수의학석사학위논문

임상적으로 정상인 개에서의 전산화단층촬영술에서 흡기와 호기시 기관지 크기의 변화에 대한 평가

Computed Tomographic Evaluation of Bronchial Collapsibility during Inspiration and Expiration in Clinically Normal Dogs

2018 년 2 월

서울대학교 대학원

수의학과 임상수의학(수의영상의학) 전공

오 다 영

수의학석사학위논문

임상적으로 정상인 개에서의 전산화단층촬영술에서 흡기와 호기시 기관지 크기의 변화에 대한 평가

Computed Tomographic Evaluation of Bronchial Collapsibility during Inspiration and Expiration in Clinically Normal Dogs

2018 년 2 월

서울대학교 대학원

수의학과 임상수의학(수의영상의학) 전공

오 다 영

Computed Tomographic Evaluation of Bronchial Collapsibility during Inspiration and Expiration in Clinically Normal Dogs

지도교수 윤 정 희

이 논문을 수의학석사학위논문으로 제출함

2017 년 10 월

서울대학교 대학원

수의학과 임상수의학(수의영상의학) 전공

오 다 영

오다영의 석사 학위논문을 인준함

2017 년 12 월

위 원 장 ______ 최 민 철 ______ (인)

부위원장 ______ 윤 정 희 ______ (인)

위 원 ______ 최 지 혜 ______ (인)

ABSTRACT

Computed Tomographic Evaluation of Bronchial Collapsibility during Inspiration and Expiration in Clinically Normal Dogs

Dayoung Oh

Major in Veterinary Clinical Sciences (Radiology)

Department of Veterinary Medicine

Graduate School

Seoul National University

Computed tomography (CT) has been generally used to diagnose bronchial collapse and bronchomalacia in humans during forced inspiration and expiration. In veterinary medicine, modalities commonly used to evaluate bronchial collapse are radiography, fluoroscopy, and flexible bronchoscopy. CT can also be used to assess bronchial collapse, but its application has not been studied in dogs. The purpose of this study was to evaluate bronchial collapsibility with CT in clinically normal dogs during forced inspiration and expiration to provide availability of CT as another diagnostic tool for bronchial collapse.

Thoracic CT images were obtained from 10 normal dogs with a 64-row multidetector CT. All scans were performed in forced inspiration and expiration. The percentage of bronchial collapsibility was defined as the inspiratory minus the expiratory dimension, divided by the inspiratory dimension. The evaluated bronchi were mainstem and lobar bronchi, and the dorsal and ventral segmental bronchi of the left cranial lobar bronchus.

Bronchial narrowing during inspiration and expiration was clearly confirmed on CT in all dogs and differences in collapsibility were found depending on the location of the bronchus. The mean bronchial collapsibility of all bronchi was 38.20±15.17%; a collapsibility of over 50% was found in the dorsal (n=7) and ventral (n=4) segmental bronchi of the left cranial lobar bronchus, and the left caudal (n=5) and right middle (n=2) lobar bronchus. The collapsibility of the dorsal segment of the left cranial lobar bronchus and left caudal lobar bronchus was statistically different from the ones in the right cranial, caudal, and accessory lobar bronchi ($P < 0.05$).

In conclusion, CT during forced inspiration and expiration can be used as a valuable modality to noninvasively assess bronchial collapse. Furthermore, because more than a 50% collapsibility was found in normal bronchi, a higher diagnostic level is recommended for detecting pathologic bronchial collapse and different criteria of bronchial collapsibility will be needed depending on the location of each bronchus.

………………………………………………………………………………………………

Keywords: bronchial collapsibility, computed tomography, forced expiration, forced inspiration, normal dogs

CONTENTS

INTRODUCTION

Bronchial collapse is a common cause of chronic cough in dogs, especially small or toy breed dogs, and related to malacic change characterized by weakness of the cartilage supporting the bronchial wall.[1-5] The imaging modalities used to diagnose bronchial collapse are radiography and dynamic fluoroscopy. But bronchi in all anatomic locations are difficult to visualize with radiography and fluoroscopy, especially in small breed dogs; furthermore, the evaluation is operator-dependent, hence not objective. Flexible bronchoscopy is regarded as a gold standard technique for the diagnosis of bronchomalacia (BM).[1-4,6] Generally, BM is confirmed by identification of more than a 50% reduction in bronchial lumen with bronchoscopy in dogs.[1,4,7,8] In humans, besides bronchoscopy, computed tomography (CT) is used to noninvasively evaluate bronchial collapse during forced inspiration and expiration or a dynamic expiratory phase, with BM being diagnosed when a luminal reduction of more than 50% is found.[8-10] However, recently an expiratory reduction of more than 50% was identified in healthy human volunteers, so it is suggested that the criteria for diagnosing BM need to be narrowed. Moreover, the bronchial collapsibility of the left and right mainstem bronchi and the bronchus intermedius differ from each other.[11]

In veterinary medicine, an evaluation of collapsibility in the trachea with CT during forced end-inspiration and expiration has been reported and normally maximum narrowing of tracheal lumen was suggested.[12] However, there has been no study using CT to assess bronchial narrowing in dogs. The application of CT to diagnose bronchial collapse in dogs is possible if inspiration and expiration are controlled.

The purpose of this study was to evaluate bronchial collapsibility using CT during forced inspiration and expiration in clinically normal dogs in order to offer availability of CT as another diagnostic tool for bronchial narrowing. We hypothesized that bronchial narrowing would be clearly identified by CT during induced respiration and that collapsibility would differ depending on the location of the bronchus, as it does in humans.

MATERIALS AND METHODS

1. Animals

All procedures and standards of animal care were approved by the Seoul National University Institutional Animal Care and Use Committees (SNU-170804-3). Ten clinically healthy beagle dogs were included in this study: 7 male (5 intact) and 3 female (2 spayed) dogs with a mean age of 4.9 years (range: 4–6 years). The dogs had no respiratory clinical signs and no history of airway disease. Inspiratory and expiratory radiographs and fluoroscopy revealed unremarkable findings and lung and heart sounds were normal. The mean body weight was 13.7 kg (range: 12.0–16.0 kg), with a mean body condition score of 5/9 (range: 4-6) and no obese dogs. All dogs were anesthetized using the following protocol: sedation with intravenous acepromazine (0.02 mg/kg), induction with intravenous alfaxalone (2 mg/kg) to the cephalic vein through an intravenous 24-gauge catheter and maintenance with isoflurane in 100% oxygen via an endotracheal tube.

