ABSTRACT

AMANDA FARMER
The Effects of Extubation with an Inflated Versus Deflated Endotracheal Tube Cuff on Endotracheal Fluid Volume in the Dog
(Under the Direction of DR. ERIK HOFMEISTER)

An endotracheal tube (ETT) is frequently used for airway management during anesthesia, and proper inflation of the ETT cuff is critical for patient safety. Pressure of the cuff must be high enough to seal the trachea to prevent aspiration, yet low enough to avoid damaging the airway. During extubation, the ETT cuff is routinely deflated before removal to minimize trauma to the trachea and larynx. However, if there is concern about fluid remaining in the trachea, the ETT is sometimes extubated with the cuff inflated or partially inflated. Presently, there is little information regarding the potential benefits of extubation with an inflated ETT cuff. The purpose of this study was to investigate the effective protection against liquid aspiration in canines provided by the removal of inflated and deflated ETT cuffs. Sixteen female beagle cadavers were orotracheally intubated in lateral recumbency, and the ETT cuffs were inflated to a closing pressure of 20 cm H$_2$O before barium was introduced orad to the cuff. The dogs were randomly assigned to an ETT cuff extubation condition of deflated or unchanged from the original closing pressure. After extubation, the cadavers were x-rayed, and the radiographs were assessed to determine the amount of barium remaining in the trachea. It was determined that the dogs in the deflated ETT cuff group had an average of 0.9 mL more residual intratracheal contrast than dogs extubated with an inflated ETT cuff. Therefore, extubation with the cuff inflated will remove contents and will most likely prevent aspiration.

INDEX WORDS: Endotracheal Tube, Endotracheal Tube Cuff, Intubation, Extubation, Aspiration.
THE EFFECTS OF EXTUBATION WITH AN INFLATED VERSUS DEFLATED
ENDOTRACHEAL TUBE CUFF ON ENDOTRACHEAL FLUID VOLUME IN THE DOG

by

AMANDA ROSE FARMER

A Thesis Submitted to the Honors Council of the University of Georgia
in Partial Fulfillment of the Requirements for the Degree

BACHELOR OF SCIENCE
in BIOLOGY

with HIGHEST HONORS.

Athens, Georgia
2009
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by

AMANDA ROSE FARMER

Approved:

Erik Hofmeister
Dr. Erik Hofmeister
Faculty Research Mentor

Approved:

Jamie Williams
Dr. Jamie Williams
Reader

Approved:

David Williams
Dr. David S. Williams
Director, Honors Program, Foundation Fellows and Center for Undergraduate Research Opportunities

Approved:

Pamela Kleiber
Dr. Pamela B. Kleiber
Associate Director, Honors Program and Center for Undergraduate Research Opportunities
DEDICATION

This thesis is dedicated to my family for their endless love and support, and for always helping me believe that I have the ability to accomplish all of my goals. Without their encouragement, I could not have achieved the success I have thus far.
ACKNOWLEDGEMENTS

I would like to thank Dr. Erik Hofmeister providing me with the opportunity to explore my interest in clinical research, and for the support and guidance he provided throughout my undergraduate research experience. Additionally, I would like to thank Dr. Jamie Williams and Dr. Cody Laas for their time and contributions to this research. Without the help of the individuals mentioned above, this thesis would not have been possible.
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CHAPTER 1
INTRODUCTION

Orotracheal intubation with a cuffed endotracheal tube (ETT) is commonly performed in canine patients during general anesthesia.\textsuperscript{1} The ETT is inserted orotracheally into the patient between the arytenoid cartilages, and the cuff is then inflated to establish and maintain a patent airway, as well as to prevent the aspiration of fluid past the cuff. There are two types of ETT cuffs that are often used during general anesthesia: low-pressure, high-volume cuffs (LPHV) and high-pressure, low-volume cuffs (HPLV). The more recently developed LPHV cuffs are often preferred in general anesthesia because the cuff is less likely to over-distend and cause trauma to or necrosis of the tracheal wall.\textsuperscript{2} However, LPHV cuffs can be difficult to use for the intubation of small animals due to the size of the cuff, increasing the risk of trauma to the airway.\textsuperscript{3} For this reason, HPLV cuffs are sometimes used during anesthesia involving small animals.

