Effect of brachycephalic, mesaticephalic, and dolichocephalic head conformatons on olfactory bulb angle and orientation in dogs as determined by use of in vivo magnetic resonance imaging

Aseel K. Hussein, BVMS, MSc; Martin Sullivan, BVMS, PhD; Jacques Penderis, BVSc, PhD

Objective—To determine the effect of head conformation (brachycephalic, mesaticephalic, and dolichocephalic) on olfactory bulb angle and orientation in dogs by use of in vivo MRI.

Animals—40 client-owned dogs undergoing MRI for diagnosis of conditions that did not affect skull conformation or olfactory bulb anatomy.

Procedures—For each dog, 2 head conformation indices were calculated. Olfactory bulb angle and an index of olfactory bulb orientation relative to the rest of the CNS were determined by use of measurements obtained from sagittal T2-weighted MRI images.

Results—A significant negative correlation was found between olfactory bulb angle and values of both head conformation indices. Ventral orientation of olfactory bulbs was significantly correlated with high head conformation index values (ie, brachycephalic head conformation).

Conclusions and Clinical Relevance—Low olfactory bulb angles and ventral olfactory bulb orientations were associated with brachycephalia. Positioning of the olfactory bulbs, cribriform plate, and ethmoid turbinates was related. Indices of olfactory bulb angle and orientation may be useful for identification of dogs with extremely brachycephalic head conformatons. Such information may be used by breeders to reduce the incidence or severity of brachycephalic-associated diseases. (Am J Vet Res 2012;73:946–951)
smaller craniofacial angle, compared with dogs of other breeds. The gene associated with a brachycephalic head shape has been mapped to a region on canine chromosome 1 and seems to be common to all dogs of brachycephalic breeds. Candidate genes within this chromosome region that may be associated with brachycephaly include THBS2 and SMOC-2, although there is a high probability that genes in other chromosome regions are modified in brachycephalic dogs.

Dogs of brachycephalic breeds, including Boxers, English Bulldogs, French Bulldogs, Pugs, and Boston Terriers, are popular pets. One reason that has been proposed for the popularity of these breeds is the similarity between the brachycephalic head shape in those dogs and the head shape of human infants. The popularity of brachycephalic dogs as pets has resulted in breeding selection for physical appearance rather than for function. Survival of dogs with extreme brachycephaly may only be possible in some instances with breeding, medical, or surgical interventions (eg, artificial insemination and cesarean section in English Bulldogs). Brachycephalic head conformation is correlated with high bite strength and is considered to impart a selective advantage in certain groups of wild carnivora (eg, hyenas [which are able to crush bone with their jaws] and extinct scavengers); this perceived benefit is the basis for selective breeding of dogs used for fighting. Comparison of head conformations among dogs of different breeds and dogs within a breed is possible by use of head conformation indices. Dogs that have similar head conformation index values have similar head shape characteristics and predispositions to particular diseases. Dogs of brachycephalic breeds are predisposed to the development of a variety of diseases affecting the upper airways, eyes, facial morphology, and CNS. These disease predispositions can be directly or indirectly attributed to the brachycephalic head phenotype; some examples include cleft palate and lip, brachycephalic obstructive airway syndrome, quadrigeminal cysts, and gliomas.

Examination of physical characteristics of pedigree dog breeds may be useful in understanding the anatomic basis of a variety of diseases. Although head conformation indices provide objective measures of the degree of brachycephaly in dogs, they are not accurate measures of other physical characteristics that are related to brachycephaly. Development of such physical characteristics is presumably mediated through expression of modifying genes other than those responsible for brachycephalic head conformation. In particular, the head conformation characteristics associated with a small craniofacial angle (which affects the physical characteristics of eyes, airways, and CNS) cannot be predicted with traditional head conformation indices. Descriptions of the physical characteristics of the brain associated with a small craniofacial angle are extremely limited. One physical CNS characteristic that seems to be related to head conformation and may be directly related to the position of ethmoid turbinates (which is different in brachycephalic dogs than in dogs of other head conformations) is the position of olfactory bulbs.

Olfactory bulb position may be best determined by evaluation of radiographic and CT images of the head. A quantitative measure of extreme brachycephaly would be useful for the prediction of brachycephalic-related disease predispositions in dogs and for the selection of dogs for breeding. The purposes of the study reported here were to determine the association between head conformation (brachycephalic, mesaticephalic, and dolichocephalic) and olfactory bulb angle and orientation, to determine the olfactory bulb angle and orientations associated with brachycephaly, and to determine whether the degree of ventral olfactory bulb orientation correlates with the degree of brachycephaly (which would allow that measure to be used as an indicator of extreme brachycephaly).

