Advance Publication

The Journal of Veterinary Medical Science

Accepted Date: 29 June 2021

J-STAGE Advance Published Date: 9 July 2021

©2021 The Japanese Society of Veterinary Science

Author manuscripts have been peer reviewed and accepted for publication but have not yet been edited.

1 *Full paper*

2 *Internal Medicine*

3

4 **Dynamic computed tomography evaluation of the nasopharynx in normal**
5 **Beagle dogs**

6

7 **Running head: DYNAMIC CT OF NASOPHARYNX IN DOGS**

8

9 Daji NOH¹⁾, Sooyoung CHOI²⁾, Hojung CHOI³⁾, Youngwon LEE³⁾, Kija LEE¹⁾, *

10

11 ¹⁾College of Veterinary Medicine, Kyungpook National University, Daegu 41566,

12 Korea

13 ²⁾College of Veterinary Medicine, Kangwon National University, Chuncheon

14 24341, Korea

15 ³⁾College of Veterinary Medicine, Chungnam National University, Daejeon 34134,

16 Korea

17

18 ***Corresponding author: Kija LEE**, College of Veterinary Medicine,

19 Kyungpook National University, 80 Daehak-ro, Buk-gu, Daegu 41566, Korea,

20 Fax: +82-53-950-5955, E-mail: leekj@knu.ac.kr

21 **ABSTRACT**

22 Pharyngeal collapsibility has been used as diagnostic criteria in dogs,
23 whereas the normal range and quantitative method have not been studied.
24 Dynamic and static computed tomography (CT) was performed in 23 normal
25 Beagle dogs to quantify the nasopharyngeal collapsibility at different locations.
26 Using dynamic CT, maximum and minimum nasopharyngeal cross-sectional areas
27 (CSAs) were measured at the level of the cranial end of the soft palate, pterygoid
28 hamulus, foramen lacerum, bony labyrinth, and caudal end of the soft palate. The
29 ratio of all maximum and minimum CSA to nasopharyngeal CSA at the level of
30 the caudal hard palate (rCSAmax and rCSAmin) and the nasopharyngeal
31 collapsibility were calculated. The differences of rCSAmax, rCSAmin, and
32 nasopharyngeal collapsibility were analyzed at various locations. The
33 nasopharyngeal collapsibility at the level of foramen lacerum, bony labyrinth, and
34 caudal end of soft palate were higher than the others. At the level of the caudal
35 end of the soft palate, rCSAmin was lower than that of the foramen lacerum and
36 bony labyrinth, whereas rCSAmax at foramen lacerum was higher than that of the
37 caudal end of the soft palate. These results indicated that the nasopharynx at the
38 level of foramen lacerum and caudal end of the soft palate were considered
39 notable locations for evaluating collapsibility. Dynamic CT could show the
40 nasopharyngeal dynamic profile and will be an adequate modality for evaluating

41 nasopharynx. Our results will be helpful for further comparative studies in dogs
42 with and without nasopharyngeal collapse.

43 **KEY WORDS:** collapsibility, dog, dynamic computed tomography, nasopharynx

44 INTRODUCTION

45 Maintenance of the upper airway patency depends on a balance between
46 forces dilating or collapsing the airway. These forces are composed of tissue
47 stresses that act as radials through the airway and local airway pressure in the
48 upper and thoracic airways [1]. During the respiratory cycle, local airway pressure
49 changes, and affects the luminal area of the upper airway and the pharyngeal walls
50 [6, 14, 19]. When an anatomic abnormality or pharyngeal dilator myopathy are
51 present, the change of the luminal area in the upper airway is increased, causing a
52 clinical pharyngeal collapse in humans [3, 9, 20]. For dogs, this is still unclear due
53 to lack of studies [23, 24]. In small animal practice, pharyngeal collapse is
54 anecdotally encountered on radiographs in both non-brachycephalic and
55 brachycephalic dogs with and without stertor. In previous studies, the pharyngeal
56 collapse is defined as complete when the pharynx losses the total air column, or
57 partial air column when the luminal collapsibility is over the 50% in fluoroscopic
58 study [23, 24]. However, there have been no studies focusing on a detailed
59 quantification method for nasopharyngeal collapsibility and its normal range in
60 dogs.

61 In veterinary medicine, computed tomography (CT) has been used in
62 several studies of brachycephalic obstructive airway syndrome owing to its
63 advantages in evaluating the entire upper respiratory system in detail and allowing
64 reconstruction of original data into multiplanar and 3-dimensional images [10, 12,

18]. However, these studies used static CT, which has limitations because it does not reflect the dynamics of changes in the upper airway. In contrast, dynamic CT has the advantage of the feasibility of acquiring high-quality images that sufficiently delineate the upper airway contour and quantify the dynamic profile, as well as the advantages of static CT [9, 26, 28]. However, there have been very few dynamic CT studies of the upper airway in dogs [11].

