Vet Dermatol 2022; **33**: 214–220 DOI: 10.1111/vde.13067

Brachycephaly in French bulldogs and pugs is associated with narrow ear canals

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Background – Brachycephalic dog breeds have multiple skull malformations which may lead to anatomical changes in the external auditory canal. It is our frequent observation that in the otoscopic examination of the external ear in these breeds we are unable to visualise the tympanic membrane as a consequence of extreme narrowing of the proximal ear canal. Additionally brachycephalic dogs reportedly are predisposed to otitis externa (OE) and otitis media.

Objectives – To characterizse the transition of the cartilaginous ear canal to the bony meatus acusticus externus using computed tomography (CT) and to investigate a possible association with OE in brachycephalic dogs.

Materials and methods – Seventy-five client-owned dogs [pugs (n = 20), French bulldogs (n = 55)] were included and assessed for OE using an owner questionnaire and otoscopic and cytological examinations. In dorsal plane CT scans, the diameter of the porus acusticus externus was measured using novel methodology. The results were compared with a normocephalic control group without preexisting otological disorders.

Results – Brachycephalic dogs had a significantly smaller porus acusticus externus diameter (2.6 mm) than normocephalic dogs (5.0 mm). Of the brachycephalic dogs, 32% had OE yet this was not statistically significantly related to the diameter of the porus acusticus externus. Middle ear effusion (44%) and narrowing of the external ear canal (82.6%) were significantly more frequent in brachycephalic dogs. Only five of 150 eardrums could be visualised otoscopically.

Conclusions and clinical relevance – Malformation of the porus acusticus externus causes severe stenosis of the proximal ear canal in brachycephalic dogs. A connection between stenosis of the external auditory canal and OE could not be confirmed.

Introduction

Upper airway obstruction has been described frequently in brachycephalic dogs. These breeds have several abnormalities of the skull, including deformities of the nasal cavity, frontal sinus and orbita.[1-4] Several studies have demonstrated that brachycephalic syndrome involves more than the upper respiratory tract, and includes the spine, skin, eyes and teeth.[5-8] In addition, brachycephalic dogs appear to be predisposed to fluid accumulation in the tympanic bullae.[9] Computed tomography (CT) and magnetic resonance imaging (MRI) examinations of the head in bulldogs and pugs frequently have detected subclinical tympanic bulla changes,[10-12] with a reported prevalence of ≤36%.[13] French bulldogs (FB) and pugs have more rostrally located tympanic bullae, with thicker walls and a smaller volume than other breeds.[14]

Little is currently known about whether the described anatomical changes also extend to the external auditory canal. Otoscopic examination of these breeds repeatedly has shown extreme narrowing of the external auditory canal and problems with eardrum visualisation (Figure 1).[15] These changes repeatedly have been found in both symptomatic and asymptomatic dogs in our clinic. Unfortunately, these changes complicate the diagnosis of middle ear diseases and the treatment of inflammation in the external ear canal, because, for example, myringotomy is not possible under video-otoscopic view. Therefore, it is important to determine the anatomical cause of the stenosis.

The prevalence of otitis externa (OE) in dogs ranges from 10 to 20%; however, in brachycephalic dogs, the percentage appears to be significantly higher.[16,17] The causes of ear disease usually are multifactorial [17] and it is unclear how significant a factor stenosis of the ear canal is in these breeds.

The objectives of the present study were as follows: (i) to evaluate the acoustic meatus in brachycephalic dog breeds, particularly the porus acusticus externus, using CT images, and to compare these findings with a group of normocephalic dogs, and (ii) to determine the presence of and possible association with OE by means of otoscopic and cytological findings.

Accepted 21 December 2021

Sources of Funding: This project was entirely self-funded and independent of commercial input.

Conflict of Interest: No conflicts of interest have been declared. By answering the questionnaire, all owners have agreed to become part of the study. Ethical approval was not required because computed tomography and the entire otological examination are part of our standard work-up for the brachycephalic syndrome. Parts of this paper were presented at the annual DVG congress, Berlin, Germany, 2017.