**Materials and Methods**

**Animals**—Forty dogs (with various head conformations) evaluated at the University of Glasgow Small Animal Hospital were prospectively included in the study from March 2009 through September 2010. All dogs underwent MRI of the head for evaluation of conditions that did not affect skull conformation or olfactory bulb anatomy. Acquisition of MRI images of heads for calculation of head conformation indices was accomplished during diagnostic MRI without prolonging the duration of the general anesthesia for any of the dogs. Informed consent for use of clinical data was granted by owners of the dogs (the consent statement was included as part of the hospital clinical consent form). Ethical approval was granted by the Faculty of Veterinary Medicine Ethics and Welfare Committee of the University of Glasgow.

**Olfactory bulb angle and orientation**—The MRI images were acquired with an MRI scanner with a 1.5-T magnet and included T2- and T1-weighted images in sagittal and transverse planes and a T1-weighted transverse image acquired following IV administration of gadopentetate dimeglumine (94 mg/kg). A sagittal T2-weighted MRI image that included the entire head, from the nasal planum (rostrally) to the intercondylar notch of the foramen magnum (caudally), was one of the images acquired. Measurements of skull dimension were determined from MRI images, and head conformation (cephalic) index values were calculated for all dogs by use of a historical formula as follows:

\[
HCl_{sk} = \frac{\text{skull width} \times 100}{\text{skull length}}
\]

where skull width is the widest width between the outer margins of the left and right zygomatic arch and skull length is the distance from the prosthion (most rostral point of the interincisive suture of the alveolar process of the maxilla) to the inion (most caudal midline point of the external occipital protuberance of the occipital bone). Head conformation index values were also calculated for all dogs by use of another formula as follows:

\[
HCl_{sn} = \frac{\text{skull width} \times 100}{\text{skull base length}}
\]

where skull width is the widest width between outer margins of the left and right zygomatic arch and skull base length.
base length is the distance from the prosthion to the basion (most rostral point of the ventral margin of the foramen magnum of the occipital bone).

Olfactory bulb angle and orientation relative to the rest of the CNS were calculated from sagittal T2-weighted MRI images. Olfactory bulb angle was determined by measuring the angle between the olfactory bulb fissure (groove separating an olfactory bulb from the rest of the brain) and the baseline of the cranial cavity (line from the oral aspect of the hard palate [rostrally] to the intercondylar notch of the foramen magnum [caudally]; Figure 1). In addition, each dog was categorized as having 1 of 5 olfactory bulb orientation types on the basis of the orientation of the olfactory bulb relative to the rostral aspect of the cranial cavity (determined with sagittal MRI images). Briefly, olfactory bulbs were divided into 4 quadrants of equal height (long axis of quadrants oriented from caudodorsal to craniocaudal) on sagittal MRI images, and these 4 quadrants were numbered from ventral to dorsal (or from caudal to rostral in dogs with olfactory bulbs located ventral to the rostral aspect of the cranial cavity); 1 represented the most ventral (or caudal) quadrant, and 4 represented the most dorsal (or rostral) quadrant. A line was drawn perpendicular to the baseline of the cranial cavity to the rostral-most aspect of the cranial cavity. Categories 2, 3, and 4 comprised dogs with progressively greater ventral orientation of olfactory bulbs. Dogs in which olfactory bulbs were oriented so far ventral that there was no contact with the perpendicular line (ie, the perpendicular line contacted the internal surface of the squama frontalis of the frontal bone immediately dorsal to olfactory bulbs) were categorized as having olfactory bulb orientation type 5.

Statistical analysis—Commercially available statistical software* was used for all data analyses. Normal Gaussian distributions of data were determined via the Kolmogorov-Smirnov test with the Dallal-Wilkinson-Lilliefors corrected P value. Linear regression analysis was performed to determine the relationship between olfactory bulb angle and head conformation index values. A 1-way ANOVA with a Bonferroni multiple comparison posttest was used to determine whether olfactory bulb orientation was associated with values of head conformation indices.12 For all analyses, values of P ≤ 0.05 were considered significant.

Results

The 40 dogs included in the study comprised the following breeds: Cavalier King Charles Spaniel (n = 11), Boxer (4), Labrador Retriever (4), Shih Tzu (3), mixed (3), Lhasa Apso (2), West Highland White Terrier (2), and Chihuahua, Pug, Mastiff, Miniature Schnauzer, Pointer, Belgian Shepherd Dog, Bichon Frise, English Springer Spaniel, Giant Schnauzer, Staffordshire Bull Terrier, and Deerhound (1 each). All dogs were mature (age range, 1 to 17 years).
Olfactory bulb angle was typically smaller in brachycephalic dogs versus dogs with other head conformations (Figure 2). Results of linear regression indicated olfactory bulb angle decreased significantly \( (P < 0.001) \) with increasing head conformation index value (ie, brachycephalic conformation) as determined by HCl\_sl\textsuperscript{1} \( (R^2 = 0.6779) \) and HCl\_sl\textsuperscript{2} \( (R^2 = 0.6113; \text{Figure 3}) \).

