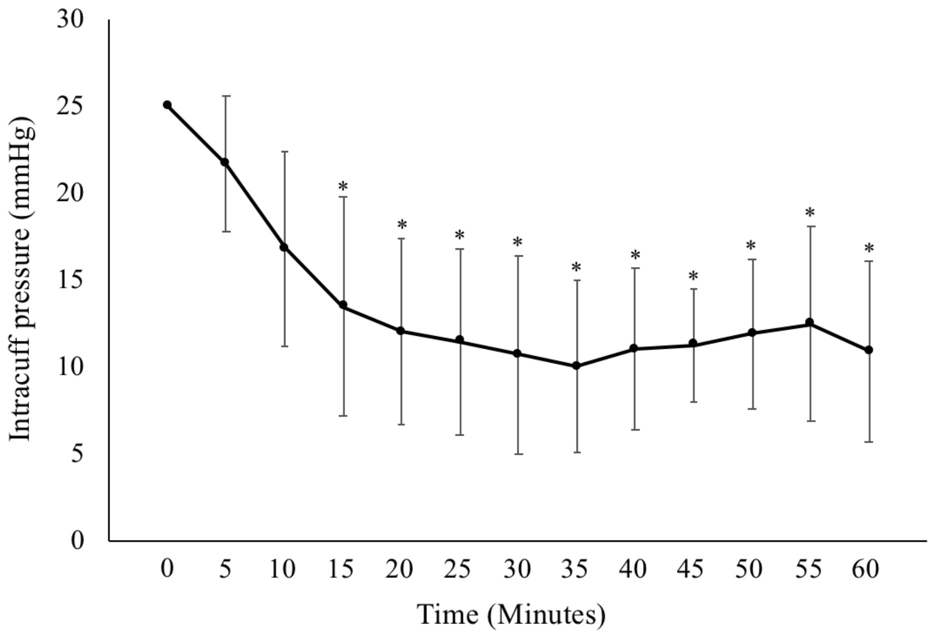


Fig. 3. Change in intracuff pressures (mean ± SD) over 1 hour following endotracheal intubation in nine Beagle dogs. *Significantly different from baseline (0 minutes) ($p < 0.05$).

Table 3. Air leak pressures (cmH_2O and conversion to mmHg; 1 cmH_2O = 0.736 mmHg) and the corresponding intracuff pressures (mmHg) obtained after endotracheal intubation (T_0) and after 60 minutes of anesthesia (T_{60})

Measurement time	**Air leak pressure**		**Intracuff pressure**
minutes	cmH_2O	mmHg	mmHg
T_0	21.2 ± 2.0	15.6 ± 1.5	25.0 ± 0.0
T_{60}	18.8 ± 3.3*	13.8 ± 2.4	10.9 ± 5.2*

*Significantly different from T_0 ($p < 0.05$). Air leak pressure changes were as follows: decreased in 6/9 dogs, no change in 2/9 dogs, increased in 1/9 dog.

Discussion

The aim of this study was to evaluate changes in intracuff pressure over time and how these changes affected air leak pressure. The results of this study showed that intracuff pressure significantly decreases over time without intervention and that air leak pressure may or may not decrease with declining intracuff pressures.

After intubation with a cuffed endotracheal tube, the cuff should be able to achieve an airtight seal when inflated to pressures of 20–25 mmHg (Mosley, 2015). Generally, intracuff pressures are measured once following endotracheal intubation. However, the pressure within the cuff is a dynamic process that is influenced by various factors. The results of the present study revealed that intracuff pressures significantly decrease over time without intervention. This result is consistent with previous studies where intracuff pressures were intermittently and continuously monitored in critically ill patients under mechanical ventilation (Sole, 2002; Sole *et al*, 2002; Sole *et al*, 2009; Nseir *et al*, 2009; Sole *et al*, 2011). Alterations in intracuff pressures have been attributed to various factors, including the design of the cuff, anesthetic depth, head and neck position, body temperature, anesthetic gas mixture, and the use of neuromuscular blocking drugs (Girling *et al*, 1999; Sole *et al*, 2009; Kako *et al*, 2015). Previous studies have shown that hypothermia, head extension, and neuromuscular blockade lead to decreases in intracuff pressures (Girling *et al*, 1999; Neto *et al*, 1999; Kako *et al*, 2015), while head and neck flexion and the presence of nitrous oxide within the anesthetic gas mixture lead to increases in intracuff pressures (Stanley *et al*, 1974; Kako *et al*, 2015). The results of the present *in vitro* study revealed that intracuff pressures decrease similarly at both room and body temperature (decreased by 4.6 and 5.1 mmHg after 1 hour, respectively) when the cuff is not lubricated. Moreover, the position of the head and neck was kept constant in all dogs during the intracuff pressure measurements and neuromuscular blocking agents were not administered. Therefore, in this study, it can be concluded that temperature, head and neck position, and neuromuscular blockade were not influencing factors.

According to the results of this study, the decrease in intracuff pressure over time may be attributed to: 1) the inherent properties of the cuff, 2) the use of a lubricant, and 3) muscle relaxation. Firstly, the decrease in intracuff pressures observed *in vitro* in the non-lubricated tubes at both room and body temperatures may be attributed to the elastic properties of the cuff itself, similar to that of a balloon. Secondly, the results of this *in vitro* study revealed that cuff lubrication significantly decreased intracuff pressures at both room and body temperature (decreased by 11.4 and 10.3 mmHg after 1 hour, respectively). This may be the result of a difference in frictional force between the cuff and syringe barrel compared with the non-lubricated tubes. Finally, when compared with the *in vitro* study, the additional decrease in intracuff pressures observed during the *in vivo* study (decreased by 14.1 mmHg after 1 hour) may be attributed to the relaxation of the muscles surrounding the trachea during anesthesia. In this study, anesthetic depth was assessed using respiratory rate and the end-tidal concentration of isoflurane (ET_{iso}). The ET_{iso} increased during the first 10–15 minutes but then remained relatively constant during the remaining one hour, while respiratory rate non-significantly increased towards the end of the 60-minute observation time. The increase in ET_{iso} may have resulted in an increase in muscle relaxation surrounding the trachea thus resulting in a decrease in intracuff pressures. The change in respiratory rate towards the end of the 60-minute observation period also may have affected tracheal muscle tone. However, because muscle tone was not assessed in this study and the extent of muscle relaxation depends on the response of the individual to the sedative, induction agent, and inhalation agent used, it is difficult to ascertain how individual tracheal muscle tone varied during the 60-minute period. Therefore, future studies assessing how tracheal muscle tone affects intracuff pressures are warranted.

