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Prevalence and inheritance of and selection for hip dysplasia in seven breeds of dogs in Sweden and benefit:cost analysis of a screening and control program

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Objective—To determine the prevalence and changes over time in the prevalence of hip dysplasia; to ascertain whether prevalence or severity of hip dysplasia was associated with sex of the dogs, age at which coxofemoral joint status was evaluated, or ancestral background; to determine the effects of selective breeding; and to conduct an economic evaluation of the hip dysplasia program operated by the Swedish Kennel Club.

Design—Analysis of radiographic evaluations of coxofemoral joint conformity.

Animals—83,229 dogs from 7 breeds registered by the Swedish Kennel Club.

Procedure—All radiographs were scrutinized by a single radiologist (LA), and coxofemoral joint conformation was classified as normal or dysplastic, with the degree of dysplasia classified as 1, 2, 3, or 4.

Results—Decreasing prevalence of hip dysplasia corresponding to selection of breeding stock and high heritabilities was found. Sex differences were documented in 3 of the breeds. This was interpreted as breed differences in the distribution of genes related to hip dysplasia. Economic analyses showed that costs of screening and registration of coxofemoral joints was less than the value of dogs estimated to have been saved from moderate, severe, or very severe hip dysplasia in 6 of the breeds.

Clinical Implications—Documented effects of age suggest that all dogs should be screened at the same age, rather than screening a few dogs at an older, more revealing age. In screening and control programs based on an open registry with access to family records, decreasing prevalence of hip dysplasia can be expected, and related to selection of breeding stock. (*J Am Vet Med Assoc* 1997;210:207–214)

Malformation of the coxofemoral joint in dogs, referred to as hip dysplasia, was first described by Schnelle in 1937.[1] It was, however, not until the 1950s that the high prevalence of this condition was recognized around the world.[2-4] Today, there is a general agreement that conformity of the coxofemoral joint can be identified by means of radiography and that the joint can be classified as normal or dysplastic to various degrees on the basis of radiographic appearance. Furthermore, several studies have shown that hip dysplasia is a polygenic trait influenced by environmental factors.[5-8] Heritability estimates ranging from 0.1 to 0.6 have been obtained in studies of various populations and breeds.[9-12]

As part of the effort to reduce the prevalence of hip dysplasia in dogs, radiologic screening of coxofemoral joint conformation has been performed extensively in several countries around the world. The veterinary profession has, in various forms, shared responsibility for this work with kennel clubs, breed clubs, and independent establishments.[13-18] In Sweden, centralized evaluation and registration of radiographs of the coxofemoral joints of dogs began as early as 1958. Since 1970, this work has been administered by the **Swedish Kennel Club (SKC)**, thereby making it possible to relate all results to the ancestral background of each dog.

In Sweden, 70% of all dogs born are purebred, and almost all of the purebred dogs are registered by the SKC. Since 1976, the dog owners who submit radiographs for evaluation of coxofemoral joint conformation have signed an agreement allowing the results of that evaluation (negative or positive) to be registered by the SKC. In 1979, all results of radiographic evaluations of coxofemoral joint conformation registered by the SKC became available to the public. As a service to breeders, it has been possible since 1983 to obtain information on coxofemoral joint status of any individual dog for which radiographs have been evaluated, all the progeny of any individual dog, all dogs within a breed in relation to year of birth, and all breeding dogs in relation to year of birth and litters born. Consequently, it has been possible since 1983, when choosing dogs for breeding, to obtain information on coxofemoral joint status of the parents, grandparents, and littermates of these dogs as well as, when applicable, the coxofemoral joint status of any progeny. In response to requests from the national clubs for several breeds, it has been mandatory since 1984 that coxofemoral joint status be known for the sire and the dam if the progeny are to be registered by the SKC.

These measures have led to a dramatic shift toward use, as breeding stock, of dogs that have been evaluated and found not to have hip dysplasia, which has been accompanied by a decreased prevalence of hip dysplasia in most breeds.[19] However, many questions concerning the effectiveness of radiographic screening of coxofemoral joint conformation remain. The purposes of the study reported here were to de-

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Supported by Agria Insurance Ltd and the Swedish Kennel Club.

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termine the prevalence and changes over time in the prevalence of hip dysplasia in selected breeds of dogs in Sweden; to ascertain whether prevalence or severity of hip dysplasia in these breeds was associated with sex of the dogs, age at which coxofemoral joint status was evaluated, or ancestral background; to determine the effects of selective breeding on the prevalence of hip dysplasia in these breeds; and to conduct a benefit: cost evaluation of the hip dysplasia screening and control program operated by the SKC.

