Preventive Veterinary Medicine 114 (2014) 114–122

Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed

Prevalence and co-occurrence of hip dysplasia and elbow dysplasia in Dutch pure-bred dogs

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ARTICLE INFO

Article history:
Received 29 April 2013
Received in revised form 29 January 2014
Accepted 3 February 2014

Keywords:
Hip dysplasia
Elbow dysplasia
Dutch pure-bred dogs

ABSTRACT

Hip as well as elbow dysplasia (HD, ED) are developmental disorders leading to malformation of their respective joints. For a long time both disorders have been scored and targeted for improvement using selective breeding in several Dutch dog populations. In this paper all scores for both HD and ED, given to pure bred dogs in the Netherlands from 2002 to 2010, were analyzed. Heritabilities and correlations between HD and ED were calculated for the 4 most frequently scored breeds. Heritabilities ranged from 0.0 to 0.37 for HD related traits (FCI-score, osteoarthritis, congruity, shape and laxity (Norberg angle); FCI: Fédération Cynologique Internationale) and from 0.0 to 0.39 for ED related traits (IEWG score, osteoarthritis, sclerosis and indentation; IEWG: International Elbow Working Group). HD related traits showed high genetic and residual correlations among each other but were only to a minor extent correlated with ED related traits, which also showed high correlations among each other. Genetic correlations were higher than residual correlations. Phenotypic and genetic trends since 2001 for the four most scored breeds were slightly positive but decreasing over time, indicating that selection over the past decade has not been effective.

1. Introduction

Hip and elbow dysplasia are two common developmental orthopedic disorders in dogs which can cause lifelong disability. Both are considered complex diseases with multiple genes as well as environmental factors influencing susceptibility to these disorders (Distl et al., 1991; Swenson et al., 1997a,b; Mäki et al., 2000, 2002; Malm et al., 2008; Stock et al., 2011; Lewis et al., 2011).

The prevalence of hip dysplasia (HD) ranges from 0 to 74% (OFA) within the different breeds and heritability estimates have been reported ranging from 0.1 to 0.6. Heritability indicates which part of the differences observed between dogs is due to genetics. Elbow dysplasia (ED) shows similar diversity in reported prevalence from 0 to 64% (Orthopedic Foundation for Animals: OFA), and heritability estimates from 0.1 to 0.77 (Hedhammar et al., 1979; Guthrie and Pidduck, 1990; Grøndalen and Lingaas, 1991; Distl et al., 1991; Swenson et al., 1997a,b; Mäki et al., 2000, 2002; Malm et al., 2008; Hou et al., 2010; Stock et al., 2011; Lewis et al., 2011).

To reduce prevalence, screening programs have been implemented for both HD and ED in the Netherlands. For several breeds HD scoring is mandatory for breeding, although the maximum score allowed differs between breeders' clubs, depending on the prevalence of HD and the size of the HD-free breeding population. Screening for ED

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http://dx.doi.org/10.1016/j.prevetmed.2014.02.001
0167-5877/

is not so common yet and is restricted to a few breeds in which the breeders club is actively involved in reducing the prevalence of ED.

HD and ED may become clinically evident during or just after the fast growth period. Breed differences in growth rate during this period might partly explain the differences in frequency between breeds and even between sexes of the same breed (Mäki et al., 2002). Although HD and ED are observed in all sizes of dogs, they are especially frequent in large breed dogs, which have a relatively high rate of longitudinal bone growth.

Little is known about the co-occurrence of HD and ED in dogs, though a slight phenotypic correlation has been reported in a Finnish cohort of Rottweilers (Mäki et al., 2000) and in a limited French multiple-breed data-set including Bernese Mountain Dogs, Rottweilers and other breeds (Cachon et al., 2010). Genetic correlations between HD and ED within one breed have also been reported, ranging widely between breeds from −0.09 in Golden Retrievers to 0.37 in Rottweilers (Mäki et al., 2000, 2002; Malm et al., 2008; Hartmann et al., 2010; Stock et al., 2011; Lewis et al., 2011).

The objective of this study is to estimate the prevalence of HD and ED in the Netherlands, and to assess whether there are differences in prevalence between the sexes. In addition, the genetic and residual relationship between HD and ED scores are reported in the four breeds most frequently screened for both HD and ED, i.e. the Labrador Retriever (LR), Golden Retriever (GR), Bernese Mountain Dog (BMD), and Newfoundland (NF).

2. Material and methods

2.1. Animals

From 2002 to 2010 a total of 35,046 pedigree dogs of various breeds were screened for HD, ED, or both (Table 1). In total dogs of 214 breeds were screened for HD, and dogs of 117 breeds were screened for ED. Heritability, and residual and genetic correlations were determined in the four breeds most frequently screened for both HD and ED, i.e. LRs, GRs, BMDs and NFs. In these four breeds, screening for both disorders is mandatory in order to allow breeding with these dogs. The Dutch Kennel Club (www.raadvanbeheer.nl) provided pedigree files, which included the sex of dogs. Pedigrees from 1990 onwards were electronically available.

