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Prevalence and genetic parameters for hip dysplasia in Italian population of purebred dogs

Enrico Sturaro[1], Lucia Menegazzo[1], Paolo Piccinini[2],
Giovanni Bittante[1], Paolo Carnier[1], Luigi Gallo[1]

[1] Dipartimento di Scienze Animali. Università di Padova, Italy
[2] Centrale di lettura delle malattie scheletriche ereditarie. Ferrara, Italy

Corresponding author: Prof. Luigi Gallo. Dipartimento di Scienze Animali. Università di Padova. Viale dell'Università 16, 35020 Legnaro (PD), Italy - Tel. +39 049 8272657 – Fax: +39 049 8272669 – Email: luigi.gallo@unipd.it

ABSTRACT

This paper aimed to assess the prevalence of hip dysplasia (HD) in some breeds of dogs widely diffused in Italy and to estimate heritability of HD in German Shepherd and Boxer Italian populations. Data consisted of radiographic findings taken on 32,900 dogs (18,665 females and 14,225 males) of 7 breeds (German Shepherd; Boxer; Labrador Retriever; Golden Retriever; Rottweiler; Dobermann; Cane Corso) screened at an age of 17.9 ± 7.0 months. Radiographs of the coxofemoral joints, taken by 478 veterinarians, were scored for HD grade by a single veterinarian panelist according to a grading procedure based on a 5-class linear system (from A, no signs of dysplasia, to E, severe dysplastic hip changes). Logistic regression analysis was used for studying the relationships between selected explanatory variables with the outcome of the diagnosis for HD. Variance components, direct and maternal heritability have been estimated for German Shepherd and Boxer dogs using a REML animal model procedure. Prevalence of HD (hip joint graded C or worse) for the pool of breeds involved approached 22%, with large differences among breeds. In dogs diagnosed as dysplastic, the mild form (grade C) was largely prevalent for all breeds. When compared to the German Shepherd, the Cane Corso exhibited a significantly higher risk, whereas the Dobermann, Labrador and Rottweiler showed a significantly lower risk of being affected by HD. The probability of being diagnosed as dysplastic increased with the increasing of the age of dogs at screening and with the decreasing of experience of x-raying veterinarians. The effect of birth year of dogs on the outcome of the HD diagnosis was significant, but evidenced an inconsistent trend through years. Heritability estimates approached 0.24 and 0.15 for Boxers and German Shepherds, respectively, whereas maternal heritability was close to 0.03 for both breeds. Results from this study demonstrated that HD is fairly prevalent in some breeds of dogs commonly found in Italy, and its reduction should be a goal in breeding schemes of purebred dogs. Age at screening and experience of the x-raying veterinarians are disturbance factors to be considered in screening programs for HD. Heritability estimates for HD was low, but additive genetic variance seems enough for conjecturing selection programs aimed to decrease hip joints disease. Given the low heritability values, current selection schemes based on phenotypic records seem ineffective, whereas the use of breeding values estimated under BLUP animal model procedures should be recommended for gaining genetic progress of Italian dog populations.

Key words: Dogs, Hip dysplasia, Genetic parameters.

RIASSUNTO
PREVALENZA E PARAMETRI GENETICI DELLA DISPLASIA DELL'ANCA IN CANI DI RAZZA PURA ALLEVATI IN ITALIA

Obiettivi di questa ricerca sono la determinazione della prevalenza della displasia dell'anca (DA) in alcune razze canine ampiamente allevate in Italia, l'analisi di alcune fonti di variazione ambientali della patologia articolare e la stima dei parametri genetici della DA nelle popolazioni italiane di Pastore Tedesco e Boxer. I dati utilizzati derivano dagli esiti radio-