All dogs were categorized as having olfactory bulb orientation type 3, 4, or 5; no dogs were categorized as type 1 or 2 (including dogs of breeds typically considered to be dolichocephalic). Results of ANOVA indicated that high olfactory bulb orientation types (ie, ventral olfactory bulb orientations) were significantly \( (P < 0.001; R^2 = 0.5738) \) associated with high head conformation index values. Dogs categorized as having olfactory bulb orientation type 5 (ie, dogs with the most ventral olfactory bulb orientation) had mean ± SD HCl\_sl\textsuperscript{1} and HCl\_sl\textsuperscript{2} index values of 80.1 ± 8.5 and 89.4 ± 12.1, respectively (Figure 4). Dogs categorized as having olfactory bulb orientation type 4 had mean ± SD HCl\_sl\textsuperscript{1} and HCl\_sl\textsuperscript{2} index values of 69.1 ± 6.9 and 76.1 ± 7.7, respectively. Dogs categorized as having olfactory bulb orientation type 3 had mean ± SD HCl\_sl\textsuperscript{1} and HCl\_sl\textsuperscript{2} index values of 57.7 ± 7.8 and 64.9 ± 10.5, respectively.

Figure 2—Representative sagittal T2-weighted MRI images of the heads of 3 dogs illustrating typical olfactory bulb angles associated with brachycephalic (A), mesaticephalic (B), and dolichocephalic (C) head conformations. Notice that brachycephalic head conformation is associated with the smallest olfactory bulb angle.

Figure 3—Regression lines indicating the relationship between olfactory bulb angle and head conformation index values of 40 client-owned dogs undergoing MRI for diagnosis of conditions that did not affect skull conformation or olfactory bulb anatomy. A—Relationship between olfactory bulb angle and HCl\_sl\textsuperscript{1} \( (R^2 = 0.6779; P < 0.001) \). Values of HCl\_sl\textsuperscript{1} were determined with the following formula: HCl\_sl\textsuperscript{1} = skull width \times 100

| skull length, where skull width is the widest width between outer margins of the left and right zygomatic arch and skull length is the distance from the prosthion (most rostral point of the interincisive suture of the alveolar process of the maxilla) to the inion (most caudal midline point of the external occipital protuberance of the occipital bone). B—Relationship between olfactory bulb angle and HCl\_sl\textsuperscript{2} \( (R^2 = 0.6113; P < 0.001) \). Values of HCl\_sl\textsuperscript{2} were determined with the following formula: HCl\_sl\textsuperscript{2} = skull width \times 100

| skull base length, where skull width is the widest width between outer margins of the left and right zygomatic arch and skull base length is the distance from the prosthion to the basion (most rostral point of the ventral margin of the foramen magnum of the occipital bone).
phalic or dolichocephalic breeds.4 Olfactory bulbs are have shorter and wider heads versus dogs of mesaticephalic breeds such as Boston Terriers, Pugs, and Bulldogs; these dogs head shape typical for dogs of brachycephalic breeds described for dogs, including brachycephalic dogs.18 Form plate (which outlines the ethmoid fossa) has been of the head. The radiographic appearance of the cribiform plate, and their orientation is directly identified. Olfactory bulb orientation can be determined directly rating the olfactory bulb from the rest of the brain. Orientation of olfactory bulb fissure to describe the groove separation or groove. Therefore, we used the term olfactory bulb fissure to describe the groove separating the olfactory bulb from the rest of the brain. Orientation of olfactory bulbs can be determined directly by evaluating MRI images, particularly T2-weighted images, in which fluid within olfactory bulb fissures can be identified. Olfactory bulb orientation can be indirectly determined by identifying the position of the ethmoidal fossa on the cribriform plate (depending on the depth of the ethmoidal fossa) and are separated from the rest of the forebrain by a visible groove.16,17 To the authors knowledge, there is no recognized anatomic term to describe this separation or groove. Therefore, we used the term olfactory bulb fissure to describe the groove separating the olfactory bulb from the rest of the brain. Orientation of olfactory bulbs can be determined directly by evaluating MRI images, particularly T2-weighted images, in which fluid within olfactory bulb fissures can be identified. Olfactory bulb orientation can be indirectly determined by identifying the position of the ethmoidal fossa on the cribriform plate (which outlines the ethmoid fossa) has been described for dogs, including brachycephalic dogs.18 Therefore, indirect determination of olfactory bulb orientation is possible with radiography. In the present study, dogs with extreme brachycephalic conformations had ventral olfactory bulb orientations. Disease presentations had ventral olfactory bulb orientations. Disease may , in part, be explained as a simple consequence of brachycephaly on cranial cavity shape.21 Brachycephaly is associated with different facial, cranial cavity, and CNS characteristics versus those in domestic dogs with other head conformations. Determination of the olfactory bulb angle may be useful for estimation of the degree of brachycephaly in dogs undergoing MRI for investigation of intracranial disease, particularly when MRI images do not include the entire skull (which would preclude calculation of head conformation index values). Measures of olfactory bulb angle and orientation may be useful for identification of dogs with extreme brachycephaly and for determination of the correlation between the degree of brachycephaly and the incidence and severity of brachycephalic-related conformational characteristics of the CNS, airways, and eyes.