Materials and Methods

For this study, computerized records of coxofemoral joint status and ancestral background of dogs born between 1976 and 1989 that were available from the SKC on Jan 1, 1991 were used. Data on 7 breeds (German Shepherd Dogs, Golden Retrievers, Labrador Retrievers, Newfoundlands, Rottweilers, Bernese Mountain Dogs, and Saint Bernards), comprising a total of 83,229 dogs, were chosen for analysis, because these breeds represent high and medium-high prevalences of hip dysplasia (Table 1). All Newfoundlands and Saint Bernards were at least 12 months old when evaluated. A small fraction of German Shepherd Dogs, Golden Retrievers, Labrador Retrievers, Rottweilers, and Bernese Mountain Dogs evaluated before 1980 were between 9 and 12 months old when evaluated, but most dogs were evaluated when they were between 12 and 18 months old. Age at the time of examination has been routinely included in the records only since 1985. Therefore, analyses of age were based mainly on records of dogs born since 1985. Regression analyses of age effects were based on dogs evaluated when they were between 12 and 24 months old.

Evaluation procedure—All dogs were identified by their registration number tattooed in the left ear. Radiographs were submitted by veterinary clinics and hospitals throughout the country. Approximately 200 clinics and hospitals participated in the program by 1991. Dogs were sedated or anesthetized during the examination procedure, and at least 1 radiograph was taken with the dog on its back with its hind legs extended and slightly adducted.

All radiographs were scrutinized by a single radiologist (LA), and coxofemoral joint conformation was classified as normal or dysplastic, with the degree of dysplasia classified as 1, 2, 3, or 4. The grading system was a modification of that originally suggested by Schnelle in 1954,[2] and each joint was classified separately. Joints with a deep, cup-shaped acetabulum and narrow, even joint space in which the center of the femoral head was medial to or even with the acetabular rim were classified as normal. Joints with a slightly shallow acetabulum and slight incongruence between the acetabulum and the femoral head in which the center of the femoral head was lateral to the acetabular rim were classified as grade-1 (slight) dysplasia. Joints with a moderately shallow acetabulum and obvious incongruence between the acetabulum and the femoral head in which the femoral head was loosely fitted in the acetabulum were classified as having grade-2 (moderate) dysplasia. Joints with a severely shallow acetabulum with subluxation of the femoral head were classified as having grade-3 (severe) dysplasia. Joints with luxation of the femoral head were classified as having grade-4 (very severe) dysplasia.

Severity of osteophyte formation and osteoarthritic deformation, which in most instances were secondary to hip dysplasia, was graded separately so as to not influence the evaluation of joint conformation. Dogs with deep acetabula but obvious signs of laxity were reexamined at an older age before a final evaluation was given. A transparent disk with concentric circles, as suggested by Norberg and described by Olsson,[20] was helpful when the position of the center of the femoral head was being determined.

Table 1—Number of dogs examined between 1976 and 1989 and age at examination for 7 breeds of dogs included in a radiographic screening program for hip dysplasia that was run by the Swedish Kennel Club

Breed	Total No. of dogs examined	No. of dogs for which age at examination was known	Age at examination (mo)		
			Mean	SD	Median
German Shepherd Dog	31,951	14,371	17.9	11.0	14
Golden Retriever	20,571	9,383	17.5	10.1	14
Labrador Retriever	16,915	6,412	19.7	12.4	15
Newfoundland	4,708	2,108	21.2	11.7	17
Rottweiler	4,030	2,311	16.2	6.6	14
Bernese Mountain Dog	3,197	1,701	16.6	7.4	14
Saint Bernard	1,857	824	21.0	11.8	17

Statistical analyses—For purpose of analysis, coxofemoral joint evaluations were transformed to a numeric score, with normal being given a score of 1; grade-1 dysplasia, a score of 2; grade-2 dysplasia, a score of 3; grade-3 dysplasia, a score of 4; and grade-4 dysplasia, a score of 5. Data from all dogs were linked to the dogs' registration numbers and their ancestral backgrounds. Although scores were available for both coxofemoral joints of each dog, only the score for the more severely affected joint was used in the analyses.

All statistical calculations were performed with the use of a computerized statistical program.[a] Sex differences were tested by means of χ^2 analysis. The outcomes of matings between normal dogs and slightly or more severely affected dogs were tested by use of the same technique. The influences of age and ancestral background on prevalence and severity of hip dysplasia were estimated by means of multiple regression analyses.

Heritabilities were calculated as realized heritabilities, using regressions of sons on sires and daughters on dams, except for Rottweilers, for which regressions of all offspring on sires and on dams were used.[21] The measurement of sire and dam was repeated for each offspring.[22] The effect of age was analyzed only for German Shepherd Dogs and Labrador Retrievers, because the large numbers of dogs of these breeds made such analyses possible. Sampling errors of the heritabilities were calculated with respect to family structures in the material.[23]

The costs involved in the Swedish program for radiographic screening for hip dysplasia were calculated by multiplying the actual number of dogs evaluated by the recommended fee for evaluation plus the cost of central evaluation and registration (average costs for the study period were \$40 + \$10 = \$50). The economic benefit of the program was calculated by multiplying the estimated number of dogs saved from moderate, severe, and very severe hip dysplasia within the entire population of dogs in each breed (estimated by comparing the prevalence in 1988 with that in 1976) by the cost of purchasing a dog of these breeds (equal to \$700, on average, for the period). A benefit:cost ratio was constructed as the quotient between the economic value of saved dogs and the costs of the program.

