Prevalence of spondylosis deformans and estimates of genetic parameters for the degree of osteophytes development in Italian Boxer dogs[1]

P. Carnier[2]*, L. Gallo*, E. Sturaro*, P. Piccinini†, and G. Bittante*

*Department of Animal Science, University of Padova, 35020 Legnaro, Italy
†Centre for the Screening of Skeletal Diseases (CeLeMaSche), 44100 Ferrara, Italy

ABSTRACT: The aim of this study was to assess the prevalence of spondylosis deformans and to investigate genetic aspects of the degree of osteophytes development (DOD) in the Italian Boxer dog population. A total of 849 Boxer dogs was radiographed on the thoracic, lumbar, and sacral regions of the spine and scored for DOD. Grading of DOD was performed for all 20 intervertebral sites comprised within the first thoracic site (site T1-T2) and the site between the seventh lumbar and the first sacral vertebra (site L7-S1). Scores for DOD ranged from 0 (no osteophytes development) to 3 (presence of a bony spur formed by osteophytes on adjoining vertebrae). The first five thoracic sites exhibited no variation for DOD and were not considered in the analysis. The prevalence of spondylosis deformans was 84%, and frequency of dogs showing at least one intervertebral site that scored 3 for DOD was 50%. Scores for DOD at different sites were analyzed as different traits. Nongenetic effects influencing DOD scores were sex, age at screening, and the kennel. Posterior densities of heritability (h^2) were estimated using a univariate Bayesian analysis. Eight sites exhibited a posterior probability greater than 0.8 for $h^2 > 10\%$ and were considered in a multivariate restricted maximum likelihood analysis. Estimated h^2 from multivariate analysis ranged from 25 to 48% (SE from 5 to 7%). Three sites exhibited h^2 estimates greater than 40%. Genetic correlations for DOD scored at different sites ranged from 0.07 to 0.96. All thoracic sites had estimated correlations larger than 0.85 with other thoracic sites. Genetic correlation between the first and the second lumbar site was 0.91. Correlations between thoracic sites and the first two lumbar sites ranged from 0.5 to 0.9. Sites L6-L7 and L7-S1 also exhibited weak relationships with all remaining sites. Breeding values of dogs for DOD at the eight sites were predicted using estimated covariance matrices. A selection index for DOD was computed from predicted breeding values and a set of relative weighting factors produced by a panel of veterinarians. The index was the most important effect influencing phenotypic differences between dogs for average DOD score, number of affected sites, and number of sites with a DOD score > 1 ($P < 0.001$). The degree of osteophytes development is a trait showing exploitable additive genetic variance, and breeding programs for decreasing prevalence and severity of spondylosis deformans might focus on this trait.

Key Words: Boxer, Dog, Genetic Correlations, Heritability, Osteophytes Development, Spondylosis Deformans

 J. Anim. Sci. 2004. 82:85–92

Introduction

The dog is the nonhuman species for which the largest number of genetic disorders are known (Ostrander et al., 2000), but current breeding programs for purebred dogs focus on a limited number of genetic diseases. Within the group of skeletal disorders, hip and elbow dysplasia have been investigated the most, and genetic parameters for traits associated with these diseases have been reported (e.g., Leppanen et al., 2000; Maki et al., 2000; Olherth et al., 2001).

Genetic aspects of other skeletal diseases like spondylosis deformans have been studied less. Spondylosis deformans is a degenerative disease of the spine exhibiting the presence of one or more osteophytes, showing different degrees of development, at the level of vertebral bodies (Hansen, 1952; Morgan, 1967). Severe spondylosis causes stiffness in the back, lameness, change of gait, and pain. Hence, decreasing the incidence and severity of spondylosis is desirable for enhancing longevity and welfare of dogs.

Incidence of spondylosis in the Boxer breed (Murlebach and Freudiger, 1973; Eichelberg and Wurster,

[1]Financial support by the University of Padova (code CPDA 027842) is gratefully acknowledged. The authors are also indebted to Ente Nazionale Cinofilia Italiana for providing pedigree information. E. Groeneveld is acknowledged for the use of the VCE program.

[2]Correspondence—phone: +39 049 8272664; fax: +39 049 8272633; e-mail: paolo.carnier@unipd.it.

Received March 26, 2003.
Accepted September 11, 2003.

1982) is high and increases, as well as becomes more severe, as the dogs age (Mattoon and Koblick, 1993). Some studies (Murlebach and Freudiger, 1973; Eichelberg and Wurster, 1982) postulated that spondylosis might have a genetic basis. Langeland and Lingaas (1995) reported heritability (h^2) estimates ranging from 0.42 to 0.62 for the maximum degree of osteophyte development and from 0.13 to 0.47 for the number of affected intervertebral sites, but these estimates exhibited very large standard errors and did not differ significantly from zero.

