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A Radiographic Stress Technique for Evaluation of Coxofemoral Joint Laxity in Dogs

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Objective—To develop a radiographic stress technique to quantify hip joint laxity in dogs.
Study Design—Prospective study on client-owned dogs presented for hip dysplasia screening.
Animal Population—302 nonselected dogs (63 breeds).
Methods—Dogs were sedated and placed in dorsal recumbency. During pelvic radiography, the femoral heads were displaced manually in a craniodorsal direction. On these stress radiographs, the degree of lateral displacement of the femoral heads was assessed in terms of a subluxation index (SI) and compared with the degree of femoral head subluxation and the severity of hip dysplasia found on conventional extended hindlimb radiographs.
Results—The degree of subluxation on stress radiographs was significantly greater than on conventional radiographs. Correlation between the severity of canine hip dysplasia (CHD), graded according to conventional techniques, and the degree of subluxation, induced by radiographic stress technique, was positive ($r = .57$; $P < .0001$). Two critical SI values were noted. Of the dogs with an SI value of 0.3 or less, 99% were classified as CHD grade normal, borderline, or mildly dysplastic. In dogs with an SI value between 0.3 and 0.5, CHD grading ranged from normal to severely dysplastic. Of the dogs with an SI value greater than 0.5, 95% had dysplastic hip joints.
Conclusions—Hip joint laxity cannot be quantified precisely on standard position radiographs. The proposed stress technique yields significantly higher degrees of femoral head subluxation than the standard position.

CANINE HIP DYSPLASIA (CHD) is still common, despite radiographic screening of breeding dogs for nearly 30 years.[1,2] In Switzerland, CHD is currently seen in 42% of all purebred dogs evaluated.[3] The main reasons for the poor success of screening programs are that the genetic quality of breeding dogs cannot be assessed reliably on the basis of conventionally taken radiographs, that dysplastic animals are still used for breeding purposes, and that no strict progeny testing is applied. The incidence of CHD may be reduced only if the genetic quality of breeding animals is ascertained more exactly. This can be achieved by estimating the breeding value of an animal. The breeding value reflects the genetic quality of the animal for a specific trait. It is a statistical number derived from the quality of the close relatives and the offspring in particular for this trait. Breeding value estimation is well known in farm animal breeding. In canine breeding, it is not commonly used, mainly because of incomplete data collection and lack of awareness by the dog owners. Therefore an improved radiological technique must be developed that defines hip joint quality of a potential breeding dog more reliably. We have developed a new radiological technique to quantify coxofemoral joint laxity.

Radiography is the only accepted tool for large-

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scale screening of dogs for CHD, but it does not accurately reflect the genetic composition of a dog or the risk for passing CHD to the offspring.[4-19] Coxofemoral laxity is considered the most important factor promoting CHD.[20-31] Yet the degree of coxofemoral joint laxity cannot be evaluated reliably using the standard radiographic positioning of the dog with the hindlimbs pulled caudally and rotated inwards.[27,32,33] This method causes overextension of the hip joint and spiral tensioning of the nonelastic joint capsule, resulting in repositioning of a subluxated femoral head back into the acetabulum.[27]

Radiographic stress techniques attempt to quantify maximal dislocation of the femoral head from the acetabulum. In early stress techniques, the hindlimbs were pulled caudally, an object was then placed between the thighs, and the stifles were pushed against each other, resulting in lateral displacement of the femoral heads.[22,26,29,30,34-36] As in the standard leg-extended technique, however, full subluxation of the femoral head was inhibited, and maximal extent of laxity could not be reliably determined. Nonetheless, most of the stress studies noted a positive correlation between the degree of coxofemoral laxity and coxarthrosis.