Results

Prevalence of hip dysplasia—During the period studied (1976 to 1989), the prevalence of hip dysplasia of any grade, as well as moderate, severe, or very severe hip dysplasia (grades 2, 3, or 4), decreased in all breeds (Fig 1). The decrease in prevalence of all grades of hip dysplasia was most prominent in Rottweilers.

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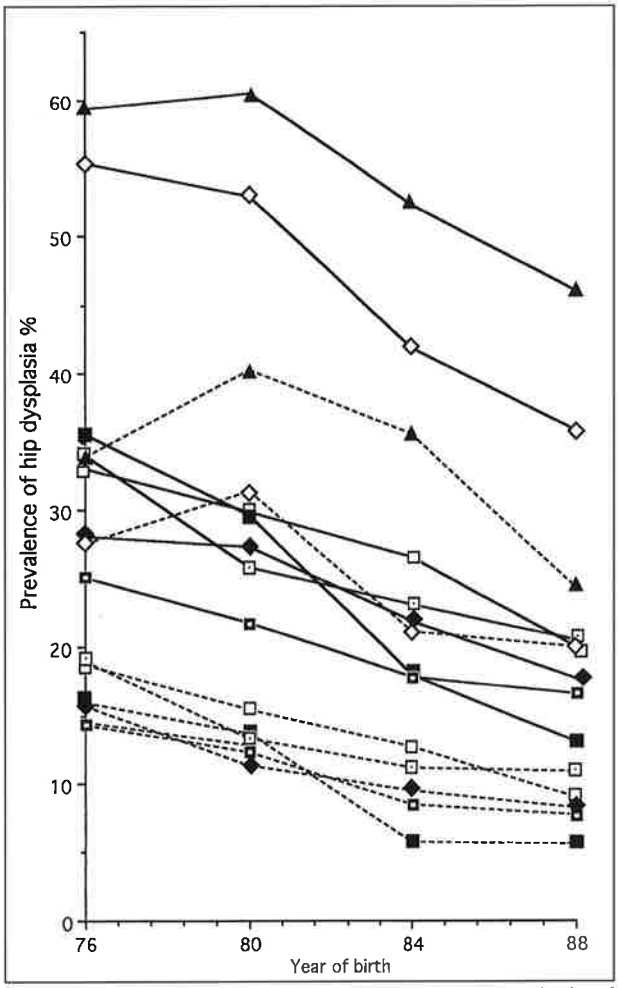

Figure 1—Prevalence, by year of birth, of hip dysplasia of any grade (solid lines) and of moderate, severe, or very severe hip dysplasia (grades 2, 3, or 4; dotted lines) among dogs of 7 breeds, examined and registered by the Swedish Kennel Club. Breeds represented are Saint Bernard (▲; n = 1,859), Newfoundland (◇; n = 4,708), Rottweiler (■; n = 4,030), German Shepherd Dog (⊡; n = 31,951), Bernese Mountain Dog (□; n = 3,197), Golden Retriever (◆; n = 20,571), and Labrador Retriever (◘; n = 16,915).

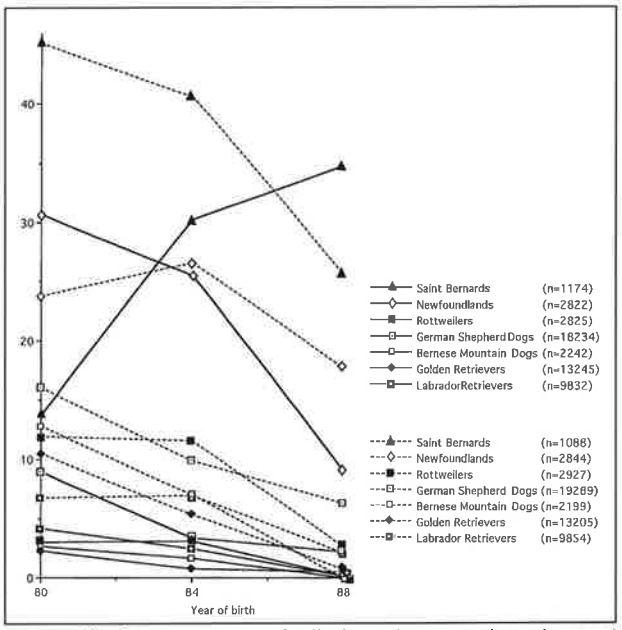

Figure 2—Percentages of all dogs born and registered with the Swedish Kennel Club that were born to dysplastic sires (solid lines) or dysplastic dams (dotted lines). n = total number of registered offspring born between 1980 and 1988 to dogs that had been examined for hip dysplasia.