2. Imaging procedure

The dogs were positioned in sternal recumbency and scan direction was from cranial to caudal. Respiration was controlled manually with a reservoir bag of the anesthetic machine. Thoracic CT images were obtained using a 64-row multidetector CT scanner (Aquilion 65; Toshiba, Japan) with the following imaging conditions: 120 kVp, 150 mAs, 0.75 sec/rotation, 1.0 mm scan slice thickness without reconstruction intervals, and 1.0 helical pitch. Two helical scans were performed on each animal; for the first scan, forced inspiration was induced by manually compressing the reservoir bag with a pressure of 20 cm H_2O to reach peak inspiration, and breath-hold was maintained until the examination terminated. The second scan was performed during forced expiration, which was accomplished by manual hyperventilation to induce a transient apnea due to decreasing end-tidal CO_2 pressure. To avoid complications due to hypocapnia, manual ventilation was applied immediately after the end of the second scan.

3. Image analysis

The bronchi were assessed at nine anatomic levels: the right (RMB) and left mainstem bronchus (LMB), the dorsal (LB1D1) and ventral segmental bronchus (LB1V1) branching out from the left cranial lobar bronchus, the left caudal lobar bronchus (LB2), right cranial lobar bronchus (RB1), right middle lobar bronchus (RB2), right accessory lobar bronchus (RB3), and right caudal lobar bronchus (RB4). For accurate evaluation of the bronchial lumen, multiplanar reconstruction (MPR) was applied, where images were reconstructed in the direction perpendicular to the long axis of each bronchial lumen near the bronchial bifurcation; this was possible as long as the bronchial wall was imaged entirely (Figure 1). On reformatted images, the cross-sectional area was measured by manual tracing of the airway luminal border with electronic calipers on forced inspiratory and expiratory images for each bronchus (Figure 2). The percentage of bronchial collapsibility between inspiration and expiration was calculated thus: $C_{lu} = 100 \cdot [1 - A_{lue} / A_{lui}]$, where C_{lu} is bronchial collapsibility, A_{lue} is luminal area at forced expiration, and A_{lui} is luminal area at forced inspiration.[11] Additionally, bronchial collapsibility was obtained from reformatted transverse, sagittal and dorsal images by measurement of the smallest diameter of each bronchus near to the bronchial bifurcation (Figure 3). All images were viewed with lung window settings (width, 1600 HU; level, −550 HU) because in this view the interface between the bronchial lumen and wall is better defined.[5,11]

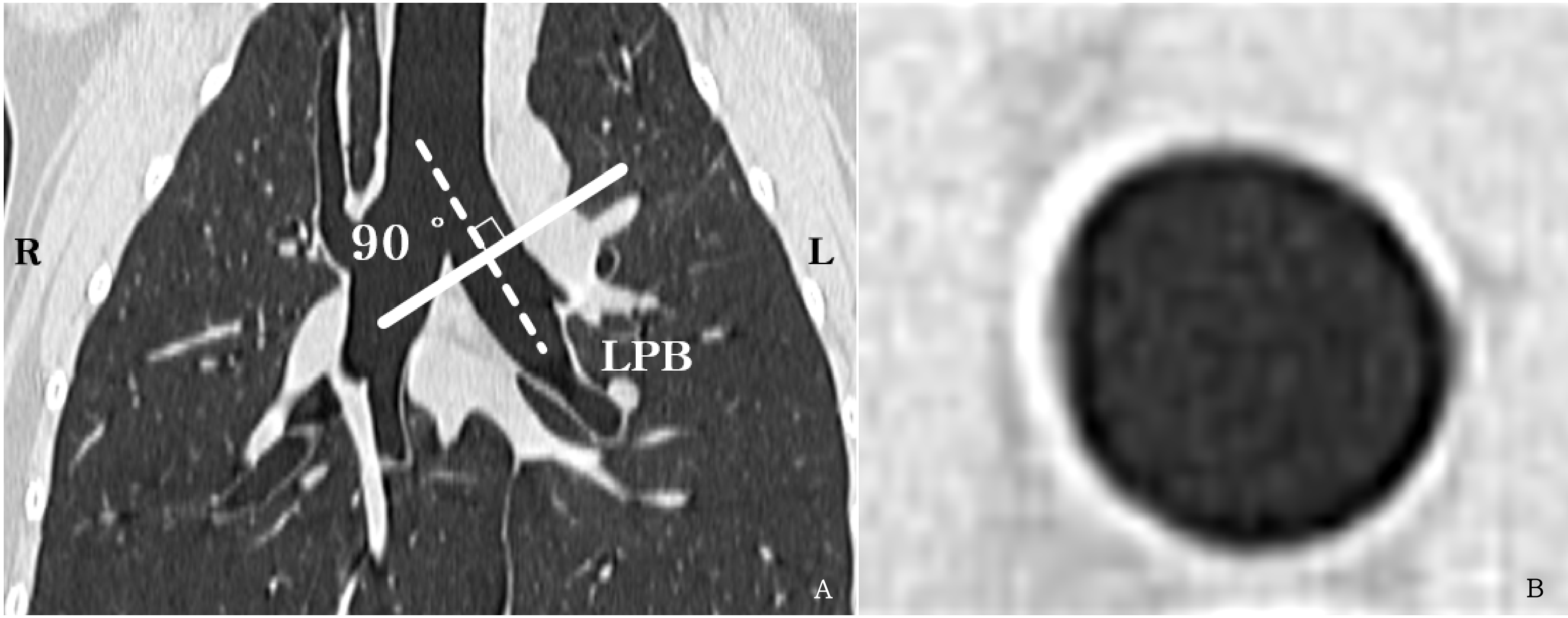

Figure 1. Dorsal (A) and cross−sectional images (B) perpendicular to the long axis of LPB. Image was reconstructed at the near location after bronchial bifurcation as long as the bronchial wall was imaged entirely at the cross−sectional area.