In humans, there are differences in pharyngeal collapsibility by location, according to the presence or severity of obstructive sleep apnea [6, 13]. In dogs, a study in Pugs and French Bulldogs with obstructive airway syndrome showed that the smallest nasopharyngeal cross-sectional area (CSA) was located at the level of the caudal end of the soft palate [12]. However, the previous study evaluated the nasopharyngeal CSA using conventional CT and not by comparing the maximum and minimum cross-sectional area using dynamic CT. Thus far, there has been no study for nasopharyngeal collapsibility by location in dogs. Based on previous studies in humans that showed pharyngeal collapsibility in normal subjects and its variation by location [6, 13, 14, 19], we hypothesized that normal dogs have nasopharyngeal CSA change according to their respiratory cycle, and the degree of nasopharyngeal CSA change may differ depending on the location. Moreover, we hypothesized that nasopharyngeal collapsibility is correlated with adjacent structures, including soft palate and epiglottis. The study aimed to analyze nasopharyngeal collapsibility at various locations and to analyze its correlation

86 with adjacent structures using static and dynamic CT in normal dogs.
87 Consequently, our study aimed to determine the locations for evaluating
88 nasopharyngeal collapsibility.

89

90 **MATERIALS AND METHODS**

91 *Animals*

92 A prospective and cross-sectional designed study was performed.
93 Twenty-three male Beagle dogs were included in the study. The mean age was 5.0
94 years (1.8–5.5 years), and the mean body weight was 10.3 kg (8.0–13.3 kg). All
95 procedures were in accordance with Kyungpook National University Animal Care
96 and Use Committee guidelines (No. KNU 2020-0033). All dogs had a physical
97 examination including cardiac and lung auscultation, and cervical tracheal
98 manipulation to check the presence of coughing. Dogs with nasal discharge,
99 sneezing, coughing, stertor, stridor, and retching were not included in this study.
100 Before the CT scan, thoracic radiographs, a complete blood count, and a
101 biochemical serum profile were performed. Ventrodorsal and right lateral thoracic
102 radiographs were acquired in all dogs to identify the presence of lower airway
103 collapse, cardiac disease, and pulmonary disease.

104

105 *Experimental protocol*

106 Based on previous research showing that endotracheal intubation could
107 change airway pressure [18], endotracheal intubation was not performed in this
108 study. For sedation, 0.02 mg/kg medetomidine (Domitor; Pfizer, New York, NY,
109 U.S.A) was injected intravenously. The dog was positioned in sternal recumbency
110 on the CT table. The head was held up using a sponge to maintain it in an
111 extended neutral position with the hard palate parallel to the CT table. A self-
112 manufactured bite block was placed between both canine teeth to maintain mouth
113 opening for better visualization of upper airway structure [17]. The tongue was
114 pulled out between the bite blocks. The respiratory rate was recorded after the
115 respiratory rate fell to less than 20 breaths/min.

116 CT scans were performed using 32-Multislice CT (AlexionTM; Canon
117 Medical System, Otawara, Japan). The examination range included the rhinarium
118 to the third cervical vertebra to evaluate the length and thickness of soft palate and
119 to help choose the locations for dynamic CT. The CT scan parameters were as
120 follows: 120 kV, 130 mA, 1.0 mm slice thickness, and 0.75 sec rotation times. All
121 transverse images perpendicular to the hard palate and reconstructed sagittal
122 images were obtained.

123 Transverse images were reviewed focused on the nasopharynx, and the
124 following locations for the subsequent dynamic CT scans were chosen: (1) at the
125 caudal hard palate (Fig. 1B); (2) at the cranial end of the soft palate, defined as the
126 point where the torus palatinus discontinues (Fig. 1C); (3) at the pterygoid

127 hamulus, defined as the point where the pterygoid hamulus extends to most
128 ventral (Fig. 1D); (4) at the foramen lacerum, defined as the point where the
129 widest canal of foramen lacerum is shown (Fig. 1E); (5) at the bony labyrinth (Fig.
130 1F); and (6) at the caudal end of the soft palate, defined in front of the point where
131 the soft palate diverges (Fig. 1G).

132 Dynamic CT scan was performed including at least two breathing cycles
133 at 1-sec intervals. A field of view was used with the image being acquired in such
134 a way as to place the nasopharynx in the center for each location. The dynamic
135 CT images were obtained at the cranial end of the soft palate, pterygoid hamulus,
136 foramen lacerum, bony labyrinth, and caudal end of the soft palate, respectively.
137 After dynamic CT scan, 0.1 mg/kg atipamezole (Antisedan; Pfizer) was injected
138 intramuscularly for sedation reversal and the condition was monitored until the
139 dogs were able to stand on their own.