2.2. Phenotyping

Official HD grading as regulated by the Fédération Cynologique Internationale (FCI, 2010) requires a ventrodorsal radiographic view of the hip joints with extended hind limbs; the HD-score ranges from A (free of HD) to E (severely affected by HD) (Brasss, 1989; Morgan et al., 2000). The Dutch screening panel takes four different characteristics into account, i.e. osteoarthritis (OA) (6 levels), joint congruity (8 levels), shape/contour of the acetabulum and femoral head (4 levels), and laxity of the hip joints (Norberg angle, continuous scale). Only laxity is registered for both hip joints separately; other characteristics have one overall assessment each. The HD scoring was performed on a weekly basis by a team of three experts (diplomates in radiology or othopedic surgery) simultaneously. Team members independently scored the anonymous radiographs. The final score was obtained by majority vote. When animals were scored with HD-C or higher, they were considered dysplastic.

Official ED screening as regulated by the International Elbow Working Group (IEWG) requires at least two, but preferably four radiographic views of each elbow. In the Netherlands, four radiographic views are required for scoring in LRs, GRs, BMDs, Rottweilers, German Shepherd Dogs and Bordeaux Dogs; a medio-lateral view with flexed elbow (MLflexed), a medio-lateral view with extended elbow (MLextended), a craniocaudal view (CrCd) and a craniolateral–caudomedial view (CrLCdM) (Voorhout and Hazewinkel, 1987). All other breeds minimally require a MLextended and a CrLCdM radiographic view. Elbow radiographs were scored according to IEWG guidelines; for each elbow the degree of OA was assessed (4 levels) at five standardized locations, the presence of osteosclerosis (2 levels), and the presence of an indentation of the humeral condyle (2 levels) was recorded. In case any of the four primary causes for ED (i.e. fragmented medial coronoid process (FCP), elbow incongruity (INC), osteochondritis dissecans (OCD) and/or ununited anconeal process (UAP)) could be observed or was suspected, this was also recorded (free, suspect or affected). These characteristics together determined the final ED grade (IEWG). Similarly to the HD-scoring a team of three experts scored the radiographs independently and the final grade was obtained by majority voting. Dogs which were scored grade 1 (or higher) were considered dysplastic. HD and ED screening occurred separately in time.

All characteristics that were scored for both HD and ED, except for laxity (Norberg angle), were scored using an ordinal scale. Distances between levels are not necessarily equal and to estimate these distances, a normal distribution underlying all categories was assumed. All available HD records ($n = 34{,}620$) and ED records ($n = 9788$) were used to ascertain the prevalence and calculate the category mean for each level (Fig. S1, Van Grevenhof et al., 2009).

2.3. Heritability and correlation calculations

Single trait and multi-trait (bivariate) analyses were conducted using the program ASReml (Gilmour et al., 2009). A single trait analysis using model 1 tested whether breed and age at screening were significantly associated with HD and ED, and the underlying characteristics that were scored for HD (including OA, congruity, shape and laxity) or ED (including OA, sclerosis and indentation) for all breeds (y_{ijk}).

$$y_{ijk} = \mu + \text{breed}_i + \text{age}_j + e_{ijk} \quad \text{(model 1)}$$

where μ represents the mean, breed is a fixed effect, age at screening (in days) is a covariate (age_{HD} or age_{ED} depending on the category), and e is the residual. Data on sex of the animal was available only for the four most scored breeds.

Table 1
The number of breeds (n_b), number of evaluations (n_e) and percentage positive of hip and elbow dysplasia (HD, ED) per breed type (FCI-classification) with >50 evaluations from 2002 until 2010 in the Netherlands.

Breed type (FCI classification number)	HD			Breed type (FCI classification number)[a]	ED		
	n_b	n_e	%HD		n_b	n_e	%ED
Mastiff type Molossoid breeds (2.2.1)	18	4171	29.6	Mastiff type Molossoid breeds (2.2.1)	15	751	19.7
Bull type Terriers (3.3)	3	259	25.5	Mountain type Molossoid breeds (2.2.2)	13	957	18.6
Water Dogs (8.3)	6	523	24.1	Swiss Mountain and Cattle Dogs (2.3)	4	1328	13.3
British and Irish Setters (7.2.2)	4	430	20.0	Cattle Dogs (except Swiss) (1.2))	2	170	6.5
Flushing Dogs (8.2)	9	1450	17.6	Sheepdogs (1.1)	29	987	5.8
Mountain type Molossoid breeds (2.2.2)	20	2627	17.5	Retrievers (8.1)	6	5033	5.2
Schnauzers (2.1.2)	3	165	17.0	Bull type Terriers (3.3)	2	120	4.2
Nordic Watchdogs and Herders (5.3)	7	250	16.8	Scenthound related breeds (6.3)	1	229	3.9
Swiss Mountain and Cattle Dogs (2.3)	4	1821	15.5	Breed types with < 50 evaluations	45	213	9.9
Cattle dogs (except Swiss) (1.2)	2	678	15.2				
Spaniel type Pointing Dog (7.1.2)	9	1882	13.3				
Poodles (9.2)	4	243	12.3				
Sheepdogs (1.1)	48	8526	11.8				
Retrievers (8.1)	6	7580	11.3				
'Griffon' type Pointing Dogs (7.1.3)	5	214	10.7				
Pinschers (2.1.1)	3	376	9.8				
Asian Spitz and related breeds (5.5)	10	599	9.3				
Continental type Pointing Dogs (7.1.1)	10	1009	8.2				
Large and medium-sized Terriers (3.1)	5	285	6.0				
Scenthound related breeds (6.3)	2	670	5.7				
Nordic Sledge Dogs (5.1)	3	405	5.4				
Tibetan Companion and Toy Dogs (9.5)	2	180	4.4				
Rough-haired Sighthounds (10.2)	1	50	4.0				
Breed types with <50 evaluations	30	227	30.0				
Total for all HD evaluations	214	34,620	15.0	Total for all ED evaluations	117	9788	8.9