During extubation at the end of anesthesia, the ETT cuff is routinely deflated before removal in order to reduce trauma to the trachea and the larynx.\textsuperscript{1} However, if there is concern about fluid remaining in the trachea, the ETT is sometimes removed with the cuff partially inflated to remove excess fluid.\textsuperscript{1} In current literature, there is no evidence supporting the potential benefits of removing the endotracheal tube with the cuff inflated. Previous investigations have found that removal of a laryngeal mask airway (LMA) with an inflated cuff removes more secretions than when it is removed with a deflated cuff. A LMA differs from an ETT in that the LMA sits tightly over the top of the larynx, and is not inserted into the trachea. An investigation involving human patients has shown that extraction of the LMA with the cuff inflated removes approximately 0.5 g more secretions than with the cuff deflated.\textsuperscript{4} Although the
results would most likely vary, removing an ETT with the cuff inflated should have a comparable effect. The purpose of this study was to investigate the effect of extubation with the ETT cuff inflated versus deflated on residual endotracheal fluid volume in normal canine cadavers. The hypothesis was that a fully inflated ETT cuff would more effectively remove tracheal fluid than a fully deflated ETT cuff.
Sixteen adult canine cadavers were intubated in lateral recumbency with a 9 mm cuffed PVC ET tube (Sheridan CF, Hudson RCI, Research Triangle Park, NC, USA). The cadavers used were all female beagles under 2 years of age. The dogs had been anesthetized for a separate project when they were alive, and the 9 mm ETT was determined to be a suitable fit for all the dogs used in that study. A 5 mm red rubber catheter was taped to the outside of the ETT with the tip of catheter lying just orad to cuff (Figure 1). The ETT was inserted orotracheally and positioned with the tip at the thoracic inlet by external palpation of the trachea. Each subject’s lungs were then inflated to a pressure of 20 cm H₂O. Air was added to the cuff until no audible leaking of air around the tube was evident, and the circuit pressure held constant at 20 cm H₂O.

Figure 1: HPLV endotracheal tube. High pressure, low-volume (HPLV) 9 mm endotracheal tube with 5 fr red rubber catheter attached with the tip of catheter lying just orad to cuff.
After the ETT was inserted, and the desired cuff pressure achieved, 3 mL of 60% w/v barium sulfate suspension (Liquid E-Z-Paque, E-Z-EM Canada Inc., Westbury, NY, USA) was introduced orad to the cuff via the red rubber catheter and allowed to set for 5 minutes. A single lateral thoracic radiograph of each cadaver was obtained prior to extubation to confirm the absence of contrast leakage distal to the cuff. The kVp and mAs settings were standardized at 96 and 2.8, respectively, for all lateral radiographs. Cadavers were randomly assigned to one of two groups of ETT cuff extubation pressures via lottery. In one group, the cuff was removed without deflation from the original closing pressure of 20 cm H$_2$O (Group INF) and, in the second group, the ETT cuff was completely deflated before removal (Group DEF). Orthogonal thoracic radiographs were obtained of each cadaver immediately following extubation (Figure 2, Figure 3).

**Figure 2: Extubation with cuff deflated.** Lateral cervical radiographs obtained from canine cadavers given intratracheal contrast and then extubated with the cuff deflated.
Figure 3: Extubation with cuff inflated. Lateral cervical radiograph obtained from canine cadavers given intratracheal contrast and then extubated with the cuff inflated.