140

141 *CT data analysis*

142 All CT imaging assessments and measurements were performed using a
143 picture archiving and communication system (PACS) and its software (ZeTTA
144 PACS Viewer; Taeyoung Soft, Seoul, Korea).

145 Using the mid-sagittal images of head and neck, the angle between hard
146 palate and dorsal margin of the vertebral canal of axis was measured to verify the
147 uniformity of CT scan positions. Based on the method in a previous study [9], soft

148 palate length and thickness was measured at bone windows (window width, 2,700
149 HU; window level, 350 HU). The soft palate length was defined as the distance
150 from the caudal margin of the hard palate to the tip of the soft palate. The soft
151 palate thickness was defined as the thickest distance between the dorsal and
152 ventral margin of the soft palate perpendicular to the soft palate length. On the
153 transverse images of the head, nasopharyngeal CSA was measured at the level of
154 the caudal hard palate. Regions of interest were drawn manually following the
155 inner edge of the nasopharynx and were consequently calculated using the PACS
156 software. In addition, the location of the epiglottis, whether it was below or above
157 the soft palate, was recorded.

158 Using the dynamic CT images of the nasopharynx, maximum and
159 minimum nasopharyngeal CSA were measured at bone windows at five locations:
160 cranial end of the soft palate, pterygoid hamulus, foramen lacerum, bony labyrinth,
161 and caudal end of the soft palate. For normalization, the ratio of all maximum and
162 minimum CSAs at different locations to nasopharyngeal CSA at caudal hard
163 palate ($rCSA_{max}$ and $rCSA_{min}$) was calculated. The nasopharyngeal
164 collapsibility was calculated at five locations: cranial end of the soft palate,
165 pterygoid hamulus, foramen lacerum, bony labyrinth, and caudal end of the soft
166 palate. Nasopharyngeal collapsibility was defined as the percentage of the
167 difference between the maximum and minimum nasopharyngeal CSA, divided by
168 the maximum nasopharyngeal CSA.

$$\text{Collapsibility (\%)} = \frac{\text{maximum CSA} - \text{minimum CSA}}{\text{maximum CSA}} \times 100$$

170

171 *Statistical analysis*

172 All statistical analyses were performed using a commercial software
 173 program (SPSS 24.0; IBM SPSS statistics, NY, U.S.A). Shapiro–Wilk tests were
 174 used for the assessment of normality. According to distribution, Pearson or
 175 Spearman’s correlation was used to evaluate the association of body weight with
 176 the dimensions of the soft palate and nasopharyngeal area variants, including
 177 maximum and minimum nasopharyngeal CSAs, rCSAmax, rCSAmin, and
 178 nasopharyngeal collapsibility at the cranial end of the soft palate, pterygoid
 179 hamulus, foramen lacerum, bony labyrinth, and caudal end of the soft palate.
 180 Moreover, the association between the dimensions of the soft palate and
 181 nasopharyngeal collapsibility was analyzed. Mann-Whitney U tests were used to
 182 ascertain the difference of nasopharyngeal collapsibility according to the
 183 epiglottis location.

184 To identify the differences in the nasopharynx at different locations,
 185 repeated ANOVA tests followed by post hoc Bonferroni test were performed in
 186 rCSAmax, rCSAmin, and nasopharyngeal collapsibility. *P*-values less than 0.05
 187 were considered significant.

188

189 **RESULTS**

190 The mean value $\pm$ standard deviation (SD) of the angle between hard
191 palate and dorsal margin of the vertebral canal of axis was $172.9^\circ \pm 4.5^\circ$ (range,
192 165.7° – 178.7°). The mean values $\pm$ SD for soft palate length and thickness were
193 64.51 ± 4.89 mm and 6.48 ± 1.14 mm, respectively. The mean values $\pm$ SD for the
194 dimensions of the soft palate, maximum and minimum nasopharyngeal CSA,
195 rCSAmax, and rCSAmin are summarized in Tables 1 and 2. The median values
196 with an interquartile range of nasopharyngeal collapsibility are summarized in
197 Table 3.

198 There was significant positive correlation between soft palate thickness
199 and body weight ($r = 0.574$, $P < 0.001$, Table 1). Among the nasopharyngeal area
200 variants, collapsibility at the bony labyrinth showed a positive correlation with
201 body weight ($r = 0.499$, $P < 0.05$, Table 3).

202 In the analysis of the correlation between the dimensions of the soft
203 palate and nasopharyngeal collapsibility, collapsibility at the caudal end of the
204 soft palate showed a negative correlation with soft palate length ($r = -0.445$, $P <$
205 0.05) and collapsibility at the pterygoid hamulus showed a positive correlation
206 with soft palate thickness ($r = 0.427$, $P < 0.05$).