grafici effettuati su 32.900 soggetti (18.665 femmine e 14.225 maschi) appartenenti a 7 razze (Pastore Tedesco; Boxer; Labrador Retriever; Golden Retriever; Rottweiler; Dobermann; Cane Corso) sottoposti ad esame radiografico ad un'età di 17,9±7,0 mesi. Le radiografie dell'articolazione coxo-femorale, effettuate da 478 veterinari, sono state sottoposte a diagnosi per la DA ad opera di un unico lettore; lo stato delle anche è stato valutato utilizzando un sistema lineare a 5 classi (da A, nessun segno di displasia, ad E, severo grado di DA). I dati sono stati sottoposti ad analisi di regressione logistica per studiare le relazioni intercorrenti tra l'esito della diagnosi per la DA e alcune possibili variabili esplicative. Si è infine proceduto, limitatamente a Pastore Tedesco e Boxer, alla stima delle componenti di varianza e dell'ereditabilità diretta e materna utilizzando una procedura REML animal model. La prevalenza della DA (grado C o superiore) nel pool di razze esaminate è risultata vicina a 22%, con una certa variabilità tra razze; in particolare i soggetti di razza Dobermann e Cane Corso hanno presentato la prevalenza inferiore (4,8%) e superiore (28,1%), rispettivamente. La displasia di grado leggero (C) è risultata nettamente predominante per i cani diagnosticati displasici in tutte le razze considerate. Quando paragonati ai Pastori Tedeschi, i soggetti di razza Cane Corso hanno presentato una probabilità di diagnosi sfavorevole significativamente superiore (odds ratio: 1,53) e quelli di razza Dobermann, Rottweiler e Labrador una probabilità di diagnosi sfavorevole significativamente inferiore (odds ratio: 0,16; 0,75; 0,86; rispettivamente). La probabilità di diagnosi di DA è aumentata con l'aumentare dell'età al controllo e con il diminuire dell'esperienza del veterinario radiografante. L'effetto dell'anno di nascita sull'esito della diagnosi è risultato significativo, ma ha presentato un andamento non univoco negli anni. Le stime di ereditabilità diretta sono risultate pari a 0,24 e 0,15 per il Boxer ed il Pastore Tedesco, rispettivamente, mentre l'ereditabilità materna è risultata inferiore allo 0,03 in entrambe le razze. In conclusione, i risultati di questo studio evidenziano che la DA è una problematica diffusa in diverse razze allevate in Italia; la messa in atto di strategie finalizzate a diminuirne prevalenza e severità appare pertanto giustificata. Età al controllo e livello di esperienza del veterinario radiografante sono fattori di disturbo che dovrebbero essere considerati dai programmi di screening delle razze canine. La DA appare caratterizzata da bassi valori di ereditabilità; tuttavia, l'entità della variabilità genetica riscontrata sembra giustificare la predisposizione di interventi selettivi finalizzati alla riduzione dell'incidenza della patologia. Dati i modesti valori di ereditabilità, gli schemi di selezione attuali, basati principalmente sui record fenotipici dei candidati riproduttori, sembrano sostanzialmente inefficaci, mentre risultati concreti potrebbero essere ottenuti utilizzando sistemi di valutazione dei riproduttori basati su indici genetici BLUP animal model.

Parole chiave: *Cani, Displasia dell'anca, Parametri genetici.*

Introduction

Hip dysplasia (HD) is an orthopaedic defect characterized by the development of a loose, ill-fitting hip joint (Henricson *et al.*, 1966; Brass, 1989) that might result in a degenerative joint disease (Lust, 1997). This defect was described first by Schnelle (1935) in some large breeds of dogs, but specific studies on prevalence and genetic aspects of this condition started only after the Second World War (Schales, 1956; Henricson and Olsson, 1959).

Hip dysplasia is currently considered a major health problem in dogs, although its prevalence is widely variable among breeds (Mäki, 2004). When exhibited, clinical signs of HD vary from decreased exercise tolerance to severe lameness; moreover, being a weak structure, hip joint in dysplastic animals is more liable to injury from normal activity and can impair the working performance of dogs (Orthopedic Foundation for Animals, 2003).

Diagnosis of HD is based on a radiographic examination according to specific protocols aimed to standardize both the collection and the evaluation of radiograph for HD severity (Willis, 1989). Radiological screening of the coxofemoral joint has been introduced by several kennel clubs with the aim of reducing the prevalence of HD in breeding dogs.

Many studies indicated HD as a quantitative genetic trait, for which genes and environment exert combined effects on the phenotypic expression of this defect (Leighton *et al.*, 1977; Swenson *et al.*, 1997; Hamann *et al.*, 2003; Mäki, 2004). Growth rate, nutrition and exercise level during puppyhood are the major environmental factors regarded to influence the development of HD in predisposed dogs (Lust and Farrell, 1977; Fries and Remedios, 1995; Kealy *et al.*, 2000).

