Original Article

Morphological and Morphometric Variations of the Tympanic Bulla Between Domestic Shorthair and Brachycephalic Cats Utilizing Computed Tomography

Naparee Srisowanna[1,2] Damri Darawiroj[3] Nan Choisunirachon[4]

Chutimon Thanaboonnipat[4] Sirinun Pisamai Tabtieang[4*]

Abstract

Tympanic morphology of the dogs was reported to be varied due to the characteristics of the skull types. The small tympanic bulla is normally seen in brachycephalic dogs. However, this variation in narrowed-skull shaped cats has not been unveiled yet. The objective of this study was to describe the tympanic morphology of cats between brachycephalic and domestic shorthair (DSH) cats. Computer tomography (CT)-skull images of 15 domestic shorthair cats and 11 brachycephalic cats were evaluated for tympanic dimension on transverse and dorsal planes and the tympanic bone thickness. All parameters were compared between both groups. The results revealed that all tympanic parameters measured from the transverse and dorsal CT images were comparable between groups ($P > 0.05$) except the tympanic bone thicknesses. The result showed that the tympanic bone thickness of the brachycephalic cats was significantly thicker than that of the DSH cats (0.13 ± 0.02 vs 0.10 ± 0.01 cm, $P = 0.0005$). In conclusion, the present study provides information on CT tympanic morphology between the brachycephalic and DSH cats. Contrast this to the dog's information, skull type was not an effect on tympanic bullae dimension but played a major role on the tympanic bone thickness. This information could be useful during the interpretation of the tympanic bullae related lesion on the CT images.

Keywords: brachycephalic cat, computer tomography, dimension, domestic short hair, tympanic bulla

[1]*The Small Animal Hospital, Faculty of Veterinary Science, Chulalongkorn University, 10330, Bangkok, Thailand*
[2]*Department of Anatomy, Faculty of Veterinary Medicine, Kasetsart University, 10900, Bangkok, Thailand*
[3]*Department of Anatomy. Faculty of Veterinary Science, Chulalongkorn University, 10330, Bangkok, Thailand*
[4]*Department of Veterinary Surgery. Faculty of Veterinary Science, Chulalongkorn University, 10330, Bangkok, Thailand*
***Correspondence**: Sirinun.p@chula.ac.th* (S.P. Tabtieang)

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Introduction

Middle ear effusion is characterized by fluid filling in the tympanic bullae, which is caused by multifactorial etiologies resulting in eustachian tube dysfunction (Milne *et al.*, 2020; Krainer and Dupré, 2021). Head and neck pain, head shaking, hearing impairment, and neurologic disease, including facial nerve paralysis, Horner syndrome, and vestibular syndrome, are clinical appearances of middle ear disease (Paterson, 2017; Belmudes *et al.*, 2018). However, some patients may be asymptomatic (Owen *et al.*, 2004; Guerin *et al.*, 2015; Salgüero *et al.*, 2016; Mielke *et al.*,2017). Although middle ear effusion can occur in any sex, age, and breed, brachycephalic breeds are more likely to be affected (Owen *et al.*, 2004; Hayes *et al.*, 2010; Foster *et al.*, 2015; Mielke *et al.*, 2017). In cats, middle ear effusion is commonly found concurrent with upper respiratory diseases such as rhinitis, inflammatory polyps, nasal tumors, and soft palate abnormalities (Gotthelf, 2004; Detweiler *et al.*, 2006; King *et al.*, 2007; Woodbridge *et al.*, 2012; Schuenemann *et al.*, 2022). According to the previous report, cats with the sinonasal disease showed a higher prevalence of bulla effusion than cats without the sinonasal disease (Detweiler *et al.*, 2006; Shanaman *et al.*, 2012; Mascarenhas, 2022). However, there is no information that revealed an association among sinonasal disease, bulla effusion, and tympanic bulla morphology in brachycephalic cats.