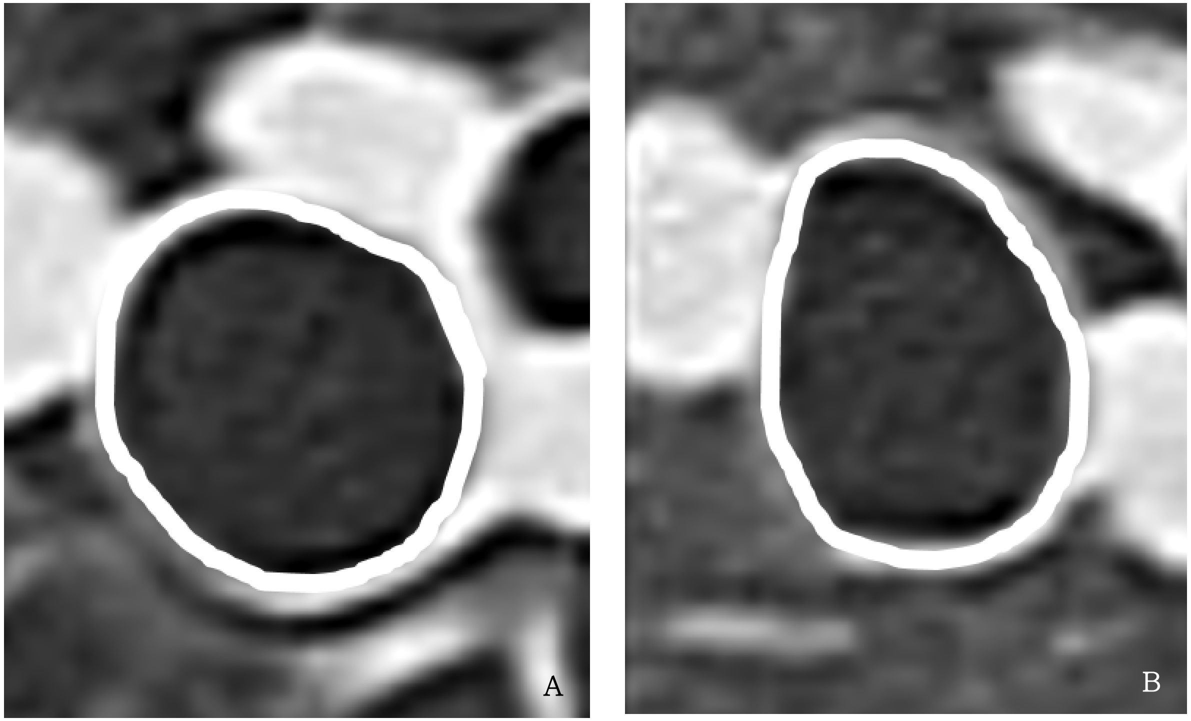

Figure 2. Cross−sectional areas of RB4 during forced inspiration (A) and expiration (B). The bronchial lumen was an oval shape in forced expiration. The bronchial dimension was measured by manual tracking of the inner aspect of bronchial wall with electronic caliper.

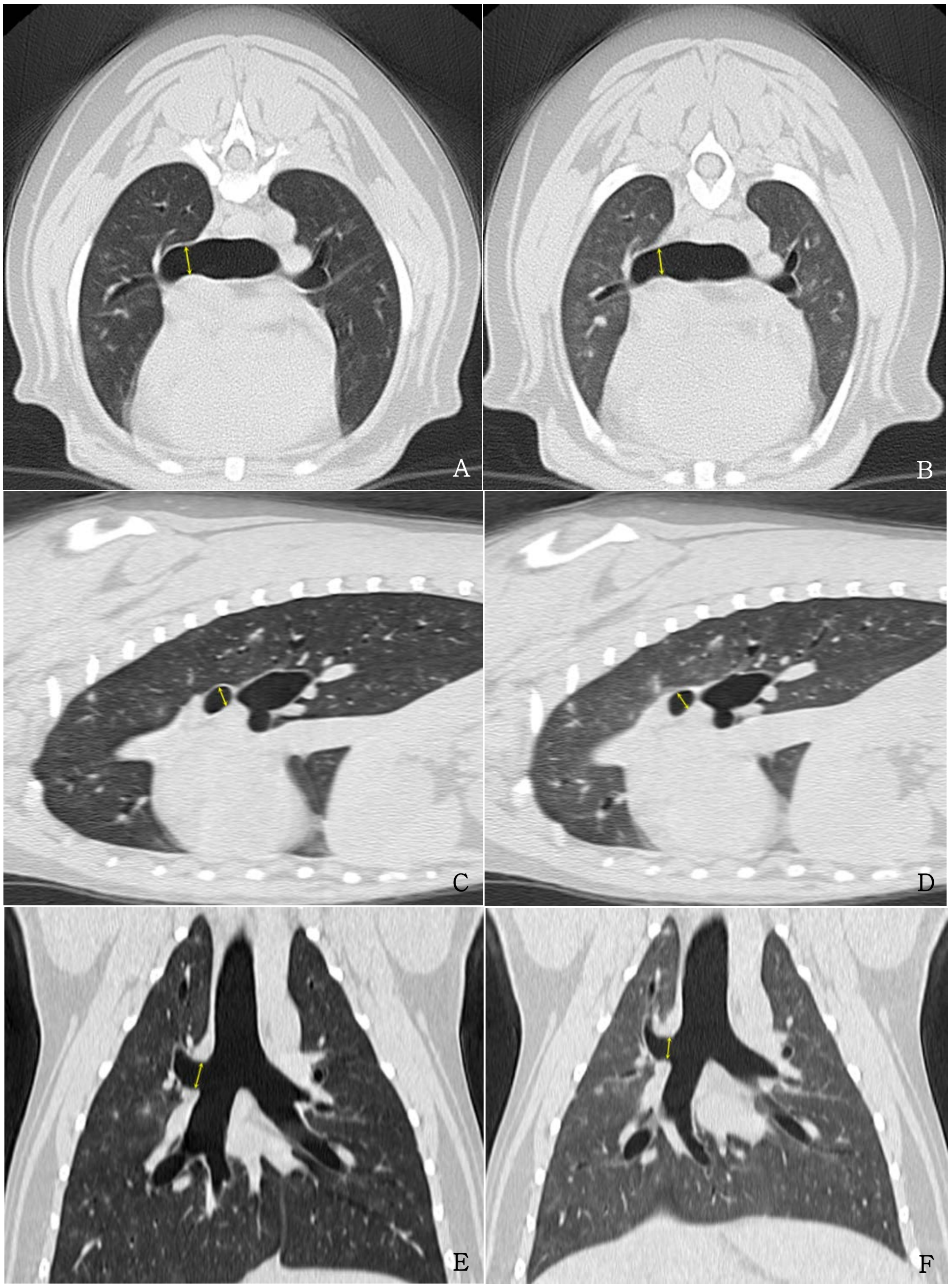

Figure 3. Images of transverse (A, B), sagittal (C, D) and dorsal (E, F) planes at RB1 level. The shortest diameters (double arrows) were measured at the nearest location of the bronchial bifurcation during forced inspiration (A, C, E) and expiration (B, D, F).