207 The epiglottis was located below and above the soft palate in 13 and 10
208 dogs, respectively. In the analysis of differences in nasopharyngeal collapsibility
209 according to epiglottis location, collapsibility at the caudal end of the soft palate

210 was significantly larger when the epiglottis was located under the soft palate ($P =$
211 0.026).

212 In the analysis of the differences of nasopharyngeal area variants
213 according to locations in each dog, there were significant differences in rCSAmax,
214 $F(2.01, 44.29) = 5.08, P < 0.05$; rCSAmin, $F(1.86, 41.01) = 6.35, P < 0.01$; and
215 nasopharyngeal collapsibility, $F(1.83, 40.17) = 11.79, P < 0.01$. The results of
216 Bonferroni post hoc tests in nasopharyngeal area variants according to locations in
217 each dog are presented in Fig. 2.

218

219 **DISCUSSION**

220 In this study, nasopharyngeal CSA change during the respiratory cycle
221 was detected and there was remarkable nasopharyngeal collapsibility at the level
222 of foramen lacerum, bony labyrinth, and caudal part of the soft palate in normal
223 Beagle dogs. These findings support the hypothesis that nasopharyngeal CSA
224 change may exist even in normal dogs, and the degree of nasopharyngeal CSA
225 change may differ depending on the location. Moreover, nasopharyngeal
226 collapsibility has relationships with dimension of the soft palate and with
227 epiglottis location.

228 There are several diagnostic imaging modalities to evaluate the anatomic
229 or dynamic changes of the upper airway in dogs especially in brachycephalic
230 breeds including radiography, rhinoscopy, fluoroscopy, static CT, and magnetic

231 resonance imaging (MRI) [10, 12, 15, 16, 18, 21, 23, 24]. Among these modalities,
232 fluoroscopy has been used in dogs with obstructive airway syndrome because it
233 has the feasibility of real-time assessment of the dynamic profile of the upper
234 airway and can be used without general anesthesia using an endotracheal tube [23,
235 24]. However, this has its limitation in that only 2-dimensional evaluation is
236 possible. In humans, dynamic CT and MRI are used for evaluating dynamic
237 changing of the upper airway in obstructive sleep apnea patients [9, 13]. Both
238 modalities have the advantage of its feasibility of acquiring high-quality images
239 and quantifying the dynamic profile. Considering that dogs need anesthesia for
240 CT or MRI scans, MRI has the disadvantage as the anesthetic time is longer than
241 that of CT. However, dynamic CT has several advantages including brief scan and
242 anesthetic time and easy processing of imaging data for multiplanar reconstruction
243 [9]. Therefore, dynamic CT was used in this study to evaluate dynamic profiles of
244 the nasopharynx.

245 In this study, endotracheal intubation was not performed because it can
246 induce artificial pressure given in the dogs [18]. During spontaneous inspiration
247 with intubation, the negative airway pressure is generated by respiratory
248 musculature to overcome the resistance of the endotracheal tube, aggravating the
249 nasopharyngeal collapse in humans [8]. In brachycephalic dogs, changes of
250 nasopharyngeal pressure may not appear because the endotracheal tube may act as
251 a bypass, leading to reduced air flow through the nasopharynx [24]. Therefore, the

252 results of the present study aim to reflect the natural pressure gradient during
253 respiration, excluding artificial pressure factors. In addition, endotracheal
254 intubation could affect the CSA of the caudal nasopharynx and soft palate length
255 and it may preclude the evaluation of changing of nasopharyngeal dynamics [18,
256 24]. By not performing endotracheal intubation, this study could measure the
257 nasopharyngeal CSA and soft palate length reflecting the same conditions as in
258 the nature state.

259 In this study, we measured the angle between the hard palate and the
260 dorsal margin of the vertebral canal to quantify the degree of head flexion. In a
261 previous study on horses, pharyngeal diameter decreased with head flexion, which
262 limited the airflow. This may result in turbulence followed by dynamic
263 nasopharyngeal collapse [4]. Thus, the dog was positioned in an extended neutral
264 position, enabling the avoidance of artificial nasopharyngeal collapse. The angle
265 measured between head and cervical vertebrae was used to normalize the effect of
266 head flexion in the nasopharyngeal area.

267 In humans, obstructive sleep apnea patients have a more collapsible
268 velopharynx compared with normal subjects [6]. However, there has been no
269 comparative study for nasopharyngeal collapsibility according to specific location
270 in dogs with and without upper airway obstruction. In this study, various locations
271 were selected to evaluate nasopharyngeal CSA and collapsibility at the level of
272 the cranial end of the soft palate, pterygoid hamulus, foramen lacerum, bony

273 labyrinth, and the caudal end of the soft palate. These anatomical levels for
274 nasopharyngeal evaluation were chosen based on previous studies on
275 brachycephalic dogs, and on their easiness to find that could be used in landmarks
276 on CT [12, 15, 16, 25].