In addition to the treatment dogs, a control group was created consisting of 4 female beagle cadavers under 2 years of age. Dogs in the control group were intubated in lateral recumbency with a 5 mm cuffed PVC ET tube (Sheridan CF) with the same red rubber catheter attachment as the treatment dogs. Each dog received a discrete amount of barium (1, 2, 3 or 4 mL), that was introduced orad to the cuff via the red rubber catheter and allowed to set for 5 minutes. A single lateral thoracic radiograph of each control group cadaver was obtained prior to extubation to confirm the absence of contrast leakage distal to the cuff. The ETT cuff was fully deflated and removed slowly to minimize disturbance of the contrast, and lateral thoracic radiographs of control group cadavers were obtained immediately after extubation.
Post-extubation radiographs were scored by 3 independent, blinded reviewers (1 Diplomate ACVR, 1 Diplomate ACVA, and one third year radiology resident) by two different methodologies. In the first scoring system, each reviewer simultaneously evaluated all of the treatment group radiographs. Then the reviewer ranked each cadaver from 1-16, least to most, based on relative volume of residual intratracheal contrast (See Appendix A). The second scoring system was performed by each reviewer without referring to the previously performed rank list. Reviewers compared post-extubation radiographs of each cadaver to all four control group radiographs. The scale was essentially a 41-point scale, in 0.1 mL increments, anchored at 0, 1, 2, 3, and 4 mL by the control radiographs. Each reviewer then estimated to the 0.1 mL the residual intratracheal volume of contrast after extubation based on the known volume of intratracheal contrast in the control dogs. Criteria utilized for evaluation of residual intratracheal contrast in both scoring systems was based on degree of opacity and extent of contrast distributed within the tracheal lumen. Reviewers additionally evaluated all pre-extubation radiographs to confirm an absence of contrast leaking distal to the endotracheal tube cuff. Reviewers repeated the process approximately 2 months later without referring to initial scorings.

Normality was determined using the Kolmogorov-Smirnoff test. Cadaver age and weight were evaluated by a Mann-Whitney test. Ranks were compared among groups for each observer and the observers’ combined results using the Mann Whitney U test. Intratracheal volume was compared for each observer and all observers combined using the unpaired t-test. Ranks and volume were correlated for each observer and between observers using linear regression. Fleiss Kappa was calculated for interobserver agreement by dividing the dogs for each observer into the
dogs with the lowest 8 ranks and the dogs with the highest 8 ranks to create two categories.

Reliability for the test-retest was determined using simple correlation as well as calculating the intraclass correlation coefficient (ICC) for consistency with the two-way mixed model for average measures. Significance was sent at $\alpha < 0.05$. 

CHAPTER 3
RESULTS

The dogs included in this study had a mean body weight of 10.7 kg with a standard deviation of 1.7 kg. Radiographic evaluation determined that dogs in the DEF group had significantly more intratracheal contrast than dogs in the INF group (Table 1). On visual examination of the radiographs, most of the contrast was located in the oropharynx and nasopharynx. There was significant correlation between rank score and volume estimates for all observers: Observer 1 $R^2=0.90$, Observer 2 $R^2=0.90$, and Observer 3 $R^2=0.84$, all $P<0.0001$. For comparison among evaluators for rank scores, there was significant correlation: Observer 1 versus Observer 2 $R^2=0.72$, Observer 1 versus Observer 3 $R^2=0.75$, and Observer 2 versus Observer 3 $R^2=0.77$, all $P<0.0001$. For comparison among evaluators for volumes, there was significant correlation: Observer 1 versus Observer 2 $R^2=0.80$, Observer 1 versus Observer 3 $R^2=0.75$, and Observer 2 versus Observer 3 $R^2=0.71$, all $P<0.0001$. Fleiss Kappa for agreement among evaluators was 0.875. Contrast was not identified distal to the endotracheal cuff on any of the pre-extubation radiographs.

After conducting the test-retest, there was significant correlation between original rank scores and rank scores determined during test-retest: Observer 1 $R^2=0.87$, ICC=0.96; Observer 2 $R^2=0.87$, ICC=0.96, Observer 3 $R^2=0.75$, ICC=0.93, and combined $R^2=0.83$, all $P<0.0001$. There was also a significant correlation between original volume and volume determined after the test-retest: Observer 1 $R^2=0.94$, ICC=0.99; Observer 2 $R^2=0.73$, ICC=0.92, Observer 3 $R^2=0.80$, ICC=0.94, and combined $R^2=0.86$, all $P<0.0001$. 
**Table 1: Evaluator rank and volume comparisons.** Comparison of rank and volume by three observers between dogs extubated with the endotracheal tube cuff deflated (DEF) or inflated (INF). Values are given as median for rank and mean ± standard deviation for volume.