[a] FCI, Fédération Cynologique Internationale.

In the four breeds that were most frequently screened for both HD and ED, heritabilities and estimated breeding values (EBVs) were calculated using a single trait analysis (model 2) including the factor sex (2) while genetic correlations were calculated with a bivariate analysis for two traits at the time.

$$y_{ijk} = \mu + \text{breed}_i + \text{sex}_j + \text{age}_k + \text{animal}_k + e_{ijk} \quad \text{(model 2)}$$

Model 2 included a mean (μ), sex as fixed effect, age (in days; according to HD or ED trait) as covariate, animal and residual (e) as random effects. Random animal genetic effects were assumed to be normally distributed $N(0, A\sigma_a{}^2)$, where A represents an additive genetic relationship matrix. It takes all relationships based on the pedigree into account. Random residual effects were also assumed to be normally distributed $N(0, I\sigma_e{}^2)$. For the breed specific heritability the breed factor was omitted from the model. Heritability was calculated by dividing the variance component of the animal genetic effect by the total variance. Estimated breeding values were obtained simultaneously.

3. Results

The total prevalence of HD (score HD-C or higher) in all screened dogs (n = 34,620) of various breeds was 15% when categorizing the breeds according to the FCI classification (FCI, 2010), HD was most prevalent among the Mastiff-like breeds (Table 1). The three breeds most affected by HD all belong to this category. Prevalence per breed was highly variable among breeds (supplementary Table S1). Among breeds with more than 500 observations, the prevalence in the Bullmastiff (51.9%), Italian Corso Dog (32.8%) and Boxer (26.8%) was much higher than the prevalence in the Rhodesian Ridgeback (6.4%) and Belgian Shepherd Dog varieties (4–6%).

Screening for ED was less common than for HD and the overall prevalence of ED in all screened dogs (n = 9788) was 8.9% (Table 1). ED was also most prevalent in the Mastiff-like breeds (supplementary Table S2). Among breeds with more than 100 observations, the highest prevalence of ED in this screening population was observed in the Dogue de Bordeaux (32.9%), the lowest in the Rhodesian Ridgeback (3.9%). The prevalence of the different forms of ED for LRs, GRs, BMDs and NFs are shown in Table 2. FCP was by far the most frequent form of ED in this multiple-breed data set, with 94% of positive ED cases diagnosed with FCP, followed by INC (18%) and OCD (10%). UAP was rarely reported (1.5%). Four percent of dogs were diagnosed with OA of the elbow joint without any signs of primary disease. In total, 26% of all cases were diagnosed with multiple forms of ED.

The four breeds most frequently screened for HD and ED were tested for a sex predisposition (Table 3), which revealed that GRs had significantly higher prevalence of HD in females than in males with a male to female ratio of 1:1.3. The other three breeds analyzed, showed no significant differences in prevalence for HD between the sexes. In LRs a significant sex predisposition for ED was observed in males, but not in the GR, BMD or NF. Significantly more male LRs were affected with ED than females, with a male to female ratio of 1.5:1.

In total 9274 dogs of various breeds were examined for both hip and elbow dysplasia (Table 4). Overall there

Table 2
Distribution of primary diseases encompassing elbow dysplasia (ED); overall and for the four most screened breeds shown as percentage of the total number of cases.

Primary diseases	Total population	Labrador Retriever	Golden Retriever	Bernese Mt. Dog	Newfound-land
OA without primary disease	4.1	2.9	6.0	1.8	5.0
Only OCD	0.9	2.3	2.4		
Only FCP	68.0	81.0	65.5	48.2	73.9
Only UAP	0.6				0.8
Only INC	0.6			2.4	
FCP and OCD	7.7	8.6	16.7	1.2	10.9
FCP and UAP	0.7				0.8
FCP and INC	15.8	4.0	4.8	45.3	8.4
FCP and INC and OCD	1.4	1.1	4.8	1.2	
FCP and INC and UAP	0.1				
FCP and INC and UAP and OCD	0.1				
OCD	10.1	12.1	23.8	2.4	10.9
FCP	93.8	94.8	91.7	95.9	94.1
UAP	1.5				1.7
INC	18.0	5.2	9.5	48.8	8.4
Total population size	9788	3333	1503	1221	622
Number of cases	868	174	84	170	119
Percentage of cases (%)	8.9	5.2	5.6	13.9	19.1

OA, osteoarthritis; OCD, osteochondritis dissecans; FCP, fragmented coronoid process; UAP, ununited anconal process; INC, elbow incongruity.