In contrast to cats, middle ear effusion in brachycephalic dogs, related to numerous complex anatomical features of the skull morphology, including auditory structures (Salgüero *et al.*, 2016; Mielke *et al.*, 2017; Krainer and Dupré, 2021) has been reported. This variance could result from the excessive proliferation of soft tissue and bone structures inside a small skull (Grand and Bureau, 2011). The thickening of the tympanic bulla wall and the small size of the tympanic cavity volume are two primary risk factors for eustachian tube dysfunction or obstruction, which results in middle ear disease in brachycephalic dogs (Foster *et al.*, 2015; Salgüero *et al.*, 2016, Mielke *et al.*, 2017). Several studies have revealed that brachycephalic dogs, particularly those with brachycephalic airway obstruction syndrome, have a higher prevalence of middle ear effusion without clinical manifestation than mesaticephalic and dolichocephalic breed dogs (Owen *et al.*, 2004; Hayes *et al.*, 2010; Mielke *et al.*, 2017; Krainer and Dupré, 2021; Schuenemann *et al.*, 2022). The reason may be associated with a thickened soft palate in bulldogs, French bulldogs, and pugs, as well as in Cavalier King Charles spaniels (CKCS) (Hayes *et al.*, 2010; Salgüero *et al.*, 2016). In addition, decreasing nasopharyngeal dimension and small size with flattening shape of tympanic bulla in CKCS correlated with otitis media effusion (Hayes *et al.*, 2010; Mielke *et al.*, 2017). While these reports described canine middle ear effusion associated with congenital variation of brachycephalic skull conformation, particularly tympanic bulla malformation (Salgüero *et al.*, 2016; Hayes *et al.*, 2010; Mielke *et al.*, 2017). There is no related information on short-headed cats.

The middle ear canal and tympanic bulla can be examined using a variety of techniques, such as an otoscope, radiograph, ultrasound, computer tomography (CT), and magnetic resonance imaging (MRI) (King *et al.*, 2007). However, the gold standard for otitis media diagnosis is the histological finding of tissue inflammation in the middle ear canal (Rohleder *et al.*, 2006). As a result, it could be challenging to diagnose whether middle ear disease is present. While CT is a more efficient and superior imaging tool for investigating bone features like the tympanic bulla (Foster *et al.*, 2015), MRI is increasingly employed to look for abnormalities in the skull and provides incredibly valuable information about the soft tissue structure of the ear canal. In comparison to the radiography and sonography, CT is the most accurate and trustworthy diagnostic imaging technique (Rohleder *et al.*, 2006; King *et al.*, 2007).

To the best of our knowledge, there is no research regarding tympanic variation in brachycephalic cats. Therefore, in this study, we hypothesized that the tympanic bulla dimension, including the tympanic bone thickness of brachycephalic cats, would differ from those of domestic shorthair (DSH) cats. Besides, the prevalence of subclinical middle ear disease would be more detected in the brachycephalic cats than in the domestic shorthair cats.

Materials and Methods

Study design: This study was conducted as a retrospective study using the previous CT images of the normal head and neck cats that attended for other, previous research (Klaengkaew, *et al.*, 2021; Thammasiri *et al.*, 2021; Yuwatanakorn *et al.*, 2021). All previous studies were approved by the institutional guidelines and conformed to the Chulalongkorn University Animal Care and Use Committee (CU-ACUC), approval number 1631073, 1831094, and 1931039.

Animals: Due to the retrospective nature, instead of the animal, the pre-contrast enhanced CT images of the included cats were used in this study. All CT images were obtained by the 64-slice, helical CT scanner (Optima CT 660, General Electric, Japan at 120 kVp and automated mA. The field of view for all scans was set to cover all the cat's body. The other parameters were 1.25-mm of slice thickness, 1.25 mm of slice interval, collimator pitch at 0.969, and matrix size of 512 x 512. The inclusion criteria of the included samples were the good quality of CT images of the normal cats. Those cats must be over 1 year of age. The CT data were excluded if the CT images unveiled the lesion at the sinonasal, ear, brain, and adjacent area around the tympanic bulla. Furthermore, if the history of the cats indicated that the cats had the vestibular sign, CT data were excluded. All clinical demographic information data of included cats such as age, sex, and body weight were recorded.

Methods: The CT images of the cats were retrieved from the Picture Archiving and Communication System (PACS) in the Digital and Communications in Medicine (DICOM) format. Subsequently, data were analyzed using the DICOM viewer software (Osirix, Geneva, Switzerland) on a non-CT unit workstation and 2560 x 1440 pixel-monitor. The CT images, at first, multiplanar reconstruction was performed to adjust the alignment of the skull and tympanic bulla. In brief, the tympanic bulla of both sides must be symmetrical and reveal the widest dimension. After that, the following parameters were evaluated using digital calipers on the bone window display using 1500 Hounsfield Units (HU) of window width and 300 HU of window level (Mielke *et al.*, 2017).

