Nasopharyngeal Dimensions From Computed Tomography of Pugs and French Bulldogs With Brachycephalic Airway Syndrome

Dorothee Heidenreich, Gabriele Gradner, Sibylle Kneissl, and Gilles Dupré

Department of Small Animals and Horses, Clinic for Small Animal Surgery, Ophthalmology, Dentistry, Physiotherapy and Rehabilitation, University of Veterinary Medicine Vienna, Vienna, Austria

Corresponding Author
Dorothee Heidenreich
Clinic for Small Animal Surgery,
Ophthalmology, Dentistry, Physiotherapy and Rehabilitation
University of Veterinary Medicine Vienna
Veterinaerplatz 1
A-1210 Vienna
Austria
dorotheeheidenreich@hotmail.com

Submitted January 2015
Accepted July 2015

DOI:10.1111/vsu.12418

Objective: To describe the nasopharyngeal airway dimensions of two brachycephalic breeds and to localize the area of smallest airway dimensions.
Study Design: Prospective, descriptive, computed tomographic imaging study.
Animals: Thirty pugs and 30 French bulldogs with brachycephalic upper airway syndrome.
Methods: The thickness and length of the soft palate, cross-sectional area of the airway passage dorsal to the soft and hard palates, and cross-sectional area of the frontal sinus were measured and normalized to each dog's skull index and body weight before statistical comparison between breeds. Nasopharyngeal turbinates and surrounding airway space, and a possible relationship between the canine tooth angulation and the severity of airway obstruction were assessed.
Results: Pugs had significantly smaller cross-sectional areas of the airway dorsal to the soft and hard palates than French bulldogs. In both breeds, the smallest nasopharyngeal cross-sectional areas were located dorsal to the caudal end of the soft palate. The soft palate of pugs was significantly shorter than that of French bulldogs and also significantly thinner when normalized to each dog's skull index. Pugs more commonly exhibited nasopharyngeal turbinates. Pugs had significantly smaller air-filled cavities at the location of the frontal sinus. No correlation between the nasopharyngeal dimensions and canine tooth angulation was observed.
Conclusion: Computed tomographic assessment of the upper airway morphology showed the smallest nasopharyngeal cross-sectional areas were located dorsal to the caudal end of the soft palate in both breeds. Pugs had a smaller nasopharyngeal cross-sectional area despite smaller soft palate dimensions than French bulldogs.

Brachycephalic airway syndrome (BAS) is an established cause of respiratory distress in brachycephalic dog breeds.[1,2] The shortened skull bones in these breeds are not accompanied by reduction of the associated soft tissue structures, resulting in a compressed nasal passage[3] and altered pharyngeal anatomy.[4–7] The most frequently reported primary components of BAS are stenotic nares and an elongated, thickened soft palate.[8] These primary abnormalities are thought to increase the negative luminal pressure on inspiration, leading to the development of mucosal edema, everted laryngeal saccules, and laryngeal collapse.[2,9] Other BAS-associated abnormalities include a hyperplastic tongue, hypoplastic trachea, and gastrointestinal abnormalities.[10,11] One study also found that collapse of the left cranial bronchus is significantly associated with laryngeal collapse.[12] Presence of nasopharyngeal turbinates and rostral aberrant conchae has more recently been reported but the impact of these abnormalities on the development of airway obstruction in dogs with BAS is unclear.[2,13–16]

Descriptions of dog breeds affected by BAS vary because of differences among regional breed populations. The most frequently affected breeds worldwide are pugs, English bulldogs, and French bulldogs.[10–12,14,17–21] Both pugs and French bulldogs are categorized as extremely brachycephalic dogs,[22] but there are breed differences in clinical signs and skull conformation. French bulldogs frequently have gastroesophageal disease, which might be secondary to increased respiratory effort[10,11] and their soft palate dimensions were described to be greater compared to other brachycephalic dogs.[19] In contrast, pugs were frequently affected by bronchial collapse[12] and their larynx was found to be more severely collapsed compared to French bulldogs.[23] Pugs have nasopharyngeal turbinates more frequently than other brachycephalic breeds, with failure for the growth of these turbinates to stop.[7,13–14] Pugs' skull conformation is different from that of French bulldogs because of dorsal rotation of the rostral maxilla in pugs.[24–26] This is thought to be associated with a minuscule or even absent frontal sinus.[27] Whether there is a