Heritability for HD has been estimated for several dog populations using different methods; estimates exhibited a wide variation, ranging from 0.1 to 0.6 (Swenson *et al.*, 1997; Leppänen *et al.*, 2000; Mäki *et al.*, 2000; Ohlerth *et al.*, 2001; Mäki *et al.*, 2002; Wood *et al.*, 2002). Therefore, the existence of additive genetic variance for this trait stresses the role of selection as a tool for reducing HD prevalence in purebred dog populations.

In Italy the first screening plan of HD has been started by the Centre for the Screening of Skeletal Diseases (CeLeMaSche) in cooperation with some kennel clubs. Until now, raw screening results have been used for phenotypic selection only, whereas prevalence and genetic parameters of HD for the Italian population of purebred dogs have never been provided, even for the most popular breeds.

Therefore, the present paper aimed to assess the prevalence of hip dysplasia in seven breeds of dogs screened in Italy and to estimate heritability of HD scores for the German Shepherd dog and the Boxer Italian populations.

Material and methods

Sources of data

Data for this study consisted of screening results from dogs belonging to the following breeds: German Shepherd Dog (GSD); Boxer (BX); Labrador Retriever (LR); Golden Retriever (GR); Rottweiler (RW); Dobermann (DB); Cane Corso (CS). The screening program was run by CeLeMaSche in cooperation with kennel clubs according to a voluntary screening scheme. Only dogs screened at an age comprised between 11 months to 4 years were retained for the analysis. Average age at screening was 17.9 ± 7.0 months. Overall data set included records of 32,900 dogs (14,225 males and 18,665 females) screened during the years from 1988 to 2004. The number of screened dogs by breed and sex are given in Table 1.

Radiographs of the coxofemoral joints, taken by 478 veterinarians, and information on the dates of birth and screening, sex and identification code of dogs were submitted to CeLeMaSche. Radiographs were scored for HD grade by a single veterinarian panelist according to the current FCI (Fédération Cynologique Internationale) grading system based on a 5-class linear scoring system (Leppänen and Saloniemi, 1999): A: no signs of dysplasia; B: healthy, with slight changes in conformation of the joint; C: mild dysplastic changes; D: moderate dysplastic changes; E: severe dysplastic changes.

The hip score data of GSD and BX were merged with pedigree database, updated by the Italian Kennel Club (ENCI). The pedigree information file included identification numbers of the breeder, dog and litter, sex code and date of birth. For GSD the dogs in the data originated from 10,373 litters; 3376 sires, 1160 of which with radiographic records; 6739 dams, 2543 of which with radiographic records; and 2622 breeders. The pedigree file used in the genetic analysis of hip scores included 26,705 dogs.

For BX the dogs originated from 3003 litters; 1163 sires, 516 of which with radiographic records; 2282 dams, 823 of which with radiographic records; and 785 breeders. The pedigree file included 7913 dogs.

Statistical analysis

a) logistic regression

Statistical analysis was performed using logistic regression procedure. Because this analysis is

Table 1.   Number of screened dogs by breed and sex.

Breed	Female	Male	Overall
German Shepherd	10,782	7914	18,696
Boxer	2594	2131	4725
Dobermann	1785	1486	3271
Rottweiler	1723	1409	3132
Labrador Retriever	840	568	1408
Golden Retriever	588	436	1024
Cane Corso	353	291	644
Overall	18,665	14,225	32,900

specific for binary traits, grades of HD were previously transformed as follows: dogs with grade A and B for HD were considered not affected; dogs graded C, D or E for HD were considered affected.

The risk of occurrence of hip dysplasia due to selected explanatory variables has been evaluated using estimates and confidence intervals of odds ratio (OR). Odds ratios are relative measures of risk ranging from 0 to $+ \infty$. Values of OR > 1 or OR < 1 indicate an increased or a decreased risk of disease occurrence, respectively, in comparison to a "reference condition" summarized by the intercept of the logistic regression model.