(i) Skull index: Skull index was the ratio between the skull width to the skull length. While the skull length was the distance between the most rostral point of the inter-incisive suture of the alveolar process of the maxilla to the most caudal midline point of the external occipital protuberance of the skull. The skull width was the distance between the most lateral margin of the right and the left zygomatic arch.

(ii)Tympanic bulla width: Tympanic bulla width was measured on 2 CT image planes. Tympanic bulla widths on both transverse and dorsal planes were measured at the maximal internal dimension at the level of the tympanic membrane, extending to the inner bony meatus (Fig. 1).

(iii)Tympanic bulla height: Tympanic bulla height was measured on the transverse plane, which was the maximal internal dimension 90 degrees perpendicular to the tympanic bulla width (Fig. 2).

(iv)Tympanic bulla length: Tympanic bulla length was measured on the dorsal plane, which was the maximal internal dimension 90 degrees perpendicular to the tympanic bulla width (Fig. 3).

(v)Tympanic bulla thickness: Tympanic bulla thickness was measured on the transverse plane, which was the thickness of the most ventral, perpendicular tympanic bone (Fig. 4).

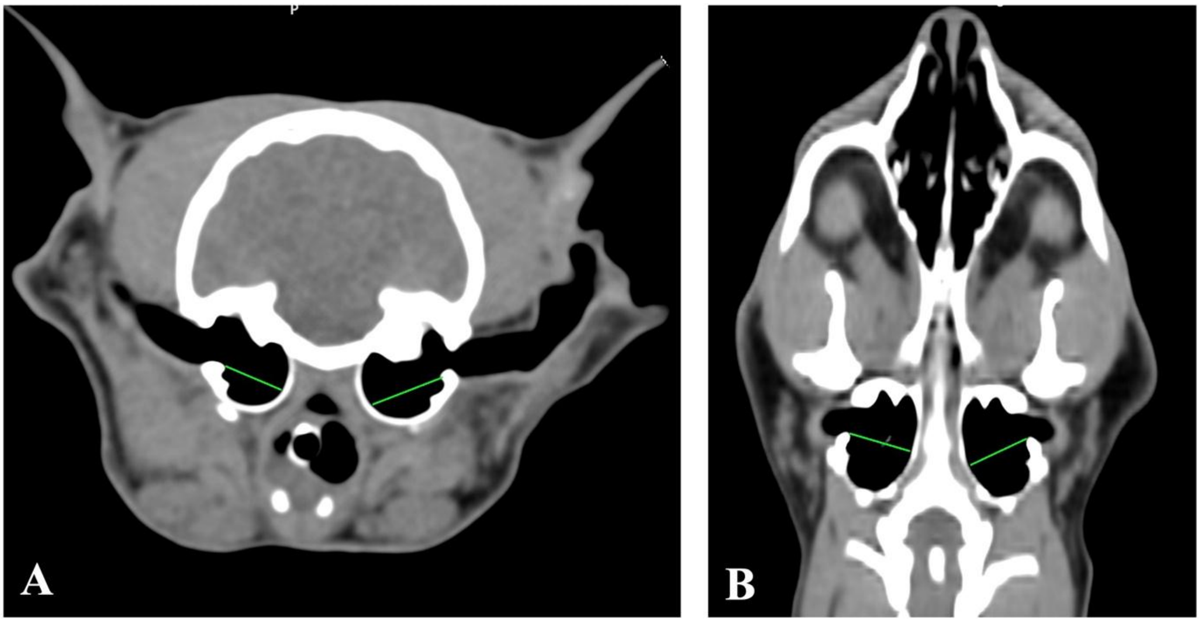

Figure 1 CT images depict tympanic bulla width measurement (green line) in the transverse plane (A) and dorsal plane (B).