The present study aimed to assess the prevalence of spondylosis deformans and to investigate genetic aspects of the degree of osteophytes development (**DOD**) in the Italian Boxer dog population.

Materials and Methods

Data and Osteophytes Development Grading

Data comprised of screening results of 851 Boxer dogs (469 females and 382 males) enrolled from 1997 to 2001 in the screening program for spondylosis deformans arranged jointly by the Centre for the Screening of Skeletal Diseases and the Italian Boxer Club. The screening program was specifically arranged for investigating the prevalence of spondylosis deformans in the population and genetic aspects of the DOD. Hence, a major concern was for the randomness of the screening process. All members of the Italian Boxer Club (breeders and owners of dogs) were asked to involve in the screening program all animals that were at least 1 yr old or older, including also breeding dogs. It was not possible for a breeder to screen only some animals (i.e., dogs exhibiting clinical signs of the disease or dogs that were progeny of affected or suspected dogs), and results of the screening process did not influence registration of animals by the Italian Boxer Club.

Radiographs on thoracic, lumbar, and sacral regions of the spine were taken by 156 veterinarians and graded for DOD by a single panelist. Starting from the site between the first and the second thoracic vertebra (site T1-T2) and moving to the site between the seventh lumbar and the first sacral vertebra (site L7-S1), grading of DOD was performed using the method of Langeland and Lingaas (1995). A score for DOD was attributed to each site (20 sites) using a four-grade linear system (Figure 1): grade 0 = no osteophytes development detected; grade 1 = small osteophytes placed on the edge of the epiphysis were observed, but did not exceed the vertebral edge; grade 2 = osteophytes were enlarged beyond the edge of epiphysis, but did not connect to osteophytes on the opposite vertebra; and grade 3 = osteophytes placed on adjoining vertebrae connected one to each other, thus establishing an appreciable bony spur.

The data also included information on dog identification, dates of birth and of x-ray screening, sex, kennel, and x-raying veterinarian. Age of dogs at x-ray assay ranged from 10 to 84 mo ($\bar{x}$ = 20 mo, SD = 10 mo).

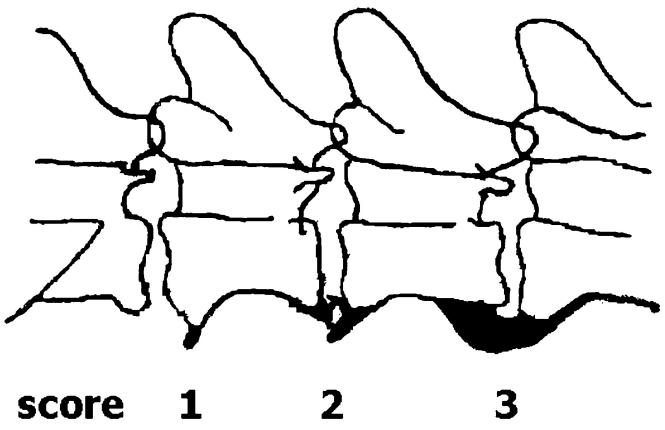

Figure 1. Grading of the degree of osteophytes development (from Langeland and Lingaas, 1995).

Pedigree records were obtained from the pedigree register of the Italian Boxer dog population, which is routinely updated by the Italian Association of Dog Breeders. Records of two screened dogs were removed from the data file because parents of these animals were unknown. Dogs involved in the screening program were progeny of 329 sires and 552 dams. Pedigrees were traced back for as many generations as available, resulting in a total of 3,087 dogs in the analysis. Useless pedigree information (i.e., ancestors without pedigree and with one progeny only) was discarded.

Statistical Analysis

Statistical analyses were performed considering scores for DOD at different intervertebral sites as different traits and by using linear model methodology for normally distributed data, albeit DOD scores were ordered categorical traits. The method of choice in the analysis of ordered categorical traits is the threshold model (Gianola and Foulley, 1983), and the use of sire models is suggested when applying threshold model analysis to estimate genetic parameters (Moreno et al., 1997). In this study, preference was given to the use of linear models because of known problems due to biased inference regarding variance components resulting from the application of a threshold sire model when the number of progeny per sire is small and the amount of information associated with a fixed effect (i.e., the kennel effect in our analysis) is limited (Moreno et al., 1997). Moreover, estimation of the kennel effects would have been troublesome under a threshold model because of the extreme category problem (Misztal et al., 1989; Moreno et al., 1997). Because DOD scored at the first five sites (from site T1-T2 to site T5-T6) exhibited no phenotypic variation, analyses were performed using only 15 scores (traits) per dog.