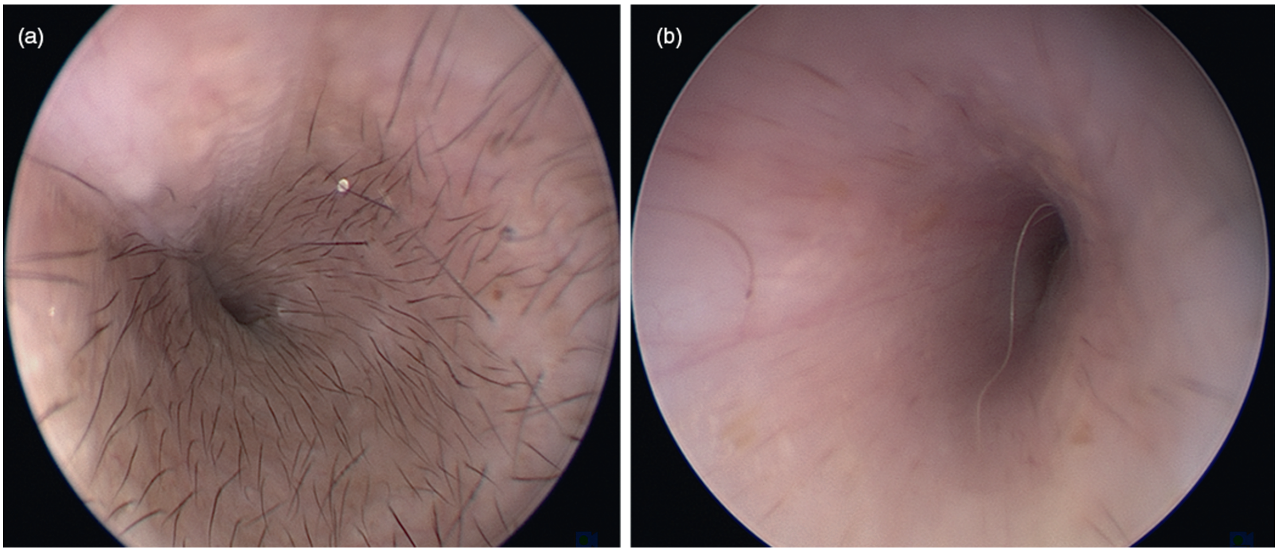

Figure 1. Otoscopic examination of the horizontal part of the external auditory canal in two French bulldogs (a, b). The ear canals show no signs of inflammation or secretions. The eardrum cannot be visualised otoscopically due to stenosis.

Materials and methods

Ethical approval was not required because CT and otological examination were part of our standard work-up for the brachycephalic syndrome. By answering the questionnaire, all owners agreed to become part of the study.

Study population

A prospective group of two breeds of brachycephalic dogs (FB and pugs) were examined. All brachycephalic dogs were referred to the Ear, nose and throat (ENT) Unit of the Small Animal Department, University of Leipzig, for surgical correction of brachycephalic airway syndrome.

The dogs' owners completed an anamnestic questionnaire and gave consent to participate in this study. The dogs were anaesthetised for further diagnosis. After a CT examination of the head with special attention to the air-filled structures such as the nose, nasopharynx, middle ear and auditory canal, the upper airways and the external auditory canals were examined endoscopically, and swab samples were taken for cytological examination. This procedure is part of our standardised work-up before airway surgery for brachycephalic syndrome.

Retrospective image data of normocephalic dogs were used for the comparison of CT measurements. The selection criterion was a body mass of 6–16 kg. The exclusion criteria were anamnestic indications for the presence of otitis and other ear pathologies such as trauma or neoplasia.

Questionnaire and otoscopic and cytological examination

All brachycephalic animals were assessed for the presence of OE using three evaluation criteria: an owner questionnaire and otoscopic and cytological examinations of the external ear canals. If a positive response to two or more criteria was given, the dog was classified as having OE. Based on these results the dogs were divided into two groups: otitis externa (OE) and non-otitis externa (N-OE).

All dog owners were given a questionnaire (see Supporting information, Appendix S1) asking about present and past clinical signs of OE and otitis media (OM), such as head shaking, scratching and ear pain, and any concurrent dermatological signs and treatment history for otitis. If two or more of the eight questions were answered positively, the evaluation criterion questionnaire was rated as abnormal.