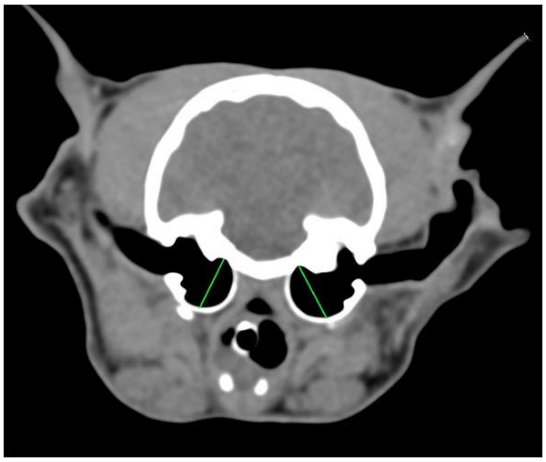

Figure 2 A CT image depicts tympanic bulla height measurement (green line) in the transverse plane.

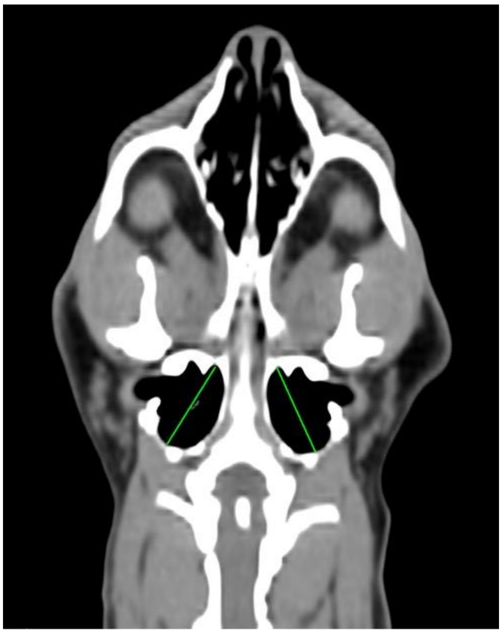

Figure 3 A CT image depicts tympanic bulla length measurement (green line) in the dorsal plane.

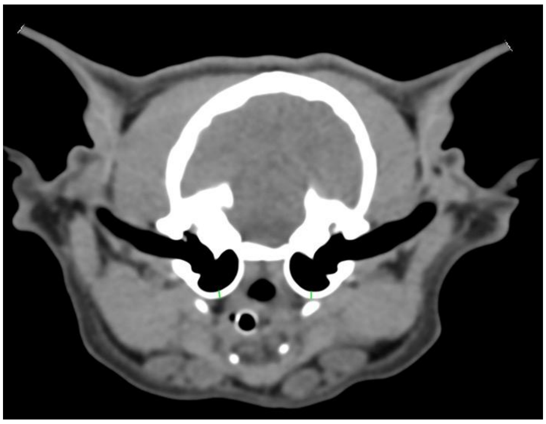

Figure 4 A CT image depicts tympanic bulla thickness measurement (green line) in the transverse plane.

Statistical analysis: Statistical analyses were performed by GraphPad Prism 10 software (GraphPad Software; CA; USA). Results were expressed as mean ± standard deviation (SD). Normality distributions were tested with the Shapiro–Wilk test. The average value results between left and right tympanic bone thickness in each group were analyzed by paired t-test. The average tympanic bone thicknesses were compared between groups by the Mann Whitney test. Pearson's correlation coefficient and Spearman's correlation coefficient were used to investigate the correlations between parameters. Statistical significance was considered if the P value was less than 0.05.

Results

A total of 11 brachycephalic cats and 15 DSH cats were included in this study. The mean ages of the brachycephalic cats and DSH were 5.09 ± 3.83 years (median 3 years; range 1 – 12 years) and 6.20 ± 3.80 years (median 5 years; range 1 – 12 years), respectively. There were 4 females (1 intact and 3 neutered) and 7 males (2 intact and 5 neutered) in the brachycephalic group, and there were 13 females (2 intact and 11 neutered) and 2 males (2 neutered) in the DSH group. The mean bodyweight of the brachycephalic group was 3.51 ± 0.85 kg (range 2 – 4.7 kg), while the mean body weight of the DSH group was 3.87 ± 0.85 kg (range; 2.6 – 5.0). The brachycephalic group consisted of Persian (7), Scottish fold (2), and British Shorthair (2). The age and body weight of included cats in both groups are comparable.