277 The level of the caudal end of the soft palate and foramen lacerum were
278 considered suitable locations for detecting nasopharyngeal CSA change. The
279 nasopharynx at the level of the caudal end of the soft palate showed lower
280 rCSAmin and higher collapsibility. This result is consistent with a previous study
281 that showed the smallest nasopharyngeal CSA at the level of the caudal end of the
282 soft palate in Pugs and French Bulldogs with obstructive airway syndrome [12].
283 These results may imply that the collapsibility at the caudal end of the soft palate
284 may be high, regardless of symptoms or breed differences. This suggests that
285 other levels of the nasopharynx may be needed to avoid overlapping of
286 collapsibility when comparing dogs with and without obstructive airway
287 syndrome. The nasopharynx at the foramen lacerum level was noteworthy as the
288 rCSAmax and rCSAmin were higher than those of the caudal soft palate level and
289 showed higher collapsibility than those of the cranial end of the soft palate and
290 pterygoid hamulus in normal dogs. This may indicate that the nasopharynx at the
291 foramen lacerum level could show differences in nasopharyngeal collapsibility
292 with little overlap between normal dogs and dogs with clinical nasopharyngeal

collapse. Further comparative studies of the nasopharynx using dynamic CT are needed in dogs with and without nasopharyngeal collapse.

In this study, positive correlations were found for nasopharyngeal collapsibility at the level of the pterygoid hamulus with soft palate thickness and nasopharyngeal collapsibility at the level of the bony labyrinth with body weight. These results are partially consistent with a previous study that revealed the soft palate thickness is the most relevant parameter in dogs with severe brachycephalic obstructive airway syndrome, whereas soft palate length is not [10]. In addition, weight gain can cause adipose tissue deposition on the soft palate, and obesity is a possible risk factor for development of pharyngeal collapse [22, 24]. These previous studies and result of present study suggest that either thickening of the soft palate or weight gain, or both, could affect nasopharyngeal collapsibility even in normal non-brachycephalic dogs.

In this study, dogs with the epiglottis located below the soft palate had higher nasopharyngeal collapsibility at the level of the caudal end of the soft palate. Epiglottis-overlying soft palate may cause the narrowing of the caudal nasopharyngeal area, resulting in high negative pressure. Similar to this condition, dorsal displacement of the soft palate in equines obstructs the normal airflow, resulting in more severe dynamic obstruction of the upper respiratory tract [5]. Moreover, the epiglottis may block the upward movement of the soft palate when it is located above the soft palate, causing lower nasopharyngeal collapsibility. In

314 this condition, the inspiration-induced negative pressure causing nasopharyngeal
315 CSA change may be disturbed by the epiglottis blocking the upward movement of
316 the soft palate. Anatomically, the natural location of the epiglottis at rest is dorsal
317 to the soft palate, allowing nasal breathing. However, when breathing through the
318 mouth, the epiglottis moves downward in mesaticephalic dogs [2]. When a dog
319 with respiratory distress presents open mouth breathing, nasopharyngeal
320 collapsibility at the level of the caudal end of the soft palate may be higher in dogs
321 with obstructive airway signs.

322 This study had some limitations. First, an anesthetic drug that may affect
323 respiratory system was used because of the inevitable necessity of anesthesia for
324 CT scans of dogs. However, respiratory depression of medetomidine alone is
325 lower than other sedatives, even at sublethal doses [27]. Moreover, medetomidine
326 is safe and widely used even in brachycephalic dogs with obstructive airway
327 syndrome [7]. Second, the dynamic CT scan was performed at fixed scan intervals,
328 and CT images at maximal inspiration and expiration may not have been obtained,
329 which may be reflected in the calculated nasopharyngeal collapsibility. Third,
330 Beagle dogs were used in this study and the result may differ from brachycephalic
331 dogs, which have different upper airway conformation [22]. However, considering
332 that nasopharyngeal collapse was also encountered in non-brachycephalic dog
333 breeds [23, 24], the method described in this study would be applicable to non-
334 brachycephalic dogs in small animal practice.

335 In conclusion, the findings from this study indicate that measurements of
336 the nasopharyngeal collapsibility at the level of the caudal end of the soft palate
337 and the foramen lacerum are considered useful locations. Either thickening of the
338 soft palate, weight gain, or epiglottis location could affect the nasopharyngeal
339 collapsibility even in normal Beagle dogs. Dynamic CT could show the dynamic
340 profile of the airway and would be an adequate modality for evaluating the
341 nasopharynx in dogs. Further dynamic CT study of the nasopharynx is needed to
342 compare the collapsibility in dogs with and without obstructive airway syndrome.