In this study, 100% of dogs showed a decrease in intracuff pressure over time. This finding was different to that of past research. In a previous study by Kako *et al*. (2015) where continuous intracuff pressure measurements were obtained during prolonged surgical procedures of pediatric patients, intracuff pressure was not stable in all 30 patients included in the study. In 20% of patients, intracuff pressure increased by greater than 10 cmH_2O compared to baseline, while air needed to be added to the cuff to maintain a seal in 23% of the patients. This difference may be attributed to the fact that the pediatric patients were undergoing surgical procedures and had varying body position (supine, prone, and lateral). In the present study, no surgical interventions were applied to the dogs and all dogs were placed in one position (dorsal recumbency). Another factor may be the depth in which the endotracheal tubes were placed within the trachea. Previous studies showed that endotracheal tubes that were placed deeper into the trachea were associated with a greater incidence of lower intracuff pressure (Sole *et al*, 2009). In human medicine, it is suggested that the distal tip of the endotracheal tube be located in the middle third of the trachea (Dorsch and Dorsch, 1984). In veterinary medicine, it is recommended that the distal tip of the endotracheal tube not extend beyond the thoracic inlet (Clarke *et al*, 2014b). In the present study, all dogs were intubated to the level of the thoracic inlet, which is deeper than that recommended in human medicine. Therefore, the deeper location of the endotracheal tube tip within the trachea may have contributed to the 100% incidence of decreased intracuff pressure over time. However, future studies in dogs evaluating how different depths of endotracheal tube insertion affect intracuff pressures are warranted.

Proper inflation of the endotracheal tube cuff to 18–25 mmHg should be able to prevent air leaks at airway pressures of 20–30 cmH_2O (Thomas and Lerche, 2011; Mosley, 2015). A previous study by Finholt *et al*. (1985) revealed that muscle tone significantly affects air leak pressures while the rate of fresh gas flow into the breathing system and varying endotracheal tube depth within the trachea do not affect air leak pressures. Full muscle relaxation with neuromuscular blocking agents resulted in significantly lower air leak pressures compared with full recovery from neuromuscular blockade (Finholt *et al*, 1985). In the present study, although neuromuscular blocking agents were not administered, a significant change in air leak pressure was noted after 1 hour of anesthesia, with decreases observed in six out of nine (66.6%) dogs. These results may be explained by increased muscle relaxation compared to the baseline air leak pressure test, which was performed within 10 minutes of induction of anesthesia. On the other hand, no change in air leak pressure was observed in two (22.2%) dogs while an increase in air leak pressure by 1 cmH_2O was observed in one (11.1%) dog. Audible leaks and triggering of the ventilator alarm are generally considered to be indicators of a cuff leak. Some may argue that the cuff provides an adequate seal if these issues are not observed (Sole *et al*, 2009).

Previous studies have shown that even though a leak is not clinically observed, underinflation of the endotracheal tube cuff may be associated with silent aspiration (Nseir *et al*, 2009). Specifically, studies suggest that there is a high risk of aspiration when intracuff pressure is <18 mmHg (25 cmH_2O) (Verma, 2006; Mosley, 2011; Mosley, 2015). In the present study, although a significant decrease in intracuff pressure was observed from 15 minutes, mean intracuff pressure decreased to lower than 18 mmHg at 10 minutes. These results suggest that, at 10 minutes, there is increased risk for silent aspiration.

In human medicine, current textbooks recommend that intracuff pressures be measured and adjusted approximately 10 minutes after endotracheal intubation to allow for softening of the cuff material according to body temperature and because the occlusive volume will vary with muscle tone (Dorsch and Dorsch, 2008). In veterinary medicine, it is recommended that cuff inflation be checked approximately 15 or 30 minutes after the onset of anesthesia because tracheal diameter may change due to muscle relaxation (Thomas and Lerche, 2011). The results of this study further strengthen the recommendation for additional monitoring of intracuff pressures, especially 10 minutes after intubation.

There were several limitations to this study. The first limitation was related to the small sample size. A larger sample size would have provided greater statistical significance, as well as more precise and reliable results. The second limitation was that two dogs needed to be re-intubated due to moderate resistance of endotracheal tube passage through the trachea and inadequate air leak pressure, respectively. This may have affected the degree to which intracuff pressures changed over time, but it is likely that the overall trend in intracuff pressure alterations would not be affected. A third limitation was that only one type of lubrication method was used in this study. Future studies comparing the effects of different lubrication methods (water, saliva, water-soluble lubricant, etc.) on intracuff pressures in both the *in vitro* and *in vivo* setting are warranted. Another limitation was that mild hypotension was observed in four dogs, which could have affected tracheal mucosal perfusion pressures. Although no clinical complications with respect to the hypotensive episodes was observed, it is difficult to ascertain that no tracheal mucosal damage occurred because bronchoscopy was not performed to confirm the absence of tracheal damage. Finally, in the present study, in order to prevent pulmonary barotrauma, the adjustable pressure limiting valve was opened once circle pressures reached 25 cmH_2O, and the air leak pressure was recorded as >25

cmH_2O if no air leak was detected at airway pressures of 25 cmH_2O. If the study was performed excluding these dogs, the data may have shown more limited results. In the present study, one dog had a seal at 25 cmH_2O during the first air leak pressure measurement before the 1 hour of continuous intracuff pressure measurements, while another dog had a seal at 25 cmH_2O during the second air leak pressure measurement performed after the 1 hour of intracuff pressure measurements. Therefore, if the actual air leak pressures were estimated, the values are unlikely to significantly alter the results.