Nongenetic Effects

Nongenetic effects considered in the mixed linear models for estimating variance components and genetic

parameters of DOD scores were from preliminary analyses. Age of dogs at screening was classified into six classes (12 mo or less, 13 to 16, 17 to 22, 23 to 28, 29 to 39, and 40 mo or more). Because the kennel and x-raying veterinarian effects were partly confounded, only the kennel effect was retained in the analysis. Effects due to age at screening, kennel, and sex were statistically significant for a number of sites and were included in genetic models aimed at estimating (co)variance components.

Estimation of (Co)variance Components and Genetic Parameters for DOD Score

Estimation of (co)variance components for DOD score was conducted in two steps : 1) the first step was exploratory and was based on 15 univariate Bayesian analyses performing numerical integration using the Gibbs sampler; 2) the second step aimed to estimate (co)variance matrices for DOD score at different sites and was based on a multivariate restricted maximum likelihood REML analysis.

Mixed linear models included nongenetic effects previously described and the additive genetic effect of dogs and took into account all known additive relationships (3,087 animals).

Univariate Bayesian analyses were based on conditional densities and on the scalar form of the Gibbs sampler presented by Wang et al. (1994). Prior scaled inverted chi-squared distributions were assumed for residual and additive genetic variances. The hyperparameters of scaled inverted chi-squared distributions (ν and s^2) were equal to –2 and 0, making the prior distribution flat (Wang et al., 1994).

Each Bayesian analysis was carried out generating a single Gibbs chain. Size of the chain and burn-in length were chosen by comparing results obtained for two randomly selected sites with chain and burn-in period of different sizes and by subjective inspection of plots of values from the Gibbs chain. Because computing time was short, the length of the generated chain (1,200,000 samples) and of the burn-in period used (200,000 samples) were conservatively determined by multiplying the originally chosen length by 10. Samples were saved every 10 iterations.

Posterior densities of h^2 and additive genetic variance of DOD score were estimated using a nonparametric density estimation technique based on average shifted histograms (Scott, 1992). The posterior median was used as point estimate of variance components and heritabilities. Lower and upper bounds of symmetric 95% probability density regions for h^2 and additive genetic variance and the posterior probability for $h^2 > 10\%$ were obtained from the estimated marginal densities. Sites exhibiting a posterior probability lower than 0.8 for $h^2 > 10\%$ were not considered in the multivariate restricted maximum likelihood (REML) analysis. This reduced the number of traits in the analysis from 15 to eight. Analyses based on REML were performed using the software package VCE (Neumaier and Groeneveld, 1998).

Prediction of Breeding Values and Selection Index Procedures

Estimated (co)variance matrices from REML analysis were used to predict breeding values of dogs for DOD score at eight intervertebral sites (site T9-T10, T10-T11, T11-T12, T12-T13, L1-L2, L2-L3, L6-L7, and L7-S1). Breeding values were predicted using a full multivariate (eight traits) animal model. Predicted breeding values and prediction error variances and covariances of the predicted breeding values were obtained using the PEST program (Groeneveld, 1994).

A panel of veterinarians was asked to establish, on the basis of their own knowledge and experience, relative weighting factors for setting up a selection index. Some intervertebral sites, if affected by the disease, were considered by the veterinarians to be more important than others because of expected consequences on the functional life of dogs.

When breeding values are predicted using a multivariate BLUP animal model procedure, optimal index weights (Schneeberger et al., 1992) are computed as:

$$b = G_{11}^{-1} G_{12} \nu$$

where b is a vector of index weights, G_{11} is the additive genetic covariance matrix of traits in the index, G_{12} is the additive genetic covariance matrix between traits in the index and traits in the aggregate genotype, and ν is a vector of economic values. In our study, $G_{11} = G_{12}$ because the index traits are the same traits included in the aggregate genotype, and as a consequence, $b = \nu$. Hence, the index for a dog was simply computed as:

$$I = \nu' g$$

where I is the index, ν is the vector of relative weighting factors produced by the veterinarians, and g is a vector of predicted breeding values for DOD score at eight intervertebral sites. The accuracy of the index for animal i was computed as:

$$r_{HI(i)} = \sqrt{\frac{\sigma^2_{I(i)}}{\sigma^2_H}}$$

where $r_{HI(i)}$ is the accuracy of the index, $\sigma^2_{I(i)}$ is the variance of the index, and σ^2_H is the variance of the aggregate genotype. The variance of the index for animal i ($\sigma^2_{I(i)}$) was computed as (Schneeberger et al., 1992):

$$\sigma^2_{I(i)} = \nu' Var(\hat{u}_i) \nu = \nu' (a_{ii} G_{11} - C_{ii}) \nu$$

where $Var(\hat{u}_i)$ is the (co)variance matrix of the predicted breeding values for DOD score at eight intervertebral