Logistic regression analysis was performed using the LOGISTIC procedure of SAS (SAS/STAT, 1990) according to the following model:

$$\ln\left[\frac{\pi}{1-\pi}\right] = \mu + \sum_{i=1}^{6} b_{1i}B_{iz} + b_2 S_z + \sum_{j=1}^{2} b_{3j}A_{jz} + \sum_{k=1}^{3} b_{4k}EXP_{kz} + \sum_{l=1}^{9} b_{5l}YB_{lz}$$

where:

$\ln\left[\frac{\pi}{1-\pi}\right]$ is the logit of Y (Y = 1 for dogs affected by HD, Y = 0 for dogs not affected by HD) and π is the probability that Y = 1;

μ is the intercept of the logistic regression model, expressing the "reference" animal (German Shepherd dog, female, born before 1993, x-rayed when it was young by a veterinarian with a very high x-raying experience).

Categorical explanatory variables were defined as follows:

- breed effect (B): six dummy variables were created and German Shepherd dog was used as reference breed (intercept of the model), as it was the breed with the largest number of screened dogs;
- sex of the dog (S): one dummy variable was created and female was used as reference sex (intercept of the model);
- age of the dog at screening (A): it was classified into three classes (young, intermediate and old) according to the within breed mean and standard deviation of age at screening. Two dummy variables were created and young class was used as reference age (intercept of the model);
- experience of the x-raying veterinarian (EXP): it was classified in 4 classes, on the basis of the number of dogs x-rayed by the veterinarian: 1 = low experience, with a maximum of 25 dogs x-rayed; 2 = moderate experience, from 26 to 75 dogs x-rayed; 3 = high experience, from 76 to

150 dogs x-rayed; 4 = very high experience, more than 150 dogs x-rayed. Three dummy variables were created and class 4 (very high experience) was taken as reference class (intercept of the model);
- year of birth of dogs (YB): to have a sufficient number of records in each year of birth, dogs born before 1993 were grouped in a single class (YB = 1992), and dogs born in 2002 were grouped with dogs born in 2001. Nine dummy variables were created and 1992 was considered as reference year of birth (intercept of the model).

b) estimation of (co)variance components

Data of GSD and BX dogs were analysed by restricted maximum likelihood animal model procedures to estimate (co)variance components for hip scores, using the software package VCE (Groeneveld, 1998). The mixed linear model was as follows:

$$y = Xb + Z_d u_d + Z_m u_m + e$$

where y is a vector of hip scores, b is an unknown vector of nongenetic fixed effects (sex, age at screening, year of birth of the dogs and experience of x-raying veterinarian), u_d is an unknown random vector of additive genetic direct effects of dogs, u_m is an unknown random vector of additive genetic maternal effects of dogs, and e is an unknown random vector of residual. The terms X, Z_d and Z_m are known incidence matrices relating hip scores records to b, u_d and u_m, respectively.

The distributional assumption about the random terms of the model was:

$$[u_d'\ u_m'\ e'\ y']' \sim N([0'\ 0'\ 0'\ (Xb)']', \Phi)$$

where

$$\Phi = \begin{vmatrix} A\sigma_d^2 & A\sigma_{dm} & 0 & AZ_d'\sigma_d^2 \\ A\sigma_{dm} & A\sigma_m^2 & 0 & AZ_m'\sigma_m^2 \\ 0 & 0 & I\sigma_e^2 & I\sigma_e^2 \\ Z_d A\sigma_d^2 & Z_m A\sigma_m^2 & I\sigma_e^2 & V \end{vmatrix},$$

σ_d^2 is the additive direct genetic variance, σ_{dm} is the additive genetic covariance between direct and maternal effects, σ_m^2 is the additive maternal genetic variance, σ_e^2 is the residual variance, **A** is the numerator of Wright's relationship matrix, and

$$V = Z_d AZ_d'\sigma_d^2 + Z_m AZ_m'\sigma_m^2 + (Z_d AZ_m' + Z_m AZ_d')\sigma_{dm} + I\sigma_e^2$$

Table 2.   Distribution of hip dysplasia (HD) grades and prevalence of HD by breed.

