Original Study

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Indication, management, and outcome of brachycephalic dogs requiring mechanical ventilation

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Abstract

Objectives – To evaluate the frequency, and need for mechanical ventilation (MV) in a population of brachycephalic dogs (BD) compared with non-BD. Also, to describe the pre-MV abnormalities, ventilator settings used, the cardiovascular and pulmonary monitoring results and complications encountered in the same BD population. In addition, we sought to identify factors associated with successful weaning and describe outcomes of BD requiring MV.
Design – Retrospective observational study (1990–2008).
Setting – University Small Animal Teaching Hospital.
Animals – Fifteen BD managed with MV.
Interventions – None.
Measurements and Main Results – Signalment, indication for MV, ventilator settings, arterial blood gas values, duration of MV, complications, and outcome were recorded for each patient enrolled in study. BD were more likely to receive MV than non-BD ($P = 0.036$). Out of the 15 dogs that fulfilled the inclusion criteria 7 (47%) underwent MV for impending respiratory fatigue, 6 (40%) for hypoxemia and 2 for hypercapnea. The most common underlying disease was aspiration pneumonia. Duration of MV ranged from 2 to 240 hours (median 15 hours). Seven patients were weaned (47%). Seven dogs had a temporary tracheostomy tube and 5 of them (71%) were weaned. Dogs that were weaned had a significantly greater preweaning trial PaO_2/FiO_2 ratio than those that were not (359 ± 92 versus 210 ± 57 mm Hg, $P = 0.025$). No significant difference for weaning success between dogs with and those without a tracheostomy was detected ($P = 0.132$). The discharge rate was 27% (all from the respiratory fatigue group).
Conclusion – Among all dogs admitted to ICU, BD were more likely to receive MV than non-BD. Aspiration pneumonia was frequently identified as the underlying cause of respiratory compromise. The survival rate for BD undergoing MV was not markedly different from previous studies. Weaning of BD from MV may be facilitated by employing preemptive strategies such as performing tracheostomy tube placements.

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Keywords: canine, positive pressure ventilation, temporary tracheostomy

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Introduction

Brachycephalic dogs (BD) have skulls that are as long as they are wide. Their popularity as a pet, combined with congenital anomalies, may have exacerbated their unique conformational characteristics and made them prone to upper airway disease,[1] also known as 'brachycephalic syndrome' (BS). BS is a well-described condition in which affected dogs have narrowed nostrils (in 58.1–84.9% of BD[2,3]), an elongated and thickened soft palate (87.1–96%[2,3]), everted laryngeal saccules (54.8–58.1%[2,3]), and a hypoplastic trachea[4] (38.2–46%[2,3]). As BD share the same anatomical derangements with people suffering from the sleep apnea syndrome, English Bulldogs have been used as a spontaneous model for research purposes in this field.[5] Several studies have demonstrated laryngeal and pharyngeal dysfunction in this breed that makes them more prone to upper airway collapse, especially during sleep.[6–9] In addition, the increased negative intrathoracic pressure may predispose these animals to gastroesophageal reflux, vomiting, or regurgitation, which increase the risk of aspiration pneumonia and its associated complications.[3,10] The culmination of these conformational abnormalities, explains why dyspnea is such a common presenting complaint in these breeds of dogs.[2]

In the critical care setting, mechanical ventilation (MV) is considered the therapy of choice when a patient is unable to oxygenate or ventilate adequately and medical management has failed.[11–18] Animals with impending respiratory fatigue, but normal or unobtainable oxygenation and ventilation parameters, may also benefit from MV.[19] It is commonly recognized that MV in veterinary patients is not a benign procedure. MV is associated with potential complications (eg, pneumonia, cardiovascular impairment, ventilator-induced lung injury, corneal, or oral ulcerations) and requires very meticulous management. The likelihood of patient survival and discharge is closely related with the indication for MV, for example, inadequate oxygenation or ventilation. Previous studies in dogs and cats have demonstrated discharge rates of 22% for those with severe pulmonary disease/hypoxemia and 39–57% for those animals with primary hypoventilation that requires MV.[12,13]

Similar to the perceived risks associated with general anesthesia in BD,[20] it is plausible that the risk of MV is greater for BD compared with other breeds. This might be due to several reasons: first, their upper airways may be edematous (from hyperpnea-induced trauma) and their soft palate elongated, making intubation and weaning more difficult. Second, the laryngeal flaccidity could be worsened by anesthesia, making extubation and weaning more challenging. The presence of a hypoplastic trachea and increased respiratory secretions might also increase the risk for airway obstruction and prolong the resolution of pneumonia. Finally, acute upper airway obstruction increases negative pressure in the chest during inspiration and promotes interstitial edema (often referred to as negative pressure pulmonary edema or noncardiogenic edema).[21] Little is known about the chronic consequences of this phenomenon on the anatomy and physiology of the lower airways.[22–24] This could mandate more aggressive ventilator settings and make weaning more difficult.