In 1977, Badertscher[24] developed the half axial view, avoiding hip joint overextension. The femurs were displaced from the caudally extended position to a 45° angle to the table top, a more physiologic limb position. A wooden lath of 5- to 10-cm width was placed on the pelvic symphysis. Adducting the stifles resulted in subluxation only in a lateral direction. The extent of femoral head dislocation doubled when compared with the standard extended hindlimb technique. A similar technique was later described by Belkoff et al.[25] The femurs were displaced laterally with a distractor. In 14% of the evaluated joints, this technique gave false-negative results.

Smith et al[27,37] positioned the hindlimbs at an 80° angle to the table top, avoiding joint capsule tensioning. They used a distractor but achieved lateral displacement only because there was no dorsal force component. The degree of instability was quantified by a dimensionless distraction index (DI = d/r), defined as the ratio of the distance from the center of the femoral head to the center of the acetabulum (*d*) and the radius of femoral head (*r*) (Fig 1). Dogs with a DI less than 0.3 did not develop CHD.[27] In a similar study, 87% of Labrador Retrievers with a DI less than 0.4 at the age of 4 months developed normal hips, whereas 57% of dogs with a DI 0.4 or greater became dysplastic.[31] The admissible DI range for normal coxofemoral development varied among breeds.[38] With the same DI, German Shepherd dogs tended to develop coxarthrosis more readily than Rottweilers.[39] Because not every lax hip inevitably develops coxarthrosis, Smith et al[28,31] hypothesized that dogs with subluxating femoral heads, but not afflicted with coxarthosis, are carriers for a CHD disposition. Currently, no data supporting the latter hypothesis have been published.

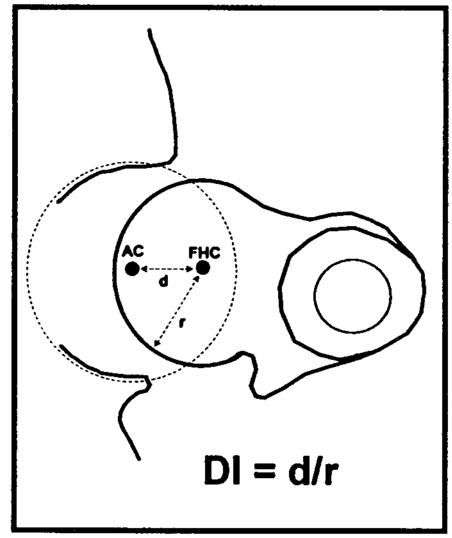

Fig 1. Assessment of the subluxation index (SI), which is identical to the distraction index (DI) by Smith et al.[27] The index is defined as the distance (*d*) of the femoral head center (*FHC*) from the acetabular center (*AC*) divided by the radius (*r*) of the femoral head (*DI = d/r*) (Courtesy of Dr. Gail K. Smith and Penn Hip.)

When a dog is in motion, the acetabular roof is exposed to a craniodorsally acting force.[40-44] We therefore assume that an unstable femoral head subluxates both craniodorsally and laterally, typical also for traumatic luxation. Because existing stress radiographic techniques test lateral subluxation only, we developed a stress technique that provokes maximal cranial, dorsal, and lateral displacement of the femoral head. The results of evaluation of radiographs obtained from the new stress positioning technique are compared with the results obtained from conventional radiographic views.

MATERIALS AND METHODS

A total of 302 dogs (63 breeds) underwent a radiographic screening examination for CHD. Breed distribution reflected the current Swiss canine population.[45] The most common breeds and numbers of dogs examined are listed in Table 1. Average age at the time of examination was 1.86 ± 1.05 years (median, 1.55 years). Age distribution is shown in Table 2. There was no gender predominance.