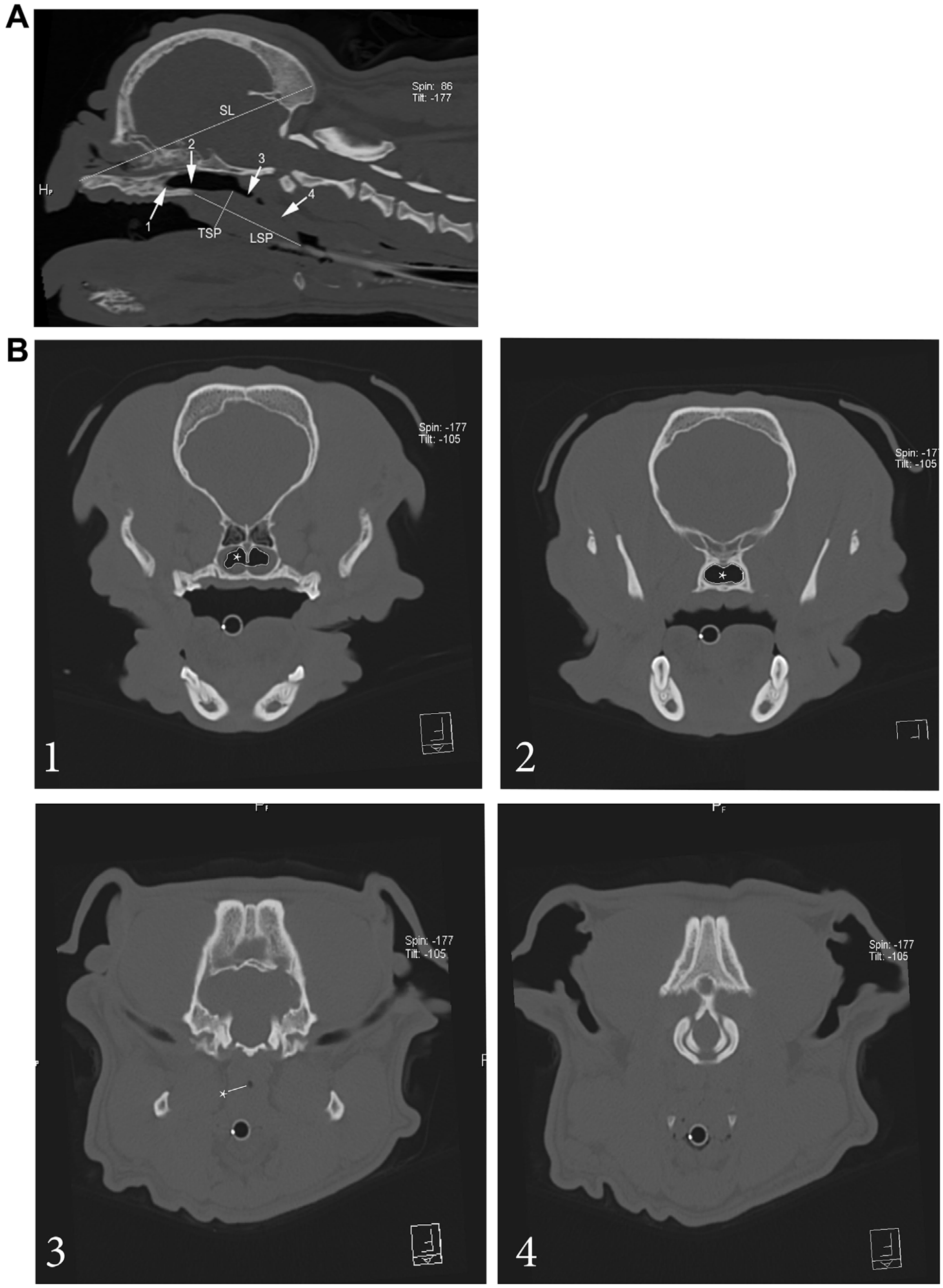

Figure 1 (A) Mid-sagittal computed tomography (CT) images of a French bulldog showing measurements of the skull length (SL), soft palate length (LSP), and soft palate thickness (TSP). The SL was measured from the prosthion to the inion to calculate the skull index[22] with the skull width (see Fig 2). The TSP was measured at its greatest distance perpendicular to the LSP. (B) Transverse CT images corresponding to the locations of the cross-sectional area measurements of the nasopharynx (*); (1) the beginning of the nasopharynx defined as the point where the nasal septum discontinues; (2) at the end of the hard palate; (3) dorsal to the soft palate at the level of the caudal border of the tympanic bulla, and (4) at its smallest dimension dorsal to the soft palate.

difference in the nasopharyngeal dimensions between these two breeds has not been described. In cats, the degree of brachycephaly was found to correlate with more horizontally positioned canine teeth.[26] This relationship has not been assessed in brachycephalic dogs.

Several diagnostic imaging modalities are used to evaluate the anatomic and dynamic changes associated with BAS, including radiography, upper airway endoscopy, and computed tomography (CT). In particular, CT allows for reformatting of the obtained data into multiplanar and 3-dimensional images.