The objectives of this study were to describe the indications for MV, the pre-MV abnormalities (eg, clinical, laboratory findings, diagnostic imaging diagnosis, when available), anesthetic protocols used, ventilator settings, cardiovascular and pulmonary monitoring results and complications encountered in a population of BD. Finally, we aimed to identify factors associated with successful weaning from MV and determine outcomes in BD that received MV.

Materials and Methods

Medical records were searched to identify dogs that received MV in the ICU between 1990 and 2008 by searching for the billing code associated with setting up the MV system. Of those, data from only BD (ie, French and English Bulldogs, Pugs, and Boston Terriers) were analyzed. Inclusion was limited to those breeds because in 2 studies[3,10] French bulldogs, English bulldogs, and Pugs represented 92% of dogs presented for upper respiratory tract disease. In another study,[2] French Bulldogs, English Bulldogs, and Boston Terriers represented 77% of dogs that presented for surgical correction of their BS. A standardized spreadsheet was used to record signalment, history of previous airway surgery, indication for MV (severe hypoxemia – defined as $PaO_2 < 60$ mm Hg or $SpO_2 < 90\%$ despite a fraction of inspired oxygen, FiO_2, $> 60\%$ – severe hypercapnea – defined as $PaCO_2 > 60$ mm Hg[12] and impending respiratory fatigue-based on clinical judgment or absence of blood gases/SpO_2), clinical findings and laboratory results within 4 hours before MV, diagnostic imaging diagnosis, results of bacterial culture obtained from the lower airways, sedation, or anesthesia protocols (including orotracheal or tracheostomy tube sizes), additional medical therapy administered, duration of MV, complications and outcome for each patient. Ventilator settings, arterial blood gases (temperature corrected), arterial blood pressures measurements (direct or indirect oscillometry), pulse oximetry recordings, and end-tidal CO_2 measurements were also recorded and presented as the average over the first 6 hours of MV (dogs who were on MV for < 6 hours were excluded from this section) and over the entire course of MV. The number of measurements reported represents the number of available measurements for the given parameters. All medications administered during the course of MV were gathered from the records. Only the most commonly used drugs were reported. Necropsy results were also recorded when available.

Statistical analysis

For all noncategorical data, data sets were evaluated for normality using the Shapiro-Wilk test. For normally distributed data, mean ± standard deviation is reported. For nonparametric data, median and range is reported. The Fisher exact test was used to examine whether tracheostomy was associated with MV weaning success or failure. One-way ANOVA on ranks was used to examine whether the observed duration of MV differed depending on the indication for placing the patient on MV (ie, hypoxemia, hypercapnia, or fatigue). Chi-square testing was used to determine whether BD presenting to our institution were more likely to receive MV as compared with nonbrachycepahlic breeds during the study period. Student's *t*-test was used to determine if there was a significant difference in the final, preweaning trial PaO_2/FiO_2 ratio in dogs successfully weaned versus those who were not. *P* values of 0.05 were considered significant in all cases.

Results

Population description

During the study period, 13,356 dogs were admitted to the ICU at our institution, 546 of which were identified as brachycephalic. A total of 360 dogs were placed on MV during this time period, 23 of which were identified as brachycephalic. BD in our ICU during this period were more likely to receive MV than non-BD ($P = 0.036$). Eight of the 23 BD that received MV were excluded from the subsequent analyses because their medical records were missing or the sheet reporting ventilator settings and monitoring results (eg, blood gases measurements, pulse oximetry, arterial blood pressure, and end tidal CO_2) was missing. Fifteen dogs subsequently fulfilled the inclusion criteria (the population description is summarized in Table 1): 6 Pugs (40%), 5 English Bulldogs (33%), 3 French Bulldogs (20%), and 1 Boston Terrier (7%). The mean age was 67 ± 42 months. The population included 1 intact female (6%), 7 spayed females (47%), 4 intact males (27%), and 3 castrated males (20%). The median body weight was 12.2 kg (6.4–33 kg). The median body condition score was 4 (3–5) out of 5. Three of the patients had surgical correction of abnormalities associated with their BS at least more than 15 months before undergoing MV.

Indication for MV

All study patients were admitted through the emergency department. Presenting complaints included dyspnea (7), gastrointestinal signs (eg, vomiting or diarrhea) (4), coughing (3), seizures (3), trauma (1), aspiration pneumonia (via referral) (1), and straining to urinate (1).