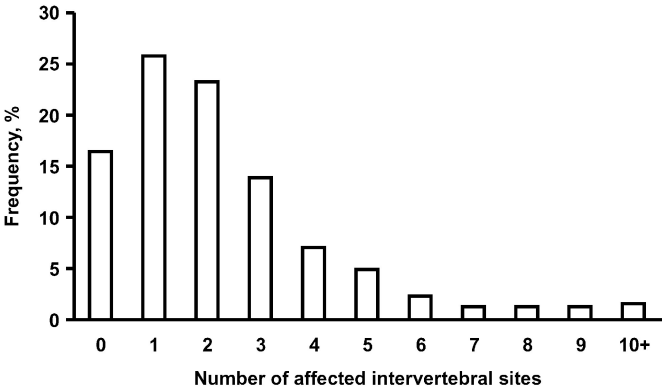

Figure 2. Frequency of dogs by number of sites showing osteophytes development.

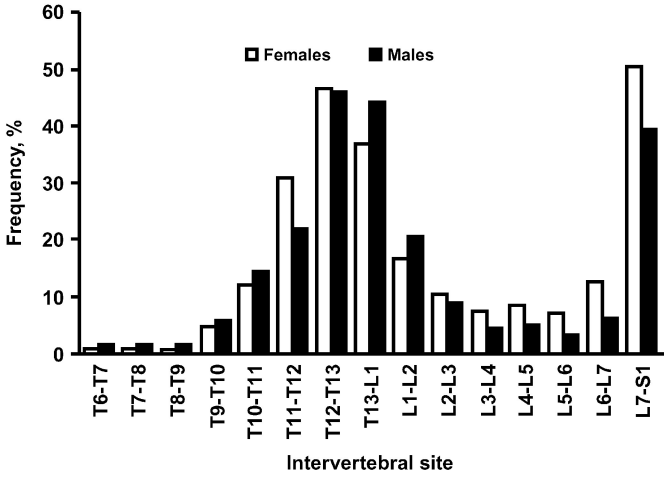

Figure 3. Frequency of affected dogs by intervertebral site (site: T = thoracic; L = lumbar; S = sacral).

sites for animal i, a_{ii} is the diagonal element of the numerator additive relationship matrix for animal i, G_{11} is the additive genetic covariance matrix of traits in the index, and C_{ii} is the prediction error (co)variance matrix of the predicted breeding values for DOD score at eight intervertebral sites for animal i. The variance of the aggregate genotype was computed as:

$$\sigma_H^2 = \nu' G_{22} \nu$$

where G_{22} (which is equal to G_{11}) is the additive genetic (co)variance matrix for the traits (DOD at eight intervertebral sites) in the aggregate genotype.

On the basis of the index, screened dogs (849 animals) were then classified into five classes: index less than –2 SD, from –2 to –1 SD, from –1 to +1 SD, from +1 to +2 SD, and index greater than +2 SD. The effect of the dog index class on average DOD score (computed using scores of all 15 sites), number of sites showing osteophytes development, and number of sites with DOD score >1 was investigated through a linear model that also included the effect of age at screening class, sex, and breeder.

Results and Discussion

Descriptive Statistics and Prevalence

Average DOD score was 0.29 (SD = 0.35) and the average number of intervertebral sites exhibiting osteophytes development was 2.37 (SD = 2.27). Frequency of dogs by number of affected intervertebral sites is presented in Figure 2. Only 16% of the sample were devoid of osteophytes development at all intervertebral sites and were considered unaffected by spondylosis deformans. Nearly a quarter of the sample showed one site with development of osteophytes and another quarter had two sites affected. More than one-third of screened dogs had three or more intervertebral sites affected by spondylosis. Frequency of dogs that showed at least one intervertebral site graded 3 for DOD, the most severe degree of development, was 50% (data not shown).

Prevalence of spondylosis deformans estimated in the present study was 84%, which was comparable to values reported by Murlebach and Freudiger (1973), Eichelberg and Wurster (1982), and Langeland and Lingaas (1995) for other Boxer populations, and confirmed the significance of this skeletal disease for Boxer dogs.

As depicted in Figure 3, frequency of affected dogs was different for different intervertebral sites. The occurrence of osteophytes development was appreciable starting from site T9-T10 and showed very high frequencies for sites within the last three thoracic and the first lumbar vertebra. Frequency of occurrence of development of osteophytes was lower but still appreciable for sites of the lumbar region, and exhibited a marked increase for the site between the last lumbar and the first sacral vertebra. This increase was higher for females than for males.