Conclusions

In conclusion, the results of this study suggested that clinically significant decreases in intracuff pressures can be expected over time. Although air leak pressures may not change according to the decrease in intracuff pressure, the risk for silent aspiration increases if intracuff pressure is less than 18 mmHg. Therefore, this study supports the need for continuous monitoring of intracuff pressure during anesthesia. However, in cases where continuous monitoring is not feasible, intermittent monitoring of intracuff pressure and air leak pressure, especially 10 minutes after the onset of anesthesia, is strongly recommended.

CHAPTER III.

Appropriate Endotracheal Tube Size Selection Using Thoracic Radiography in Dogs – A Clinical Trial

Abstract

This prospective clinical study was performed to determine the appropriate endotracheal tube size (ETS) in dogs using thoracic radiography.

Internal tracheal diameters (TD) were measured using lateral thoracic radiographs and the ETS was determined for 51 client owned dogs. After anesthesia induction, dogs were intubated and the resistance to tube insertion was scored. Air leak pressures (P_{leak}) were evaluated at intracuff pressures of 20 mmHg. If no leak was detected at airway pressures of 20 cmH_2O, it was determined that a proper seal was achieved. Re-intubation was performed if moderate resistance was noted or if P_{leak} was < 20 cmH_2O at intracuff pressures of 25 mmHg. Relationships between TD, cuff diameter (CD), and ETS and age, bodyweight, body condition score (BCS), and breed, as well as the correlation between TD and ETS, CD or the percentage of TD were analyzed statistically. Moreover, patients were separated into groups according to percentage of TD and bodyweight, and the data were analyzed statistically.

Correlations between ETS and TD ($R^2 = 0.908$; $p < 0.0005$), CD and TD ($R^2 = 0.905$; $p < 0.0005$) were very high. Moderate correlation was found between bodyweight and TD, ETS, CD ($R^2 = 0.536$, $p < 0.0005$; $R^2 = 0.565$, $p < 0.0005$; $R^2 = 0.584$, $p < 0.0005$). When patients were divided into groups according to the percentage of TD (65–70%, 75–80%, 85–90%, and 95–100%), TD significantly decreased in all groups compared to the 65–70% group ($p < 0.05$). When patients were grouped according to bodyweight, the mean TD and ETS increased as bodyweight increased.

Internal TD measured from thoracic radiographs may be a reliable method to select appropriate ETS in dogs. Larger percentages of the TD would be required for dogs with smaller TDs.

Introduction

In veterinary medicine, endotracheal intubation is not only a critical component of inhalant anesthesia, but it is also important in emergency and critical care medicine. Endotracheal intubation with an appropriately sized endotracheal tube not only prevents aspiration of fluids and limits environmental contamination with anesthetic gases, but it also allows for efficient delivery of oxygen and volatile anesthetics and enables positive pressure ventilation (Mosley, 2011; Briganti *et al*, 2012; Muir *et al*, 2013a). Endotracheal tubes that are too small will increase the work of breathing and will fail to provide an adequate seal between the cuff and trachea, while tubes that are too large may damage the tracheal mucosa (Thomas and Lerche, 2011; Hughes, 2016). Therefore, after intubation with a cuffed endotracheal tube, the cuff should be inflated to a pressure of 20–25 mmHg to ensure that the blood flow through the tracheal mucosa is not interrupted (Hartsfield, 2007). At this pressure range, the cuff should be able to attain an adequate seal when airway pressures reach 20–30 cmH_2O (Mosley, 2015).

Because the tracheal diameter (TD) of dogs is influenced by breed, bodyweight, age, and conformation, large individual variations in TD exist in dogs (Thomas and Lerche, 2011; Hughes, 2016). In clinical practice, various methods, such as external palpation of the trachea at the thoracic inlet, measurement of the nasal septal width, and approximation of the dog's lean bodyweight, are used to determine the appropriate endotracheal tube size (ETS) in dogs (Lish *et al*, 2008;

Shelby and McKune, 2014; Hughes, 2016). However, these methods rely only on estimations of tracheal size based on physical parameters and arbitrary guides.

In a previous study, the authors developed a method to select appropriately sized endotracheal tubes in Beagle dogs by measuring the internal TD of a lateral thoracic radiographic image (Shin *et al*, 2018). In that study, it was determined that using 70% of the measured internal TD was suitable for choosing the appropriate ETS in Beagle dogs. However, because only one breed was included in that study, it was uncertain whether the results could be extrapolated to other breeds. Therefore, the aim of this study was to determine whether this method can be used for other breeds of dogs and whether or not the previous '70% of the internal TD' recommendation also applied to different sizes of dogs. The hypothesis was that this method could be applied to all dogs, but the percentage of the internal TD measured on the thoracic radiograph would differ according to the dogs' size.

Materials and Methods

1. Animals

Fifty-one client owned dogs of various age and breed undergoing anesthesia for surgical or diagnostic procedures were enrolled in this study. This study was approved by the Institutional Animal Care and Use Committee of Seoul National University (SNU-170602-4-1) and written consent was obtained from the owners prior to the dog's enrollment. Dogs with evidence of tracheal or pulmonary disease were excluded from the study. Body condition score (BCS) was evaluated on a 9-point scale (Laflamme, 1997).

2. Radiographic technique and endotracheal tube size selection

Prior to anesthesia, thoracic radiographs (Comet EVA-HF525; United Radiology Systems Inc., IL, USA) were taken at maximum inspiration with the dogs in right lateral and dorsal recumbency using manual restraint. All radiographs were taken within 1–2 minutes of recumbency. The right lateral thoracic radiographic images of all dogs were viewed by one veterinary radiologist (SK) who measured the internal TD at the thoracic inlet using a previous described method (Harvey and Fink, 1982; Shin *et al*, 2018). Three measurements were obtained for each dog and the mean value was used to determine ETS. According to the previous study (Shin *et al*, 2018), using 70% of the internal TD measured on the right lateral thoracic radiographic image was suitable for selecting an optimal ETS in Beagle dogs. However, in the preliminary study, it was determined that using 70% of the internal TD to determine ETS in dogs with smaller TDs resulted in the selection of an endotracheal tube that was too small, resulting in a high rate of re-intubation. Therefore, in the main study, to reduce the incidence of re-intubation, >70% of the internal TD was used to determine ETS in patients with smaller TDs.