Prevalence of grade-1 hip dysplasia decreased from 20 to 7% and prevalence of grade-2, -3, or -4 hip dysplasia decreased from 16 to 6%. In German Shepherd Dogs, Golden Retrievers, Labrador Retrievers, and Bernese Mountain Dogs, the decrease in prevalence of grade-1 hip dysplasia was less pronounced, but prevalence of grade-2, -3, or -4 hip dysplasia decreased by 40 to 50%. In Newfoundlands, there was a less pronounced decrease in the prevalence of grade-2, -3, or -4 hip dysplasia, but the prevalence of grade-1 hip dysplasia was reduced by > 50%. For Saint Bernards, the decrease in prevalence of moderate, severe, or very severe hip dysplasia was accompanied by an increase in the prevalence of slight (grade 1) dysplasia.

Evaluation of breeding stock—By 1976, > 70% of the male and 60% of the female German Shepherd Dogs, Golden Retrievers, Labrador Retrievers, Rottweilers, and Bernese Mountain Dogs that were being used for breeding were already screened for hip dysplasia. In these breeds, the percentage of sires screened for hip dysplasia was even higher in 1988, but varied considerably from 1 breed to the next. Almost all litters born during 1988 were born to dams that had been screened for hip dysplasia. In 1976, smaller percentages of the Newfoundlands (30% of sires, 50% of dams) and Saint Bernards (20% of sires, 50% of dams) used for breeding were screened, but these percentages increased rapidly and were similar to the percentage for the other breeds in 1983 to 1985.

For 1980 through 1988, the percentages of all dogs born during the year that were born to sires and dams with hip dysplasia of any grade were calculated (Fig 2). During each year studied, there was a large difference between the proportion of individuals in the general population that had hip dysplasia (Fig 1) and the proportion born to dysplastic parents (Fig 2). These differences were a result of breeding efforts aimed at reducing the prevalence of hip dysplasia through mass selection (ie, selection of sires and dams on the basis of coxofemoral joint status). The increase in percentage of Saint Bernards born to dysplastic sires was a result of the increase in the percentage of sires for which coxofemoral joint status was known.

Effects of sex and age—When data for all years were pooled, the prevalence of hip dysplasia was found to be significantly higher in females than in males for German Shepherd Dogs ($P < 0.001$), Golden Retrievers ($P < 0.01$), and Saint Bernards ($P < 0.01$). Differences were not found for Labrador Retrievers, Rottweilers, Newfoundlands, and Bernese Mountain Dogs (Table 2). In all breeds, age at the time of examination had a significant ($P < 0.05$) effect on prevalence of hip dys-

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Table 2—Prevalence of hip dysplasia among male and female dogs of 7 breeds in Sweden

Breed	Males		Females	
	No. examined	Percentage with hip dysplasia	No. examined	Percentage with hip dysplasia
German Shepherd Dog	15,979	24	15,972	28*
Golden Retriever	4,549	19	4,798	21†
Labrador Retriever	7,853	21	9,062	21
Newfoundland	910	41	1,177	40
Rottweiler	1,152	17	1,150	18
Bernese Mountain Dog	823	23	876	23
Saint Bernard	368	47	444	57†

*Significantly ($P < 0.001$) different from percentage of affected males. †Significantly ($P < 0.01$) different from percentage of affected males.