4. Statistical analysis

All data were examined for normality with the Kolmogorov–Smirnov test. To verify the statistical difference in collapsibility across bronchi, a one–way repeated measures analysis of variance was performed. Post hoc analysis was carried out with the Dunnett T3 method because equal variance was not assumed. Spearman correlation analysis was performed to determine whether the collapsibility calculated from the cross–sectional area correlated with the percentage of collapse calculated from diameters in the transverse, sagittal, and dorsal planes. Furthermore, Spearman correlation analysis was also employed to confirm the relationship between collapsibility and size of the bronchial lumen, using the cross–sectional area during forced inspiration for calculating bronchial size. The mean and standard deviation for each bronchus were calculated individually. All analyses were performed using statistical software (SPSS, version 23.0 for Windows; SPSS, Chicago, IL, USA).

RESULTS

1. Bronchial collapsibility

A total of 90 bronchial collapsibility values were obtained in 10 dogs. Each bronchus was well visualized without any motion artifacts due to respiration. The change of bronchial lumen across forced inspiration and expiration was clearly visible in all dogs in a round or oval shape on CT images, and the collapsibility values varied with the location of the bronchus and individual (Table 1, Figure 4, 5). A bronchial collapsibility of over 50% was found at LB1D1, LB1V1, LB2, and RB2, in 7, 4, 6, and 2 dogs, respectively. In LB1D1 and LB2, the mean collapsibility for all 10 dogs exceeded 50%, and the greatest change of bronchial lumen was noticed at LB1D1 (LB1D1=51.65 ± 7.79%, LB2=51.08 ± 14.18%). In addition, generally left sided bronchi collapsed more than right sided ones. All values of bronchial collapsibility calculated using reconstructed images in transverse, sagittal and dorsal planes were smaller than those calculated using cross-sectional area (Table 2).

Table 1. Mean value and range of bronchial collapsibility using cross−sectional area of nine bronchi

Relatively expiratory reduction (%)			F value / p value	Post hoc analysis (by Dunnett T3)
Bronchus	Mean ± SD	Range		
LPB	18.42 ± 12.10	−8.23 to 30.91	14.815 / 0.000	LB1D1 > LPB, RPB, RB1, RB3, RB4 LB1V1 > RPB LB2 > LPB, RPB, RB3, RB4
RPB	9.66 ± 10.31	−15.00 to 21.29		
LB1D1	51.65 ± 7.79	40.41 to 61.39		
LB1V1	40.15 ± 15.22	14.94 to 58.45		
LB2	51.08 ± 14.18	23.33 to 64.63		
RB1	29.60 ± 11.80	9.54 to 42.74		
RB2	40.77 ± 11.16	22.42 to 57.74		
RB3	29.84 ± 8.04	15.65 to 38.69		
RB4	24.32 ± 13.07	7.72 to 39.49		

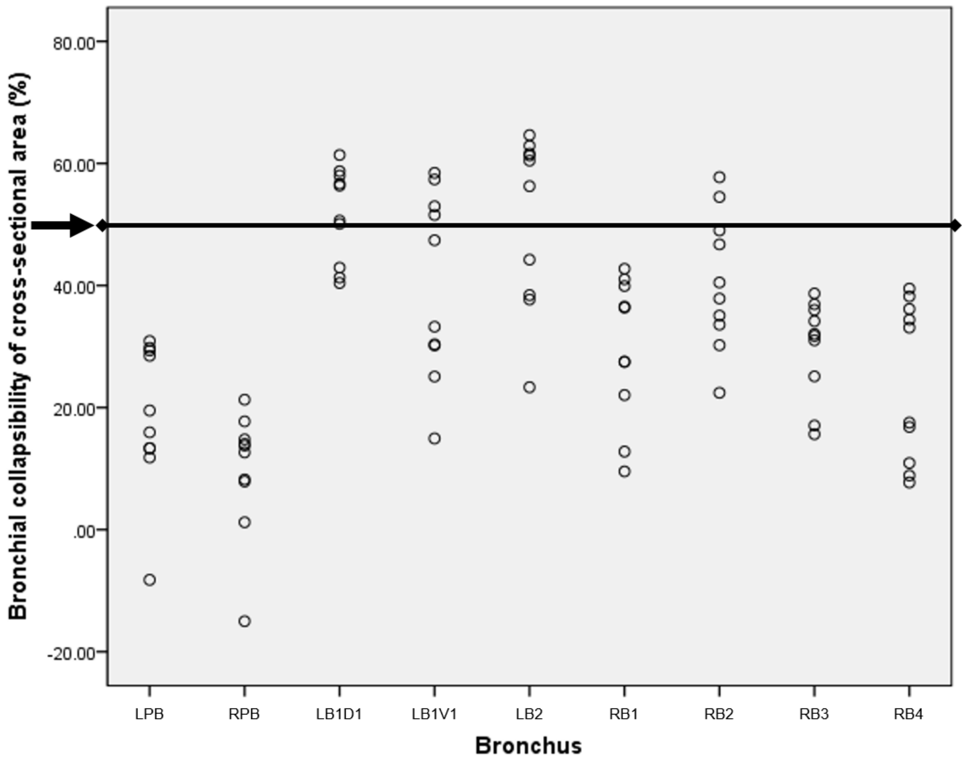

Figure 4. Scatter plot of bronchial collapsibility of cross−sectional area in nine bronchi. Arrow means 50% collapsibility and more than 50% was found in LB1D1, LB1V1, LB2 and RB2.