Table 3
Distribution of hip and elbow dysplasia (HD, ED) grades between the sexes in frequently screened breeds. Sex fractions (male | female) are relative to the total amount of dogs screened, while the fraction affected animals is relative per sex.

Breed	HD			
	n	Male | female	Affected Male | female	*p*-Value
Labrador Retriever	3746	0.28 | 0.72	0.097 | 0.106	0.148
Golden Retriever	2412	0.35 | 0.65	0.119 | 0.158	**0.009**
Bernese Mountain Dog	1479	0.21 | 0.79	0.141 | 0.145	0.886
Newfoundland	788	0.34 | 0.66	0.259 | 0.251	0.797
Breed	ED			
	n	Male | female	Affected Male | female	*p*-Value
Labrador Retriever	3332	0.26 | 0.74	0.071 | 0.046	**0.004**
Golden Retriever	1503	0.37 | 0.63	0.067 | 0.049	0.148
Bernese Mountain Dog	1221	0.20 | 0.80	0.147 | 0.137	0.697
Newfoundland	622	0.31 | 0.69	0.221 | 0.178	0.211

A chi^2-test was calculated for affected (HD-C/D/E and ED-1/2/3) versus unaffected (HD-A/B and ED free) animals. Significant *p*-values (<0.05) are presented in bold.

were significantly more dogs affected by both diseases than expected based on the overall frequencies of HD and ED (χ^2 *p*-value < 0.001). The Kappa coefficient between HD and ED, both measured as binary traits with HD-C to -E and ED grade 1 to 3 being affected, was 0.83 in the overall data set ($n = 9274$). With increasing severity of HD there was an increase in the prevalence of ED, as well as a slight increase in severity of ED (Table 4). Also, with increasing severity for ED there was an increase in both prevalence and severity for HD.

Heritability estimates were calculated for the four breeds that were most frequently screened for both HD and ED, i.e. LRs, GRs, BMDs and NFs (Table 5). Heritabilities range from 0 to 0.39. The most heritable characteristic underlying the HD score was laxity in three out of four breeds, while arthritis (OA) was the most heritable characteristic underlying ED in three out of four breeds. Age of the dog at radiographic examination was significantly ($p < 0.05$; F-test) associated with both HD and ED, but was more significant for HD. Regression coefficients of HD- and ED-score on age at scoring (in days) ranged from 0.00012 to 0.00029 for HD and from 0.00001 to 0.00029 for ED indicating that older dogs in general have a higher score.

The four characteristics that determine the final HD score (OA, congruity, shape and laxity), show only a moderate residual correlation to each other (Table 6, below the diagonal) when corrected for age at radiographic examination and breed, indicating that scoring them separately gives additional information. Of the three characteristics that underlie the ED score (OA, sclerosis and indentation), the residual correlation between sclerosis and OA is very high ($r_{residual} = 0.93$), while they both correlate only moderately to an indentation of the humeral condyle. Residual correlations between HD and ED characteristics were universally low. Phenotypic correlations (uncorrected for breed and age; data not shown) were only slightly higher

Table 4
Association between hip and elbow dysplasia (HD, ED) scores for dogs scored for both diseases, frequencies and the average normalized score of HD (ED) scores for each ED (HD) score.

Disease status	ED unaffected	ED affected	p-Value χ^2 test
HD unaffected	7541	656	8.6×10^{-11}
HD affected	927	150	

HD score	n	Frequency of ED[a] (in percentage)	Severity of ED in HD cases (average normalized ED score)
HD-A	7499	8	1.82
HD-B	698	11	1.80
HD-C	775	11	1.86
HD-D1	138	22	1.82
HD-D2/E1	154	19	1.90
HD-E2	10	30	1.94

ED score	n	Frequency of HD[b] (in percentage)	Severity of HD in ED cases (average normalized HD score)
No ED	8468	11	1.48
ED grade I	20	10	1.52
ED grade II	159	13	1.52
ED grade III	627	20	1.61

[a] ED score $\geq$ 1.
[b] HD score $\geq$ C.

Table 5
Heritability estimates (with standard errors) for four breeds for hip and elbow dysplasia (HD, ED) and underlying phenotypes based on their normalized score except for the Norberg score.