3. Anesthetic protocol and measurement of resistance

Dogs were premedicated with a combination of either acepromazine 5–10 μg/kg (Sedaject; Samu Median Co., Korea) administered intravenously (IV), medetomidine 1–5 μg/kg (Domitor; Zoetis, Korea) IV or intramuscularly (IM), midazolam 0.1–0.2 mg/kg IV or IM (Midazolam; Bukwang Pharm., Korea), diazepam 0.2 mg/kg IV (Diazepam; Samjin Pharm, Korea), butorphanol 0.2 mg/kg IV (Butorphanol; Myungmoon Pharm, Korea), hydromorphone 0.025–0.05 mg/kg IV (Dilid Inj; Hana Pharm., Korea), fentanyl 6 μg/kg/hr IV (Fentanyl citrate; Hana Pharm, Korea), remifentanil 6 μg/kg/hr IV (Ultiva; Glaxo Smith Kline, Korea), lidocaine 3 mg/kg/hr IV (2% Lidocaine HCl; Daihan Pharm., Korea), and ketamine 2 mg/kg IM or 0.6 mg/kg/hr IV (Ketalar; Yuhan, Korea). Anesthesia was induced with either propofol 4–6 mg/kg (Provive 1%; Myungmoon Pharm, Korea) or alfaxalone 2 mg/kg (Alfaxan; Jurox Pty Ltd, Australia) administered IV and maintained with isoflurane (Ifrane; Hana Pharm., Korea) in >95% oxygen. Intravenous fluids were administered throughout the procedures. Electrocardiogram, respiratory rate, arterial oxygen saturation by pulse oximetry, direct or indirect arterial blood pressure, and end-tidal carbon dioxide tension by capnometry were monitored in all dogs.

Polyvinyl chloride endotracheal tubes (RUSCH super safety clear 112482; Teleflex Medical, NC, USA) were used for all dogs. Prior to induction of anesthesia, the depth of tube insertion was predetermined by measuring the distance between the thoracic inlet and the commissure of the lip. Endotracheal intubation was performed with the dogs in either sternal or lateral recumbency with the aid of a laryngoscope with a Miller blade to visualize the larynx. During intubation, the resistance of endotracheal tube passage through the trachea was scored by the person performing the procedure and recorded as 0, no resistance; 1, mild resistance; 2, moderate resistance; and 3, severe resistance. If moderate resistance was noted, an endotracheal tube that was 0.5 mm smaller was used for intubation.

4. Measurement of air leak pressure

After intubation, the endotracheal tube was securely tied to the back of the ears to prevent movement within the trachea. The pilot balloon was connected to a 3-way stopcock extension set. A 5-mL syringe and cuff manometer (Cuff manometer, VBM, Germany) were connected to the stopcock. The stopcock was then turned "on" to the pilot balloon and air was insufflated into the cuff until intracuff pressure reached 20 mmHg. Subsequently, two air leak pressure measurements were obtained by closing the 'pop-off' valve and increasing the oxygen flowmeter to 5 L/minute. When the pressure within the rebreathing circle increased, an experienced anesthesiologist placed a stethoscope immediately cranial to the thoracic inlet and listened for any air leaks around the cuff. The air leak pressure was recorded as the pressure within the circle system at which an air leak was first audible. In order to prevent pulmonary barotrauma, the 'pop-off' valve was opened once circle pressures reached 20 cmH_2O. If no air leak was heard at airway pressures of 20 cmH_2O, it was determined that an adequate seal was achieved by the cuff. If air leak pressure was $<$20 cmH_2O, intracuff pressure was increased to 25 mmHg and an additional air leak pressure measurement was obtained. If air leak pressure was still $<$20 cmH_2O, re-intubation was performed with an endotracheal tube that was 0.5 mm larger and two additional air leak pressure measurements were obtained at intracuff pressures of 20 mmHg. Afterwards, once the patients were placed in their final position prior to the surgical or diagnostic procedure, a final air leak pressure measurement was taken at the last intracuff pressure (either 20 or 25 mmHg) at which an adequate seal was achieved between the cuff and trachea (P_{leak} = 20 cmH_2O).

5. Statistical analyses

The data were analyzed using the SPSS 22 statistical program (SPSS Inc., IL, USA). Data were presented as mean ± standard deviation (SD) or median (range) as appropriate. Linear regression analysis was performed to assess the relationships between age, bodyweight, BCS, and breed, and TD, cuff diameter (CD) or ETS. Moreover, the correlation between TD and ETS, CD, or the percentage of the TD used to determine ETS were assessed. Correlation was regarded as statistically significant when $p < 0.01$ and as very high when $R^2 > 0.900$.

In addition, patients were separated into four groups according to the percentage of TD (65–70% of TD, 75–80% of TD, 85–90% of TD, and 95–100% of TD), and the mean TD was recorded. The difference in TD between the four groups was analysed using the Kruskal-Wallis H test. Finally, patients with a BCS of 4–5/9 were separated into five groups according to bodyweight (<3 kg, 3–5 kg, 5–10 kg, 10–20 kg, and >20 kg), and the mean TD and ETS were recorded. The Kruskal-Wallis H test was used to evaluate differences in ETS between the five groups. The pairwise comparisons for the Kruskal-Wallis H test were performed using Dunn’s procedure with a Bonferroni correction for multiple comparisons.

Results

A total of fifty-one patients were studied. The mean ± SD age of the dogs enrolled was 8.5 ± 4.6 years, the mean bodyweight was 8.1 ± 5.9 kg and the median BCS was 5 out of 9 (range, 3–8). The mean TD was 9.9 ± 2.7 mm while the range of the internal diameter (ID) of the endotracheal tubes used was 3.5–8 mm (median 5.5 mm). Specific information regarding the ID, outer diameter (OD), CD, and OD/CD ratio of the endotracheal tubes used in this study were shown in Table 4. The different breeds of dogs that were enrolled in this study were presented in Table 5. All tracheas were determined to be normal based on thoracic radiographs.