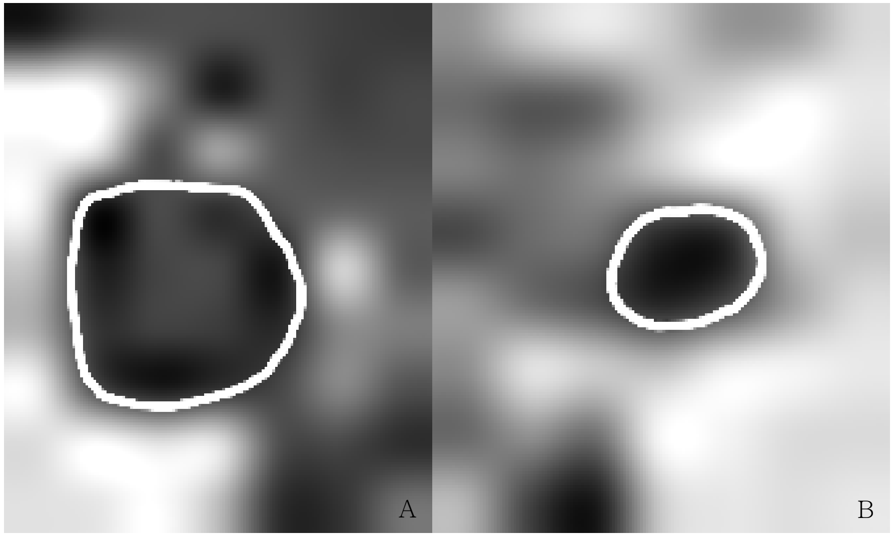

Figure 5. Cross−sectional areas of LB1D1 during forced inspiration (A) and expiration (B). Bronchial narrowing was clearly found and bronchus was round shape in forced expiration. The bronchial collapsibility was calculated as 58.01%.

Table 2. Mean value and range of bronchial collapsibility using diameters of transverse, sagittal and dorsal planes in nine bronchi

	Transverse diameter (mm)		Sagittal diameter (mm)		Dorsal diameter (mm)	
Bronchus	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
LPB	22.53 ± 12.16	4.09 to 42.11	28.87 ± 18.43	4.16 to 52.41	4.77 ± 5.96	−9.58 to 10.45
RPB	11.22 ± 10.05	−8.26 to 22.98	12.49 ± 11.65	−11.04 to 27.26	14.18 ± 6.56	2.71 to 25.23
LB1D1	31.15 ± 13.27	11.33 to 47.31	30.54 ± 9.33	18.68 to 47.16	23.56 ± 10.39	6.23 to 39.94
LB1V1	29.63 ± 8.61	17.04 to 41.83	30.78 ± 14.61	8.63 to 50.60	17.70 ± 12.28	−3.66 to 39.61
LB2	32.01 ± 11.47	13.08 to 45.60	21.74 ± 11.72	5.21 to 42.82	21.10 ± 12.07	5.91 to 39.37
RB1	22.67 ± 7.68	13.03 to 30.80	27.99 ± 6.18	16.11 to 35.99	14.70 ± 4.29	8.01 to 20.43
RB2	29.13 ± 10.79	12.41 to 49.84	25.35 ± 11.26	6.23 to 45.34	16.86 ± 10.93	3.37 to 40.93
RB3	16.21 ± 8.69	4.47 to 27.29	18.73 ± 7.39	10.32 to 34.96	15.37 ± 5.69	7.41 to 27.88
RB4	18.00 ± 11.51	1.54 to 31.39	11.72 ± 11.67	−9.77 to 29.80	20.28 ± 10.62	3.94 to 35.91

2. Statistical significance

Statistically significant differences were found between then following bronchi: between LPB and LB2, LB1D1, RB2; RPB and LB1D1, LB1V1, LB2, RB1, RB2, RB3; LB1D1 and RB1, RB3, RB4; LB2 and RB3, RB4 ($p<0.05$) (Table 1). A positive correlation between bronchial collapsibility calculated using cross-sectional area and that obtained using diameter was found in the transverse and dorsal planes, but not in the sagittal plane (transverse rho=0.850, p=0.004 and dorsal rho=0.800, p=0.010) (Figure 6). No correlation between collapsibility and bronchial size was found ($p>0.05$) (Figure 6D).

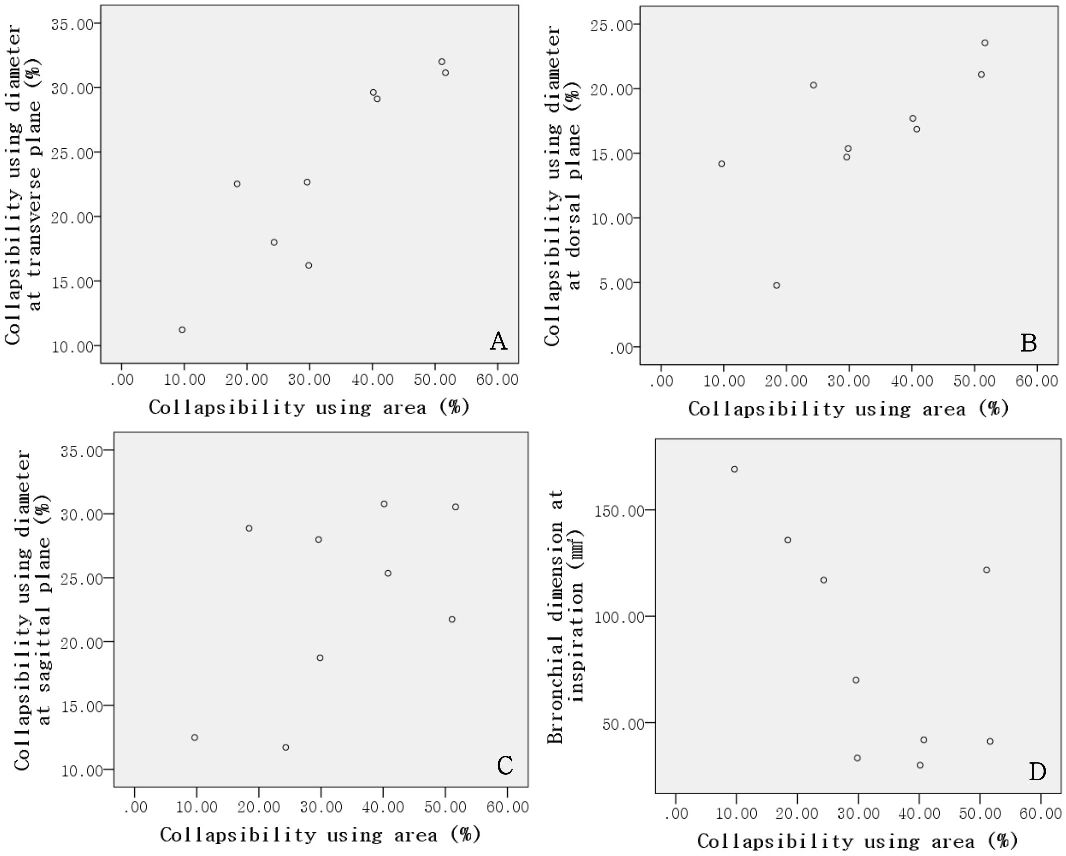

Figure 6. Scatter plots of Spearman's correlation of bronchial collapsibility between using diameters at transverse (A), dorsal (B), and sagittal planes (C) and cross-sectional areas. (D) shows Spearman's correlation between bronchial size at forced inspiration and bronchial collapsibility using cross-sectional areas. Positive correlation was found in bronchial collapsibility between using cross-sectional area and diameters in transverse (A) and dorsal (B) plane, respectively. ((A) and (B), rho=0.850, p=0.004 and rho=0.800, p=0.010, respectively)