<table>
<thead>
<tr>
<th>Observer</th>
<th>Rank (0-16)</th>
<th>Volume (mL)</th>
<th>P-value</th>
<th>Rank (0-16)</th>
<th>Volume (mL)</th>
<th>P-value</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>DEF INF P-value DEF INF P-value</td>
<td>DEF INF P-value</td>
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<tr>
<td>1</td>
<td>12.5 5 &lt;0.02</td>
<td>2.5 ± 0.8 1.0 ± 0.6 &lt;0.0008</td>
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<tr>
<td>2</td>
<td>12.5 4.5 &lt;0.02</td>
<td>1.6 ± 0.4 0.8 ± 0.6 &lt;0.007</td>
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<tr>
<td>3</td>
<td>13.5 5.5 &lt;0.005</td>
<td>1.3 ± 0.3 0.7 ± 0.5 &lt;0.009</td>
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<tr>
<td>Combined</td>
<td>13 4.5 &lt;0.0001</td>
<td>1.8 ± 0.7 0.9 ± 0.5 &lt;0.0001</td>
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CHAPTER 4
DISCUSSION

This study hypothesized that extubation with an inflated ETT cuff would more effectively remove intratracheal contrast than a fully deflated ETT cuff. The results of this study support this hypothesis, as it was determined that the dogs in the deflated ETT cuff group had an average of 0.9 mL more residual intratracheal contrast than dogs extubated with an inflated ETT cuff. Therefore, extubation with an inflated HPLV ETT cuff was an effective method for removing intratracheal fluid that could potentially lead to aspiration in canine anesthesia patients.

Oral endotracheal intubation is commonly performed in dogs, and complications are rare. However, pulmonary aspiration is a potentially serious and devastating problem that can occur during general anesthesia. Therefore, determining methods to decrease the risk of aspiration during anesthesia is of great importance. At this time, the prevalence of pulmonary aspiration during anesthesia is unknown in canine patients. In human patients, the incidence of tracheal aspiration related to intubation varies between 10 and 30%.5, 6 Pulmonary aspiration can lead to serious and potentially life-threatening inflammatory lung diseases including aspiration pneumonia.

The cuff pressure necessary to prevent aspiration in dogs during anesthesia is unknown. Previous investigations in people have shown that an intracuff pressure in the range of 25 to 30 cm H\textsubscript{2}O is necessary to prevent aspiration.7 In canine patients, there is little information regarding the correlation between intracuff pressure and lateral tracheal wall pressure. It is recommended to inflate the cuff until gas just stops leaking around the cuff with positive pressure inflation.8 This recommendation was implemented in this study. Each subject’s chest
was inflated to a pressure of 20 cm H\textsubscript{2}O, and then air was added to the cuff until no audible leaking of air around the tube was evident, and the circuit pressure no longer decreased below 20 cm H\textsubscript{2}O. This is consistent with one of the author’s clinical practice in a busy academic referral institution and was effective in this study.

Size selection of endotracheal tubes for oral-tracheal intubation in dogs has not been standardized due to variations in age, breeds, and body weights of animals. The most commonly used method for choosing the appropriate ETT size is based on the dog’s body weight, with the assumption that the dog’s tracheal diameter is directly proportional to its body mass. The accuracy of this method is highly dependent on the experience of the anesthetist. It has been found in human patients that for each 1-mm decrease in the internal diameter of the endotracheal tube, the work of breathing increases by 34% to 154%, and the airway resistance increases by 25% to 100%\textsuperscript{9,10}. Therefore, when selecting an ETT for a dog, the appropriately sized tube with the largest internal diameter possible is selected in order to minimize the work of breathing and reduce airway resistance during spontaneous ventilation. Based on this method, a 9 mm ETT was determined to be the most suitable fit for the dogs used in this study, which had a mean body weight of 10.7 kg. A smaller 5mm ETT was chosen to intubate the control dogs in order to avoid disrupting the barium during extubation while still being large enough in diameter to achieve occlusion with the cuff.