343

344 **CONFLICT OF INTEREST**

345 None of the authors have a financial or personal relationship with other
346 people or organizations that could inappropriately influence or bias the content of
347 the paper.

348

349 **ACKNOWLEDGMENTS**

350 Not applicable.

351 **REFERENCES**

- 352 1. Ayappa, I. and Rapoport, D. M. 2003. The upper airway in sleep:
353 physiology of the pharynx. *Sleep. Med. Rev.* **7**: 9–33.
- 354 2. Baker, G. J. 1972. Surgery of the canine pharynx and larynx. *J. Small Anim.*
355 *Pract.* **13**: 505–513.
- 356 3. Campana, L., Eckert, D. J., Patel, S. R. and Malhotra, A. 2010.
357 Pathophysiology & genetics of obstructive sleep apnoea. *Indian J. Med. Res.*
358 **131**: 176–187.
- 359 4. Cehak, A., Rohn, K., Barton, A., Stadler, P. and Ohnesorge, B. 2010. Effect
360 of head and neck position on pharyngeal diameter in horses. *Vet. Radiol.*
361 *Ultrasound.* **51**: 491–497.
- 362 5. Chesen, A. B. and Whitfield-Cargile C. 2015. Update on diseases and
363 treatment of the pharynx. *Vet. Clin. North Am. Equine Pract.* **31**: 1–11.
- 364 6. Ciscar, M. A., Juan, G., Martínez, V., Ramón, M., Lloret, T., Mínguez, J.,
365 Armengot, M., Marín, J. and Basterra, J. 2001. Magnetic resonance imaging
366 of the pharynx in OSA patients and healthy subjects. *Eur. Respir. J.* **17**: 79–
367 86.
- 368 7. Downing, F. and Gibson, S. 2018. Anaesthesia of brachycephalic dogs. *J.*
369 *Small Anim. Pract.* **59**: 725–733.

- 370 8. Fiastro, J. F., Habib, M. P. and Quan, S. F. 1988. Pressure support
371 compensation for inspiratory work due to endotracheal tubes and demand
372 continuous positive airway pressure. *Chest* **93**: 499–505.
- 373 9. Fleck, R., Ishman, S. L., Shott, S. R., Gutmark, E. J., McConnell, K. B.,
374 Mahmoud, M., Mylavarapu, G., Subramaniam, D. R., Szczesniak, R. and
375 Amin, R. S. 2017. Dynamic volume computed tomography imaging of the
376 upper airway in obstructive sleep apnea. *J. Clin. Sleep. Med.* **13**: 189–196.
- 377 10. Grand, J. G. R. and Bureau, S. 2011. Structural characteristics of the soft
378 palate and meatus nasopharyngeus in brachycephalic and non-
379 brachycephalic dogs analysed by CT. *J. Small. Anim. Pract.* **52**: 232–239.
- 380 11. Hara, Y. Teshima, K., Seki, M., Asano, K. and Yamaya, T. 2020.
381 Pharyngeal contraction secondary to its collapse in dogs with
382 brachycephalic airway syndrome. *J. Vet. Med. Sci.* **82**: 64–67.
- 383 12. Heidenreich, D., Gradner, G., Kneissl, S. and Dupré, G. 2016.
384 Nasopharyngeal dimensions from computed tomography of Pugs and
385 French bulldogs with brachycephalic airway syndrome. *Vet. Surg.* **45**: 83–
386 90.
- 387 13. Huon, L. K., Liu, S. Y. C., Shih, T. T. F., Chen, Y. J., Lo, M. T. and Wang,
388 P. C. 2016. Dynamic upper airway collapse observed from sleep MRI: BMI-
389 matched severe and mild OSA patients. *Eur. Arch. Otorhinolaryngol.* **273**:
390 4021–4026.