Breed:	HD grade (%)					Prevalence (C+D+E) %
	A	B	C	D	E	
German Shepherd	32.31	44.07	18.05	4.92	0.65	23.62
Boxer	22.94	51.83	20.99	4.15	0.09	25.23
Dobermann	49.71	45.49	3.94	0.86	0.00	4.80
Rottweiler	39.59	41.22	14.30	4.63	0.26	19.19
Labrador Retriever	39.20	40.06	14.13	5.33	1.28	20.74
Golden Retriever	28.81	46.78	16.40	7.81	0.20	24.41
Cane Corso	29.19	42.70	20.81	6.37	0.93	28.11
Overall	33.51	44.94	16.55	4.51	0.49	21.55

Results and discussion

Distribution of HD grades by breed is given in Table 2. When the pool of breeds involved are taken into account, nearly one third of dogs were graded as having excellent hip joint conformation (grade A) and a proportion close to 45% were diagnosed as having healthy, albeit not perfect, hip joints (grade B). Therefore, the prevalence of dogs diagnosed as dysplastic, i.e. showing hip joint status graded as C or worse, approached 22%. Females exhibited a slightly higher prevalence of dysplastic hip joints than males (data not shown in table).

Distribution of HD grades and prevalence of dysplastic dogs varied among breeds. Dobermanns showed the lowest prevalence of dysplastic dogs (less than 5%); conversely, the highest prevalence of HD was found in Cane Corso (28%). In dogs diagnosed as dysplastic, the mild form (grade C) was largely prevalent for all breeds considered and accounted for two third to over three quarters of total diagnosis of irregular hip joints. Moderate HD (grade D) was infrequent and its prevalence exceeded 5% only in Cane Corso, Labradors and Golden Retrievers. Severe HD (grade E) was rarely found in this study, and its prevalence approached 1% in Labradors and Cane Corso only.

Odds Ratio (OR) of sex and breed on the prevalence of dysplastic dogs (dogs showing C, D or E grades) are given in Table 3; females and German Shepherds were taken as references in this analysis, being the largest groups.

Generally, male dogs appeared to have a significantly lower risk to be affected by hip dysplasia when compared to females (OR = 0.89). However, when logistic regression was performed separately by breed, sex significantly affected HD diagnosis and male dogs evidenced a lower prevalence of HD occurrence than female dogs only in German Shepherds and Rottweilers (data not shown in tables). Effect of sex on the risk of HD occurrence seems disputable: some studies reported a significantly increased frequency of HD in females (Hedhammar *et al.*, 1979; Swenson *et al.*, 1997), but in others males and females were equally affected (Keller and Corley, 1989; Smith *et al.*, 1995; Mäki *et al.*, 2000) or the prevalence of HD appeared higher in males (Wood *et al.*, 2002).

Also breed significantly affected the outcome of radiographic examination. When compared to the German Shepherd, the Cane Corso appeared to have a significantly higher risk to be affected by hip dysplasia (OR= 1.53). Conversely, Dobermanns, Labradors and Rottweilers evidenced a significantly lower risk of HD occurrence (OR: 0.16; 0.86; 0.75, respectively) and Boxers and Golden Retrievers performed similarly to German Shepherds with respect to the risk of developing hip dysplasia.

The figures of prevalence of HD found in the present study for the breeds taken into account

Table 3.   Odds Ratio (OR) of sex and breed on the proportion of dysplastic dogs (dogs showing C, D or E grades; reference class: German Shepherd dog female).

	Odds ratio:		P value
	Point estimate	95% confidence interval	
Sex:				
- male	0.89	0.85	0.94	< 0.01
- female[1]	1.00	-	-	-
Breed:				
- Boxer	1.05	0.97	1.14	ns
- Dobermann	0.16	0.14	0.19	< 0.01
- Rottweiler	0.75	0.68	0.83	< 0.01
- Labrador retriever	0.86	0.75	0.99	< 0.05
- Golden retriever	1.07	0.92	1.25	ns
- Cane Corso	1.53	1.28	1.83	< 0.01
- German Shepherd[1]	1	-	-	-

[1] *Reference class*

are generally higher than those reported by OFA (Orthopedic Foundation for Animals, 2003), which probably holds the largest data base for skeletal diseases in the world. Prevalence of HD and number of evaluations reported by OFA for the selected breeds taken into account in this study were as follows: 10.9% from nearly 3700 Boxer dogs; 6.1% from nearly 11,900 Dobermann dogs; 20.5% from nearly 84,000 Rottweiler dogs; 12.4% from nearly 166,500 Labrador Retriever dogs; 20.3% from nearly 105,500 Golden Retriever dogs; 37.6% from nearly 310 Cane Corso dogs; 19% from nearly 83,700 German Shepherd dogs.