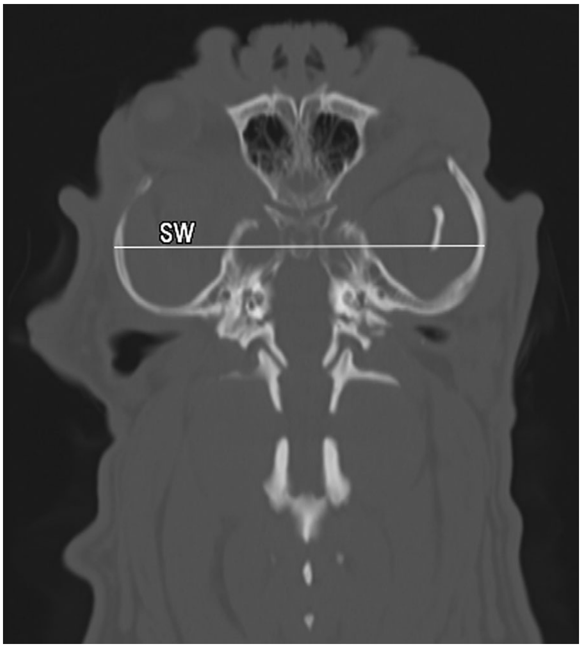

Figure 2 Dorsal computed tomography image of a French bulldog depicting the measurement of the skull width (SW), which is defined as the distance between the zygomatic arches at its widest point. The skull index (skull width × 100)/(skull length)[22] was calculated for each dog individual and used to normalize the measurements.

This provides detailed information of the entire upper airway, including the pharyngeal structures. Previous studies have suggested that such images are best evaluated with the mouth in an open position.[28] Among various head indices used to account for the different sizes of the examined dogs, the Evans skull index[22] is the most widely accepted. Only 3 studies involving CT evaluation of the upper airway anatomy in brachycephalic dogs have been published. One study focused on the anatomic structures in the nasal cavity,[14] a second reported aberrant turbinates in English bulldogs,[16] and the other evaluated the dimensions of the soft palate and nasopharyngeal meatus.[19] Neither study described the nasopharyngeal airway dimensions by comparing pugs and French bulldogs nor measured the cross-sectional area of the nasopharynx. Moreover, the size of the frontal sinus, the orientation of the canine teeth or age has not been related to the nasopharyngeal space.

This study describes and compares the morphology of the nasopharynx in pugs and French bulldogs and localizes the area of smallest airway dimensions. It was hypothesized that pugs would have smaller nasopharyngeal dimensions, more frequently have nasopharyngeal turbinates, and have smaller frontal sinuses than French bulldogs.

MATERIALS AND METHODS

A prospective CT imaging study of the upper airway morphology of 30 client-owned pugs and 30 client-owned

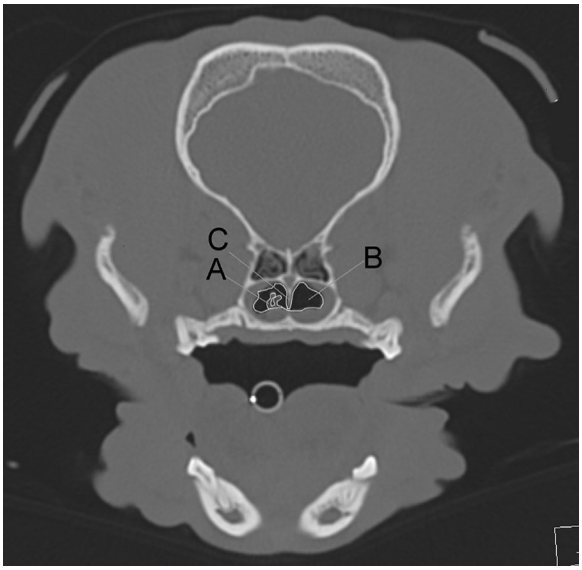

Figure 3 Transverse computed tomography image of a French bulldog with aberrant nasopharyngeal turbinates (A) at the beginning of the nasopharynx (B). The measurement of the turbinates began at the level of the end of the nasal septum (C) and extended caudally on every transverse computed tomography slice until reaching the caudal end of the turbinates. The cross-sectional area of the nasopharynx on the same slices was measured to calculate the area of the nasopharynx not occupied by the nasopharyngeal turbinates. The smallest cross-sectional area was normalized to the skull index and body weight before statistical analysis.

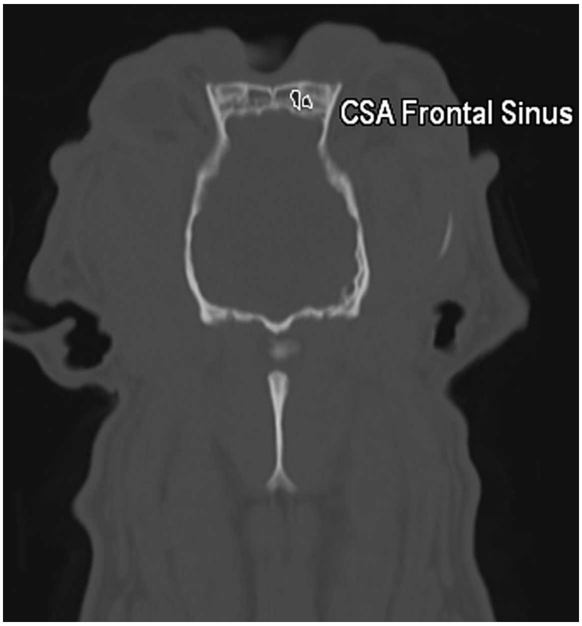

Figure 4 Dorsal computed tomography image of a French bulldog for assessment of the cross-sectional area of the frontal sinuses, which were measured on dorsal views and normalized to the skull index and body weight before statistical comparison.