The authors’ goals when developing the scoring system were to produce an effective, convenient, simple, and repeatable method to estimate the relative volume of residual intratracheal contrast. To the authors’ knowledge, there is not a similar method described in the literature. The minimal inter- and intra-observer variability, significant correlation between rank score and volume estimates, and the significant difference seen between the DEF and INF groups
in this study support the validity of this scoring system. Computed tomography and nuclear scintigraphy are both effective imaging modalities utilized to semi-quantitatively evaluate regions of interest. However, these modalities are more expensive and less available than radiography and therefore were not used in this study. Barium suspension was ultimately chosen as the radiographic contrast agent because it is easily detected radiographically, readily available, and inexpensive. Additionally, barium suspension was chosen because of the use of cadavers instead of live subjects in this study. In live canine patients, barium sulfate has been shown to cause acute to severe aspiration pneumonia, and even a small amount of barium aspiration can be seen years later in the lung parenchyma, lung macrophages, and the tracheobronchial lymph nodes.\textsuperscript{11}

The scoring system utilized in this study proved both robust and reliable. Correlation among observers with respect to rank and volume were both excellent. The Fleiss Kappa of 0.875 is in the range considered "almost perfect agreement."\textsuperscript{12} This indicates that the inter-observer variability is minimal, suggesting that multiple independent reviewers would come to the same conclusion using this scoring system. The test-retest correlation and intraclass correlation coefficient values were all also similarly high. These results indicate that the findings are stable over time, and that the results would have been similar regardless of when the scoring was performed by the observers. Therefore, this scoring system or a similar one may be expected to perform well in other studies.

This study confirmed that extubation with an inflated HPLV ETT cuff was effective in removing intratracheal contrast. However, other potential adverse effects, mainly damage to the tracheal wall, were not assessed. The endotracheal tube cuff may damage the tracheal mucosa, and extubation with the cuff inflated may scrape along the mucosa and cause further injury.\textsuperscript{13, 14}
Therefore, orotracheal intubation should always be performed by a highly trained and experienced professional. It is also important to note that removal of the ETT with the cuff inflated decreases the amount of residual intratracheal contrast, but it does not eliminate the contrast completely; thus, it does not completely eliminate the risk of aspiration during anesthesia. Additionally, extubation of the ETT with the cuff inflated may or may not be as effective in removing biological substances of different viscosities from the trachea. The barium used as a contrast agent in this study may differ in viscosity from that of regurgitant fluid. Regurgitant fluid may behave differently than barium, and the results with regurgitant fluid may be different from that obtained with barium. The scoring system employed gave an indirect assessment of the amount of fluid that the inflated ETT cuff removed versus the fluid removed by the deflated ETT cuff. Determining a method to directly measure the residual contrast, perhaps by weight of the residual barium or utilizing a different imaging modality, could have yielded more accurate results than by the scoring system described. Further, it should be noted that fresh (euthanized 1-3 hours before the study) cadavers were used for this study instead of living dogs. For this reason, it is possible that the trachea of the cadavers may have responded differently to extubation than if the study would have utilized live subjects. This is unlikely; however, because it has been found that 24 hours of postmortem changes at room temperature introduced minimal changes on the viscoelastic shear properties of the canine respiratory mucosa.15

In conclusion, this study determined that the dogs in the deflated ETT cuff group had an average of 0.9 mL more residual intratracheal contrast than dogs extubated with an inflated ETT cuff. Thus, extubation with the cuff inflated will remove liquid contents from the proximal trachea.
APPENDIX A

TRACHEAL EXTUBATION EVALUATION FORM

Dog Number _____

**Pre-extubation:**

Is there contrast in trachea? _____
Is there contrast in oropharynx? _____
Is there contrast in nasopharynx? _____
Does contrast extend distal in cuff? _____

**Post-extubation:**

Is there contrast in trachea? _____
Is there contrast in oropharynx? _____
Is there contrast in nasopharynx? _____

Rank number (1-15) of intra-tracheal contrast (1-with least, 15-with most). _____
Or (which ever we decide)
Group rank (1-4, 1 is 25% with least amount of contrast, etc.): _____
(This is based on subjective evaluation of all images simultaneously and comparing opacity and distribution.)

How much residual contrast do you think is in the **trachea**? Circle a hash mark. (This is based on comparison to control images.)

<table>
<thead>
<tr>
<th>No contrast</th>
<th>1 ml</th>
<th>2ml</th>
<th>3ml</th>
<th>4ml</th>
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WORKS CITED