Nongenetic Effects

Least squares means and significance for sex and age at screening effects on DOD score at different sites are presented in Table 1. Differences between female and male dogs means for DOD score were statistically significant for a limited number of sites and mostly for the caudal sites of the spine, where osteophytes appeared more frequently (Figure 3) and developed in females more often than in males.

Age of dogs was a relevant effect for DOD at many intervertebral sites (Table 1). In general, the younger a dog was at screening, the better its status was for spondylosis. This result is in agreement with that reported by Langeland and Lingaas (1995). Because of significant age at screening effects, dogs should be compared for DOD when screened at a similar age, or if screening occurs at a different age, after adjustment of DOD scores for age effects. From a practical point of

Table 1. Least squares means and significance for sex and age at screening effects on the score for the degree of osteophytes development

	Sex, score			Age at screening class, score						
Site[a]	Female	Male	P^b	<12 mo	13 to 16	17 to 22	23 to 28	29 to 40	>40	P
T6-T7	0.014	0.016	NS	0.000	0.022	0.018	0.024	0.078	0.009	NS
T7-T8	0.027	0.025	NS	0.001	0.047	0.041	0.046	0.099	0.095	NS
T8-T9	0.044	0.048	NS	0.003	0.035	0.040	0.106	0.115	0.123	**
T9-T10	0.146	0.150	NS	0.007	0.055	0.074	0.188	0.258	0.431	***
T10-T11	0.428	0.482	NS	0.118	0.100	0.265	0.419	0.906	0.921	***
T11-T12	0.605	0.544	NS	0.075	0.288	0.431	0.601	0.837	1.213	***
T12-T13	0.919	0.946	NS	0.644	0.696	0.869	0.865	1.312	1.213	***
T13-L1	0.659	0.833	*	0.603	0.569	0.777	0.836	0.723	0.968	*
L1-L2	0.336	0.416	NS	0.145	0.213	0.369	0.498	0.320	0.711	***
L2-L3	0.280	0.248	NS	0.060	0.088	0.309	0.272	0.442	0.538	***
L3-L4	0.238	0.173	NS	0.010	0.080	0.280	0.480	0.409	0.618	***
L4-L5	0.275	0.203	NS	0.040	0.069	0.322	0.410	0.661	0.284	***
L5-L6	0.269	0.152	*	0.019	0.039	0.146	0.204	0.507	0.348	***
L6-L7	0.340	0.152	***	0.034	0.119	0.232	0.305	0.538	0.247	***
L7-S1	1.396	1.169	*	0.991	1.148	1.457	1.063	1.548	1.489	*

*$P < 0.05$.
**$P < 0.01$.
***$P < 0.001$.
NS = not significant.
[a]T6-T7 through L7-S1 are intervertebral sites; T = thoracic, L = lumbar, S = sacral.

view, radiographic examination of the spine might be performed when dogs are screened for hip dysplasia (i.e., between 12 and 16 mo of age), to facilitate breeders and owners in controlling this skeletal disease and to improve efficiency of selection. Eichelberg and Wurtser (1983) reported a positive correlation between screening results for spondylosis obtained from 1 to 2 yr of age and further screenings performed later in a dog's life. Hence, early screening of Boxer dogs for spondylosis can be argued to be feasible and effective, but further investigation and specific studies are needed.

For all sites, the kennel effect accounted for a significant portion of the variation of DOD (data not shown). This effect accounts for differences in the rearing environment up to weaning for pups sold at weaning and, for dogs that do not leave the kennel, it also accounts for environmental differences that occur later in life. It is also likely that this effect accounts for differences due to the use of different dog strains in different kennels.

Genetic Effects

The median of marginal posterior densities for h^2 and additive genetic variance component, bounds of symmetric 95% probability density region, and posterior probability of $h^2 > 10\%$ obtained from univariate Bayesian analysis are reported in Table 2. The median of estimated posterior densities, which was used as the point estimate of h^2 and additive genetic variance, was heterogeneous across sites, and ranged from 3 to 44% for h^2 and from 0.04 to 0.80 points^2 for additive genetic variance of DOD score. The posterior probability of $h^2 > 10\%$ was higher than 0.8 for eight sites, and point estimate of h^2 was greater than 25% for six sites or greater than 30% for four sites. Sites T11-T12, L2-L3, and L7-S1 exhibited the highest estimates of h^2. Despite similar frequencies of affected dogs and average DOD scores for some sites (e.g., sites T12-T13 and T13-L1), estimates of h^2 for these sites were different (33 vs 17%). Moreover, for some sites showing low incidence (e.g., site T10-T11 and L2-L3), h^2 estimates were close to or greater than 30%.

Point estimates of additive genetic standard deviation of DOD score were higher than 0.5 points for eight intervertebral sites, namely the last four thoracic and the first two and the last two lumbar sites. For these sites, the lower bound of symmetric 95% probability density region of additive genetic variance also was far from zero.