Six (40%) patients suffered from severe hypoxemia: 1 dog had severe pulmonary contusions and a pneumothorax, 1 had cardiogenic pulmonary edema due to severe mitral valve regurgitation and 4 had pneumonia. Two dogs (13%) were ventilated due to hypercapnea. One dog presented for seizures and was hypoventilating while another had a laryngeal foreign body with severe soft tissue swelling impeding airflow. Seven (47%) patients suffered from respiratory fatigue: 5 animals in this group received MV for pneumonia. One had both pneumonia and upper airway obstruction due to BS and the last dog suffered from both pneumonia and cardiopulmonary arrest.

Clinical findings before MV

The temperature, heart rate, and respiratory rate before initiating MV were, respectively: 37.2 ± 1.5°C (98.9 ± 2.7°F) (11 dogs), 144 ± 39/min (8 dogs), and 56 ± 22/min (9 dogs). Crackles were ausculted over the thorax in 4/9 dogs on presentation. Lungs sounds were recorded as harsh in 4/9 dogs and normal in 1 dog.

Laboratory findings pre-MV

Arterial blood gases were available for 3 patients; results are presented in Table 2. Venous blood gases were available for 5 patients and results are presented in Table 3. The mean PCV and total plasma protein were 43 ± 11% and 5.0 ± 1.5 g/dL, respectively.

Diagnostic imaging abnormalities pre-MV

Thoracic radiographs were obtained in 11 dogs before initiation of MV. The final radiographic diagnoses were bronchopneumonia (7), cardiogenic edema (1), lung abscess (1), esophageal foreign body (1), and normal chest (1). Computer-assisted tomography was performed in 1 patient and documented evidence of bronchopneumonia in addition to collapse of the thoracic trachea and mainstem bronchi.

Lower airway culture results

Bacteriological cultures from the lower airways, obtained by endotracheal wash, were submitted for 12 dogs before initiation or within the first 12 hours of MV. One dog's airway bacterial culture yielded 3 different species of bacteria and another cultured 2 different microbes. The remaining patients had a positive culture for single agents. The organisms identified included *Escherichia coli* (5), *Enterococcus sp.* (3), *Streptococcus sp.* (3), *Staphylococcus sp.* (3), multidrug resistant *Klebsiella pneumoniae* (1), *Staphylococcus sciuri* (1), and *Pseudomonas aeruginosa* (1). One dog had a negative culture while receiving cefazolin and metronidazole, as well as a second negative culture following the addition of gentamicin.

Samples were resubmitted for culture after starting MV in 5 patients and novel organisms were isolated from all samples, including: *E. coli* (1), *Acinetobacter sp.* (1), *Enterobacter cloacae* (1), *Enterococcus faecium* (1), *P. aeruginosa* (1), Methicillin-resistant *Staphylococcus aureus* (1), and another *Staphylococcus sp.* of unknown species (1).

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Table 1: Population description, sedation protocol, endotracheal intubation characteristics, duration of mechanical ventilation (MV), and outcome of brachycephalic dogs undergoing MV

	Breed	Age (months)	Body weight (kg)	Indication for MV	Induction of anesthesia*	Maintenance of anesthesia	Oro-tracheal tube size	Tracheo-stomy tube size	Duration of MV (h)	Weaned?	Outcome
Patient 1	EB	96	28	Severe hypoxemia	Diazepam Fentanyl Hydromorphone Propofol	Cistracurium Diazepam Fentanyl	11	∅	14	No	Euthanized
Patient 2	FB	40	9	Respiratory fatigue	None	Propofol	6	∅	5	Yes	Survived
Patient 3	EB	42	23	Respiratory fatigue	Diazepam Fentanyl	Fentanyl	∅	5	14	Yes	Euthanized
Patient 4	BT	48	10	Severe hypoxemia	Diazepam Oxymorphone	Pentobarbital	Unknown	∅	15	No	Died
Patient 5	P	98	11	Severe hypercapnea	Midazolam Propofol	Midazolam Propofol	5	Unknown	15	Yes	Euthanized
Patient 6	EB	38	33	Severe hypoxemia	Acepromazine Butorphanol Diazepam Oxymorphone Pentobarbital Phenobarbital	Pentobarbital	∅	Unknown	18	Yes	Euthanized
Patient 7	P	88	9	Respiratory fatigue	Diazepam Fentanyl Hydromorphone Propofol	Fentanyl Propofol	4.5	∅	20	Yes	Survived
Patient 8	P	71	8	Severe hypoxemia	Fentanyl Midazolam Propofol	Midazolam Propofol	3.5	∅	2	No	Euthanized
Patient 9	P	166	12	Severe hypoxemia	Diazepam Fentanyl Hydromorphone Ketamine Propofol	Diazepam Fentanyl Ketamine	6	∅	64	No	Euthanized
Patient 10	P	63	6	Severe hypercapnea	Diazepam Etomidate Fentanyl Midazolam Propofol	Diazepam Fentanyl Midazolam Propofol	∅	3.5	3	No	Euthanized
Patient 11	EB	133	20	Severe hypoxemia	Diazepam Fentanyl Midazolam Phenobarbital Propofol	Diazepam Fentanyl Midazolam Propofol	7	4	240	No	Euthanized
Patient 12	EB	32	30	Respiratory fatigue	Acepromazine Butorphanol Fentanyl Midazolam Phenobarbital Propofol	Butorphanol Fentanyl Midazolam Propofol	10	4	90	Yes	Survived
Patient 13	P	36	9	Respiratory fatigue	Fentanyl Midazolam Propofol	Fentanyl Midazolam Propofol	5	∅	4	No	Died
Patient 14	FB	13	12	Respiratory fatigue	Acepromazine Fentanyl Midazolam Propofol	Fentanyl Midazolam Propofol	7	5	94	Yes	Survived
Patient 15	FB	47	12	Respiratory fatigue	Propofol	Midazolam	4.5	∅	6	No	Euthanized