DISCUSSION

The results of this study support the hypotheses that the collapsibility of each bronchus could be evaluated from inspiratory and expiratory CT images, and the bronchial collapsibility would differ depending on the location of bronchus, as it does in humans.

In the present study, evaluation of bronchial narrowing with CT was performed by inducing forced inspiration and expiration. In general, a pressure of 15–30 cm H_2O can inflate the lung, and pressures of 15–20 cm H_2O and 20–30 cm H_2O have been recommended for reaching peak inspiratory pressure with normal lungs in small and large animal species, respectively.[13] In general, a pressure of 15 cm H_2O has been used in dogs for end-inspiratory pressure, but could underdistend the airway enough in large breeds.[12,14] Considering that medium sized dogs were included in this study, a pressure 20 cm H_2O was thought to be acceptable to achieve peak inspiration in beagle dogs, and no pressure-related complications were found during CT scans. Forced expiration is the expiration of expiratory reserve volume in addition to tidal volume and can be induced using conscious breathing technique or cough in humans; however, the latter methods could not be applied to the dogs because of their anesthetized state during the CT examination. In present study, short-term apnea caused by low end tidal CO_2 pressure after hyperventilation was induced to trigger forced exhalation.[12,14] Because of the longer expiratory duration following the transient apnea, total expiratory volume was increased beyond the tidal volume, so that the resulting expiration was considered forced rather than simple. Since thoracic radiographic examinations were performed during simple respiration, bronchial narrowing may not have been detected despite measuring in the simple expiratory phase. With fluoroscopy, coughing can be induced, but the evaluation is operator-dependent so that a quantitative evaluation of bronchial narrowing cannot be accomplished. In contrast, with CT, bronchial narrowing could be detected by inducing forced expiration. Therefore, it can be inferred that forced respiration could induce luminal change of bronchi more strongly than simple respiration, and that a more accurate evaluation of bronchial lumen was achieved by CT than radiography or fluoroscopy.

Significant differences in bronchial collapsibility existed depending on the location of each bronchus; the bronchus with the greatest mean collapsibility was LB1D1, followed by LB2, and RB2 (Table 1). LB1D1 and LB2 showed mean bronchial collapsibility of over 50%, which was statistically significantly higher than that of the other bronchi. In dogs with tracheobronchial disease or brachycephalic syndrome, bronchial collapse is commonly accompanied and the most strongly affected bronchi were LB1D1, LB2, and RB2.[1-3,7,15,16] The results of this study are consistent with these findings in that LB1D1, LB2, and RB2 collapsed the most in normal dogs, as well as in the dogs with bronchial abnormalities; thus it seems likely that the bronchi collapse especially easily in these three locations. In addition, this study found no correlation between bronchial collapsibility and luminal size. One study found that the luminal change of the smaller bronchi is greater because they are more distensible than the larger ones.[17] In contrast, another study has shown that the smaller intrathoracic airways widen and narrow less markedly during respiration with bronchoscopy.[18] One report has demonstrated that one of the factors affecting bronchial collapse during forced expiration is location, because bronchial collapsibility relies not only on the rigidity of the bronchial wall, but also on the surrounding lung parenchyma of each bronchus.[19] The results of the present study suggest that the luminal change of bronchi during forced respiration depends on the location, not the luminal size. Therefore, different criteria should be established depending on the bronchial location when evaluating bronchial collapse using CT. Especially in the evaluation of LB1D1 and LB2, diagnostic criteria for bronchial collapse should be raised.

In this study, some bronchi narrowed more than 50% and a maximal 61.39% bronchial lumen change was detected at LB1D1 in one dog. Meanwhile, bronchial shape during expiration remained round or oval, unlike the shape of the trachea, in which the dorsal membrane develops an invagination (Figure 2b, 5b). Studies on tracheal collapsibility have reported that the percentage of expiratory reduction in tracheal cross-sectional area is as great as 24% in normal dogs, and the tracheal lumen may narrow transiently by up to 75% during forced expiration.[12,18] However, no study on the normal range of bronchial narrowing during forced expiration in dogs was found.

The pressure gradient between intrabronchial and atmospheric pressure drives the air to flow from the bronchus to the mouth during expiration. In forced expiration, contraction of the expiratory muscles supports this mechanism by increasing intrathoracic pressure;[20] the imbalance between increasing intrathoracic pressure and decreasing intrabronchial pressure induces a dynamic compression of the airway. In other words, intrabronchial pressure decreases progressively toward atmospheric pressure until intrabronchial pressure equals intrathoracic pressure. After this point, intrabronchial pressure becomes lower than intrathoracic pressure and a dynamic compression of the airway occurs at this time.[20]

It has been reported a tracheal and bronchial collapsibility of over 50% was found during forced expiration in healthy human volunteers, and the relevant studies suggested that a higher threshold of airway collapsibility is needed for diagnosing BM.[10,11,21] Another study in humans suggested that a collapsibility threshold of over 80% be applied to diagnose BM using dynamic expiratory CT.[10] The results of the present study are resemble these human studies in that exceeding a bronchial collapsibility of over 50% was present in normal dogs during forced expiration. Therefore, since BM can be underdiagnosed using the criterion of a collapsibility of over 50%, narrower diagnostic criteria should be established by further study with patients with BM.