All dogs were anaesthetised for CT, otoscopic examination and sample collection using a standardised anaesthetic protocol.[18]

The swab specimens (nonsterile cotton-tipped applicator) for cytological examination were obtained from the junction of the vertical and horizontal ear canals with 360° rotation, rolled onto a glass microscope slide, air-dried and stained using a modified Wright's stain (Henry Schein; Melville, NY, USA).[19,20] Stained slides were inspected first under ×40 magnification to identify a representative area (Axioskop 20, Carl Zeiss; Jena, Germany). Samples were obtained by one investigator; they were then blinded and evaluated microscopically by another independent examiner blinded to the otoscopic results. During this examination, 10 oil immersion fields (OIF) (×1,000) were counted in areas with optimal layer thickness without artifacts, and the average number of neutrophils, yeast and bacteria per sample then was calculated.[21] If five or more yeast cells or cocci per OIF, or one or more rod or neutrophilic granulocytes per OIF were observed, the evaluation criterion cytology was rated positive.[19,22,23]

Otoscopic examination was performed using a rigid endoscope [Hopkins telescope (0°, 2.7° and 18 cm), Karl Storz; Tuttlingen, Germany). The course of the entire examination was documented (Image1 S with three-chip full HD camera head TH100; Karl Storz), stored digitally (AIDA, release 1.3, 100–240 VAC, 50–60 Hz; Karl Storz), and evaluated using the Otitis Index Score (OTIS3).[24] Videos were obtained by one investigator and then blind-evaluated by another examiner independently of the cytological results. Here, the presence of the clinical parameters erythema, oedema/swelling, erosions/ulceration, and exudate was documented, and their severity was graded from 0 to 3 (0, none; 1, mild; 2, moderate; 3, severe).[24] The number of all parameters formed the total clinical score (from 0 to 12). Clinical scores ≥4 differentiated those with abnormal endoscopic findings from healthy ears.[24] Additionally, the unobstructed view of the eardrum, its integrity and the presence of hair in the ear canal were documented.

Computed tomography

In all dogs, CT of the head was performed preoperatively for the planning of intranasal surgery for brachycephalic syndrome.[18]

A multi-line spiral CT (Mx8000 Brilliance, 6-line, Philips Healthcare; Hamburg, Germany) was used for examination of the head and neck region. The animals were placed in sternal recumbency, and the upper jaw was fixed with a positioning aid to align the hard palate parallel to the table. The field of view extended from the nasal planum to the first cervical vertebra. The slice thickness was 1 mm, with 200 mAs, 120 kV and automatic dose adjustment, for the pitch 0.6 and – 0.5 increments on a modified lung window (WL –300, WW 2,500)[25] from reconstructed dorsal plane images. IntelliSpacePortal 11 (Koninklijke Philips N.V.; Eindhoven, the Netherlands) was used to

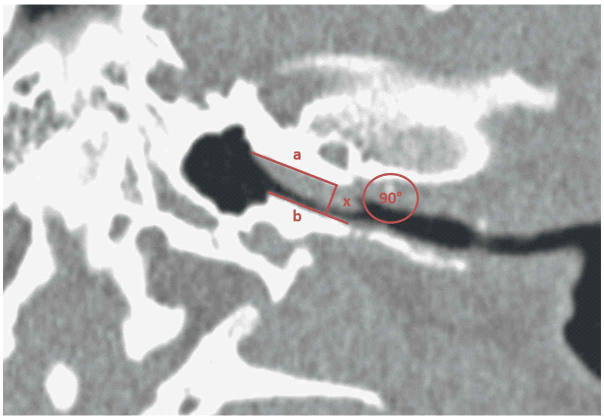

Figure 2. Measuring the diameter of the porus acusticus externus. The external auditory canal of a French bulldog is shown (dorsal cross-section) by computed tomography. The cranial (a) and caudal (b) bony wall of the horizontal part of the auditory canal was idealised with a straight line. Both lines are connected at right angles to each other at the outer bony margin. The distance between the two straight lines (x) is measured as the diameter of the porus acusticus externus.

display and evaluate the soft tissue and bone structure images. For the measurement, the level was chosen in which the junction to the vertical part of the auditory canal and eardrum was clearly visible, and the horizontal part of the acoustic meatus could be seen in its entire length and width.