For the tympanic parameters including skull index, tympanic bulla width, tympanic bulla height and tympanic bulla length results, the brachycephalic group had significantly higher skull index value than that of the DSH group (P = 0.0008) (Fig. 5). The tympanic bulla width, tympanic bulla height and tympanic bulla length between the right and the left sides in each cat were not significantly different. Both tympanic bulla width and tympanic bulla length measured on the dorsal plane of cats in the DSH group were significantly higher than those of cats in the brachycephalic group (P = 0.015 and P = 0.0237, respectively). However, other tympanic parameters were not significant differences between groups.

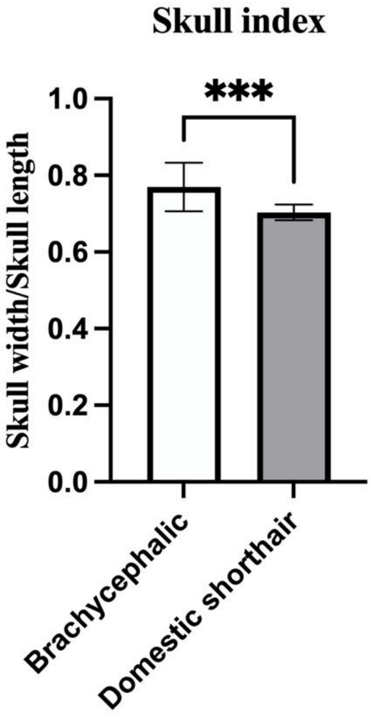

Figure 5 Bar graph showing the average skull index of brachycephalic breeds and domestic shorthair cats (mean ± SD). (asterisk: Significant difference was detected)

The tympanic bulla thickness between the right and the left sides of each cat was not significantly different. Interestingly, the tympanic bulla thickness of cats in the brachycephalic group was significantly higher than that of the DSH group (P = 0.0005) (Fig.6 and 7).

For the correlations between age and body weight with all tympanic parameters and tympanic thickness, no significant correlation was presented. In the context of nasal disorders associated with effusion of the tympanic bulla, our study found only one cat from each brachycephalic group (1 out of 11) and domestic shorthair group (1 out of 15) exhibited a confluence of tympanic bulla effusion and concurrent sinonasal disease.

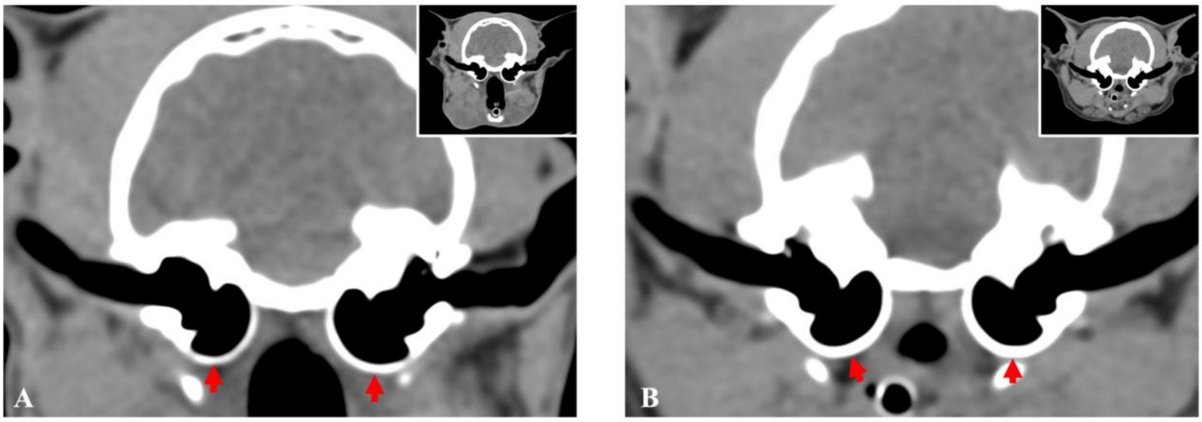

Figure 6 CT images depict varying tympanic bulla thickening (red arrow) in a domestic shorthair (A) and a brachycephalic cat (B).