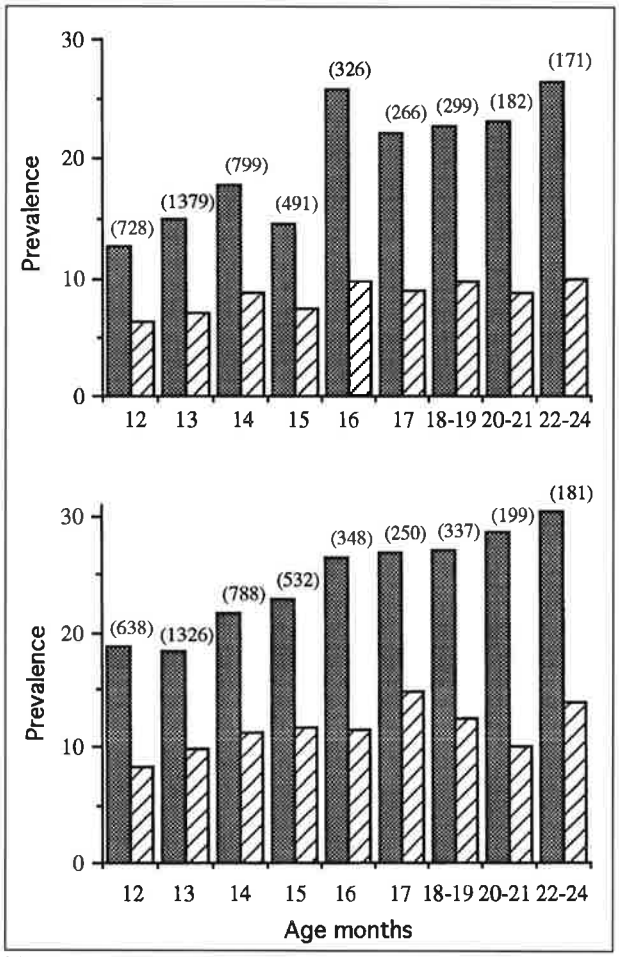

Figure 3—Prevalence of hip dysplasia (solid bars) and of moderate, severe, or very severe hip dysplasia (striped bars) in male (top) and female (bottom) German Shepherd Dogs as a function of age at the time of examination. Only litters from unaffected parents were included. Numbers in parentheses represent number of dogs examined.

plasia, even when offspring from dysplastic parents were not included (Fig 3).

Heritability—All heritability estimates were moderate to high (Table 3). Because a significant effect of sex could be demonstrated in several breeds, heritability estimates were calculated for males and females separately in all breeds except Rottweilers, for which

Table 3—Estimates of heritability of hip dysplasia in 7 breeds of dogs registered with the Swedish Kennel Club

Breed	Regression coefficient	Heritability ± SE
German Shepherd Dog*		
Sons on sires	0.24	0.48 ± 0.11
Daughters on dams	0.25	0.50 ± 0.07
Golden Retriever		
Sons on sires	0.17	0.34 ± 0.09
Daughters on dams	0.24	0.47 ± 0.08
Labrador Retriever†		
Sons on sires	0.27	0.54 ± 0.21
Daughters on dams	0.30	0.60 ± 0.13
Rottweiler		
Offspring on sires	0.24	0.48 ± 0.20
Offspring on dams	0.09	0.18 ± 0.10
Newfoundland		
Sons on sires	0.23	0.44 ± 0.11
Daughters on dams	0.27	0.54 ± 0.08
Bernese Mountain Dog		
Sons on sires	ND	ND
Daughters on dams	0.34	0.68 ± 0.18
Saint Bernard		
Sons on sires	0.20	0.40 ± 0.17
Daughters on dams	0.20	0.40 ± 0.12

*Regression coefficient for effect of age (mo) on prevalence of hip dysplasia was 0.02. †Regression coefficient for effect of age (mo) on prevalence of hip dysplasia was 0.01. ND = not determined; regression coefficient not significantly different from 0.

the scarcity of data on affected parents prevented such analyses. The effect of age at examination on prevalence of hip dysplasia was included in the calculation of heritabilities for German Shepherd Dogs and Labrador Retrievers, because data sets for these breeds were large enough to include the age effect in the analyses.

Prevalence of hip dysplasia in progeny—The prevalence of hip dysplasia among progeny was lowest when both parents had normal coxofemoral joints and was highest when both parents were dysplastic or when coxofemoral joint status was not known (Table 4). There was a positive relation between the prevalence of hip dysplasia of any grade and the prevalence of moderate, severe, or very severe hip dysplasia (ie, matings of dysplastic parents resulted not only in more dysplastic progeny but also in progeny with more severe grades of hip dysplasia). When data for all 7 breeds were merged into 1 data set, it was found that matings of normal parents to markedly dysplastic parents (grade 2, 3, or 4) resulted in progeny with a significantly ($P < 0.001$) higher prevalence of hip dysplasia than did matings of normal parents to slightly dysplastic (grade 1) parents.

The prevalence of hip dysplasia and marked (grade 2, 3, or 4) hip dysplasia in progeny of different sires varied greatly. For instance, the prevalence of hip dysplasia in the progeny of the 3 sires most widely used during the period from 1976 through 1989 varied between 9 and 35% for German Shepherd Dogs, between 6 and 23% for Rottweilers, and between 19 and 40% for Bernese Mountain Dogs, even though all sires were unaffected.

Benefit:cost analysis—Total cost of the Swedish hip dysplasia screening program from 1976 through 1988 was estimated to be nearly $4 million (Table 5). The economic benefit of the program was estimated by comparing the prevalence of grade-2, -3, or -4 hip dys-

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Table 4—Prevalence of hip dysplasia among dogs born in Sweden between 1976 and 1988, classified according to hip joint status of parents