*Initial induction or reinduction if the patient was waking up.

Severe hypoxemia was defined as $PaO_2 < 60$ mm Hg or $SpO_2 < 90\%$ despite a fraction of inspired oxygen $> 60\%$, severe hypercapnia was defined as $PaCO_2 > 60$ mm Hg[12] and impending respiratory fatigue-based on clinical judgment or absence of blood gases/SpO_2.

EB, English Bulldog; FB, French Bulldog; BT, Boston Terrier; P, Pug; ∅, no tube of this type placed.

Table 2: Arterial blood gas measurements throughout mechanical ventilation in study brachycephalic dogs

	n	pH	$PaCO_2$ (mm Hg)	Bicarbonate (mmol/L)	Base excess (mmol/L)	PaO_2/FiO_2 (mm Hg)
Arterial blood gas for the first 6 hours of MV	7	7.34 ± 0.09	46 ± 13	24 ± 5	− 1 ± 5	254 ± 131
Arterial blood gas during MV	10	7.33 ± 0.08	42 ± 8	22 ± 5	− 4 ± 6	285 ± 119

n, number of patients; FiO2, fraction of inspired oxygen.

The dog with cardiogenic edema cultured *S. sciuri* within the first 12 hours of MV. Neither a necropsy nor airway bacteriological culture were submitted for the dog with the esophageal foreign body nor for the dog with normal thoracic radiographs. The dog with no bacterial growth initially had radiographic evidence of pneumonia, which was confirmed on necropsy.

Anesthetic protocols

On average, 4 drugs (range 0–6) were used for induction (initial induction or reinduction if the patient was waking up). The drugs used for induction and maintenance of anesthesia are presented in Table 1. The sizes of the tracheal tube (oro- or trans-tracheal) are also reported in Table 1 (if more than 1 tube size was used, only the largest size is reported).

Initial ventilator settings

Pressure-control ventilation was initially used in 7 dogs, volume-control ventilation in 3 dogs. The initial ventilator control setting was not available for the 5 remaining patients. Fifty-three percent of the patients ($n = 8$) were started with assist/control ventilation while 5 others (33%) were placed on synchronized intermittent mandatory ventilation. Continuous positive airway pressure (a spontaneous breathing mode) was initially used in 1 dog. The original mode was not available for 1 dog.

Ventilator settings and patient monitoring results for the first 6 hours

The initial settings for each patient are presented in Table 4. For the first 6 hours, the average ventilator settings are presented in Table 5 ($n = 11$ unless indicated otherwise). The mean FiO_2 and mean airway pressure were 65 ± 18% (35 measurements) and 10 ± 4 cm H_2O ($n = 10$, 31 measurements), respectively. Repeated arterial blood gas measurements were available for 7 patients (11 measurements). The mean pH, $PaCO_2$, HCO_3^-, BE, PaO_2/FiO_2 are summarized in Table 2. The systolic, mean, and diastolic blood pressures were, 122 ± 10 mm Hg ($n = 10$, 27 measurements), 85 ± 9 mm Hg ($n = 9$, 23 measurements), and 67 ± 16 mm Hg ($n = 9$, 23 measurements), respectively.