Table 1 Age, Body Weight, Skull Index, Dimensions, and Angles for 30 Pugs and 30 French Bulldogs (FB)

	Body Weight (kg)	Age (Years)	Skull Index	Soft Palate Thickness (cm)	Soft Palate Length (cm)	Canine Tooth Angle (°)
Pugs	9.2 (2.4)	3.1 (1.5)	0.96 (0.03)	0.82 (0.14)	4.64 (0.11)	110.20 (0.11)
FB	12.2 (2.5)	2.5 (1.1)	0.92 (0.01)	1.17 (0.25)	5.43 (0.53)	108.58 (9.42)

French bulldogs was conducted. All dogs had clinical signs compatible with BAS and their upper airways were evaluated using a standardized CT protocol. The dogs were not related to each other and any dogs with previous surgery of the upper airway were excluded from the study. The age, body weight, and sex of all dogs were recorded. Hematology and serum biochemistry analysis was performed before general anesthesia for CT evaluation of the head and neck. The dogs were placed in sternal recumbency using a sponge to maintain the head in an extended neutral position with the hard palate parallel to the table. All dogs were intubated and the mouth was held open with the same mouth gag. A 16-slice helical CT scanner (Somatom Emotion; Siemens AG, Erlangen, Germany) was used with a gantry rotation time of 1 second, tube voltage of 120 kV, tube current of 80–120 mA, and field of view of 100–150 mm. The scan started rostral to the nose and extended to the 4th cervical vertebra. Multiplanar reformatting was performed with a slice thickness of 2–3 mm and slice reconstruction interval of 1–2 mm.

Quantitative Assessment of CT Images

Multiplanar reformatting and 3-dimensional reconstructions with bone window settings were used to produce images of the skull. Distances and angles were measured with imaging software (OsiriX, version 5.6; Pixmeo, Geneva, Switzerland) and cross-sectional areas were measured with a workstation (*syngo* MultiModality Workplace; Siemens). The same investigator (DH) made all measurements.

The skull index, calculated as (skull width × 100)/(skull length),[22] was assessed for each dog. The skull length, defined as the distance between the prosthion and inion, was measured on mid-sagittal views (Fig 1). The skull width, defined as the distance between the zygomatic arches, was measured on dorsal views (Fig 2). The length and thickness of the soft palate were assessed on mid-sagittal views. The length of the soft palate was measured from the end of the hard palate to the caudal end of the soft palate on mid-sagittal views. The thickness of the soft palate was measured perpendicular to this line and the greatest value was recorded (Fig 1). The canine tooth angle was assessed on sagittal views and defined as the angle between a line positioned over the hard palate and a line positioned over the center of the canine tooth.

The cross-sectional area of the nasopharynx, defined as the air passage extending from the caudal end of the choanae to the caudal free border of the soft palate,[22,29] was measured on reconstructed transverse views (Fig 1). The minimum diameter of the entire nasopharynx dorsal to the hard and soft palates was assessed. Additionally, the cross-sectional area of the airway was quantified at 3 specific points: (1) at the beginning of the nasopharynx, defined as the point where the nasal septum discontinues, (2) at the end of the hard palate, and (3) dorsal to the soft palate at the caudal border of the tympanic bulla (Fig 1). The nasopharyngeal and soft palate dimensions were also normalized to each dog's body weight and skull index before statistical comparison between breeds.

In dogs where aberrant turbinates were seen in the nasopharynx in bone window CT-images, the cross-sectional area of the turbinates was measured on transverse views. These measurements began at the level of the end of the nasal septum and extended caudally on every transverse CT slice until reaching the caudal end of the turbinates. The cross-sectional area of the nasopharynx on the same slices was measured to calculate the area of the nasopharynx not occupied by the nasopharyngeal turbinates (Fig 3). The smallest area around nasopharyngeal turbinates was normalized to each dog's body weight and skull index, and subsequently compared with the other cross-sectional areas of the nasopharynx to determine the area and location of the smallest airway passage.

The greatest cross-sectional area of the 2 air-filled frontal sinuses was measured on dorsal views (Fig 4) and normalized to each dog's body weight and skull index before statistical comparison. Dogs without frontal sinuses were given a cross-sectional area of 0 for this assessment.