Conversely, prevalence estimates observed in Italian populations is generally lower than those reported by Mäki (2004) for German Shepherds, Rottweilers, Labradors and Golden Retrievers registered in the Finnish Kennel club. The lower risk of being diagnosed as affected for Labradors and Rottweilers with respect to German Shepherd dogs found in the present study is in agreement with data from the Finnish Kennel club reported by Mäki (2004), who found a higher prevalence of HD in German Shepherd dogs (37%) with respect to Rottweilers (32%) and Labradors (25%).

However, it is a conventional wisdom that estimates of prevalence from official data bases may be lower than the true breed prevalence, because

owners frequently request a preliminary radiograph and submit to official evaluation only radiographs with high probability of being classified as not severely affected. To this regard, Smith (1997) reported that only 56% of radiographs taken during a 2-year period in a veterinary hospital of Pennsylvania University were submitted to official interpretation, and radiographs not submitted had a 10-fold higher prevalence of HD than those submitted. This widespread behaviour may cause a substantial bias of HD official data bases which results in a corresponding bias when genetic parameters and dog breeding values are estimated. Moreover, this situation may decrease the confidence of breeders in screening programs and can certainly impair the efficacy of a screening program as a tool for improving hip joint health status of dogs. Therefore, it seems urgent that breeders associations consider this widespread practice and find the way for coping with it.

As shown in Figure 1, age at screening significantly influenced the risk of being diagnosed as affected by HD. Generally, the older the dogs at screening, the higher tended to be the risk of a HD diagnosis: when compared to dogs young at screening (13.2 ± 1.2 months), dogs with intermediate age (16.9 ± 2.6 months) showed a 10% increase and dogs old at screening (29.3 ± 7.0 months) a

Figure 1.   Odds ratio (OR) of class of age of dogs at screening on the proportion of dysplastic dogs (dogs showing C, D or E grades; reference class: dogs young at screening).
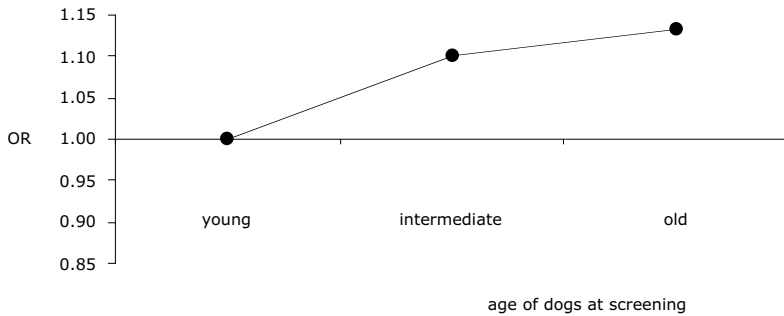

age of dogs at screening

Figure 2.   Odds ratio (OR) of number of dogs x-rayed by veterinarians (low: ≤ 25; moderate: 26 – 75; high: 76 – 150; very high: > 150) on the proportion of dysplastic dogs (dogs showing C, D or E grades; reference class: very high number).
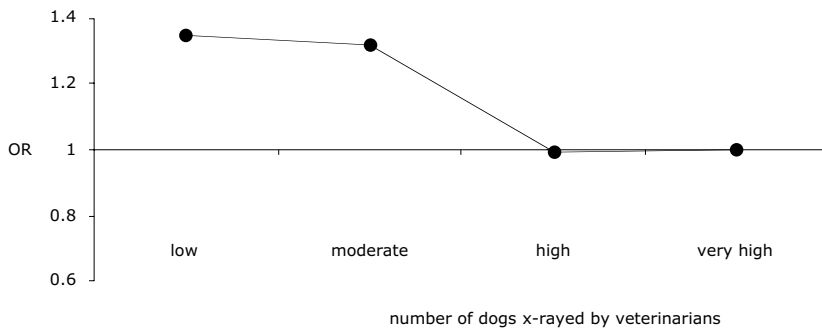