There was no resistance to endotracheal tube insertion through the trachea in 37/51 (72.5%) dogs while mild resistance was noted in 14/51 (27.5%) dogs. Intubation was performed in sternal recumbency in 47 dogs while the remaining four dogs were intubated in right lateral recumbency. The final body position prior to the surgical or diagnostic procedures was as follows: dorsal recumbency in 27 dogs, sternal recumbency in 18 dogs, and left lateral recumbency in six dogs. Twelve dogs (23.5%) needed to be re-intubated with a 0.5 mm larger endotracheal tube while one dog (2%) needed to be intubated with a 0.5 mm smaller endotracheal tube. No complications related to endotracheal intubation were observed in all dogs after completion of the experiment.

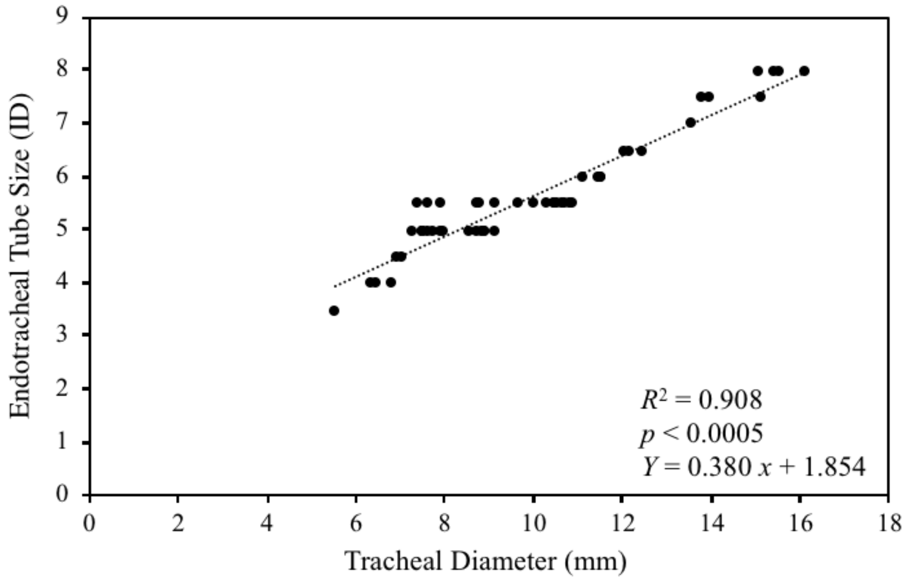
There was a significant correlation between bodyweight and TD, ETS, and CD (R^2 = 0.536, $p < 0.0005$; R^2 = 0.565, $p < 0.0005$; R^2 = 0.584, $p < 0.0005$), as well as between the percentage of TD and TD, ETS, and CD (R^2 = 0.718, $p < 0.0005$; R^2 = 0.483, $p < 0.0005$; R^2 = 0.504, $p < 0.0005$), but the linear relationships were not very high. No correlation was found between TD, ETS, CD and age, breed and BCS ($R^2 < 0.1$; $p > 0.05$). The linear relationships between ETS and TD (R^2 = 0.908), CD and TD (R^2 = 0.905) were very high (Fig. 4). The formulae for these regression lines were as follows: ETS = 1.854 + (0.380 x TD) and CD = -0.292 + (1.702 x TD). There was an inverse relationship between TD and the percentage of TD used to select ETS (Fig. 5). When the patients were grouped according to the percentage of TD used to select ETS, the percentage of TD used increased as TD decreased (Table 6). *Post hoc* analysis revealed statistically significant differences in TD between the 65–70% and 75–80% (p = 0.014), 65–70% and 85–90% (p = 0.0005), and 65–70% and 95–100% (p = 0.0005) groups, but not between any other group combinations. The mean TD and ETS as well as the range of ETS used in patients with BCS 4–5/9 that were grouped according to bodyweight were shown in Table 7. Statistically significant differences in ETS were found between the ≤ 3 kg and 10–20 kg (p = 0.002), ≤ 3 kg and > 20 kg (p = 0.002), and 3–5 kg and > 20 kg (p = 0.038) groups. Although the mean TD and ETS increased as bodyweight increased, there was overlap in the range of ETS used.

Table 4. Internal diameter (ID), outer diameter (OD), cuff diameter (CD) and the OD:CD ratio for the RUSCH super safety clear endotracheal tubes

ID (mm)	OD (mm)	CD (mm)	OD:CD ratio
2.5	4.0	8.0	1: 2.0
3.0	5.0	8.0	1: 1.6
3.5	5.3	8.0	1: 1.5
4.0	6.0	10.5	1: 1.8
4.5	6.3	10.5	1: 1.7
5.0	6.7	13.0	1: 1.9
5.5	7.3	16.5	1: 2.3
6.0	8.0	18.5	1: 2.3
6.5	8.7	20.5	1: 2.4
7.0	9.3	24.0	1: 2.6
7.5	10.0	26.0	1: 2.6
8.0	10.7	26.0	1: 2.4
8.5	11.3	28.0	1: 2.5
9.0	12.0	28.0	1: 2.3
9.5	12.7	29.0	1: 2.3
10.0	13.3	29.0	1: 2.2

Table 5. Breeds of dogs enrolled in the study

Breed	No. of cases
Maltese	8
Poodle	7
Mix	6
Schnauzer	5
Cocker Spaniel	4
Dachshund	4
Shih-tzu	4
Pomeranian	2
Pekingese	2
Labrador Retriever	1
Golden Retriever	1
Shar-pei	1
Jindo dog	1
Beagle	1
French Bulldog	1
Scottish Terrier	1
Bichon Frisé	1
Chihuahua	1