Hip joint status of parents	German Shepherd Dog			Golden Retriever			Labrador Retriever			Newfoundland		
	Off-spring (No.)	% With dysplasia	% With marked* dysplasia	Off-spring (No.)	% With dysplasia	% With marked* dysplasia	Off-spring (No.)	% With dysplasia	% With marked* dysplasia	Off-spring (No.)	% With dysplasia	% With marked* dysplasia
normal X normal	21,768	23	11	16,763	21	10	13,318	18	9	2,187	34	18
normal X grade-1 hip dysplasia	2,849	37	20	774	33	17	686	31	18	723	46	27
normal X marked hip dysplasia	412	40	24	192	46	20	136	30	18	244	61	39
hip dysplasia X hip dysplasia	233	59	37	33	46	24	31	48	26	136	62	39
normal X unknown	4,838	26	12	2,098	29	14	1,935	28	16	657	47	26
unknown X unknown	1,293	33	17	605	36	20	698	34	22	533	63	39
hip dysplasia X unknown	558	40	22	106	46	24	111	50	34	228	62	39

Hip joint status of parents	Bernese Mountain Dog			Rottweiler			Saint Bernard		
	Off-spring (No.)	% With dysplasia	% With marked* dysplasia	Off-spring (No.)	% With dysplasia	% With marked* dysplasia	Off-spring (No.)	% With dysplasia	% With marked* dysplasia
normal X normal	3,374	20	8	2,547	24	11	591	47	26
normal X grade-1 hip dysplasia	210	29	13	203	40	20	252	58	36
normal X marked hip dysplasia	17	24	6	15	53	40	242	65	41
hip dysplasia X hip dysplasia	9	56	33	—	—	—	104	68	47
normal X unknown	321	28	14	381	31	15	364	62	39
unknown X unknown	80	34	16	41	29	12	177	59	44
hip dysplasia X unknown	19	32	16	10	30	0	127	75	52

*Grade-2, -3, or -4 dysplasia.

Table 5—Estimated costs and economic benefits of a radiographic screening program for hip dysplasia in dogs in Sweden

Breed	Cost of screening ($)	Projected benefit		Benefit:cost ratio
		No. of dogs*	Value ($)	
German Shepherd Dog	1,519,950	3,547	2,461,900	1.6
Golden Retriever	967,400	1,842	1,289,400	1.3
Labrador Retriever	815,600	1,379	965,300	1.2
Newfoundland	230,450	165	220,500	1.0
Rottweiler	188,900	369	258,300	1.4
Bernese Mountain Dog	147,200	243	184,100	1.3
Saint Bernard	74,900	794	555,800	7.4
Total	3,944,400	8,339	5,935,300	

*Estimated No. of dogs saved from moderate, severe, and very severe hip dysplasia, based on comparison of prevalence in 1977 (Saint Bernard) or 1976 (all other breeds) and prevalence in 1988.

plasia in 1976 (1977 for Saint Bernards) with the corresponding prevalence in 1988 and assigning dysplastic dogs a value equal to the estimated cost of purchasing a new dog. For all breeds except Newfoundlands, the benefit:cost ratio, based on accumulated values and costs, was > 1.0 in 1988 (ie, the total cost for screening was lower than the total value of dogs saved from moderate, severe, and very severe hip dysplasia over the period from 1976 through 1988). In most breeds studied, the benefit:cost ratio had already exceeded 1.0 by 1984. Notice that the calculated benefit includes only the estimated savings associated with decreasing the prevalence of moderate, severe, and very severe dysplasia. The benefit of the decreased prevalence of grade-1 hip dysplasia was not included, but represents an additional bonus.

Discussion

Results of the present study suggest that hip dysplasia, evaluated by radiologic screening as described, is a polygenic trait, the prevalence of which can be reduced through selective breeding. At the time this study was performed, dogs born later than 1988 had not been screened to the same extent as dogs born during previous years. Therefore, to avoid selection bias, changes in prevalence of hip dysplasia were analyzed only for dogs born before 1989, by comparing prevalence with that of dogs born in 1976. The same time span was used in the economic evaluation of the program. Only a small fraction (10%) of the Saint Bernards born in 1976 were screened; therefore, dogs born in 1977 were used as the reference.

The prevalence of hip dysplasia decreased in all 7 breeds studied. Decreases in the prevalence of hip dysplasia have been reported for other nationwide screening programs.[16,17,19] However, this large of a decrease in the prevalence of hip dysplasia has previously been documented only in well-controlled, small populations of dogs bred for specific purposes.[8,24] Breed differences in this study in the amount of decrease in the prevalence of hip dysplasia can be attributed to variations in the intensity of selection applied over the period, as well as to differences in prevalence at the beginning of the study.

The Swedish screening program for hip dysplasia is different from most other systems. For example, rather than allowing secondary joint changes such as osteophytes and osteoarthritic deformations influence the grading, these changes are reported separately. Having only 1 radiologist evaluate all radiographs adds

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to the precision of the scoring system by eliminating between-reader variation.