Table 2 Mean (Standard Deviation) Nasopharyngeal (N) Cross-Sectional Areas for 30 Pugs and 30 French Bulldogs (FB)

	Cranial N (cm^2)	Caudal N (cm^2)	Minimum Hard Palate (cm^2)	Minimum Airway Around Nasopharyngeal Turbinates (cm^2)	N at Bulla (cm^2)	Minimum Soft Palate (cm^2)	Frontal Sinus (cm^2)
Pugs	0.38 (0.11)	0.48 (0.08)	0.37 (0.10)	0.30 (0.16) n = 12	0.26 (0.19)	0.01 (0.07)	0.13 (0.13)
FB	1.05 (0.20)	0.99 (0.21)	0.96 (0.20)	0.86 (0.26) n = 3	0.33 (0.37)	0.12 (0.24)	2.19 (1.63)

Table 3 Soft Palate Dimensions and Canine Tooth Angle Normalized to Skull Index (SI) or Body Weight (W) for 30 Pugs and 30 French Bulldogs (FB)

	Soft Palate Thickness/SI (cm)	Soft Palate Thickness/W (cm/kg)	SoftPalate Length/SI (cm)	Soft Palate Length/W (cm/kg)	Canine Tooth Angle/SI (°)	Canine Tooth Angle/W (°/kg)
Pugs	0.86 (0.19)	0.09 (0.19)	4.84 (0.55)	0.53 (0.55)	115.39 (12.05)	12.91 (12.05)
FB	1.26 (0.31)	0.10 (0.31)	5.88 (0.62)	0.46 (0.62)	117.50 (10.25)	9.30 (10.25)
P-value	.00	.17	.00	.01	.09	1.0

Statistical Analysis

A Kolmogorov–Smirnov test confirmed the assumption of normal distribution of all dimensions. The dimensions were summarized as mean and standard deviation (SD) and compared between breeds using an independent samples *t*-test. A $P < .05$ was considered significant. To assess the association of the canine tooth angle with the degree of BAS.[26] Pearson linear correlation was performed between the canine tooth angle and (1) the skull index, (2) the cross-sectional areas of the frontal sinus, and (3) the minimal cross-sectional area dorsal to the hard palate with Pearson's correlation coefficient (r) reported. Correlation between age and cross-sectional area dorsal to the soft palate was also evaluated. A potential association between dorsal rotation of the maxillary bone and small cross-sectional area dorsal to the hard palate was analyzed using Fisher's exact test. A $P < .05$ was considered significant. Statistical software was used for all analyzes (SPSS version 21.0, SPSS Inc, Chicago, IL).

RESULTS

Thirty pugs and 30 French bulldogs were evaluated including 10 female and 20 male pugs, and 11 female and 19 male French bulldogs. There were consistent significant differences in nasopharyngeal dimensions between breeds after normalization to the skull index or to body weight (Tables 1 and 2), except for the thickness of the soft palate. The thickness of the soft palate was significantly shorter and thinner in pugs when normalized to the skull index but only significantly shorter in pugs when normalized to body weight. There were no significant difference between breeds in skull indices and canine tooth angles (Tables 1 and 3). The minimum cross-sectional area of the airway passage dorsal to the soft palate was significantly smaller in pugs than in French bulldogs (Tables 4 and 5). The smallest nasopharyngeal cross-sectional area was located dorsal to the soft palate at its caudal end in both breeds. The cross-sectional area dorsal to the soft palate at the level of the tympanic bulla was not significantly different between breeds (Tables 4 and 5). Pugs had a significantly smaller cross-sectional area of the nasopharynx dorsal to the hard palate than French bulldogs (Tables 4 and 5). The minimum cross-sectional area dorsal to the hard palate was located cranially at the beginning of the nasopharynx in pugs and at the end of the hard palate in French bulldogs. Nasopharyngeal turbinates were found in 12 pugs and 3 French bulldogs. In both breeds, the minimum cross-sectional area of the airway around these turbinates was smaller than the minimum cross-sectional area of the nasopharynx dorsal to the hard palate but greater than that of the airway passage dorsal to the soft palate both at its smallest location and at the level of the tympanic bulla. The cross-sectional area of the frontal sinus was significantly smaller in pugs than in French bulldogs (Tables 4 and 5). Most pugs had no air-filled cavities at this location, whereas the French bulldogs had a mean (SD) cross-sectional area of the frontal sinuses of 2.19 (1.63) cm^2. Pugs with miniscule frontal sinuses also had a small cross-sectional area dorsal to the hard palate ($P = .02$). There was no correlation between the canine tooth angle and the skull index or the size of the frontal sinus ($r = 0.219$, $r = 0.155$, respectively), or between the minimal cross-sectional area dorsal to the hard palate and canine tooth angle ($r = 0.411$). Age was not correlated with the cross-sectional area dorsal to the soft palate at the level of the tympanic bulla ($r = -0.054$).