The following CT features were recorded for each ear:

- Maximum diameter of the porus acusticus externus; a detailed description of the measurement method is provided below (Figure 2).
- Material/fluid in the tympanic bulla; if present, it was graded as mild, moderate or severe depending on the percentage of the bulla that was occupied (<30%, 30–60% or > 60%, respectively).
- Material/fluid within the bony external ear canals was graded as normal, mild, moderate or severe depending on 0%, <30%, 30%–60% or > 60% filling of the ear canal diameter, respectively (Figure 3).

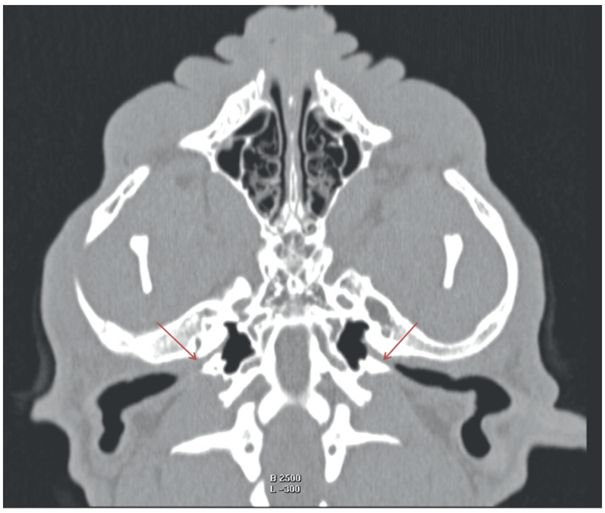

Figure 3. Skull of a French bulldog shown in a dorsal cross-section from computed tomography (2,500/−300).
The lumen of the bony part of the horizontal auditory canal is blocked by soft tissue and/or fluid (red arrow).

Measurement of the porus acusticus externus

The porus acusticus externus was selected for the description and measurement of the auditory canal's irregular course. A newly developed measurement technique was used to determine the maximum diameter of the left and right porus in millimetres (Figure 2). The cranial and caudal bony walls of the horizontal part of the ear canal were idealised with a straight line in the dorsal CT representation. At the outer edge of the cranial wall, a perpendicular line was measured to connect the two straight lines as an idealised maximum diameter of the porus acusticus externus.

All CT measurements were compared to those obtained from the normocephalic group.

Statistical methods

Statistical analysis was performed using Prism (v7, GraphPad Software; La Jolla, CA, USA). The D'Agostino–Pearson normality test was carried out to check if the values were normally distributed. For the normally distributed data, a one-way ANOVA was used after testing for equality of variance using Brown–Forsythe and Bartlett's tests, followed by *post hoc* Bonferroni correction for the alpha error accumulation. The results are presented as mean ± standard deviation. For non-normally distributed data, the Kruskal–Wallis test was used before Dunn's multiple comparisons test. The results are presented as median values with interquartile ranges (IQRs). Statistical significance was set at $P < 0.05$. To investigate the relative risk of a characteristic with brachycephalic or normocephalic head shape, contingency tables were examined using Fisher's exact test (two-sided, 95% confidence interval). The relative risk, odds ratio and sensitivity/specificity were investigated via the Koopmann Asymptotic Score, Baptista–Pike method and hybrid Wilson–Brown method, respectively.

Results

A total of 75 brachycephalic dogs (20 pugs, 55 FB) were included in this prospective study. Of these, 54 were male (three of these neutered) and 21 were female. From our database, CT examinations of 37 nonbrachycephalic dogs were evaluated retrospectively. The breed distribution is listed on Table 1. They were examined radiologically for reasons other than ear diseases. The comparison of age, weight and diameter of the porus acusticus externus of pugs, FB and the control group is summarized on Table 2. The median diameter of the porus acusticus externus was 2.6 mm (IQR 2.3–2.9) in brachycephalic patients and 5 mm (4.5–5.5) in the control group ($P < 0.0001$). No significant difference in the right and left diameters was found in any group [right side: median 2.5 mm (IQR 2.2–2.8), left side: median 2.6 mm (IQR 2.3–2.9)] (Figure 4).