	All 4 breeds combined	Labrador Retriever	Golden Retriever	Bernese Mt. Dog	Newfoundland
Hip dysplasia (n)	8238	3687	2350	1422	759
FCI score	0.20 ± 0.02	0.10 ± 0.03	0.18 ± 0.04	0.31 ± 0.06	0.23 ± 0.08
OA	0.17 ± 0.02	0.07 ± 0.03	0.14 ± 0.04	0.25 ± 0.06	0.26 ± 0.08
Congruity	0.22 ± 0.02	0.22 ± 0.03	0.28 ± 0.05	0.18 ± 0.05	0.23 ± 0.07
Shape	0.05 ± 0.01	0.06 ± 0.02	0.06 ± 0.03	0.00 ± 0.00	0.01 ± 0.04
Laxity	0.30 ± 0.02	0.26 ± 0.04	0.33 ± 0.05	0.37 ± 0.06	0.22 ± 0.08
Elbow dysplasia (n)	6652	3317	1498	1215	622
IEWG score	0.18 ± 0.02	0.13 ± 0.03	0.12 ± 0.04	0.16 ± 0.05	0.33 ± 0.09
OA	0.20 ± 0.03	0.19 ± 0.04	0.12 ± 0.04	0.16 ± 0.05	0.39 ± 0.09
Sclerosis	0.15 ± 0.02	0.13 ± 0.03	0.09 ± 0.04	0.12 ± 0.05	0.29 ± 0.09
Indentation	0.06 ± 0.02	0.24 ± 0.04	0.05 ± 0.04	0.00 ± 0.00	0.00 ± 0.00

FCI, Fédération Cynologique Internationale; IEWG, International Elbow Working Group; OA, osteoarthritis.

Table 6
Residual and genetic correlations (with standard errors) between several HD and ED phenotypes based on an analysis of all 4 breeds combined. Genetic correlations are shown above the diagonal while residual correlations are given below the diagonal.

	HD-OA	HD-congruity	HD-shape	HD-laxity	ED-OA	ED-sclerosis	ED-indentation
HD-OA	–	0.77 ± 0.04	0.98 ± 0.04	−0.61 ± 0.05	0.06 ± 0.10	0.06 ± 0.11	0.06 ± 0.15
HD-congruity	0.53 ± 0.01	–	0.83 ± 0.07	−0.75 ± 0.03	−0.14 ± 0.09	−0.17 ± 0.09	−0.19 ± 0.14
HD-shape	0.55 ± 0.01	0.44 ± 0.01	–	−0.64 ± 0.08	−0.19 ± 0.15	−0.16 ± 0.16	−0.03 ± 0.23
HD-laxity	−0.48 ± 0.01	−0.57 ± 0.01	−0.47 ± 0.01	–	0.09 ± 0.08	0.08 ± 0.09	0.28 ± 0.13
ED-OA	0.06 ± 0.01	0.01 ± 0.01	0.04 ± 0.01	−0.03 ± 0.01	–	[a]	0.84 ± 0.08
ED-sclerosis	0.05 ± 0.01	0.00 ± 0.01	0.03 ± 0.01	−0.02 ± 0.01	0.93 ± 0.00	–	0.78 ± 0.09
ED-indentation	0.00 ± 0.01	0.02 ± 0.01	0.00 ± 0.01	−0.01 ± 0.01	0.41 ± 0.01	0.37 ± 0.01	–

[a] Did not converge; OA, osteoarthritis.

than the corrected ones, indicating that these correlations are not very breed dependent. Genetic correlations are a bit higher than the residual correlations, but follow the same trend as the residual correlations (Table 6, above the diagonal), with moderate to high genetic correlations between characteristics of the same disease, and only low genetic correlations between HD- and ED-traits. The genetic and residual correlation between the overall HD and ED score were −0.03 (±0.10) and 0.04 (±0.01), respectively, determined in the analyses encompassing the four breeds.

Within the population of dogs screened for HD (n = 34,620), the incidence of HD had decreased for dogs born between 2001 and 2009 (Fig. 1A, dashed line). This was also true for the four individual breeds screened most often for both disorders, i.e. the LRs, GRs, BMDs and NFs. The average Estimated Breeding Value (EBV) for the corresponding years of birth (Fig. 1C), showed the same downward trend, most notably for the LRs. The population screened for ED (n = 9788) showed little improvement in the incidence of ED (Fig. 1B). Of the four individually