In the literature, the only study dealing with the estimation of genetic parameters for traits related to spondylosis deformans was by Langeland and Lingaas (1995). They reported h^2 estimates, obtained using both regression of offspring on parents and paternal half-sibs correlation, ranging from 0.42 to 0.62 for the maximal degree of osteophytes development and from 0.13 to 0.47 for the number of sites exhibiting osteophytes development. However, due to the limited size of the sample, estimated parameters were not statistically different from zero. Results from the present study support the hypothesis that genetic effects are involved in and affect the occurrence and severity of spondylosis deformans: h^2 estimates are moderate for several intervertebral sites and the amount of additive genetic variation is large enough to be exploited in breeding programs aiming to decrease the prevalence and the degree of severity of the disease.

Estimates of h^2 obtained in this study for several intervertebral sites fall within the range of h^2 estimates reported for traits related to more investigated skeletal

Table 2. Median of marginal posterior densities and bounds of symmetric 95% probability density region of heritability (h^2) and additive genetic variance (σ_a^2) and posterior probability of $h^2 > 10\%$ for the score of the degree of osteophytes development obtained in univariate bayesian analysis

	h^2, %				σ_a^2, score^2		
Site[a]	PM[b]	L95%[c]	U95%[d]	$P(h^2 > 10\%)$[e]	PM	L95%	U95%
T6-T7	10	1	24	46	0.051	0.019	0.083
T7-T8	3	0	13	7	0.042	0.000	0.079
T8-T9	8	0	24	41	0.069	0.000	0.123
T9-T10	22	4	41	90	0.190	0.083	0.264
T10-T11	29	12	47	99	0.409	0.255	0.538
T11-T12	44	25	63	100	0.569	0.414	0.706
T12-T13	33	12	53	99	0.598	0.353	0.803
T13-L1	17	2	39	73	0.383	0.137	0.604
L1-L2	19	4	38	86	0.329	0.150	0.476
L2-L3	37	13	61	99	0.435	0.244	0.585
L3-L4	7	1	23	33	0.170	0.000	0.326
L4-L5	8	0	24	37	0.189	0.000	0.353
L5-L6	10	1	28	51	0.202	0.002	0.354
L6-L7	27	4	51	92	0.360	0.142	0.516
L7-S1	35	13	57	99	0.797	0.478	1.066

[a]T6-T7 through L7-S1 are intervertebral sites. T = thoracic, L = lumbar, S = sacral.
[b]PM = median of the posterior density.
[c]L95% = lower bound of symmetric 95% probability density region.
[d]U95% = upper bound of symmetric 95% probability density region.
[e]$P(h^2 > 10\%)$ = posterior probability for values of h^2 greater than 10%.

disorders of dogs; in a recent review, Breuer et al. (2001) reported h^2 estimates ranging from 20 to 60% and from 10 to 50% for traits related to hip dysplasia and elbow dysplasia, respectively. Because breeding programs for hip and elbow dysplasia have been established for several dog breeds in a number of countries, these programs might be adapted to allow for selection for spondylosis deformans when the disease is relevant for the population.

The eight sites showing probability greater than 0.8 for $h^2 > 10\%$ were considered in a REML multivariate analysis to estimate genetic correlations. Results are presented in Table 3. Multivariate analysis led to heritability estimates higher than those obtained in the univariate procedure. Increases of h^2 estimates ranged from 1 to 11 points, and estimates at three sites were greater than 40%. Standard errors of estimated h^2 were small, ranging from 0.05 to 0.07.

Phenotypic correlations for DOD at different sites were moderate, ranging from 0.05 to 0.60, whereas genetic correlations were higher. Genetic correlations were heterogeneous and, as a general feature, their size was higher for adjoining sites than for sites far away. Indeed, all thoracic sites exhibited correlations larger than 0.85 with other thoracic sites and DOD scores at the first and at the second lumbar site were highly correlated. An exception was the moderate additive genetic correlation between sites L6-L7 and L7-S1. These two sites also exhibited weak relationships with all remaining sites, whereas estimated genetic correlations

Table 3. Estimates of heritability (diagonal), genetic (above diagonal) and phenotypic correlations (below diagonal) for the score of the degree of osteophytes development at eight intervertebral sites obtained with multivariate restricted maximum likelihood analysis[a]