DISCUSSION

This comparative description of the upper airway morphology of pugs and French bulldogs using CT imaging showed pugs have significantly smaller nasopharyngeal airway dimensions

Table 4 Cross-Sectional Area of the Nasopharynx (N) and Frontal Sinus Normalized to Skull Index (SI) for 30 Pugs and 30 French Bulldogs (FB)

	Cranial N/SI (cm^2)	Caudal N/SI (cm^2)	Minimum Hard Palate/SI (cm^2)	Minimum Airway Around Nasopharyngeal Turbinates/SI (cm^2)	N at Bulla/SI (cm^2)	Minimum Soft Palate/SI (cm^2)	Frontal Sinus SI (cm^2)
Pugs	0.40 (0.12)	0.50 (0.09)	0.39 (0.10)	0.32 (0.07) n = 12	0.27 (0.20)	0.01 (0.07)	0.14 (0.13)
FB	1.13 (0.21)	1.08 (0.23)	1.04 (0.22)	0.94 (0.12) n = 3	0.35 (0.41)	0.13 (0.26)	2.37 (1.75)
P-value	.00	.00	.00	.00	.34	.03	.00

Table 5 Cross-Sectional Area of the Nasopharynx (N) and Frontal Sinus Normalized to Body Weight (W) for 30 Pugs and 30 French Bulldogs (FB)

	Cranial N/W (cm^2/kg)	Caudal N/W (cm^2/kg)	Minimum Hard Palate/W (cm^2/kg)	Minimum Airway Around Nasopharyngeal Turbinates/W (cm^2/kg)	N at Bulla/W (cm^2/kg)	Minimum Soft Palate/W (cm^2/kg)	Frontal Sinus/W (cm^2/kg)
Pugs	0.04 (0.13)	0.05 (0.07)	0.04 (0.11)	0.03 (0.05) n = 12	0.03 (0.19)	0.001 (0.05)	0.01 (0.11)
FB	0.09 (0.20)	0.08 (0.21)	0.08 (0.21)	0.08 (0.14) n = 3	0.03 (0.42)	0.01 (0.23)	0.17 (1.74)
P-value	.00	.00	.00	.00	.80	.02	.00

than French bulldogs, even when the measurements were normalized against each dog's skull index or body weight.

Although the soft palate was longer and thicker in French bulldogs, the cross-sectional area of the nasopharynx dorsal to the soft palate was still significantly smaller in pugs with no measurable airway space in 81% of the dogs. The smallest airway passage was located at the end of the soft palate in both breeds and the cross-sectional area of the nasopharynx dorsal to the soft palate at the level of the tympanic bulla showed no significant difference between the two breeds. These findings suggest that the smallest airway dimension of the nasopharynx could be located at the end of the soft palate and that the size of the soft palate is not the only factor contributing to this smallest airway dimensions but might also be compromised by the other 3 boundaries of this airspace. Dynamic nasopharyngeal collapse secondary to increased negative luminal pressure on inspiration might decrease this space even further.

The cross-sectional area of the airspace dorsal to the hard palate was significantly smaller in pugs than in French bulldogs. This cross-sectional area was always greater than that dorsal to the soft palate, even in dogs with aberrant nasopharyngeal turbinates. The smallest area of the nasopharynx dorsal to the hard palate was located at the beginning of the nasopharynx in pugs, whereas this narrowing was found at the end of the hard palate in French bulldogs. The smaller airway passage at the beginning of the nasopharynx in pugs might be secondary to dorsorotation of the skull.[13,14,24] Dorsal rotation of the maxillary and palatine bone may also affect the orientation of the endoturbinates and could explain why nasopharyngeal turbinates are more frequently reported in this breed.[13,14] Twelve pugs (40%) and 3 French bulldogs (10%) were affected in the present study. Interestingly, although the airway passage around the aberrant nasopharyngeal turbinates was smaller than the minimum cross-sectional area dorsal to the hard palate in these dogs, it remained considerably larger than the smallest airway passage area dorsal to the soft palate. As smaller nasopharyngeal airway dimensions were found in the nasopharynx dorsal to the soft palate, the impact of nasopharyngeal turbinates on upper airway obstruction is unclear.

The frontal sinus was significantly smaller (and often absent) in pugs than in French bulldogs. Defective growth and early fusion of the basiscranial physeal cartilages result in dorsorotation of the maxillary bone in dogs with extreme brachcephaly.[22,24–25,27] The dorsal rotation of the maxillary bone could place pressure on the frontal bone, leading to subsequent underdevelopment of the frontal sinus in these dogs. This finding further supports the theory that the skull might be more severely affected by dorsorotation in pugs than in French bulldogs. Using the CT images to compare the morphology of the present cases with those of normal dogs[29,30] shows the sinuses are not only smaller but also located more ventrally in pugs and French bulldogs than in normal dogs.

No significant differences were found in the skull indices between pugs and French bulldogs in this study despite the significantly smaller nasopharyngeal airway space in pugs. This finding suggests that the commonly used skull index[31] does not reflect the upper airway dimensions precisely enough to account for the differences in morphology between these brachycephalic breeds. In addition, the skull index might not account for the dorsorotation of the brachycephalic skull. The dog's body weight may not be any more useful to standardize each dog's measurements as significant difference was the same when normalized to the skull index or the body weight. The only disparity was the thickness of the soft palate, which is reported to progressively increase in size secondary to muscle hypertrophy and mucoid gland hyperplasia[32,33] and, therefore, this result might be confounded by age.