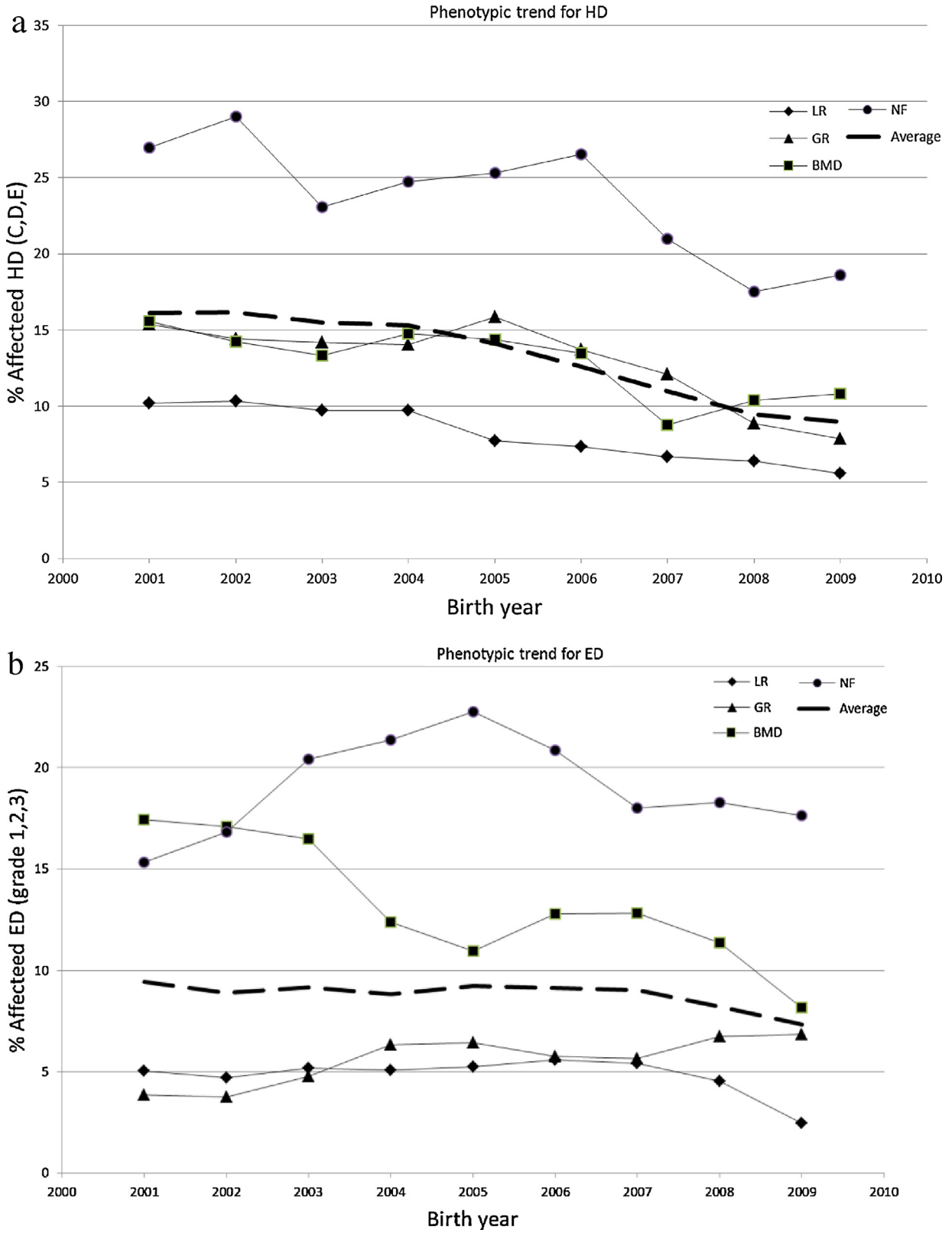
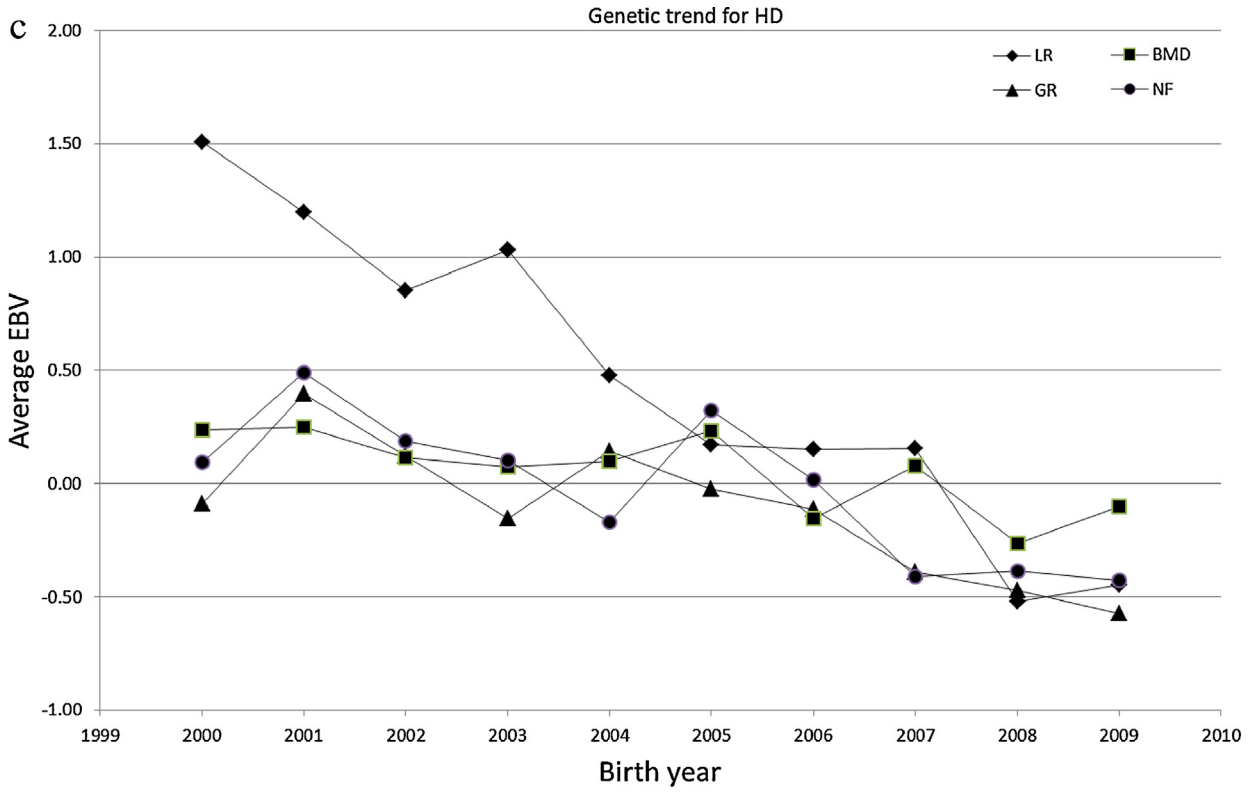