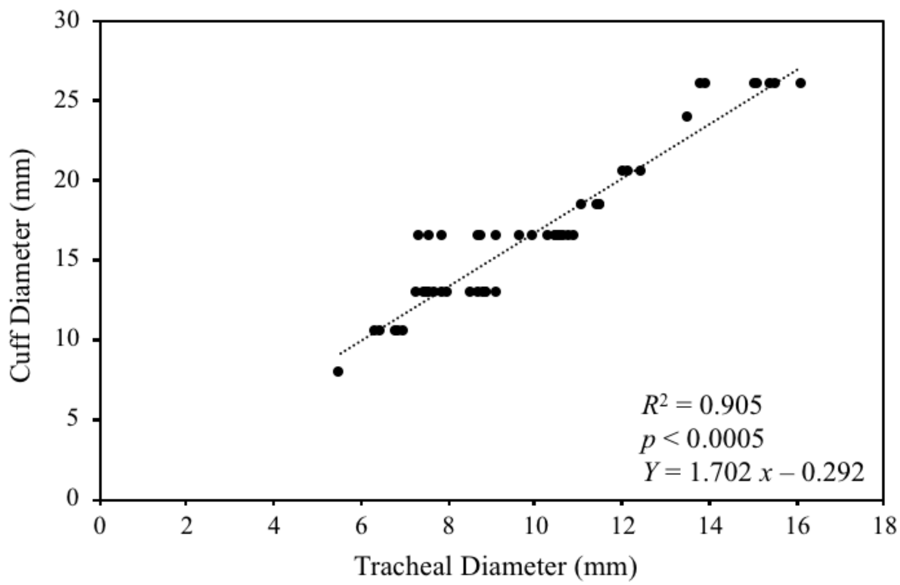


Fig. 4. Linear regression plots comparing the internal diameter of the endotracheal tube size and the endotracheal tube cuff diameter with the internal tracheal diameter measured from a lateral thoracic radiographic (n = 51 dogs).

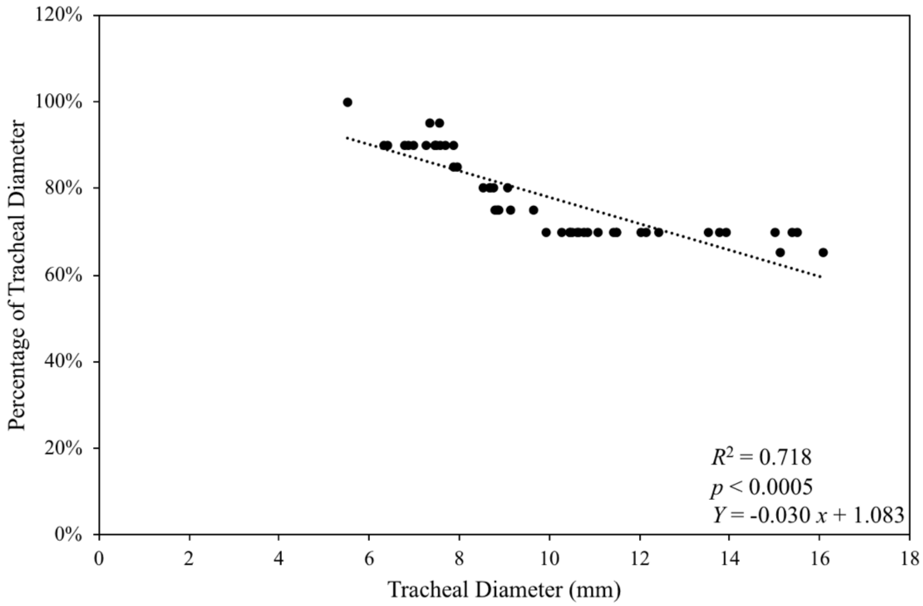


Fig. 5. Linear regression plot comparing the percentage of the internal tracheal diameter used to select the appropriate endotracheal tube size with the internal tracheal diameter measured from a lateral thoracic radiograph (n = 51 dogs).

Table 6. Data on the internal tracheal diameter (TD) and the range of TD according to the percentage of TD used to select the appropriate endotracheal tube size for dogs enrolled in the study

Percentage of TD	No. of cases	Internal TD (mm)	Range of TD (mm)
65–70	24	12.30 ± 1.97	9.96 – 16.10
75–80	10	8.92 ± 0.32*	8.55 – 9.66
85–90	14	7.30 ± 0.53*	6.33 – 7.97
95–100	3	6.82 ± 1.13*	5.53 – 7.58

*Significant difference from the 65–70% group ($p < 0.05$).

Table 7. Data on the internal tracheal diameter (TD), internal diameter (ID) of endotracheal tube size (ETS), and the range of ETS according to the bodyweight of patients with a body condition score of 4–5/9

Bodyweight (kg)	No. of cases	TD (mm)	ETS (ID)	Range of ETS (ID)
≤ 3	5	7.29 ± 1.04	4.5 ± 0.5	4.0 – 5.0
3 – 5	10	8.24 ± 1.17	5.0 ± 0.5	5.0 – 6.0
5 – 10	8	9.61 ± 1.35	5.5 ± 0.5	4.5 – 5.5
10 – 20	6	12.29 ± 2.53	6.5 ± 1.0*	5.5 – 8.0
> 20	3	14.41 ± 0.96	7.5 ± 0.5*†	7.5 – 8.0

*Significant difference from the ≤ 3 kg group ($p < 0.05$). †Significant difference from the 3–5 kg group ($p < 0.05$).

Discussion

The aims of this study were 1) to determine whether the internal tracheal diameter (TD) measured on a lateral thoracic radiographic image could be used to determine the appropriate endotracheal tube size (ETS) in different breeds of dogs, and 2) to determine whether the previous recommendation of using '70% of the internal TD' applies to all sizes of dogs. The results of this study showed that this method can be applied to different breeds of dogs, but the percentage of the measured internal TD required to select the appropriate ETS is greater for dogs with smaller TDs. In other words, there is an inverse relationship between the measured internal TD and the percentage of TD used to determine ETS.

Appropriate ETS selection is not only important to effectively administer inhalant anesthesia and provide positive pressure ventilation, but it is also essential to prevent aspiration of fluids and damage to the tracheal mucosa (Thomas and Lerche, 2011; Muir *et al*, 2013a). Various methods are used in clinical practice to select the appropriate ETS in dogs. Direct palpation of the trachea immediately cranial to the thoracic inlet and measurement of the nasal septal width are commonly used methods, but a study by Lish *et al*. (2008) revealed that these methods have low accuracy (46% and 21%, respectively). Lean bodyweight has been used as a guide to select ETS but large individual variations in the TD of dogs can make it difficult for inexperienced veterinarians to select the optimal ETS solely based on bodyweight. In the previous study, the authors devised a method to select appropriately sized endotracheal tubes based on internal TD measurements taken from a lateral thoracic radiographic image (Shin *et al*, 2018). That study revealed that thoracic radiography may be an objective method to select appropriately sized endotracheal tubes in dogs. The results of the present study showed that both bodyweight and the TD measured from thoracic radiography statistically significantly ($p < 0.0005$) predicted ETS. However, the relationship between TD and ETS ($R^2 = 0.908$) was stronger than that between bodyweight and ETS ($R^2 = 0.565$). This suggests that TD measured from thoracic radiography is a greater predictor of ETS than bodyweight. Moreover, this study showed a 25.5% re-intubation rate, suggesting that this method may have greater accuracy (74.5%) in choosing the optimal ETS compared to direct tracheal palpation and nasal septal width.