- 391 14. Isono, S., Remmers, J. E., Tanaka, A., Sho, Y., Sato, J. and Nishino, T. 1997.
392 Anatomy of pharynx in patients with obstructive sleep apnea and in normal
393 subjects. *J. Appl. Physiol* (1985). **82**: 1319–1326.
- 394 15. Jones, B. A., Stanley, B. J. and Nelson, N. C. 2020. The impact of tongue
395 dimension on air volume in brachycephalic dogs. *Vet. Surg.* **49**: 512–520.
- 396 16. Kim, Y. J., Lee, N., Yu, J., Lee, H., An, G., Bang, S., Chang, J. and Chang,
397 D. 2019. Three-dimensional volumetric magnetic resonance imaging (MRI)
398 analysis of the soft palate and nasopharynx in brachycephalic and non-
399 brachycephalic dog breeds. *J. Vet. Med. Sci.* **81**: 113–119.
- 400 17. Laurenson, M. P., Zwingenberger, A. L., Cissell, D. D., Johnson, L. R.,
401 McPeters, M. J., Spriet, M. P., Taylor, S. L. and Pollard, R. E. 2011.
402 Computed tomography of the pharynx in a closed vs. open mouth position.
403 *Vet. Radiol. Ultrasound* **52**: 357–361
- 404 18. Liu, N. C., Troconis, E. L., McMillan, M., Genain, M. A., Kalmar, L., Price,
405 D. J., Sargan, D. R. and Ladlow, J. F. 2018. Endotracheal tube placement
406 during computed tomography of brachycephalic dogs alters upper airway
407 dimensional measurements. *Vet. Radiol. Ultrasound* **59**: 289–304.
- 408 19. Malhotra, A., Pillar, G., Fogel, R., Beauregard, J., Edwards, J. and White, D.
409 P. 2001. Upper-airway collapsibility. *Chest* **120**: 156–161.
- 410 20. Malhotra, A., Huang, Y., Fogel, R., Lazic, S., Pillar, G., Jakab, M. Kikinis,
411 R. and White, D. P. 2006. Aging influences on pharyngeal anatomy and

- 412 physiology: The predisposition to pharyngeal collapse. *Am. J. Med.* **119**:
413 72.e9–72.e14.
- 414 21. Noone, K. E. 2001. Rhinoscopy, pharyngoscopy, and laryngoscopy. *Vet.*
415 *Clin. North Am. Small Anim. Pract.* **31**: 671–689.
- 416 22. Packer, R. M. A., Hendricks, A., Tivers, M. S. and Burn, C. C. 2015. Impact
417 of facial conformation on canine health: brachycephalic obstructive airway
418 syndrome. *PLoS One* **10**: e0137496.
- 419 23. Pollard, R. E., Johnson, L. R. and Marks, S. L. 2018. The prevalence of
420 dynamic pharyngeal collapse is high in brachycephalic dogs undergoing
421 videofluoroscopy. *Vet. Radiol. Ultrasound* **59**: 529–534.
- 422 24. Rubin, J. A., Holt, D. E., Reetz, J. A. and Clarke, D. L. 2015. Signalment,
423 clinical presentation, concurrent diseases, and diagnostic findings in 28 dogs
424 with dynamic pharyngeal collapse (2008-2013). *J. Vet. Intern. Med.* **29**:
425 815–821.
- 426 25. Sarran, D., Caron, A., Testault, I., Segond, S. and Billet, J. P. 2018. Position
427 of maximal nasopharyngeal maximal occlusion in relation to hamuli
428 pterygoidei: use of hamuli pterygoidei as landmarks for palatoplasty in
429 brachycephalic airway obstruction syndrome surgical treatment. *J. Small*
430 *Anim. Pract.* **59**: 625–633.

- 431 26. Schwab, R. J., Geftter, W. B., Pack, A. I. and Hoffman, E. A. 1993. Dynamic
432 imaging of the upper airway during respiration in normal subjects. *J. Appl.*
433 *Physiol.* (1985). **74**: 1504–1514.
- 434 27. Sinclair, M. D. 2003. A review of the physiological effects of α 2-agonists
435 related to the clinical use of medetomidine in small animal practice. *Can.*
436 *Vet. J.* **44**: 885–897.
- 437 28. Yucel, A., Unlu, M., Haktanir, A., Acar, M. and Fidan, F. Evaluation of the
438 upper airway cross-sectional area changes in different degrees of severity of
439 obstructive sleep apnea syndrome: cephalometric and dynamic CT study.
440 *AJNR Am. J. Neuroradiol.* **26**: 2624–2629.

441 **FIGURE LEGENDS**

442 **Fig. 1.** The transverse CT images of the nasopharynx where dynamic CT scan
443 was performed. Sagittal (A) and transverse nasopharyngeal images are shown in
444 bone window setting (window width, 2700 HU, window level, 350 HU) at the
445 level of the caudal hard palate (B), the cranial end of the soft palate (C), defined
446 as the point where the torus palatinus discontinues, the pterygoid hamulus (D),
447 defined as the point where the pterygoid hamulus extends most ventral (white
448 arrow), the foramen lacerum (E), defined as the point where the widest canal of
449 foramen lacerum (black arrow) is shown, the bony labyrinth (F), and the caudal
450 end of the soft palate (G) where the caudal aspect of the intact soft palate (asterisk)
451 is shown.