Fig. 1. Phenotypic (a, b) and genetic (c, d) trend for hip dysplasia (HD) (a, c) and elbow dysplasia (ED) (b, d) for Labrador Retriever (LR), Golden Retriever (GR), Bernese Mountain Dog (BMD) and Newfoundland (NF) dogs.



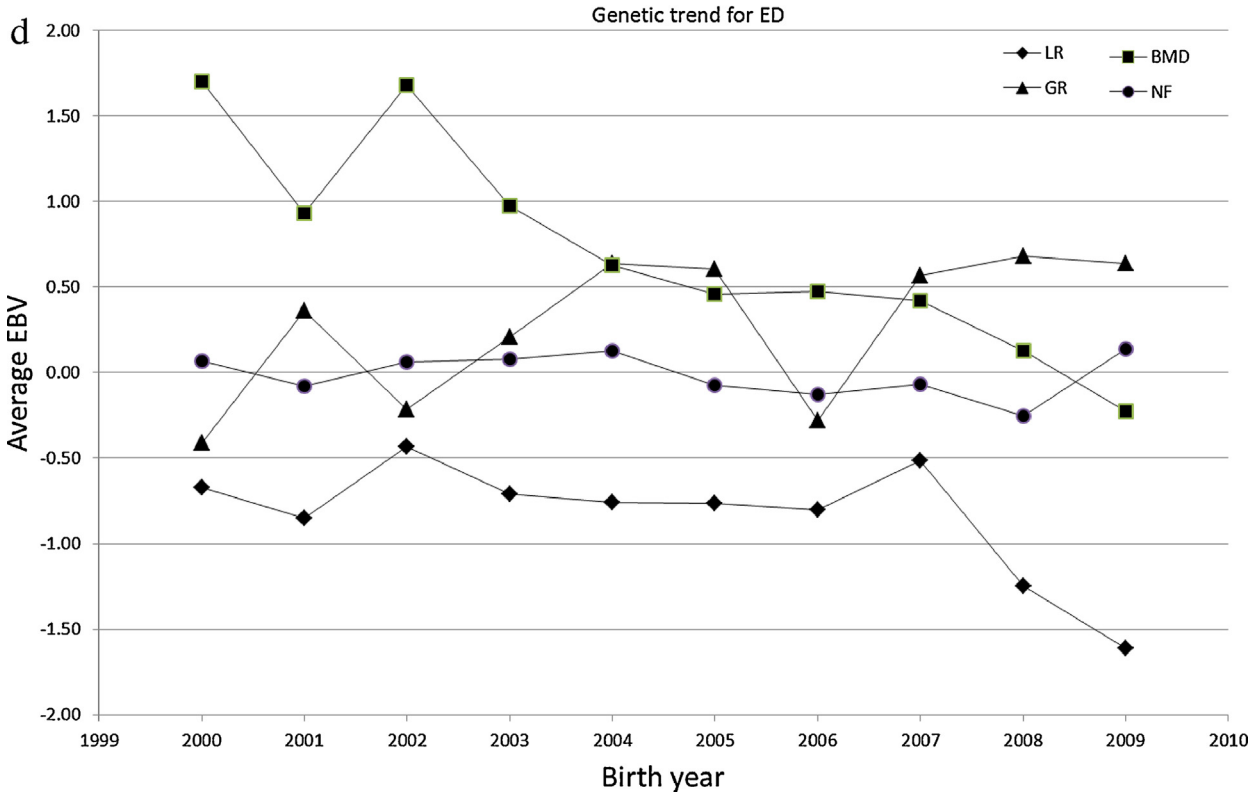


Fig. 1. (*Continued*).

depicted breeds, only the BMDs showed a decline in incidence of ED. This decline was also seen in the average EBV for this breed (Fig. 1D). The other three breeds showed no clear decline, although the average EBV for LRs born in 2008 and 2009 indicate a downward trend.

4. Discussion and conclusions

Both HD and ED were most prevalent among the Mastiff-like breeds. These breeds are relatively closely related (Parker, 2012) and share, besides common ancestors, also similar qualities/features. The breed characteristics: robust body type, weight, and skeletal maturation rate, might be genetic risk factors that predispose to skeletal dysplasia and might be fixed in these breeds, making them more susceptible to develop these disorders.