Site[b]	T9-T10	T10-T11	T11-T12	T12-T13	L1-L2	L2-L3	L6-L7	L7-S1
T9-T10	0.31	0.86	0.88	0.86	0.74	0.76	0.66	0.46
T10-T11	0.50	0.33	0.96	0.87	0.72	0.53	0.55	0.29
T11-T12	0.44	0.54	0.46	0.94	0.88	0.72	0.45	0.23
T12-T13	0.29	0.36	0.60	0.43	0.91	0.84	0.24	0.07
L1-L2	0.32	0.27	0.40	0.41	0.25	0.91	0.19	0.09
L2-L3	0.33	0.27	0.35	0.36	0.59	0.48	0.14	0.16
L6-L7	0.18	0.19	0.17	0.19	0.27	0.30	0.29	0.70
L7-S1	0.10	0.05	0.10	0.14	0.13	0.11	0.19	0.36

[a]Heritability SE ranged from 0.04 to 0.07, SE of genetic correlations from 0.03 to 0.14.
[b]T9-T10 through L7-S1 are intervertebral sites; T = thoracic, L = lumbar, S = sacral.

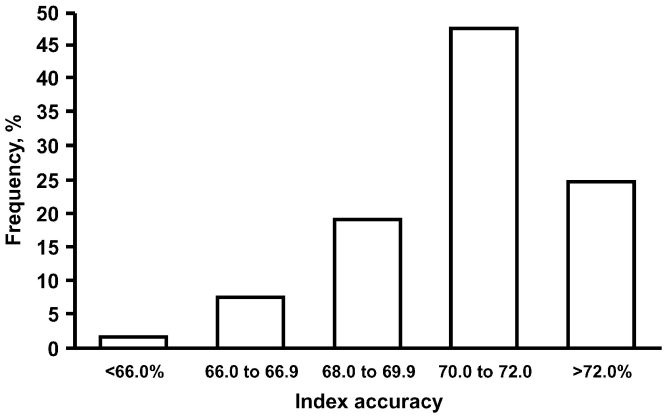

Figure 4. Frequency distribution of screened dogs based on accuracy class of the selection index for the degree of osteophytes development.

between thoracic sites and the first two lumbar sites were higher, ranging from 0.5 to 0.9. In general, standard errors of genetic correlations ranged from 0.03 to 0.14.

Evidence of heterogeneous heritabilities and of genetic correlations lower than 1 indicates that DOD scores at different sites should be considered as measures of different traits. This should be taken into account in genetic evaluation programs and selection procedures to reduce the prevalence of this disease.

A Selection Index for the Degree of Osteophytes Development

Relative weighting factors, attributed by the panel of veterinarians to the eight intervertebral sites, were 20% for sites T10-T11, T11-T12, T12-T13, and L1-L2; 6.67% for sites T9-T10 and L2-L3; and 3.33% for sites L6-L7 and L7-S1. Use of the index based on these linear weights is expected to decrease DOD more at some sites than at other sites. However, when the improvement of functional life of the dog is the breeding goal, use of a set of nonlinear weights seems more appropriate. Indeed, for some sites it might be argued that the improvement of functional life of the animal due to a decrease of DOD is greater when DOD moves from score 3 to score 2 than when it moves from score 1 to score 0. Current knowledge does not allow us to produce a set of nonlinear weighting factors and further research on these aspects is needed.

As a result of the weights used, of variances and covariances of EBV, and of additive genetic variances and covariances for DOD score at the eight sites, the accuracy of the selection index ranged from 0.59 to 0.81. Frequencies of screened dogs based on different accuracies of the index are reported in Figure 4. The accuracy of the index was equal to or greater than 0.7 for 72% of screened dogs.

Least squares means for the effect of the selection index class on average DOD score, computed averaging scores for sites from T9-T10 to L7-S1 (15 sites), number of sites showing osteophytes development, and number of sites with score > 1 are reported in Table 4. The linear model used to investigate the effect of the index class on these traits also included kennel, sex, and age at screening effects. The index class was the most important effect for all traits and accounted for 61% of variation explained by the linear model (data not shown). Least squares means for all traits (Table 4) exhibited increases when the selection index class of the dog increased. Differences between dogs with an index greater than +2 SD and those included in the lowest index class were 1 point, 5.4, and 5.3 for average DOD score, number of affected sites, and number of sites with DOD score > 1, respectively ($P < 0.001$). Hence, phenotypic differences between dogs of different index class were related not only to average DOD score, but also to the number of affected discs and to the number of sites showing development of osteophytes of larger size.