Table 1. Breed distribution of the dogs in the control group (n = 37)

Breed	No. of dogs
Mixed breed	15
Dachshund	6
Yorkshire terrier	2
Poodle	2
Jack Russell terrier	2
Pomeranian	2
Shiba inu	1
Whippet	1
West Highland white terrier	1
Scottish terrier	1
Fox terrier	1
Small Muensterländer	1
Miniature schnauzer	1
German hunting terrier	1

Table 2. Median values (with interquartile range) for age, body weight and diameter of the porus acusticus externus of pugs, French bulldogs (FB) and control group.

	Pugs	FB	Control group
Age	48.5 months (31.0–80.8)	28 months (19–41)	124 months (80.5–161.5)
Body weight	8.4 kg (6.6–10)	13 kg (11.3–14.5),	10 kg (7.4–12.4)
Diameter of porus acusticus externus	2.6 mm (2.4–2.9)	2.5 mm (2.2–2.8)	5 mm (4.5–5.5)

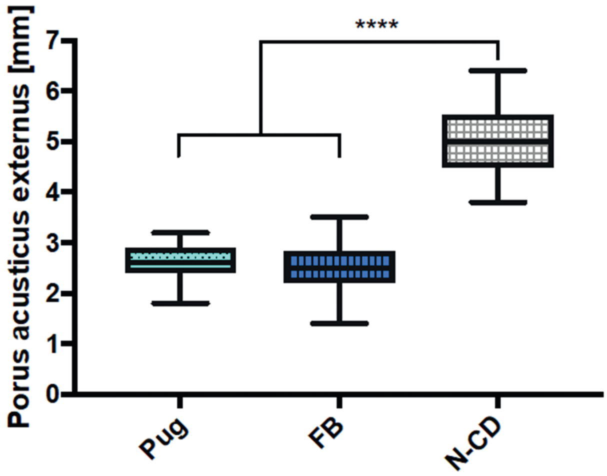

Figure 4. Diameter of the porus acusticus externus in mm determined using computed tomography for pugs (n = 20), French bulldogs (FB, n = 55) and normocephalic control dogs (N-CD, n = 37). Results are displayed as a box plot (interquartile range, median, minima, maxima); ****, $P < 0.0001$ (Kruskal–Wallis test).

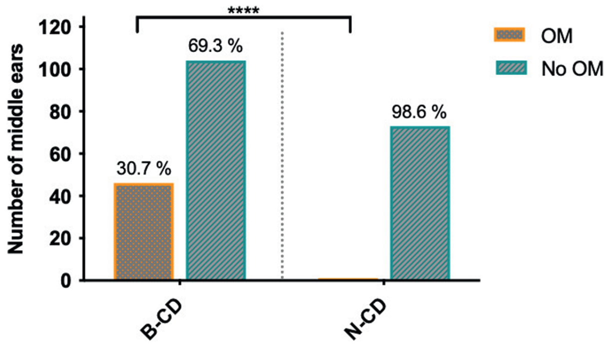

Figure 5. The number of ears with otitis media (OM), defined as tympanic cavity effusion on computed tomography in brachycephalic (B-CD, 46 of 150) and normocephalic (N-CD, one of 74) dogs.
The correlation between brachycephaly and middle ear effusion was highly statistically significant when compared to normocephaly and middle ear effusion using Fisher's exact test; ****, $P < 0.0001$.

Thirty-three of the 75 brachycephalic dogs (44%) had soft tissue isodense material in the tympanic cavity (20 unilateral, 13 bilateral). In total, 46 of 150 (30.7%) middle ears of pugs and FB were affected (Table 3). One dog in the control group had soft tissue/fluid material unilaterally in the tympanic cavity without any changes in the bulla wall and mild graduation. The dog was diagnosed with chronic idiopathic rhinitis (Figure 5).