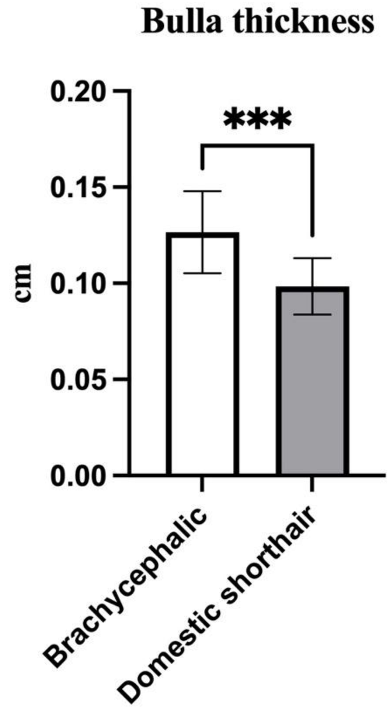

Figure 7 Bar graph showing the average bulla thickness of brachycephalic breeds and domestic shorthair cats (mean ± SD). (asterisk: Significant difference was detected.)

Discussion

Dimensions of tympanic bullae, a part of the temporal bone that contains middle ear components (tympanic cavity), were compared in brachycephalic and normocephalic (DSH) cats in this study. Both groups of mature cats with comparable (2-5 kg) body weight were employed to reduce the related factors compromising the study. The left and right tympanic bullae were also compared to rule out the individual variation. The present study used CT images to reveal the tympanic parameters of cats with different head shapes. The skull index was performed in this study to ensure the structural differences between brachycephalic and normocephalic in the case of an undistinguishable form of the head of mixed breed cat. Our findings show a significant difference in the skull length and skull width between brachycephalic and DSH cats. A previous study on the association between respiratory disease and brachycephalic cats was reported (Farnworth *et al.*, 2016). The study by Detweiler *et al*. (2006) suggested that there was a correlation between sinonasal disease and bulla effusion in cats. Sinonasal diseases, such as chronic rhinosinusitis, can cause inflammation and mucous production, leading to the obstruction of the Eustachian tube. Consequently, the accumulation of fluid in the middle ear can result in bulla effusion. Therefore, a study on the relationship between sinonasal disease and bulla effusion will be essential for understanding the complex interplay between various anatomical structures and disease processes in brachycephalic cats.

There was a significant disparity in tympanic bone thickness between brachycephalic cats and DSH cats in the study. Specifically, the tympanic bullae bone in brachycephalic cats was notably thicker than those of DSH cats. Similarly, a previous study conducted on dogs demonstrated a higher tympanic bulla wall thickness in brachycephalic breeds. However, the study did not find a significant association between tympanic bulla wall thickness and evidence of middle ear effusion (Mielke *et al*., 2017). However, the internal structures of dog and cat tympanic bullae were different, such as the appearance of a thin bony septum that incompletely separates the tympanic cavity into two portions in cat, whereas none of such septum was shown in dogs. Consequently, additional investigations are necessary to explore the potential correlation between middle ear effusion and tympanic bulla thickness in cats. Furthermore, it is essential to investigate the narrowing of the ear canal among different feline skull types, as this evidence has been previously reported in brachycephalic dogs (Töpfer *et al*., 2022).

CT is a valuable diagnostic tool that should be a crucial part of the investigative process for middle ear disease in cats. In particular, CT images allow for the visualization and assessment of bone changes in the tympanic bulla (Garosi *et al*., 2003; Belmudes *et al*., 2018). Its utilization enables accurate and detailed assessment of the severity of middle ear lesions, aiding practitioners in determining the most appropriate management approach for affected cats. By providing high-resolution cross-sectional images of the skull and middle ear structures, CT scans offer valuable insights into the extent of pathology, such as the presence of fluid accumulation, thickening of the tympanic bulla walls, and the integrity of surrounding tissues. Nevertheless, MRI offers superior contrast resolution for visualizing soft tissue changes compared to CT (Garosi *et al*., 2003; Bischoff and Kneller, 2004). In conclusion, CT imaging is a valuable tool for visualizing bone changes of the tympanic bulla in cats with middle ear disease. Its ability to provide precise and detailed images enhances diagnostic accuracy, leading to better treatment decisions and improved outcomes for affected felines, including surgical interventions.

Conflicts of interest: There is no conflict of interest in this research study.

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Authors' contribution: NS, SPT, and NC conceived the ideas of the study; DD and CT performed the analyses; NS, DD, NC, CT, and SPT wrote the manuscript; NS and SPT were major contributors in writing the manuscript, and all other authors commented on the manuscript. All authors read and approved the final manuscript.

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