Table 3: Venous blood gas measurements before mechanical ventilation (MV) in study brachycephalic dogs

	n	pH	$PvCO_2$ (mm Hg)	Bicarbonate (mmol/L)	Base excess (mmol/L)	PvO_2 (mm Hg)
Venous blood gas before MV	5	7.23 ± 0.05	51 ± 16	21 ± 5	− 6 ± 5	44 ± 16

n, number of patients.

Average ventilator settings and patient monitoring results

The ventilator settings were recorded in all 15 dogs and are presented in Table 6. Throughout ventilation, the $EtCO_2$ was 34 ± 14 mm Hg ($n = 13$, 210 measurements). The results of the arterial blood gas measurements are presented in Table 2 ($n = 10$, 146 measurements total). The systolic, mean, and diastolic blood pressures were 117 ± 37 mm Hg ($n = 13$, 243 measurements), 87 (36–107) mm Hg ($n = 11$, 238 measurements), and 66 ± 16 mm Hg ($n = 11$, 238 measurements), respectively.

Therapeutics

Fourteen dogs received IV antimicrobial therapy: ampicillin (10 dogs), enrofloxacin (7 dogs), amikacin (3 dogs), cefotaxime (3 dogs), cefazolin (2 dogs), imipenem (2 dogs), clindamycin (2 dogs), amoxicillin (1 dog), metronidazole (1 dog), ceftazidime (1 dog), ticarcillin (1 dog), chloramphenicol (1 dog), and vancomycin (1 dog). Gastrointestinal protectants (histamine-2 receptor antagonists and/or proton pump inhibitors and/or antiemetics) were used in 10 patients (67%). While all dogs received isotonic crystalloid therapy, only 8 dogs (53%) were given synthetic colloid therapy for treatment of a low colloid osmotic pressure. Seven dogs (47%) received furosemide therapy. Six patients (40%) received at least 1 dose of dexamethasone for upper airway inflammation. Parasympatholytic agents (eg, atropine or glycopyrrolate) were administered to 6 patients (40%) with profound bradycardia (ie, heart rate < 60/min). Fresh frozen plasma was used in 3 dogs (20%) for coagulopathy and vasopressors (eg, epinephrine or

Table 4: Initial ventilator settings in study brachycephalic dogs undergoing mechanical ventilation

1	Inspiratory time (s)	Total rate (breaths per minute)	PEEP ($cm\,H_2O$)	Peak pressure ($cm\,H_2O$)	Tidal volume (mL/kg)
Patient 1	1	44	6	32	8
Patient 2	1.2	44	0	17	11
Patient 3	1.1	27	3	22	Unknown
Patient 4	1.2	26	0	30	Unknown
Patient 5	1	20	6	20	16
Patient 6	Unknown	Unknown	Unknown	Unknown	Unknown
Patient 7	1.2	21	8	21	Unknown
Patient 8	1.1	19	2	18	Unknown
Patient 9	1	37	6	19	Unknown
Patient 10	0.9	25	6	20	15
Patient 11	0.8	20	5	26	9
Patient 12	1.8	15	5	23	12
Patient 13	Unknown	Unknown	Unknown	Unknown	Unknown
Patient 14	0.6	33	7	28	10
Patient 15	0.8	24	4	16	9
Mean (standard deviation)	1(0.4)	27 (12)	4 (3)	22 (5)	11 (3)
Recommended values[19]*	1	8–30	0–5	10–15	5–15

*These recommendations differ from those from the ARDSnet[35] (only for patients with acute lung injury or acute respiratory distress syndrome).
PEEP, positive end expiratory pressure.

dopamine) were used in 3 dogs (20%) with hypotension (mean arterial pressure <65 mm Hg). Two dogs (13%) received both fresh frozen plasma and vasopressor therapy for treatment of a coagulopathy and hypotension, respectively. Two dogs underwent surgical airway correction for BS during the course of MV. They underwent surgery 46 and 60 hours after initiation of MV, and were maintained on the ventilator for 240 and 90 hours, respectively. Neither of the surgeries were motivated by a failure to wean the patient off MV, although it is possible that they were performed to facilitate weaning.

Complications

The most common complications included dysrhythmias ($n = 10$), cardiac arrest ($n = 2$), and weaning failure that required a return to MV ($n = 2$). Obstruction of the airway tubing from mucous or fluid occurred in multiple patients (at least once in 8 dogs, 53%). No mouth or corneal ulcerations were recorded.

