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Short Communication

Heritability of hemivertebrae in the French bulldog using an animal threshold model

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Ordinal regression and animal threshold analyses were used to estimate the influence of fixed effects and heritabilities on the number and grade of hemivertebrae, as well as the number of coccygeal vertebrae, in 105 French bulldogs. The fixed effects of sex, year and month of birth were not significant ($P > 0.05$). The prevalence of hemivertebrae was 0.85 with a slightly higher prevalence in females compared with males. Heritability estimates for the number and grade of hemivertebrae were 0.58 and 0.53, respectively. The number of coccygeal vertebrae showed a heritability estimate of 0.35. In addition, the number of coccygeal vertebrae was negatively correlated with the number and grade of hemivertebrae. The prevalence of hemivertebrae could increase if dogs with shorter tails are preferentially selected for breeding purposes.

Hemivertebrae (wedge-shaped vertebrae) are the most common malformation of the vertebral column in chondrodystrophic breeds of dog (Done et al., 1975; Wright, 1979; Bailey and Morgan, 1992; Ruberte et al., 1995; Thilagar et al., 1998; Besalti et al., 2005; Volta et al., 2005), and the familial occurrence of this condition suggests it is a heritable trait (Done et al., 1975). Selection for 'screwed tail' in dogs is believed to increase the risk of hemivertebrae developing in the thoracic and lumbar spine (Kramer et al., 1982), which can be single or multiple (Done et al., 1975; Bailey and Morgan, 1992; Thilagar et al., 1998). Unilateral hemivertebrae occur when the right and the left halves of the vertebrae develop asymmetrically. They are wedge-shaped, with the base orientated dorsally, ventrally or laterally. Bilateral hemivertebrae (termed 'butterfly vertebrae') result from non-union of right and left halves of the vertebral body. Neurological signs, resulting from spinal cord compression, usually manifest around 3–4 months of age in affected dogs. Clinical signs include pelvic limb ataxia and paresis, loss of reflexes, kyphosis, lordosis and scoliosis at thoracic vertebra, incontinence, atrophy and atony of the pelvic limb muscles (Bailey and Morgan, 1992; Besalti et al., 2005). The aims of the present study were to quantify significant effects on the number and grade of hemivertebrae in a convenience sample of French bulldogs and to estimate heritability employing an animal threshold model.

One hundred and five French bulldogs, registered with Federacion Cynologique Internationale-affiliated breed associations in Germany [Deutscher Klub für Französische Bulldoggen (DKFB) or Deutsche Hundesport Union (DHSU)] were included in the study. The dogs were born between 1994 and 2011 and were screened for hemivertebrae by veterinarians using radiography. The vertebral column of each dog was radiographed in a lateral position, extending at least from the first thoracic (T1) to the last lumbar (L7) vertebra. All thoracic radiographs were submitted to the Institute for Animal Breeding and Genetics, University of Veterinary Medicine Hannover, for evaluation. The minimum age at examination was 11 months. Pedigree data and additional information on dogs were provided by the respective breed associations. Pedigrees included five generations of ancestors, totalling 809 animals.

The number of hemivertebrae in the thoracic and lumbar spine was determined and used for trait analysis. In addition, we employed a four-point measurement scheme to differentiate between the types of hemivertebrae, since the vertebral column angle more strongly correlates with clinical signs than the number of hemivertebrae per se (Moissonnier et al., 2011). The dorsal (distance from the leading and rear edge of the dorsal surface of the vertebral body) and ventral (distance from the leading and rear edge of the ventral surface of the vertebral body) lengths of each hemivertebra were measured and recorded (Appendix: Supplementary Fig. S1). The difference between the dorsal and ventral vertebral body lengths were calculated, then categorised into five grades (Grade 0, vertebral body lengths were identical; Grade 1, <20% difference between dorsal and ventral vertebral body lengths; Grade 2, 20–40% difference; Grade 3, 40–60% difference; Grade 4, >60% difference). For animals with multiple hemivertebrae, the highest score was used for the analysis. In addition, the number of coccygeal vertebrae was determined for each dog, based on the radiographic evidence provided.

Ordinal regression analysis was employed to test for significant systematic effects. Birth year, birth month and sex of the dog

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were regarded as fixed effects. Data analysis was performed using the GENMOD procedure of the Statistical Analysis System (SAS) software package, with a multinomial distribution and a cumulative logit link function. All genetic parameter estimates were obtained through animal threshold models using GS3.[1] A bivariate animal threshold model was employed to estimate heritabilities and correlations for the number and grade of hemivertebrae. In addition, we estimated the genetic parameters for the number of coccygeal vertebrae and their correlation with the number and grade of hemivertebrae present. In threshold models, the underlying non-observable variate was assumed to follow a normal distribution and the unknown thresholds are estimated using a standard cumulative normal distribution function. Threshold models were shown to better fit ordinal data compared to linear models (Stock et al., 2007).

Hemivertebrae were found to be present in 89/105 of the dogs examined. The frequencies for Grades 0–4 of hemivertebrae were 0.15, 0.34, 0.23, 0.20 and 0.08, respectively. Of the 89 affected dogs, 41 were male and 48 were female. Hemivertebrae were most often located between T6 and T12 thoracic vertebrae. Ordinal regression analysis did not show any significant effects for birth year, birth month and sex, using the traits number and grade of hemivertebrae.

Heritability estimates were 0.58 ± 0.15 (mean ± standard error) for the number of hemivertebrae and 0.53 ± 0.16 for the grade of hemivertebrae, based on the relative difference between the dorsal and ventral vertebral body lengths. Additive genetic and residual correlations between the number of hemivertebrae and the scored differences were 0.69 ± 0.24 and 0.44 ± 0.25. The number of coccygeal vertebrae showed a heritability of 0.35 ± 0.19. Additive genetic correlations for the number of coccygeal vertebrae with the number and grade of hemivertebrae were estimated at -0.39 ± 0.49 and -0.37 ± 0.46, respectively.

The study findings support a hereditary component to development of hemivertebrae in French bulldogs. Despite the high prevalence of this condition, estimates for heritability are fairly high, which might indicate an unequal distribution of severe cases and dogs free from this condition among families. Selective breeding, based on phenotype, must take into account the relatively small number of dogs that are unaffected. Therefore, progress in reducing the prevalence of the condition will likely be slow due to the limited number of breeding animals with the desired (unaffected) phenotype. We, and others, suggest that dogs with an extreme phenotype (i.e. screwed tails) should not be rewarded in competitive dog shows, nor preferentially selected for breeding purposes (Kramer et al., 1982). Although genetic progress could be made quite rapidly by utilising the limited number of long tailed dogs available, there would be a risk of reduced genetic variability (decreased heterozygosity) in the population and hence emergence of other undesirable characteristics. Selection of dogs for the long tailed phenotype should take into account other health traits and also genome-wide heterozygosity, as determined via genotyping by the canine Illumina high density beadchip.

The present study suggests a genetic disposition to the number and grade of hemivertebrae. The presence of a larger number of coccygeal vertebrae correlated with a lower number and less severe grade of hemivertebrae, although the large standard error of the correlation estimates indicates that further work is required in a larger sample of dogs.

[1] See: http://snp.toulouse.inra.fr/~alegarra/ (accessed 27 March 2015).

Conflict of interest statement

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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Appendix: Supplementary material

Supplementary data to this article can be found online at doi:10.1016/j.tvjl.2015.10.044.

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