In the previous study, it was determined that using 70% of the internal TD was suitable for selecting the appropriate ETS in dogs. However, because the previous research was performed with only one breed, it was unclear whether these results could be extrapolated to other breeds. Therefore, this clinical study was performed to further investigate these results. The present study revealed an inverse relationship between TD and the percentage of TD required to determine the appropriate ETS in dogs. When patients were divided into four groups according to the percentage of TD used to select ETS, all three groups showed a statistically significant decrease in TD compared to the 65–70% group. There are two possible explanations for these findings. The first is the endotracheal tube OD/CD ratio. The endotracheal tube used in this study was the RUSCH super safety clear. As shown in Table 1, the cuff diameter/size does not increase proportionally with increasing tube sizes. Relative to the OD of the endotracheal tubes, the CD of smaller sized tubes is smaller than that of larger tubes. In other words, the OD/CD ratio is greater for larger sized tubes, and as a result, they retain the potential to achieve a seal with the trachea even when smaller percentages of the TD are used to select ETS. In contrast, larger percentages of the TD would be required for smaller tracheas because the cuffs of smaller tubes have less capacity to fill the circumference of the tracheal required to attain an adequate seal at recommended intracuff pressures of 20–25 mmHg. The second explanation is the magnification factor involved with radiographs. In the previous study by Shin *et al*. (2018), a magnification factor of approximately 9% was obtained in Beagle dogs by placing a calibration ball at the level of the trachea when the thoracic radiographs were obtained; therefore, approximately 90% of the measured internal TD was thought to represent the actual internal TD. Although magnification factors were not determined in this study, one can predict that smaller sized dogs would have a smaller magnification factor than medium/large dogs or may even have minimal magnification such that the measured internal TD may actually represent the true diameter. If so, smaller dogs would need greater percentages of the measured internal TD to select an appropriate ETS. However, future studies investigating the effect of magnification factor on ETS selection are warranted.

Endotracheal tube cuffs not only provide an adequate seal for positive pressure ventilation, but they also prevent the distal tip from injuring the mucosal lining and protect the airway by preventing secretions from being aspirated into the lungs (Verma, 2006; Volsko *et al*, 2016). In human medicine, it is recommended that the CD at residual volume be at least equal to the internal diameter of the trachea so that minimum infoldings form on the cuff when inflated to occlusion (Mehta, 1982; Dorsch and Dorsch, 2008). Cuffs that are smaller than the internal TD will need higher cuff pressures to attain a seal, which will increase the pressure exerted on the tracheal mucosa, while cuffs that are too large in relation to the TD will be more difficult to insert (increased resistance to insertion) and will have folds even when inflated to occlusion, thereby increasing the risk of aspiration along these folds (Dorsch and Dorsch, 2008). In veterinary medicine, endotracheal tubes are often chosen based on the OD or ID of the endotracheal tubes themselves. In the present study, the internal TD measured from thoracic radiography correlated well with CD ($p < 0.0005$; $R^2 = 0.905$), suggesting that the CD required for the patient can be predicted using the internal TD. However, this study did not investigate the minimum CD required to achieve an adequate seal with minimal cuff infoldings, and only studied one type of endotracheal tube cuff. Therefore, future studies investigating the feasibility of the proposed formula for other types of endotracheal tube cuffs as wells as future studies focusing on the minimum CD required to attain an adequate seal at recommended intracuff pressures (20–25 mmHg) are necessary. Nevertheless, the CD of endotracheal tubes should also be considered when choosing the appropriate ETS.

Several veterinary textbooks have provided guides to appropriate ETS selection in dogs based on approximate lean bodyweight (Muir *et al* 2013b; Hughes 2016). In the present study, patients with a normal BCS of 4–5/9 were divided into five groups according to bodyweight and the mean tube size ± SD was rounded so that ETS suitable for small animal practice could be suggested. The ETS used in this study were overall smaller than those suggested by Muir *et al*. (2013b), but similar to the sizes provided in the guide by Hughes (2016). Because the 'appropriate fit' of the endotracheal tubes was assessed using two factors (the resistance to endotracheal tube passage through the trachea and the ability of the endotracheal tube cuff to attain a proper seal when inflated to recommended pressures of 20–25 mmHg), these results may be used as a guideline to predict the appropriate ETS based on bodyweight. However, due to the small overall sample size (n = 32) and the unequal sample size between groups, especially in the >20 kg group (n = 3), it is uncertain whether these results can accurately predict the 'best fit' ETS in the clinical setting for all ranges of bodyweight. Therefore, future studies with larger sample sizes are required to assess the reliability of the results found in this study. Nevertheless, the results of this study may be used to provide evidence to support the ETS guidelines suggested by Hughes (2016).

This study had several limitations. The first limitation was that only one type of endotracheal tube was used. Cuff thickness, shape and diameter are not the same for all endotracheal tubes. Because the characteristics of the cuff can affect the resistance to endotracheal tube insertion through the trachea as well as the cuff's ability to attain an adequate seal at appropriate intracuff pressures, future studies are required to determine whether the results of this study can be extrapolated to different types of endotracheal tubes. The second limitation was the relatively small number of large and giant breed dogs included in this study. This can make it difficult to provide adequate representation for drawing conclusions from the results, and the characteristics of the overrepresented group may skew the results. Greater diversity and greater sample sizes would have provided more accurate and reliable results. The third limitation was that the resistance to endotracheal tube insertion through the trachea was scored by different people, which may have compromised the objectivity of the results. However, in order to compensate for the subjectivity of resistance scoring in this study, the authors tried to increase the objectiveness of other factors, such as only one investigator (SK) performing the measurements of the internal TD and the air leak pressure tests being performed only by experienced veterinary anesthesiologists.