number of dogs x-rayed by veterinarians

Figure 3.   Odds ratio (OR) of birth year on the proportion of dysplastic dogs (dogs showing C, D or E grades; reference year: 1992).
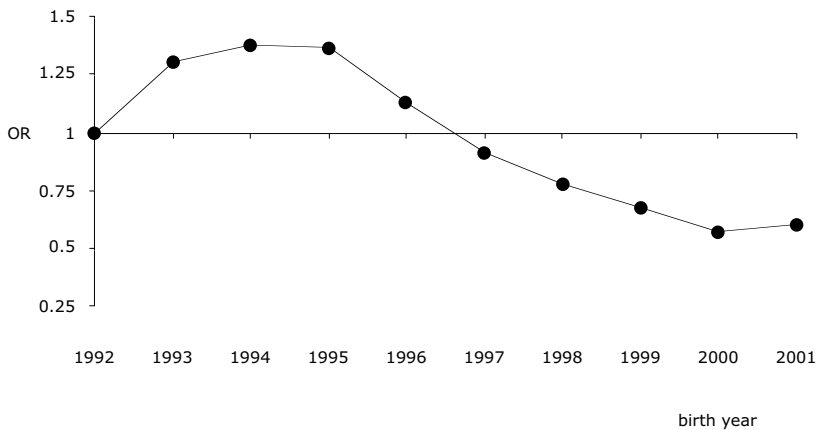

birth year

Table 4. Estimates of additive direct genetic variance (σ^2_d), additive maternal genetic variance (σ^2_m), error variance (σ^2_ε), direct heritability (h^2_d) and maternal heritability (h^2_m) for Italian population of Boxer and German Shepherd dogs (standard errors between brackets).

Breed	σ^2_d	σ^2_m	σ^2_ε	h^2_d	h^2_m
Boxer	0.138	0.015	0.429	0.236 (0.047)	0.026 (0.090)
German Shepherd	0.110	0.018	0.591	0.153 (0.023)	0.025 (0.055)

nearly 15% increase in relative risk of unfavourable diagnosis. Similar results concerning effect of age at examination have been found in other studies (Leppänen *et al.*, 2000; Mäki *et al.*, 2000; Hamann *et al.*, 2003) and these suggest that for official examination dogs should be screened at similar age and, in any case, radiographic records should be corrected for the effect of age when analysed for genetic purposes.

Also the experience of the x-raying veterinarians significantly affected the outcome of examination. As depicted in Figure 2, when compared with the most experienced veterinarians, who x-rayed more than 150 dogs, veterinarians of low or moderate experience, who x-rayed less than 76 dogs, were associated with a nearly 35% increased risk of HD affected diagnosis. Also Mäki *et al.* (2000) and Hamann *et al.* (2003) found that the experience level of x-raying veterinarians was a significant environmental effect of the HD score variation and accounted for this effect in the models used for estimating genetic parameters of hip dysplasia.

The risk of being diagnosed as affected by HD significantly varied with birth year: as reported in Figure 3, when the oldest dogs were taken as reference class, the risk increased for dogs born in the 1993 to 1996 period, but decreased for dogs born from 1997 onward. Although some mass selection against HD has probably been made by most breeders, it seems unwise to assume the apparent positive phenotypic trend for HD observed in this study for dogs born in the most recent years as a result of this selection procedures. Several studies pointed out that programs of control of hip dysplasia based on phenotypic records were largely ineffective, so that progress in reducing HD scores has not been obtained in most breeds involved (Willis,

1997; Leppänen *et al.*, 2000; Mäki *et al.*, 2002). The lowered risk of being diagnosed as affected by HD observed in the present study for the more recently born dogs is probably due to a partial confusion between birth year and age at screening, because the more recent the birth year, the higher was the percentage of young dogs screened for HD; moreover, it is possible that the frequency of radiographs not submitted to official evaluation for insufficient hip status would have increased in the most recent years.

Estimates of direct and maternal additive genetic variance and direct and maternal heritability for the Italian population of Boxer and German Shepherd dogs are given in Table 4. Genetic parameters for the other breeds were not estimated because of limited number of records or inadequate pedigree file availability.