Schlueter et al.[26] found the direction of the canine tooth is associated with dorsorotation of the upper jaw in cats and thereby related to the degree of brachycephaly. In the present study, the canine tooth angle, defined as the angle between the canine tooth and the hard palate, showed no significant differences between the two breeds. The canine tooth angle was not correlated with skull index, size of the frontal sinus, or the minimum nasopharyngeal dimension dorsal to the hard palate. As all dogs in this study were similar, a spectrum of values across which to determine correlation was not attained. It is possible that the rotation point of the upper jaw was located more caudally and, thus, did not affect the canine tooth angle. The value of canine tooth angle to estimate the degree of brachycephaly in dogs remains undetermined.

Brachycephalic dogs are described to have muscular hypertrophy and mucoid gland hyperplasia of the soft palate,[32,33] which could lead to progressive thickening of the soft palate with age and subsequent smaller dimensions of the nasopharynx dorsal to the soft palate. Age and the cross-sectional area dorsal to the soft palate did not, however, show any linear relationship; thus, the airway dimension dorsal to the soft palate is not smaller in older brachycephalic dogs. A study comparing the same dogs repeatedly as they age would be needed to investigate this issue.

In both pugs and French bulldogs in the present study, the smallest airway areas were found dorsal to the soft palate, even in dogs in which the nasopharyngeal turbinates occupied part of the nasopharynx dorsal to the hard palate. This finding suggests that nasopharyngeal obstruction caudal to the hard palate might represent a major component of the brachycephalic upper airway anomaly.

Several limitations of this study must be noted. Cranial aberrant conchae as described by Oechtering et al.[14] were not evaluated in this study because of their pleomorphic presentation, difficulty distinguishing them from normal ethmoturbinates, and inability to objectively define the airway passage in the region of interest. Another limitation is that the dogs were intubated during the acquisition of the CT images which might have led to dorsal displacement of the soft palate. However, the authors had previously compared this cross-sectional area in intubated and nonintubated pugs and French bulldogs (Heidenreich et al, unpublished data) and found no significant difference in the cross-sectional area of the airway at the level of the Eustachian tube and a decrease of only 1.7 and 0.9 mm^2 at the tip of the soft palate in intubated French bulldogs and pugs, respectively. Another limitation is that static CT imaging does not reflect dynamic nasopharyngeal changes in the upper airway. A further limitation is that no attempt was made to relate the assessed airway space with the severity of clinical signs; however, clinical signs might be also related to secondary changes (dynamic collapse of the airways).[34]

In conclusion, this study shows that the smallest nasopharyngeal airway dimension is located at the caudal end of the soft palate in both breeds. The descriptive comparison between pugs and French bulldogs has shown that pugs have significantly smaller nasopharyngeal cross-sectional area, are more frequently affected by the presence of nasopharyngeal turbinates, and have significantly smaller (miniscule) frontal sinuses than French bulldogs. Whether these findings are secondary to the greater degree of dorsorotation of the skull in pugs and their significance in relation to clinical signs and surgical treatments requires further investigation.

ACKNOWLEDGMENT

The authors thank Dr. rer. nat. Alexander Tichy for assistance with the statistical analysis.

DISCLOSURE

The authors declare no conflicts of interest related to this report.