Table 5: Ventilator settings in study brachycephalic dogs during the first 6 hours of mechanical ventilation

	Ventilator settings
Inspiration time (s)	1 ± 0.35
Total rate (breaths per minute)	19 (14–38)
PEEP ($cm\,H_2O$)	5 ± 3
Peak pressure ($cm\,H_2O$)	23 ± 7
Tidal volume (mL/kg)	10 ± 2 ($n = 6$)

PEEP, positive end-expiratory pressure; *n*, number of patients for which the information was available.

Weaning and outcome

Overall, duration of MV ranged from 2 to 240 hours (median 15 hours). The median duration in the oxygenation impairment, in the ventilation impairment and in the respiratory fatigue groups were 15 (2–240), 9 (3–15), and 14 (4–94) hours, respectively. There was no significant difference detected between those 3 groups ($P = 0.616$). Seven patients were successfully weaned (47%). Of those weaned, 3 were euthanized (due to unknown reasons) and 4 (57% of weaned) survived to discharge. Dogs that were weaned had a significantly greater final, preweaning trial PaO_2/FiO_2 ratio than those that were not (359 ± 92 versus 210 ± 57 mm Hg, $P = 0.025$). Four dogs were weaned using synchronized intermittent mandatory ventilation (3 were discharged,

Table 6: Average ventilator settings in study brachycephalic dogs (BDs)

	Average ventilator settings in BDs' population	Number of measurements
Fraction of inspired oxygen (%)	48 (35–100)	238
Inspiration time (s)	1 ± 0.27	221
Total rate (breaths per minute)	18 (15–43)	232
PEEP ($cm\,H_2O$)	5 ± 3	230
Peak pressure ($cm\,H_2O$)	18 (15–31)	236
Mean pressure ($cm\,H_2O$)	10 ± 4	227
Tidal volume (mL/kg)	10 ± 3	159

PEEP, positive end expiratory pressure.

1 was euthanized), 2 with assist/control (both were euthanized) and 1 while on continuous positive airway pressure (and survived). Five dogs were on MV for $\leq$ 6 hours (4 [67%] of them died), 6 for $>$6 hours and $\leq$ 24 hours (5 [83%] of them died), and 4 for $>$24 hours (2 [50%] of them died). Out of the 11 dogs who died, 9 (82%) died within the first 24 hours (7 of them [64%] were euthanized).

Seven dogs (47%) had a temporary tracheostomy tube placed while on the ventilator (2 of those dogs received MV between 1990 and 2005, 5 of them between 2005 and 2008). Of those, 5/7 (71%) were weaned. Two of 8 (25%) orotracheally intubated dogs were weaned. Of the 4 survivors, 2 had a tracheostomy tube at the time of weaning (see Table 1). Two dogs with a tracheostomy tube during weaning underwent surgical correction of their BS while on MV. Only 1 of them was successfully weaned. There was no significant difference detected for weaning success between dogs with and those without a tracheostomy ($P = 0.132$). The overall discharge rate was 27% ($n = 4$, all from the respiratory fatigue group). Nine patients were euthanized (7 for unreported reasons, 2 for humane reasons) and 2 died.

Necropsy diagnoses

A necropsy examination was performed on 3/11 dogs that died or were euthanized. The final diagnoses were cerebellar oligodendroglioma with no sign of pneumonia (although *Staphylococcus intermedius* had been isolated from a culture of this dog's lower airways), necrotizing interstitial pneumonia and interstitial pneumonia with pulmonary thromboemboli.

Discussion

MV can be necessary for the management of respiratory failure and several studies have demonstrated successful management of veterinary patients using MV.[14–18] BD are frequently presented with respiratory distress.[2] However, the present study is the first to document that among all dogs admitted to a veterinary hospital for intensive care BD more frequently receive MV than non-BD. Although little is known about the systemic consequences of BS (especially the consequences on the lower airways and cardiovascular system), BD have been perceived by some clinicians at our institution as poor candidates for positive pressure ventilation. Despite this perception, BD were still more likely to be placed on MV than non-BD in our ICU during the study period. The number of BD to receive MV support might have been even greater if not for the perception that they do poorly on MV.