Conclusions

In conclusion, the results of this study suggested that the internal TD measured from a lateral thoracic radiographic image was a reliable technique to select the appropriate ETS in dogs. When considering the percentage of the TD needed to choose the 'best fit' endotracheal tube, greater percentages were required for smaller TDs. This method may be useful for patients that have previously taken thoracic radiographs, either as part of the preoperative examination or for other diagnostic reasons.

GENERAL CONCLUSIONS

This study was designed to develop and evaluate a method to determine the appropriate endotracheal tube size in dogs using thoracic radiography.

In chapter I, it was determined that measuring the internal tracheal diameter at the thoracic inlet of a right lateral thoracic radiograph was useful for selecting the appropriate endotracheal tube size in Beagle dogs. Using 70% of the measured internal tracheal diameter to determine the optimal endotracheal tube size was suitable for Beagle dogs. Larger percentages resulted in high resistance to tube insertion through the trachea while smaller percentages resulted in an inadequate seal between the cuff and trachea.

In chapter II, changes in endotracheal tube intracuff pressure over time was studied in an *in vitro* setting while both changes in intracuff pressure and air leak pressure were investigated in anesthetized dogs. Significant decreases in intracuff pressures were observed over time in both the *in vitro* and *in vivo* studies. Although air leak pressure may not change over time, there is a higher risk for silent aspiration when intracuff pressures decrease to less than 18 mmHg. Therefore, this study supports the need for additional monitoring of intracuff pressures and air leak pressures, especially 10 minutes after the onset of anesthesia.

In chapter III, it was determined that the correlation between endotracheal tube size and the tracheal diameter measured from a lateral thoracic radiograph was greater than the correlation between endotracheal tube size and bodyweight, suggesting that the internal tracheal diameter was a better predictor of the appropriate endotracheal tube size in dogs. Larger percentages of the internal tracheal diameter were needed to select the optimal endotracheal tube size for dogs that had smaller tracheal diameters.

The present study demonstrated that the internal tracheal diameter measured from a lateral thoracic radiographic image is a reliable and useful method for choosing the optimal endotracheal tube size in dogs. This method may be beneficial for dogs that have formerly taken thoracic radiographic images, either for screening or diagnostic purposes. Moreover, additional monitoring of intracuff pressure and air leak pressure is recommended.

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국 문 초 록

흉부 방사선 촬영을 이용한 개의 기관내 튜브 크기 결정 방법의 평가

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본 연구의 목적은 1) 흉부 방사선 사진을 이용하여 개에서 최적의 기관내 튜브 크기를 선택하는 방법을 개발하고, 2) 적절한 크기의 기관내 튜브를 이용하여 삽관시 시간에 따른 커프 내압 및 공기 누출 압력의 변화를 관찰하고, 3) 실제 임상에서 새롭게 개발한 방법의 신뢰성 및 유용성을 평가하는 것이다.

제 1 장에서는 비글견에서 흉부 방사선 검사를 실시하여 흉곽 입구에서의 기관 직경을 측정한 후, 직경의 60, 70, 80%의 외경을 가진

기관내 튜브 크기를 선택하였다. 기관내 튜브의 삽관 시 느껴지는 저항감과 커프와 기관점막 사이의 공간을 차단하여 흡인을 방지하는 역할을 고려할 때, 비글견에서는 흉부방사선 기관 직경의 70%에 해당하는 외경을 가진 기관내 튜브를 선택하는 것이 적합함을 확인하였다.

제 2 장에서는 마취된 비글견에서 시간에 따른 기관내 튜브의 커프 내압 및 공기 누출 압력의 변화를 평가하였다. Part I 에서는 *in vitro* 상에서 8 개의 기관내 튜브를 다음과 같이 4 개의 그룹으로 분류하여 1 시간 동안 커프 내압을 기록하였다: 실온에서 윤활제 바르지 않은 그룹 (RTWOL), 실온에서 윤활제 바른 그룹 (RTWL), 체온에서 윤활제 바르지 않은 그룹 (BTWOL), 체온에서 윤활제 바른 그룹 (BTWL). Part II 에서는 9 마리 비글견에서 적절한 크기의 기관내 튜브로 삽관 후, 커프 내압과 공기 누출 압력의 변화를 측정하였다. Part I 에서는 RTWOL 과 RTWL 그룹, 그리고 BTWOL 과 BTWL 그룹에서 커프 내압의 유의적인 변화가 확인되었다. Part II 에서는 모든 개체에서 커프 내압은 시간이 지남에 따라 유의적으로 감소하였고, 공기 누출 압력은 개체에 따라 유의적인 변화가 확인되었다. 커프 내압의 감소는 커프의 탄력성, 윤활제의 사용, 그리고 마취로 인한 근육이완에 의한 것임을 확인하였다.

제 3 장에서는 51 마리의 개에서 흉부 방사선 사진을 이용하여 적절한 기관내 튜브 크기를 선택하는 방법의 신뢰성 및 유용성을

평가하였다. 각 개체의 기관 직경과 기관내 튜브 크기의 상관관계를 확인하였을 때, 기관 직경과 기관내 튜브의 크기, 기관 직경과 기관내 튜브 커프의 직경 사이에 유의적인 상관 관계를 확인하였다.

본 연구들의 결과를 통하여, 흉부 방사선 사진을 이용하여 기관 직경을 측정하는 방법은 개에서 적절한 기관내 튜브 크기를 예측하는 데 유용하고 신뢰성이 있는 방법임을 확인하였다. 따라서 소동물 임상에서 이 방법을 통하여 더욱 정확하게 기관내 튜브를 선택할 수 있을 것으로 기대할 수 있으며, 이 방법은 기관내 튜브 크기를 선택하는 객관적인 기준법을 찾는 향후 연구에서도 활용할 수 있을 것으로 기대된다.

주요어: 기관내 튜브 크기, 흉부 방사선, 커프 내압, 공기 누출 압력, 개

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