Discussion

Early fusion of ≥1 articulations between bones of the ventral part of the cranium during development results in a short basicranial skull axis in dogs with a brachycephalic head conformation.1 This results in the head shape typical for dogs of brachycephalic breeds such as Boston Terriers, Pugs, and Bulldogs; these dogs have shorter and wider heads versus dogs of mesaticephalic or dolichocephalic breeds.4 Olfactory bulbs are completely or partially housed within the ethmoidal fossa of the cribriform plate (depending on the depth of the ethmoidal fossa) and are separated from the rest of the forebrain by a visible groove.16,17 To the authors knowledge, there is no recognized anatomic term to describe this separation or groove. Therefore, we used the term olfactory bulb fissure to describe the groove separating the olfactory bulb from the rest of the brain. Orientation of olfactory bulbs can be determined directly by evaluating MRI images, particularly T2-weighted images, in which fluid within olfactory bulb fissures can be identified. Olfactory bulb orientation can be indirectly determined by identifying the position of the ethmoidal fossa on the cribriform plate (which outlines the ethmoid fossa) has been described for dogs, including brachycephalic dogs.18 Therefore, indirect determination of olfactory bulb orientation is possible with radiography. In the present study, dogs with extreme brachycephalic conformations had ventral olfactory bulb orientations. Disease predispositions of dogs of different breeds are well described; brachycephalic dogs are predisposed to development of CNS disorders including ventriculomegaly of the lateral brain ventricles, quadrigeminal cysts, and gliomas.19 The ethmoidal turbinates are attached caudally to the cribriform plate, and their orientation is directly related to the orientation of the ethmoidal fossa and olfactory bulbs. In dogs of the present study, extreme brachycephalic conformation was significantly associated with a ventral orientation of olfactory bulbs and a small olfactory bulb angle. Subjectively, ventrally oriented olfactory bulbs seemed to be associated with a flat cribriform plate and a small ethmoidal fossa. Selective breeding of dogs can be considered artificial selection, but physical characteristics similar to those that develop because of selective breeding can develop via natural selection. For example, in fossilized and living canids, ventral orientation of the cribriform plate is associated with ventral orientation of the frontal lobes of the brain.20 One of the physical abnormalities associated with brachycephalic obstructive airway syndrome is encroachment of nasal turbinates into the ventral nasal cavities, resulting in stenosis of nasal airways. The consequence of a ventral orientation of olfactory bulbs is that the cribriform plate and ethmoid turbinates are ventrally oriented, potentially protruding into nasal airways and possibly contributing to the pathogenesis of this obstructive airway syndrome in brachycephalic breeds.

There was a high degree of correlation between head conformation index value and both the angle and orientation of olfactory bulbs; small olfactory bulb angles and ventral orientation of olfactory bulbs were significantly associated with high head conformation index values (ie, extreme brachycephalia). Therefore, differences in morphology of the CNS in brachycephalic dogs versus that in dogs with other head conformations may, in part, be explained as a simple consequence of brachycephaly on cranial cavity shape.21 Brachycephaly is associated with different facial, cranial cavity, and CNS characteristics versus those in domestic dogs with other head conformations. Determination of the olfactory bulb angle may be useful for estimation of the degree of brachycephaly in dogs undergoing MRI for investigation of intracranial disease, particularly when MRI images do not include the entire skull (which would preclude calculation of head conformation index values). Measures of olfactory bulb angle and orientation may be useful for identification of dogs with extreme brachycephaly and for determination of the correlation between the degree of brachycephaly and the incidence and severity of brachycephalic-related conformational characteristics of the CNS, airways, and eyes.

References