Implications

Results from this study provide evidence that spondylosis deformans is a highly prevalent skeletal disease

Table 4. Least squares means for index class effects ($P < 0.001$) on average DOD score, number of intervertebral sites showing osteophytes development, and numbers of sites with DOD score >1[a,b]

Index class[c]	Dogs	Average DOD score[d]	Number of affected sites	Number of sites with DOD score > 1
Lower than –2 SD	24	0.084	0.93	0.15
From –2 to –1 SD	143	0.146	1.27	0.54
From –1 to +1 SD	552	0.264	2.11	1.09
From +1 to +2 SD	101	0.682	4.56	3.37
Greater than +2 SD	29	1.083	6.38	5.42

[a]DOD is the degree of osteophytes development scored from 0 to 3.
[b]The linear model included also sex, age at screening, and breeder effects.
[c]The index is a selection index computed using estimated breeding values for DOD score at eight sites and weighting factors produced by a panel of veterinarians.
[d]Computed by averaging scores attributed to 15 sites.

for the Italian Boxer dog population and that the degree of osteophytes development, evaluated at different intervertebral sites, is a trait exhibiting heritability estimates of intermediate magnitude and exploitable additive genetic variance. This ensures feasibility of selection programs to decrease prevalence and the degree of severity of the disease and offers the opportunity of implementing genetic evaluation procedures that rely on individual phenotypic observations of candidates based on x-ray assay. Furthermore, the selection index for the degree of osteophytes development proposed in this study might be provided to breeders immediately after the screening of dogs and used for planning of matings.

Literature Cited

Breur, G. J., G. Lust, and R. J. Todhunter. 2001. Genetics of canine hip dysplasia and other orthopaedic traits. Pages 267–298 in The Genetics of the Dog. A. Ruvinsky and J. Sampson, ed. CABI Publ., Wallingford, U.K.

Eichelberg, H., and H. Wurster. 1982. Untersuchungen zur Spondylosis deformans bei Boxern. Kleintierpraxis 27:59-71.

Gianola, D., and J. L. Foulley. 1983. Sire evaluation for ordered categorical data with a threshold model. Genet. Sel. Evol. 15:201–224.

Groeneveld, E. 1994. PEST Manual: Available: ftp://ftp.zgr.fal.de/pub/pest/doc/manual.ps.june94. Accessed March 25, 2003.

Hansen, H. J. 1952. A pathologic-anatomical study on disc degeneration in dog. Acta Orthop. Scand. Suppl. 11:1–118.

Langeland, M., and F. Lingaas. 1995. Spondylosis deformans in the Boxer: Estimates of heritability. J. Small Anim. Pract. 36:166–169.

Leppanen, M., K. Maki, J. Juga, and H. Saloniemi. 2000. Estimation of heritability for hip displasia in German Sheperd dogs in Finland. J. Anim. Breed. Genet. 117:97–103.

Maki, K., A. E. Liinamo, and M. Ojala. 2000. Estimates of genetic parameters for hip and elbow dysplasia in Finnish Rottweilers. J. Anim. Sci. 78:1141–1148.

Mattoon, J. S., and P. D. Koblik. 1993. Quantitative survey radiographic evaluation of the lumbosacral spine of normal dogs and dogs with degenerative lumbosacral stenosis. Vet. Radiol. & Ultrasound 34:194–206.

Misztal, I., D. Gianola, and J. L. Foulley. 1989. Computing aspects of a nonlinear sire evaluation for categorical data. J. Dairy Sci. 72:1557–1568.

Moreno, C., D. Sorensen, L. A. Garcia-Cortes, L. Varona, and J. Altarriba. 1997. On biased inferences about variance components in the binary threshold model. Genet. Sel. Evol. 29:145–160.

Morgan, J. P. 1967. Spondylosis deformans in the dog. Its radiologic appearance. J. Am. Vet. Rad. Soc. 8:17–22.

Mürhlebach, R., and U. Freudiger. 1973. Rontgenologische Untersuchungen uber die Erkrankungsformen der Spondylosis beim Deutschen Boxer. Schweiz. Arch. Tierheilk. 115:539–556.

Neumaier, A., and E. Groeneveld. 1998. Restricted maximum likelihood estimation of covariances in sparse linear models. Genet. Sel. Evol. 30:3–26.

Ohlerth, S., J. Lang., A. Busato, and C. Gaillard. 2001. Estimation of genetic population variables for six radiographic criteria of hip dysplasia in a colony of Labrador Retrievers. Am. J. Vet. Res. 62:846–852.

Ostrander, E. A., F. Galibert, and D. F. Patterson. 2000. Canine genetics comes of age. Trend Genet., 16:117–124.

Schneeberger, M., S. A. Barwick, G. H. Crow, and K. Hammond. 1992. Economic indices using breeding values predicted by BLUP. J. Anim. Breed. Genet. 109:180–187.

Scott, D. W. 1992. Multivariate Density Estimation: Theory, Practice, and Visualization. John Wiley & Sons, New York.

Wang, C. S., J. J. Rutledge, and D. Gianola. 1994. Bayesian analysis of mixed linear models via Gibbs sampling with an application to litter size in Iberian pigs. Genet. Sel. Evol. 26:91–115.