452 **Fig. 2.** Comparison of the nasopharyngeal area variants at the level of the cranial
453 end of the soft palate (CrSP), pterygoid hamulus (PH), foramen lacerum (FL),
454 bony labyrinth (BL), and the caudal end of the soft palate (CdSP) in Beagle dogs
455 ($n = 23$). All data is presented as the mean values with error bars (95%
456 confidential intervals). The ratio of maximum cross-sectional area (rCSAmax) is
457 significantly higher at the PH than that of CrSP, and rCSAmax at the level of FL
458 is significantly higher than that of CdSP (A). rCSAmin at the level of PH is
459 significantly higher than that of CrSP. rCSAmin at the level of CdSP is
460 significantly lower than that of PH, FL, and BL (B). Nasopharyngeal

461 collapsibility at CrSP and PH levels are significantly lower than those of FL, BL,
462 and CdSP levels (C). *P*-values less than 0.05 are presented as *.

Table 1. Dimensions of the soft palate and their correlation with body weight in Beagle dogs (n = 23)

Variable	Mean $\pm$ SD	Correlation coefficient with body weight
Soft palate length (mm)	64.51 $\pm$ 4.89	0.060 ^a
Soft palate thickness (mm)	6.48 $\pm$ 1.14	0.574 ^{a, **}

a, Pearson correlation coefficient; **, P < 0.01

Table 2. Maximum and minimum nasopharyngeal cross-sectional areas and its normalization at different locations in Beagle dogs (n = 23)

Location	Nasopharyngeal CSA (mm ²)		rCSAmax	rCSAmin
	Maximum	Minimum		
CrSP	0.98 ± 0.15	0.94 ± 2.29	1.02 ± 0.10	0.99 ± 0.10
PH	1.17 ± 0.33	1.12 ± 0.32	1.22 ± 0.32	1.17 ± 0.31
FL	1.25 ± 0.52	1.13 ± 0.50	1.31 ± 0.55	1.19 ± 0.53
BL	1.13 ± 0.45	1.02 ± 0.45	1.19 ± 0.50	1.07 ± 0.50
CdSP	1.03 ± 0.44	0.84 ± 0.43	1.09 ± 0.49	0.89 ± 0.46

The data presents the mean values ± standard deviation. CSA, cross-sectional area; rCSAmax, the ratio of maximum nasopharyngeal CSA to nasopharyngeal CSA at the level of the caudal hard palate; rCSAmin, the ratio of minimum nasopharyngeal CSA to nasopharyngeal CSA at the level of the caudal hard palate; CrSP, cranial end of the soft palate; PH, pterygoid hamulus; FL, foramen lacerum; BL, bony labyrinth; CdSP, caudal end of the soft palate

Table 3. The nasopharyngeal collapsibility at each location and its correlation with body weight and dimension of the soft palate in Beagle dogs (n = 23)

Nasopharyngeal collapsibility (%)			Correlation coefficient		
Location	Median	1 st / 3 rd quartile	BW	SPL	SPT
CrSP	3.3	2.5 / 4.4	-0.073	-0.102	-0.208
PH	4.6	2.0 / 7.1	0.366	-0.347	0.427*
FL	9.2	5.3 / 12.4	0.112	-0.172	0.325
BL	10.2	6.0 / 13.4	0.499*	-0.162	0.393
CdSP	15.6	7.7 / 22.3	0.132	-0.445*	0.14

BW, body weight; SPL, soft palate length; SPT, soft palate thickness; CrSP, cranial end of the soft palate; PH, pterygoid hamulus; FL, foramen lacerum; BL, bony labyrinth; CdSP, caudal end of the soft palate; *P < 0.05

Fig. 1. The transverse CT images of the nasopharynx where dynamic CT scan was performed. Sagittal (A) and transverse nasopharyngeal images are shown in bone window setting (window width, 2700 HU, window level, 350 HU) at the level of the caudal hard palate (B), the cranial end of the soft palate (C), defined as the point where the torus palatinus discontinues, the pterygoid hamulus (D), defined as the point where the pterygoid hamulus extends most ventral (white arrow), the foramen lacerum (E), defined as the point where the widest canal of foramen lacerum (black arrow) is shown, the bony labyrinth (F), and the caudal end of the soft palate (G) where the caudal aspect of the intact soft palate (asterisk) is shown.

Fig. 2. Comparison of the nasopharyngeal area variants at the level of the cranial end of the soft palate (CrSP), pterygoid hamulus (PH), foramen lacerum (FL), bony labyrinth (BL), and the caudal end of the soft palate (CdSP) in Beagle dogs ($n = 23$). All data is presented as the mean values with error bars (95% confidential intervals). The ratio of maximum cross-sectional area (rCSAmax) is significantly higher at the PH than that of CrSP, and rCSAmax at the level of FL is significantly higher than that of CdSP (A). rCSAmin at the level of PH is significantly higher than that of CdSP. rCSAmin at the level of CdSP is significantly lower than that of PH, FL, and BL (B). Nasopharyngeal collapsibility at CrSP and PH levels are significantly lower than those of FL, BL, and CdSP levels (C). *P*-values less than 0.05 are presented as *.