In the present study, most of the BD underwent MV for oxygenation impairment or impending respiratory fatigue. Aspiration pneumonia was the most common pathologic process, perhaps due to the high regurgitation frequency in BD.[3,10] A relationship has been identified between digestive (eg, esophageal deviation, cardial atony, gastro-esophageal and duodenogastric reflux, hiatal hernia, gastric stasis, mucosal hyperplasia, oesophagitis, duodenitis) and respiratory (upper airway noises, snoring) signs in BD, most likely secondary to chronic negative intrathoracic pressure due to upper airway obstruction.[3,10] GI signs resolved in 91% of cases following surgical correction of the BS.[10] Seventy-four percent of BD presenting with respiratory problems also had signs of moderate to severe gastrointestinal disorders (eg, vomiting, regurgitation, and ptyalism).[3] As might be expected, MV was not required because of upper airway obstruction due to BS within the study population (only 1 study dog with pneumonia was clinical for BS as well). This is most likely because dogs with mild to moderate clinical signs due to BS frequently undergo airway surgery before the need for emergent care, whereas those who are severely affected are typically managed with endotracheal intubation or a tracheostomy instead of MV. None of the dogs in this study population were placed onto MV within 24 hours of surgical correction of BS. Current guidelines advocate the use of MV in case of decreased ventilation ($PaCO_2 > 60$ mm Hg), decreased oxygenation ($PaO_2 <$ 60 mm Hg), or impending respiratory fatigue.[19] Only a small number of arterial blood gases were available before MV (see Table 2) but it appeared that impaired oxygenation or impending fatigue were more common than ventilatory failure. This might be a reflection of the high incidence of bacterial pneumonia within the study population. Although only available for 3 patients, the PaO_2/FiO_2 ratio before MV was low, reflecting severe pulmonary disease. The PaO_2/FiO_2 improved during MV (from 162 ± 50 to 296 ± 106 mm Hg). Despite the persistently low oxygenation ratio, MV appeared to be effective and beneficial for supporting those patients with oxygenation impairment. In the present study, dog that were weaned off MV had a significantly higher PaO_2/FiO_2 ratio. While successfully weaned BD had a significantly higher final PaO_2/FiO_2 ratio, the retrospective nature of the present study prevents the authors from recommending a threshold PaO_2/FiO_2 ratio that should be achieved before attempting weaning from MV.

Anesthesia for animals requiring MV can be challenging. In addition to respiratory system failure, these animals might also suffer from distant organ dysfunction (eg, cardiovascular, renal, hepatic), especially in those with conditions such as systemic inflammatory response syndrome, sepsis and multiple organ dysfunction syndrome. A combination of propofol, a benzodiazepine (midazolam or diazepam), and an opioid (fentanyl) was most commonly used for induction and maintenance in the current study. This is also the most frequently used anesthetic protocol for the patients undergoing MV at our institution, as it facilitates adequate anesthesia depth while diminishing the frequency of complications associated with each drug. The ideal anesthetic protocol enables changes in anesthetic plane according to the patient's needs: deep anesthesia is usually initially targeted, while a lighter plane of anesthesia is generally preferred during the weaning process. Anesthesia is not always required for MV (eg, animals in a comatose state),[12] but it was used in all cases in the present study. Of note, a paralyzing agent was used in only 1 patient. Paralytic agents are uncommonly used in our hospital due to the occasional incomplete reversal and partial paralysis that has been reported.[25] Additionally, the use of paralytics may mask an underlying problem that is causing patient-ventilator asynchrony.

Little is known about the influence of BS on the physiology of the lower airways. In the present study, the peak pressure in the BD appeared higher than the typical recommended value. This could be the result of the relatively small endotracheal tube diameter, but the elevated PIP in the face of normal tidal volumes could also reflect decreased lung or chest wall compliance in these patients. Static lung mechanics would be required to separate the relative contribution of airway resistance and respiratory system compliance to the seemingly high peak inspiratory pressure values reported herein. Otherwise, BD in our population did not appear to require unique ventilator settings (see Tables 4–6). The effects of upper airway obstruction on lower airway physiology still remain unknown. A decreased pulmonary compliance and increased pulmonary resistance associated with upper airway obstruction has been described in dogs.[23,24]

The mortality rate was highest within the first 24 hours in this study (82% of the death occurred within the first 24 hours). Specifically, dogs on the ventilator between 6 and 24 hours showed the highest mortality rate (45% of the total number of death). The lower mortality rate observed for those patients ventilated <6 hours (37% of the total number of death) might reflect a more responsive or less aggressive disease process. Similarly, the lower mortality rate (18%) among those that remained on MV for more than 24 hours may reflect the fact that those dogs were stable enough to remain on the ventilator for such an extended period. Furthermore, 64% of the dogs that died within the first 24 hours were euthanized. As MV is an expensive procedure, elective euthanasia may have artificially shortened the duration of MV. Because of the retrospective nature of this study, we could not differentiate humane, financial and medical euthanasia. If the patients that were euthanized had been given more time, it is impossible to know which patients might have benefited from MV and been discharged from the hospital.