In the present study, hip dysplasia was significantly more frequent in female than in male German Shepherd Dogs, Golden Retrievers, and Saint Bernards. This is in accordance with findings of previous surveys from Sweden and other countries.[4,8,25] However, sex differences were not found in other studies.[5,26-28] In general, males and females in a population have the same genes except for those on the sex chromosomes. A sex-related difference in prevalence of hip dysplasia could be explained by a direct effect of genes on the sex chromosomes or by an effect of secondary sex characteristics coded by genes on the sex chromosomes (eg, differences in growth rate, sex hormones, or behavioral patterns). For a trait such as hip dysplasia, where the expression of the trait depends on several genes, the latter is a more plausible explanation. For breeds in which females have a higher frequency of hip dysplasia, it is likely that these females have an increased expression of genes for the disease, compared with males. This could also be expressed as a greater tendency for males not to manifest the genes influencing hip dysplasia. The more incomplete penetrance of these genes in males results in a phenotypic classification where males have a higher frequency of these genes, compared with corresponding females. So even if hip dysplasia is not expressed phenotypically in males with the frequency that it is in females, the genes controlling the trait may still be passed on to the offspring from the sire. In the present study, the effects of sex differences were counteracted by stronger phenotypic selection of sires.

That a sex difference is seen only in some breeds of dogs, but to much lesser extent than in people,[29] suggests that there might be at least 2 variants of hip dysplasia in dogs, as is the case in human beings. It has been proposed that hip dysplasia in human beings consists of 2 entities, both of which are genetically influenced.[29] The first type, screened for at birth by various methods to detect laxity, is more common and much more frequent in females than in males. The second type, evident radiographically later in life, is less common and has a more even sex distribution.[30] If 2 types of hip dysplasia exist to some extent in dogs as well, radiologic screening for coxofemoral joint conformation and methods to evaluate coxofemoral joint laxity may, in fact, reveal partly different entities. Coxofemoral joint conformation and laxity may not be regulated by the same genes. Genes influencing hip dysplasia can differ in their frequency and impact in different breeds. Some might be major genes (ie, have a greater influence on the trait than the average gene); others may be minor.

In the present study, a significant effect of age was demonstrated in all breeds. The effect of age could be detected in both sexes for German Shepherd Dogs, Golden Retrievers, Labrador Retrievers, Rottweilers, and Bernese Mountain Dogs between 12 and 24 months old and for Newfoundlands and Saint Bernards between 12 and 36 months old. Both the prevalence of hip dysplasia and the precision of diagnosis increased with age in the age interval studied. To minimize age bias in a screening program, it is, therefore, important to evaluate as many individuals as possible at the same age or in a narrow age interval. The dogs should be evaluated before being used for breeding. The higher the minimum age at examination, the greater the chance of the dogs being radiographed earlier for various reasons. Consequently, some dogs in which hip dysplasia was detected before the minimum screening age might not be included in the screening records. The recommended age at examination could, however, vary between breeds, owing to differences in the prevalence and severity of hip dysplasia as well as in breeding strategies.

One explanation for the gradual decrease in the prevalence of hip dysplasia is obviously that selection efforts have been successful. The comparison of prevalence of hip dysplasia in parents and in the general populations illustrates the strong mass selection against hip dysplasia in the breeds studied. However, it is difficult to quantify the intensity and character of selection, owing to unknown considerations of the family records. The increasing proportion of the dog population examined also makes it difficult to differentiate between various selection criteria. The increased prevalence of grade-1 hip dysplasia and decreased prevalence of grades 2, 3, and 4 in Saint Bernards are in good agreement with the predicted behavior of a polygenic trait, if the average hip dysplasia grade is above grade 1.

In all grading systems for hip dysplasia based on radiographic appearance, there are limited possibilities for measuring differences between phenotypically normal dogs. Most affected dogs are assigned to various classes on the basis of phenotype, whereas normal dogs are often lumped together in 1 class. Various attempts to differentiate between phenotypically normal animals have been made. Examples include the English hip-scoring system and the evaluation of joint laxity by means of the distraction index.[31,32] However, in all systems, hip dysplasia acts, to varying degrees, as a threshold characteristic; that is, animals have to reach a certain level of liability before they have detectable signs of disease. The threshold of hip dysplasia does not have a distinct border. It is more like a vanishing point, and it becomes more and more difficult to differentiate the quality of dogs the better they are.

Recognizing hip dysplasia as a polygenic trait with normal distribution of genotype and phenotype, the hidden differences between nonaffected dogs, therefore, makes information on relatives, in addition to information on individuals, very informative.[33] Records on siblings and ancestors provide early information that could reveal some of the differences among phenotypically normal dogs, and thereby improve the estimation of breeding values, compared with estimations based only on individual records. Family records have already been proven to be of importance when selecting against hip dysplasia in a smaller population of German Shepherd Dogs.[8]

For older dogs, mainly sires in large populations, the construction of a selection index is 1 way to include information on relatives.[34] The large differences in the prevalence of hip dysplasia in litters from nor-

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mal sires indicate that selection based on progeny will improve the results of a breeding program.