Bronchial shape during expiration may depend on the location of smooth muscle. While a layer of smooth muscle is located dorsally in the trachea, bundles of smooth muscle exist below the cartilage all over each bronchus.[22] Because dynamic airway compression depends on the stability of the bronchial wall including not only anatomic structure and thickness but also smooth muscle, the difference in location of smooth muscle can result in the difference of compression shape between the trachea and bronchus.[10,20,23] If bronchial collapse is secondary to malacic change, the shape in collapse may be different because softened cartilage will affect the shape in addition to smooth muscle; this topic needs further study in patients with pathologic bronchial collapse.[10]

The bronchial collapsibility calculated with diameters in reconstructed transverse, sagittal and dorsal planes was smaller than that calculated with cross-sectional area, and this result is similar in humans.[11] It may be due to the fact that the images were reconstructed in the direction perpendicular to the long axis of each bronchial lumen when measuring the cross-sectional area, whereas the direction of the bronchi was not considered when measuring the diameter in the three planes. Meanwhile, the bronchial collapsibility calculated using area was correlated with that calculated using diameter at transverse and dorsal planes. In other words, if the diameter-based collapsibility in the transverse or dorsal plane is high, it can be inferred that the area-based collapsibility would be high as well. In general, reconstructed transverse, sagittal and dorsal images are obtained easily in CT examination, while a manual reconstruction process is needed additionally to gain cross-sectional images. Since positive correlations were found, measurements of diameters in the transverse and dorsal planes can indirectly predict by how much the bronchial lumen narrows. However, the correlations do not mean that the collapsibility value calculated from the diameters in the two planes can replace the area-derived value. To measure bronchial collapsibility accurately, an area-based evaluation needs to be performed.

BM can manifest either as a congenital anomaly of cartilage in the airways or as an acquired condition caused by trauma or chronic inflammation, infection, or irritation. Because it is closely associated with chronic cough and recurrent airway inflammatory disease including bronchitis and pneumonia, the diagnosis can be critical. In humans, BM has been diagnosed with CT during forced inspiration and expiration or dynamic CT during the expiratory phase.[8-11,24] In veterinary medicine, for diagnosis of bronchial collapse and airway malacic disease, plain radiography and fluoroscopy are routinely employed and flexible tracheobronchoscopy is regarded as a gold standard method.[1-4,7] However, radiography has low sensitivity to bronchial collapse and cannot differentiate between bronchial locations.[1-3] Fluoroscopy has the advantage of providing dynamic images, but detailed bronchial location is similarly hard to distinguish. In addition, evaluation using fluoroscopy is subjective, patient motion can interrupt the interpretation of images, and circumferential airway narrowing can be underestimated.[10,25] As a 3-dimensional assessment of the bronchi appears to be the most accurate way to identify bronchial collapse, the most reliable examination seems to be flexible bronchoscopy.[1,3,4] However, due to its invasiveness it can cause complications such as the accumulation of secretions, inflammation, infection, hemorrhage, pneumothorax, and pneumomediastinum, and be hard to apply in patients who have severe respiratory disease.[26] The evaluation of bronchial collapse with bronchoscopy is subjective, so the proficiency of the operator handling the endoscope can affect the diagnosis. With CT during forced inspiration and expiration, the risk of complications from the invasive procedure is greatly reduced assuming general anesthesia is accomplished safely, and objective evaluation is possible by calculating the collapsibility using an electronic caliper. Besides, a 3-dimensional assessment of the bronchi is available like in bronchoscopy, and bronchi of all locations as well with their anatomic details can be displayed. Because the results of CT examination are reported to correlate well with those from tracheobronchoscopy, it is thought that the evaluation of bronchial collapsibility by CT is as accurate and effective as endoscopy.[10]

This study defined dogs as clinically normal on the basis of no clinical respiratory symptoms, no history of respiratory disease, and unremarkable findings in radiography and fluoroscopy. By comparing bronchial collapsibility as found by CT with bronchoscopic and histopathologic findings in future studies, the relationship between changes of bronchial structure and CT imaging will be clearly identified. Because the age and body condition score of the dogs included in this study were similar, their relation with bronchial collapsibility could not be investigated. Previous studies have shown that older and more obese dogs are predisposed to BM, so further studies on the correlation between the severity of bronchial collapse as assessed by CT and age and weight are needed.[2,12] Brachycephalic dogs tend to exhibit bronchial collapse more commonly, and as the normal range of bronchial collapsibility may be different for brachycephalic breeds than for other breeds, further studies in different breeds will be required.[15]

CONCLUSION

Bronchial collapsibility could be accurately evaluated with CT during forced inspiration and expiration and was different depending on the location of the bronchus evaluated. Furthermore, in normal dogs, a 50% collapsibility of over 50% was found mainly in left sided lobar bronchi. Therefore, CT during respiration control can be another imaging modality for diagnosing bronchial collapse noninvasively and narrowed diagnostic criteria should be applied with a diagnostic threshold dependent on the location of the relevant bronchus.

REFERENCES

1. Bottero E, Bellino C, Lorenzi D, et al. Clinical evaluation and endoscopic classification of bronchomalacia in dogs. *J Vet Intern Med.* 2013;27:840–846.

2. Adamama–Moraitou KK, Pardali D, Day MJ, et al. Canine bronchomalacia: A clinicopathological study of 18 cases diagnosed by endoscopy. *Vet J*. 2012;191:261–266.

3. Johnson L, Singh M, Pollard R. Agreement among radiographs, fluoroscopy and bronchoscopy in documentation of airway collapse in dogs. *J Vet Intern Med*. 2015;29:1619–1626.

4. Della Maggiore A. Tracheal and airway collapse in dogs. *Vet Clin North Am Small Anim Pract*. 2014;44:117–127.

5. Schwarz T, Saunders J. Veterinary computed tomography. Chichester: John Wiley & Sons; 2011. 261–276 pp.

6. Won S, Lee A, Choi J, Choi M, Yoon J. Computed tomographic bronchioarterial ratio for brachycephalic dogs without pulmonary disease. *J Vet Sci*. 2015;16:221–224.

7. Johnson L, Pollard R. Tracheal collapse and bronchomalacia in dogs: 58 cases (7/2001–1/2008). *J Vet Intern Med*. 2010;24:298–305.

8. Lee EY, Boiselle PM. Tracheobronchomalacia in infants and children: multidetector CT evaluation. *Radiology*. 2009;252:7–22.

9. Baroni RH, Feller–Kopman D, Nishino M, et al. Tracheobronchomalacia: comparison between end–expiratory and dynamic expiratory CT for evaluation of central airway collapse. *Radiology*. 2005;235:635–641.