In Golden Retrievers more females than males were affected with HD, in accordance with others (Henricson and Olsson, 1959; Hedhammar et al., 1979; Swenson et al., 1997b), but Wood and Lakhani (2003) found in Labradors, and Martin et al. (1980) found in a survey in twenty breeds a male predisposition of HD whereas Torres de la Riva et al. (2013) found a strong influence of early-neutering in male, but not in female Golden Retrievers in a hospital cohort. Hou et al. (2010) observed no differences among males and females in Labrador Retrievers. In our data set, a negligible percentage of dogs participating in the screening process are neutered. However, more females were evaluated in all breeds studied, most likely because they can generate less offspring than males and more are used for breeding. This implies that males are under stronger screening selection than females, which might result in slightly better scores for screened males than for screened females. Although we cannot exclude a systematic sex-based screening bias in the incidence of HD or ED, the breed with the most significant sex difference for HD (German Shepherd Dog, p-value = 0.0001), was also the breed with a similar amount of males and females screened although this sex prevalence was not demonstrated by Leppänen et al. (2000) in this same breed. In our data set a prevalence for ED was observed in male Labrador dogs, and others demonstrated the same prevalence in this breed (Guthrie and Pidduck, 1990) and other breeds (Grøndalen and Lingaas, 1991; Beuing et al., 2000; Mäki et al., 2000; Malm et al., 2007), but not by all (Krontveit et al., 2012). These observations suggest that in these breeds, genetic risk factors might in certain breeds interact with sex-specific characteristics like sex chromosomes, hormone levels, juvenile skeletal development or differences in body weight gain, making one sex more susceptible to disease than the other.

Age at radiographic examinations has previously been reported to be associated with both HD and ED grading (Distl et al., 1991; Swenson et al., 1997a,b; Mäki et al., 2000; Malm et al., 2007, 2008; Hou et al., 2010). Because the grading of both orthopedic disorders is interdependent on the development of OA, the positive regression of HD and ED on age at examination, as demonstrated in both entities (Distl et al., 1991; Leppänen et al., 2000; Mäki et al., 2000; Kealy et al., 2000; Huck et al., 2009; Wood and Lakhani, 2003) should be interpreted with care. On radiographs, there is no clear distinction between OA due to aging, overweight, increased sensitivity (genetically susceptible), or due to joint misalignment or fragments. Screening programs are aimed at the latter two causes for OA, because the genetic component might be more important. Age at examination (and weight or body condition score if available), could be used to distinguish between the causes for OA. The prevalence of OA in hip and elbow joints shows a linear correlation with age at examination in dysplastic joints (Malm et al., 2007) and therefore any distinction based on age would be very subjective. Currently, age at examination is noted, but not corrected for in the screening programs for HD or ED in the Netherlands. Longitudinal studies in more breeds are warranted to define an age slot for screening, for ED especially when scoring is solely based on the degree of OA, rather than on the primary cause.

Phenotypic and genetic correlations between HD and ED have been reported previously and phenotypic correlations ranged from 0.1 to 0.24 (Cachon et al., 2010; Mäki et al., 2000; Malm et al., 2008), while genetic correlations ranged from −0.09 to 0.42 (Mäki et al., 2002; Stock et al., 2011; Lewis et al., 2011; Woolliams et al., 2011) in various breeds and populations. The low residual (0.04 ± 0.01) and genetic (-0.03 ± 0.10) correlations observed in this study imply that, at least in these four populations, HD and ED do not share the same genetic risk factors. An intensified selection effect, which is expected in breeds with multiple screening programs for disorders that are genetically correlated, is lacking as well. While the prevalence of HD slowly but steadily declines, there is little indication for breeding progress against ED in the Labrador and GRs or the NF but a genetic improvement for both traits in Bernese Mountain dogs, as also revealed in the study of Malm et al. (2008). Genetic correlations between the two orthopedic disorders were reported for Finnish and Swedish BMDs (0.26 and 0.06, respectively), Finnish GRs (−0.09), and Finnish and UK LRs (0.31 and 0.41, respectively) (Mäki et al., 2002; Malm et al., 2008; Woolliams et al., 2011). The large differences within and between breeds might in part be due to population differences (due to genetic drift), but other contributing factors are the large differences in screening protocols between countries, including sedation requirements during radiography, number and orientation of radiographic views required for scoring, percentage of the total population screened and the scoring system itself. A universal scoring system for both disorders with higher efficacy would be required in order to compare results across populations. Implementation of the use of estimated breeding value as well as genome-wide association mapping and quantitative trait loci mapping to elucidate the genetic basis of both entities (Malm et al., 2008) could bring the effect of screening on prevalence on a higher level.

In summary, the prevalence of canine hip and elbow dysplasia varies considerably among Dutch breeding populations. Both traits had low to moderate heritability. Phenotypically there is a slight positive correlation but genetically these traits did not seem to be correlated, based on the four most recorded breeds. Phenotypic and genetic trends were non-existent or tended to be decreasing over time, indicating that use of the screening results in breeding

programs has up to 2010 not been taken up to a large extent.

Conflict of interest

All authors declare that there is no conflict of interest.

Acknowledgements

Dr. M. van Hagen of the Dutch Kennel Club is acknowledged for her cooperation. Masterfoods, a division of Mars Petcare, is kindly acknowledged for their financial support.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.prevetmed.2014.02.001.

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