Various methods of regression analysis and ANOVA have been used to estimate the heritability of hip dysplasia. Most investigators have used ANOVA[8,10,34]; only a few have made use of both methods.[6,7,9,11] Heritabilities are estimated on the basis of degree of resemblance between relatives. The choice of relatives to use depends on the available records. Heritability estimates are valid only within the population in which they are calculated. Prevalence of dysplasia, selection against dysplasia, and method of estimation influence the estimates to a variable extent.[35]

Having all the records at hand, we were able to use a variety of methods to estimate the heritability, including regression analyses of offspring on parents and ANOVA. After comparing the methods, we chose to present results of the regression analyses for the following reasons. Selection based on the studied character (in this instance, hip dysplasia) influences the variance between parents and, consequently, the covariation among siblings. As a result, the heritability estimates from full- and half-sibling correlations become biased. The ANOVA on intraclass correlations between full and half-siblings resulted in unstable estimates and overestimation of maternal effects on hip dysplasia, mainly owing to stronger selection among sires than among dams.

Although regression estimates remain unbiased, even with selection among parents on the character studied, the precision is reduced. The regression method decreased the number of available records, but provided unbiased estimates of realized heritabilities, that is, the proportion of parental superiority or inferiority in hip dysplasia actually transmitted to the next generation, in contrast to estimates based on expected proportions to be transmitted. In the present study, selection against hip dysplasia was so intense in Rottweilers and Bernese Mountain Dogs that almost no phenotypic variation remained among selected parents. This made it difficult to get confident estimates of heritability, even with regression analyses. In an extreme situation, where all parents have the same coxofemoral joint status, all phenotypic differences disappear and, consequently, heritability cannot be estimated, even though the condition is still inherited.

It was shown in this study that the screening program operated by the SKC, with information linked to ancestral background in a stud book in an open registry, soon paid for itself. The prevalence of hip dysplasia was already decreasing before 1976, thanks to a certain amount of selection prior to the period covered by this study. Screening and selection to achieve a further decrease in the prevalence of hip dysplasia or to maintain the gains achieved did not cost owners of these breeds, collectively, more than two thirds of the total value of dogs estimated to have been saved from moderate, severe, or very severe hip dysplasia. In addition, a decrease in prevalence of grade-1 hip dysplasia was also achieved. A decrease in hip dysplasia of all grades results in more animals available for breeding for other inherited characteristics.

The genetic quality of normal dogs, with reference to hip dysplasia, depends on the prevalence of dysplasia in the population from which they are recruited. Consequently, a decrease in prevalence of dysplasia in the family, line, or domestic population, or even in the breed, increases the average quality of normal dogs in that breed. The Swedish screening and control system makes it possible to benefit from information at all these levels.

The progress attainable in the eradication of hip dysplasia depends on how consistently the breeding plan is followed and on the degree of precision with which breeding values of the breeding stock can be estimated. In a multifactorial polygenic threshold trait like hip dysplasia, measurement errors resulting from problems in identifying differences between phenotypically normal animals must be recognized as a major environmental factor that lowers heritability and the effects of breeding efforts. Even in traits such as hip dysplasia, which has high heritabilities (> 0.3) and a high prevalence, there is a lot to gain, owing to the threshold character of hip dysplasia, by using family records to predict the breeding values of proposed breeding animals. Including records on full- and half-siblings and parents, and maybe even grandparents, will, in most cases, be the most effective way to further improve a breeding program. Progeny testing of sires will also improve a breeding program, but bitches have already made their major contribution of puppies before they can be sufficiently evaluated.

[a]JMP 2.02, SAS Institute Inc, Cary, NC.

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Culling associated with *Neospora caninum* infection in dairy cows—M. C. Thurmond and S. K. Hietala

Objectives—To estimate the extent to which cows infected with *Neospora caninum* were culled, compared with noninfected cows, and to identify differences in reasons for culling between infected and noninfected cows.
Animals—442 Holstein cows on a commercial dairy with 36% seroprevalence for *N caninum*.
Procedure—Culling of cows was done after first calving without knowledge of *N caninum* serologic status.
Results—Risk of a seropositive cow dying was not different from that of a seronegative cow ($P = 0.50$). Seropositive cows were culled 6.3 months earlier than seronegative cows, and had a 1.6 times greater risk of being culled, compared with seronegative cows ($P = 0.004$), after adjusting for culling risk associated with abortion. For cows culled for low milk production, culling risk for a seropositive cow was twice that for a seronegative cow ($P = 0.007$).
Conclusions—The economic impact of *N caninum* infection in dairy cattle can be expected to extend beyond that for abortion alone. Costs of the disease also may include premature culling and diminished milk production.
Clinical Relevance—Plans to control *N caninum* infection on dairies should include consideration that benefits may include reduction in premature culling and increase in milk production. (*Am J Vet Res* 1996;57:1559–1562)