Soft tissue/fluid-attenuating material within the osseous external ear was detectable in 124 of 150 (82.6%) of the examined auditory canals of pugs and FB (Table 3). The finding was unilateral in 12 (17.6%) brachycephalic dogs and bilateral in 56 (82.4%). Only 14 of 74 (18.9%) dogs in the control group had soft tissue/fluid-attenuating material within the osseous external ear (mild, 10; moderate, one; severe, three).

In order to estimate the correlation between CT characteristics and otitis externa, all brachycephalic dogs were divided into OE and N-OE groups based on the owner questionnaire, and cytological and endoscopic findings. Overall, 53 of 75 (70.6%) owner questionnaires, 21 of 75 (27.9%) cytological examinations and 22 of 75 (29.3%) endoscopies were deemed suspicious for OE. A total 24 of 75 animals (32%) had at least two of three evaluation criteria and hence were included as the OE group. The remaining 51 of 75 dogs were included in the N-OE group. There was no significant difference in group allocation between the two brachycephalic breeds (OE-group, pugs 35%, FB 30,9%).

When considering the maximum diameter of the porus acusticus externus, there was no significant difference between the OE and N-OE groups. Furthermore, there was no correlation between OE/N-OE and soft tissue isodense material in the tympanic cavity. Of 46 tympanic cavities with soft tissue density detected, OE could be detected in 24, and no otitis was detected in 22. By contrast, we could detect material/fluid within the bony external ear canals significantly more frequently in animals with OE. Otitis externa was found in 47 of 124 obstructed auditory canals.

An important endoscopic examination result was that only five of 150 eardrums (3.3%) could be visualised

Table 3. Distribution (of total dogs or ears) and graduation of soft tissue isodense material in the tympanic cavity and soft tissue/fluid-attenuating material within the osseous external ear on computed tomography

			Graduation		
	Number of affected dogs	Number of affected ears	Mild	Moderate	Severe
Soft tissue isodense material in the tympanic cavity	33/75 (44%)	46/150 (30.7%)	6/46 (13%)	5/46 (10.9%)	35/46 (76.1%)
Soft tissue/fluid-attenuating material within the osseous external ear	68/75 (90.1%)	124/150 (82.6%)	18/124 (14.5%)	31/124 (25%)	75/124 (60.5%)

otoscopically and were intact. In total, 145 tympanic membranes were not visible (Figure 1).

Discussion

All brachycephalic animals showed a high degree of stenotic malformation of the proximal external auditory canal. On CT examination, stenosis of the porus acoustic externus with a reduction of the lumen to 50% of the normocephalic control group was found. However, no statistical difference between stenosis of the external auditory canal and OE was found.

In recent years, various studies have focused on breeding-induced malformations of the middle ear in brachycephalic dogs. Primarily, the conformation of the tympanic bulla and the content of the tympanic cavity have been investigated.[13,26] However, there is almost no knowledge about the stenotic malformation of the external auditory canal in brachycephalic breeds, which is a common finding in everyday clinical practice. This stenosis complicates the treatment of OE and OM because it is difficult during otoscopic examination to visualise the tympanic membrane in brachycephalic dogs. To date, the cause of this narrowing is not known and, according to the results of our study, it could be due to malformation in the bony part of the acoustic meatus.

A possible cause of stenosis of the acoustic meatus in brachycephalic breeds is malformation of the entire skull with extreme shortening of the craniofacial bone structures, as well as the discrepancy between the viscerocranium and neurocranium. The porus acusticus externus and the middle ear are located in the pars petrosa of the temporal bone [27] and are therefore affected by neurocranium malformation. This anatomical deviation is supported by results of a previous study that found a change in position and reduction in the size of the middle ear of FB.[28] It is possible that these shifts also extend to the external auditory canal. To date, no studies have measured the bony structures in this area in brachycephalic dogs. Positive contrast ear canalography in dogs revealed stenosis, particularly in the proximal part of the cartilaginous auditory canal in pugs and Pekingese.[15] In comparison to all other breeds that were examined, the tympanic membrane of these dogs could not be visualised by X-ray after contrast media had been placed in the ear canal, as the fluid could not penetrate to the tympanic membrane due to stenosis.