Weaning is a critical part of successful MV. The decision to attempt a weaning trial is based upon several criteria,[26,27] including adequate gas exchange without the need for aggressive ventilator settings, the ability to spontaneously breathe, hemodynamic stability, absence of major organ failure, and at least partial recovery from the underlying disease process.[28] Weaning of BD might be difficult for several reasons. First, if the BS is moderate to severe at the time of intubation for MV and the airway was not surgically addressed before weaning, worsening of the airway obstruction due to endotracheal tube-induced inflammation and swelling may ensue. The use of anti-inflammatory therapy or surgical intervention might then be advocated. In this study, 5 dogs received surgical treatment for BS either before or during MV. Of those 5 dogs, 3 were successfully weaned and discharged. Second, pharyngeal muscle tone might be another important factor. Laryngeal collapse, similar to that seen with obstructive sleep apnea syndrome in people, has also been reported in clinical and experimental studies.[5,6] During sleep, the muscles that maintain the pharyngeal opening, in particular the genio- and sternohyoid muscles, suffer from decreased tone that may progressively lead to narrowing and closure of the upper airway. Once hypoxia is sensed, the peripheral chemoreflex is triggered and the animal abruptly wakes up and the muscles briefly and strongly contract.[7,8] This change in tone leads to inflammation and fibrosis, which in turn further diminishes the ability of the muscle to maintain upper airway patency. This has been documented with histology and MRI examinations.[7,8] With time, BD are likely to suffer from flaccidity of their upper airways, which might be worsened during anesthesia for MV. The placement of a temporary tracheostomy tube did not seem to improve likelihood of weaning in the present study. Because of the small number of patients enrolled it is difficult to conclude definitively whether or not temporary tracheostomy increases MV weaning success rates in BD as the present study was insufficiently powered to detect small differences. However, because temporary tracheostomy bypasses the larynx and pharynx while the animal is waking up from general anesthesia, a larger study might be necessary to quantify weaning failures due to partial upper airway obstruction in patients in which tracheostomy had been performed. In the present study, 71% of patients with a tracheostomy tube were weaned. Most of the tracheostomy tubes (5/7) were placed in the last 3 years of the study period. This is potentially a reflection of the increased perceived benefit of this procedure based on clinicians' personal observations. However, the risk of placing a temporary tracheostomy, especially in BD that commonly have a hypoplastic trachea, should also be weighed against the potential benefits of the intervention. The most serious complications of a temporary tracheostomy tube placement include stricture formation at the tube site, occlusion (by blood, secretions, or skin fold), dislodgment, secondary respiratory infections, tearing of the tracheal cartilage, damage to the recurrent laryngeal nerve provoking laryngeal paralysis, pneumothorax, and pneumomediastinum.[29,30]

Almost half of the patients (47%) received furosemide therapy. Although the reason for furosemide administration was not clear in the records, it was most likely given for fluid retention secondary to MV and opioid administration[31,32] or to treat iatrogenic volume overload with pulmonary edema.

Noticeably, no oral or corneal ulceration were reported which differs from previously reported data[33] (8% and 5%, respectively[12]). This is either due to lack of documentation in the record, early death or appropriate nursing care (eye lubrication, oral cleaning and suctioning, and frequent turning).

The discharge rate for BD undergoing MV in this study (27%, with all dogs from the impending respiratory fatigue group) approximates the previously reported rate of 22% for the general dog population.[12] This could indicate that BD do not fare worse than the rest of the canine population, but no definitive conclusion can be made due to the small study sample. Patients undergoing MV for hypoventilation were underrepresented in the current study. It is therefore difficult to comment on their outcome. In addition, the use of appropriate antimicrobial therapy (based on bacterial culture and antimicrobial susceptibility testing results) could not be assessed as the time of release of the results could not be retrieved and compared with the time of changes in antimicrobial therapy. Appropriate choice of antimicrobial has been shown to influence outcome. Our results could have been influenced if the antibiotic choice was not appropriate.

The principal limitations of this study are the small number of patients and heterogenous disease processes. Additionally, the science of MV is constantly evolving, recommendations have drastically changed over recent years[34–36] and, in the present study, dogs were included over an extended time frame. The retrospective nature of this study also made it impossible to control for any variables associated with ventilation, anesthesia, or monitoring techniques and times.

The present study is the first to document that among all dogs admitted to a veterinary hospital for intensive care, BD were more likely to receive MV than non-BD. This study has also identified that aspiration pneumonia is frequently identified in BD that receive MV. The survival rate for BD receiving MV was not found to be markedly different from previous studies. Larger, prospective studies are needed to determine if survival rates might be improved with measures such as temporary tracheostomy or preweaning surgical correction of BS. Also, further prospective studies are needed to address factors such as the optimal PaO_2/FiO_2 ratio target before weaning.

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