The additive genetic variance of the animals was 0.138 and 0.110 for Boxer and German Shepherd dogs, respectively; the additive genetic maternal variance was considerably smaller than the animal genetic variance and ranged from 0.015 to 0.018 for BX and GSD, respectively. Direct heritability estimates were larger for BX than for GSD, and their magnitude approached 0.24 and 0.15, respectively, whereas maternal heritability was close to 0.03 for both breeds. Genetic correlation between direct and maternal heritability was negligible in both breeds and ranged from -0.008 to 0.002 for Boxers and German Shepherds, respectively (data not shown in table).

In literature h^2 estimates for HD in various dog breeds and populations exhibited a wide variation within the range of 0.10 to 0.60 (Swenson *et al.*, 1997; Leppänen *et al.*, 2000; Mäki *et al.*, 2000; Ohlerth *et al.*, 2001; Mäki *et al.*, 2002; Wood *et al.*, 2002). Dietschi *et al.* (2003) related this large range

of h^2 estimates to several factors: differences in methods used for estimating genetic parameters; different effects included in the models for accounting for the fixed and random effects; differences in breeds and composition of analysed samples; differences in definition of HD phenomenon, alternatively treated as a binary, ordinal or quantitative trait.

No literature data are available concerning genetic parameter estimates for Boxers. Conversely, h^2 estimates obtained in the present study for GSD are lower than those reported by others in different GSD populations. Recently Mäki *et al.* (2002) reported an h^2 estimate of 0.24 for GSD Finnish population; Hamann *et al.* (2003) found h^2 estimates ranging between 0.24 to 0.26 for GSD German population. Also, the estimate of maternal h^2 obtained in the present study was substantially lower than that reported by Hamann *et al.* (2003) for GSD, which ranged between 0.09 and 0.10. Conversely, maternal effects were found to be almost negligible also by Mäki *et al.* (2000) when genetic parameters for hip and elbow dysplasia were estimated in Finnish Rottweilers. Additive genetic maternal effect accounts for conditions caused by genetic differences among dams which may affect HD of their offspring, such as birth weight, maternal behaviour and milk production, growth rate (Dietschi *et al.*, 2003; Hamann *et al.*, 2003); however, given the negligible magnitude found in the present study, the additive genetic maternal effect could be omitted in procedures aimed to estimate breeding values for HD in the Italian population of Boxer and German Shepherd dogs.

Conclusions

Results from this study provide evidence that hip dysplasia is a skeletal disease fairly prevalent in some breeds of dogs prevalent in Italy, with a slight difference, if any, between females and males. The prevalence of dogs diagnosed as affected significantly differed among breeds but, with the only exception of the Dobermann, nearly one dog out of every four to five screened presented dysplastic changes of hip joints. In dogs diagnosed as dysplastic, the mild form was largely prevalent for all breeds considered, but it is a common opinion that true prevalence and severity of joint mal-

formation could be substantially higher, because often owners do not submit radiographs of severely affected dogs to official data bases.

Age at screening and experience of the x-raying veterinarians significantly affected the outcome of examination and should therefore be considered as disturbance factors when screening programs for HD are arranged. Namely, a standard age at screening within a breed is to be recommended if uncorrected phenotypic results of screening are used for breeding purposes.

Data from this study evidenced that hip dysplasia is a trait exhibiting heritability estimates of low magnitude in the Italian population of German Shepherd and Boxer dogs, but additive genetic variance seems enough for conjecturing selection programs aimed to decrease the prevalence and severity of hip joints disease. However, selection against hip dysplasia based on phenotypic records currently seems to be largely ineffective because of low heritability values; moreover, no information on relatives and no adjustment for biases due to environmental effects are made relying on screening results only. Conversely, a selection program based on breeding values estimated under BLUP animal model procedures could be much more effective for gaining genetic progress of Italian dog populations, allowing a full exploitation of the large amount of hip x-ray data collected for several dog breeds in recent years. Widening the number of dogs screened and, above all, reducing the frequent preselection of radiographs submitted to official screening, which is a great potential cause of bias in the accuracy of breeding values, can contribute to increase the genetic progress achievable through selection programs.

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