10. Murgu SD, Colt HG. Tracheobronchomalacia and excessive dynamic airway collapse. *Respirology*. 2006;11:388−406.

11. Litmanovich D, O’ Donnell CR, Bankier AA, et al. Bronchial collapsibility at forced expiration in healthy volunteers: assessment with multidetector CT. *Radiology*. 2010;257:560−567.

12. Leonard CD, Johnson LR, Bonadio CM, Pollard RE. Changes in tracheal dimensions during inspiration and expiration in healthy dogs as detected via computed tomography. *Am J Vet Res*. 2009;70:986−991.

13. Tranquilli WJ, Thurmon JC, Grimm KA. Lumb and Jones' Veterinary Anesthesia and Analgesia. Ames: Blackwell Publishing; 007. 514 p.

14. Makara M, Dennler M, Schnyder M, et al. Effect of ventilation technique and airway diameter on bronchial lumen to pulmonary artery diameter ratios in clinically normal beagle dogs. *Vet Radiol Ultrasound*. 2013;54:605−609.

15. 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.

16. Stadler K, Hartman S, Matheson J, O'brien R. Computed tomographic imaging of dogs with primary laryngeal or tracheal airway obstruction. *Vet Radiol Ultrasound*. 2011;52:377−384.

17. Marshall R. Effect of lung inflation on bronchial dimensions in the dog. *J Appl Physiol*. 1962;17:596−600.

18. Tams TR, Rawlings CA. Small Animal Endoscopy. St. Louis: Mosby; 2010. 342−344 pp.

19. Takishima T, Sasaki H, Sasaki T. Influence of lung parenchyma on collapsibility of dog bronchi. *J Appl Physiol*. 1975;38:875-881.

20. Zach M. The physiology of forced expiration. *Paediatr Respir Rev*. 2000;1:36-39.

21. Boiselle PM, O'Donnell CR, Bankier AA, et al. Tracheal collapsibility in healthy volunteers during forced expiration: assessment with multidetector CT. *Radiology*. 2009;252:255-262.

22. Bacha Jr WJ, Bacha LM. Color Atlas of Veterinary Histology. Chinchester: John Wiley & Sons; 2012. 195-201 pp.

23. Rayl JE. Tracheobronchial collapse during cough. *Radiology*. 1965;85:87-92.

24. Gaeta M, Minutoli F, Girbino G, et al. Expiratory CT scan in patients with normal inspiratory CT scan: a finding of obliterative bronchiolitis and other causes of bronchiolar obstruction. *Multidiscip Respir Med*. 2013;8:44.

25. Nafe LA, Robertson ID, Hawkins EC. Cervical lung lobe herniation in dogs identified by fluoroscopy. *The Can Vet J*. 2013;54:955.

26. Rha J-Y, Mahony O. Bronchoscopy in small animal medicine: indications, instrumentation, and techniques. *Clin Tech Small Anim Pract*. 1999;14:207-212.

국문초록

임상적으로 정상인 개에서의 전산화단층촬영술에서 흡기와 호기시 기관지 크기의 변화에 대한 평가

오 다 영

서울대학교 대학원

수의학과 임상수의학 (수의영상의학) 전공

강제 흡기와 호기시의 전산화단층촬영술은 인의에서 일반적으로 기관지 허탈 및 기관지연화증의 진단에 사용된다. 수의에서 이러한 질환을 진단하는 가장 일반적인 방법은 방사선 검사와 투시 검사이며, 기관지 내시경이 가장 정확한 진단 방법으로 간주된다. 전산화단층촬영술도 기관지 허탈의 진단에 있어 사용이 가능하나, 이에 대한 자세한 연구는 보고된 바가 없다. 인의에서 적용하는 방법을 수의에도 적용한다면

전산화단층촬영술 역시 기관지 허탈에 대한 하나의 유용한 진단 방법으로 사용될 수 있을 것이라 판단된다. 따라서 이번 연구의 목적은 정상 개에서의 강제 흡기와 호기시 전산화단층촬영술에서 기관지 허탈율을 평가하는 것이다. 본 연구에서는 전산화단층촬영술을 통해 정상적인 기관지 허탈이 명확하게 확인될 것이며, 기관지의 위치별로 허탈율이 다르게 확인될 것이라는 점을 가정하였다.

총 10 마리의 건강한 비글견에서 64 열 다검출기 전산화단층술을 통해 흉부 촬영을 진행하였다. 20 cm H_2O 로 압력을 가한 채 강제 흡기 촬영이 진행되었으며, 과호흡 후 일시적인 무호흡 상태를 유발한 채 강제 호기 촬영이 진행되어 총 2 번의 촬영이 이루어졌다. 기관지 허탈율은 강제 흡기시와 강제 호기시의 면적 차를 강제 흡기시 면적으로 나눈 비율로 정의하였다. 평가에 포함된 기관지는 좌, 우측 주기관지와 우측 전엽, 중엽, 후엽, 덧엽 기관지, 좌측 후엽 기관지, 좌측 전엽의 배측과 복측 구역기관지가지로 총 9 개의 영역이었다.

기관지는 전산화단층촬영술을 통해 흡기와 호기시 내강의 좁아짐이 명확하게 확인되었으며 허탈율은 기관지의 위치마다 다르게 확인되었다. 총 기관지의 허탈율은 평균 38.20±15.17% 였으며 50%를 넘는 허탈율을 보이는 기관지는 좌측 전엽의 배측 (7 마리)과 복측 (4 마리) 구역기관지가지, 좌측 후엽 (5 마리), 그리고 우측 중엽 기관지 (2 마리)가 있었다. 좌측 전엽의 배측 구역기관지가지와 좌측 후엽 기관지는 우측의 전엽, 후엽, 그리고 덧엽 기관지와 통계학적으로 차이를 보였다 ($P<0.05$). 또한 기관지가 허탈되는 형태는 모두 둥글거나 타원형 형태를 보였다.

결론적으로, 강제 흡기와 호기시 전산화단층촬영술은 기관지 허탈 평가에 있어 비침습적인 하나의 진단 방법으로 이용할 수 있을 것으로

생각된다. 더불어 정상적으로 50% 이상의 허탈율이 확인되는 기관지가 존재하는 바, CT 상 병적인 기관지 허탈은 더 높은 진단 기준이 필요할 것이며, 그 기준은 위치별로 다르게 적용되어야 할 것이다.

....

주요어: 기관지 허탈율, 전산화단층촬영술, 강제 호기, 강제 흡기, 정상개