Classic primary causes of chronic OE are hypersensitivity disorders such as atopic dermatitis (AD)[17,29-31] or abnormal anatomy of the auditory canal.[17,32,33] Therefore, we hypothesised that, in brachycephalic dogs, anatomical narrowing may exacerbate pre-exisiting inflammatory processes in the external auditory canal such as AD. In this hypothesis, the bony stenosis leads to a lack of self-cleaning, an accumulation of secretions and hair, and, finally, to the onset of OE. Because the evaluation of co-morbidities was not part of this study, the primary or secondary role of stenosis in the onset of otitis could not be confirmed. However, it should be noted that the brachycephalic dogs in our study had a higher prevalence (32%) of OE than is generally reported for dogs (10–20%).[21]

In this study, the soft tissue structures in the acoustic meatus were not measured quantitatively; however, in 82.6% of dogs, soft tissue or fluid was identified in the lumen by CT. This correlated with the presence of OE and could therefore be both a consequence and cause of inflammation. Narrowing of the ear canal resulting from cartilage changes or an increase in soft tissue may play a role in the predisposition of brachycephalic breeds to OE. Previous CT examination of dogs with OM showed that FB was the most frequently affected breed at 15%, notably for proliferative otitis.[16] This may be related to an increased rate of underlying hypersensitivity disorders [30] or the special conformation of the ear[17] or both. The high prevalence of soft tissue/fluid-attenuating material within the osseous external ear also was confirmed by the results of our endoscopic examinations, in which the view of the tympanic membrane was blocked by soft tissue in 96.7% of cases. Even in dogs without OE that had little or no secretion, it was impossible to view the tympanic membrane as a consequence of the extreme stenosis of the acoustic meatus. A general weakness of the cartilage, especially in the larynx of pugs, is described in the literature.[34] This problem also is discussed as the cause of malfunction of the Eustachian tube.[11,35-37] Pathohistological examinations should clarify whether this also applies to the cartilaginous part of the ear canal.

In this study, 33 of 75 (44%) brachycephalic dogs had soft tissue isodense material in the tympanic cavity. A previous study found a similar prevalence (36%) of tympanic effusion in asymptomatic dogs that needed to undergo brachycephalic surgery.[13] It was striking that pugs and bulldogs without OE had tympanic effusion similar to dogs with OE. This allows us to draw conclusions about the origin of the change. Generally, the transmission of OE to the middle ear is the most common cause of OM in dogs.[38-41] However, this does not seem to be the case in this study. We did not perform myringotomy and cytological and cultural analysis of the middle ear contents, and therefore the origin of the effusion cannot be known for certain. The content of the tympanic bulla in brachycephalic dogs appears to be noninflammatory [26,37], which supports the theory of a drainage disorder.

It is believed that dysfunction of the auditory tube in brachycephalic dogs could play a role here.[12,13,36] The dogs in our study showed no clinical signs[11,12] and no further evidence of OM such as lysis of the bulla wall on CT.

We note two limitations in this study. First, the owner questionnaire (Appendix S1) used to assess the symptoms of OE is a subjective assessment and owner's may have misinterpreted signs of otitis. Our criteria, namely cytology and endoscopy are more objective measurements.

Secondly, the dogs presented for brachycephalic surgery were a preselected patient population and this could have biased the study participants.

Conclusions

The high-grade stenosis of the acoustic meatus in brachycephalic dog breeds, particularly the bony porus acusticus externus and the tympanic bulla, is evidence that the ear is an organ which is extremely disturbed in form and function by selective breeding practices. However, a connection between stenosis of the external auditory canal and OE could not be confirmed. The results of this clinical study reiterate that the extent of congenital brachycephalic malformation and functional disorders go far beyond malformations of the upper respiratory tract.

Author contributions

Tanja Töpfer: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; resources; software; visualization; writing – original draft. **Gerhard Oechtering:** Conceptualization; data curation; formal analysis; investigation; methodology; software; supervision; validation; visualization; writing – review and editing. **Sarah Rösch:** Conceptualization; data curation; formal analysis; methodology; project administration; validation; visualization; writing – review and editing. **Claudia Köhler:** Conceptualization; data curation; investigation; methodology; writing – review and editing.

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Supporting Information

Additional Supporting Information may be found in the online version of this article.

Appendix S1. Owner questionnaire about typical symptoms of otitis externa