REFERENCES

1. Hendricks JC: Brachycephalic airway syndrome. *Vet Clin North Am Small Anim Pract* 1992;22:1145–1153
2. Riecks TW, Birchard SJ, Stephens JA: Surgical correction of brachycephalic syndrome in dogs: 62 cases (1991–2004). *J Am Vet Med Assoc* 2007;230:1324–1328
3. Schuenemann R, Oechtering GU: Inside the brachycephalic nose: intranasal mucosal contact points. *J Am Anim Hosp Assoc* 2014;50:149–158
4. Arrighi S, Pichetto M, Roccabianca P, et al: The anatomy of the dog soft palate. I. Histological evaluation of the caudal soft palate in mesaticephalic breeds. *Anat Rec (Hoboken)* 2011;294:1261–1266
5. Wykes PM: Brachycephalic airway obstructive syndrome. *Probl Vet Med* 1991;3:188–197
6. Trappler M, Moore K: Canine brachycephalic airway syndrome: pathophysiology, diagnosis, and nonsurgical management. *Compend Contin Educ Vet* 2011;33:E1–E4
7. Dupré G, Findji L, Oechtering G: Brachycephalic airway syndrome, in Monnet E (ed): *Small animal soft tissue surgery.* Ames, Iowa, Wiley-Blackwell, 2012, p 167
8. Harvey CE: Soft palate resection in brachycephalic dogs. II. *J Am Anim Hosp Assoc* 1982;18:538–544
9. Torrez CV, Hunt GB: Results of surgical correction of abnormalities associated with brachycephalic airway obstruction syndrome in dogs in Australia. *J Small Anim Pract* 2006;47:150–154
10. Poncet CM, Dupré GP, Freiche VG, et al: Long-term results of upper respiratory syndrome surgery and gastrointestinal tract medical treatment in 51 brachycephalic dogs. *J Small Anim Pract* 2006;47:137–142
11. Poncet CM, Dupré GP, Freiche VG, et al: Prevalence of gastrointestinal tract lesions in 73 brachycephalic dogs with upper respiratory syndrome. *J Small Anim Pract* 2005;46:273–279
12. De Lorenzi D, Bertoncello D, Drigo M: Bronchial abnormalities found in a consecutive series of 40 brachycephalic dogs. *J Am Vet Med Assoc* 2009;235:835–840
13. Ginn JA, Kumar MS, McKiernan BC, et al: Nasopharyngeal turbinates in brachycephalic dogs and cats. *J Am Anim Hosp Assoc* 2008;44:243–249
14. Oechtering TH, Oechtering GU, Nöller C: Strukturelle besonderheiten der nase brachyzephaler hunderassen in der computertomographie. *Tierörztl Prax* 2007;35:177–187
15. Billen F, Day M, Clercx C: Diagnosis of pharyngeal disorders in dogs: a retrospective study of 67 cases. *J Small Anim Pract* 2006;47:122–129
16. Vilaplana Grosso F, Haar GT, Boroffka SA: Gender, weight, and age effects on prevalence of caudal aberrant nasal turbinates in clinically healthy english bulldogs: a computed tomographic study and classification. *Vet Radiol Ultrasound* 2015;56:486–493
17. Findji L, Dupré GP: Folded flap palatoplasty for treatment of elongated soft palates in 55 dogs. *Vet Med Austria/Wien Tierärztl Mschr* 2007;95:56–63
18. Fasanella FJ, Shivley JM, Wardlaw JL, et al: Brachycephalic airway obstructive syndrome in dogs: 90 cases (1991–2008). *J Am Vet Med Assoc* 2010;237:1048–1051

19. Grand JG, Bureau S: Structural characteristics of the soft palate and meatus nasopharyngeus in brachycephalic and non-brachycephalic dogs analysed by CT. *J Small Anim Pract* 2011;52:232–239
20. Hoareau GL, Jourdan G, Mellema M, et al: Evaluation of arterial blood gases and arterial blood pressures in brachycephalic dogs. *J Vet Intern Med* 2012;26:897–904
21. Johnson LR, Mayhew PD, Steffey MA, et al: Upper airway obstruction in Norwich Terriers: 16 cases. *J Vet Intern Med* 2013;27:1409–1141
22. Evans H E (ed): *The skeleton. Millers' anatomy of the dog*. Philadelphia, WB Saunders Company, 1993, pp 122–218
23. Haimel G, Dupré G: Brachycephalic airway syndrome: a comparative study between pugs and French bulldogs. *J Small Anim Pract* 2015;early view
24. Hussein AK, Sullivan M, Penderis J: Effect of brachycephalic, mesaticephalic, and dolichocephalic head conformations on olfactory bulb angle and orientation in dogs as determined by use of in vivo magnetic resonance imaging. *Am J Vet Res* 2012;73:946–951
25. Hennet PR, Harvey CE: Craniofacial development and growth in the dog. *J Vet Dent* 1992;9:11–18
26. Schlueter C, Budras KD, Ludewig E, et al: Brachycephalic feline noses: CT and anatomical study of the relationship between head conformation and the nasolacrimal drainage system. *J Feline Med Surg* 2009;11:891–900
27. Hussein AK: MRI mensuration of the canine head: the effect of head conformation on the shape and dimensions of the facial and cranial regions and their components. PhD thesis, University of Glasgow, 2012
28. Laurenson MP, Zwingenberger AL, Cissell DD, et al: Computed tomography of the pharynx in a closed vs. open mouth position. *Vet Radiol Ultrasound* 2011;52:357–361
29. Saunders J, Schwarz T: Nasal cavities and frontal sinuses, in Saunders J, Schwarz T (eds): *Veterinary computed tomography*. Oxford, Wiley-Blackwell, pp 93–110
30. Burrow R, McCarroll D, Baker M, et al: Frontal sinus depth at four landmarks in breeds of dog typically affected by sinonasal aspergillosis. *Vet Record* 2012;170:20–25
31. Koch DA, Arnold S, Hubler M, et al: Brachycephalic syndrome in dogs. *Compendium* 2003;25:48–55
32. Pichetto M, Arrighi S, Roccabianca P, et al: The anatomy of the dog soft palate. II. Histological evaluation of the caudal soft palate in brachycephalic breeds with grade I brachycephalic airway obstructive syndrome. *Anat Rec (Hoboken)* 2011;294:1267–1272
33. Pichetto M, Arrighi S, Gobbetti M, et al: The anatomy of the dog soft palate. III. Histological evaluation of the caudal soft palate in brachycephalic neonates. *Anat Rec (Hoboken)* 2015;298:618–623
34. Meola SD: Brachycephalic airway syndrome. *Top Companion Anim Med* 2013;28:91–96