The dogs were sedated to achieve full muscle relaxation by injecting intravenously a combination of atropine (0.01 mg/kg, body weight [BW], not >0.4 mg per dog), ketamine (2 mg/kg BW), acepromazine (0.1 mg/kg BW, not > 4 mg per dog), and dextromoramide (Palfium, Janssen Pharmaceuticals, Beerse, Belgium), a synthetic opiate (0.05-0.1 mg/kg BW, upper dose in small dogs, lower dose in large dogs). The standard radiograph was taken with the hindlimbs extended. The degree of CHD was graded using the total score derived from six evaluation criteria.[46]

Owners consented to a supplementary stress technique radiograph. This stress view was taken with the dog placed in dorsal recumbency. Femurs were positioned at 60° angle to the table top; stifles were adducted and manually pushed craniodorsally by a tester during exposure; the tibia served as a lever. Such manipulation resulted in cranial, dorsal, and lateral displacement of the femoral head in an unstable hip joint (Figs 2 and 3). The technique somewhat resembles the Ortolani manipulation.[47] Maximal subluxation was assumed as long as the radiographic angle formed by the line connecting the two femoral heads and the femoral longitudinal axis did not exceed 90° on each side. A slight pelvic tilt over the long axis, reflected by a difference of the obturator foramina diameters of up to 5 mm at their broadest, was tolerated. Otherwise the radiographs were repeated. As more muscle tissue had to be penetrated, exposure was increased by 30% compared with the standard technique. Alternatively a high-speed film screen combination using the original exposure settings may be used. The degree of laxity was quantified identical to the DI method described by Smith et al[27] (Fig 1) but was termed *subluxation index* (SI) instead, to separate the results of the two dislocation techniques from each other.

The mean, standard deviation, median, and range of the point score and of the SI on the standard view as well as of the SI on the stress view were calculated for both hip joints (Table 3). The CHD grade based on conventional radiographs and the degree of joint laxity as seen on films taken in the stress position were compared. For this comparison, the results of the worse of the two hip joints were used in accordance with Fédération Cynologique Internationale policy, which rates CHD grading based on the worse of the two joints.[49] A normal hip joint corresponds to grade A (point score, 0-2), borderline to grade B (score, 3-6), mildly dysplastic to grade C (score, 7-12), moderately dysplastic to grade D (score, 13-17), and severely dysplastic to grade E (score, >17).

In 11 animals, stress views were simulated by three testers in turn, resulting in 33 stress simulations. To measure stress force, dogs were placed on a table-top scale. The vertical vector of the forces acting on the animal, before and during stress, was calculated in terms of weight difference.

In 25 of the 302 dogs, reproducibility of subluxation was tested (Table 4). Three testers in turn took a stress view of the same dog during the same sedation span. Relationships of the SI with the tester, the pelvic positioning, and a combination of these factors were then evaluated by variance analysis.[50] For these calculations, the larger of the two SI values was used. Badertscher's results[24] were converted into SI values for comparison purposes.

Table 1. Most Common Breeds of Dogs Evaluated for Canine Hip Dysplasia ($n = 302$)

Breed	n	%
German Shepherd dog	53	17.5
Labrador Retriever	38	12.6
Bernese Mountain dog	24	7.9
Golden Retriever	16	5.3
Beagle	14	4.6
Hovawart	10	3.3
Other 57 breeds, $n < 10$ per breed	147	48.8

Table 2. Age Distribution of Dogs Evaluated for Canine Hip Dysplasia ($n = 302$)

Age (y)	n	%
>1.0-1.5	144	48
>1.5-2.0	77	25
>2.0-3.0	47	16
>3.0	34	11

RESULTS

During stress simulation, the total vertical force component acting on both hip joints ranged from 86 to 141 N (mean, 107 N). In reality, the force was larger because only the vertical force component was recorded, while ignoring the horizontal force vector. Tester-induced bias and pelvic positioning as well as the interrelationship of these two parameters with SI proved to be statistically insignificant ($P > .05$) (Table 4).

No statistically significant difference was found in the results between right and left hip joint (Table 3). In contrast, there was a statistically significant difference between the SI on the standard and on the stress view (paired t-test, $P < .0001$).

Correlation between the standard position score and the stress-view SI was significantly positive ($r = .57$, $P < .0001$). Dogs graded C were subclassified into two groups. Dogs with a score between 7 and 9 points

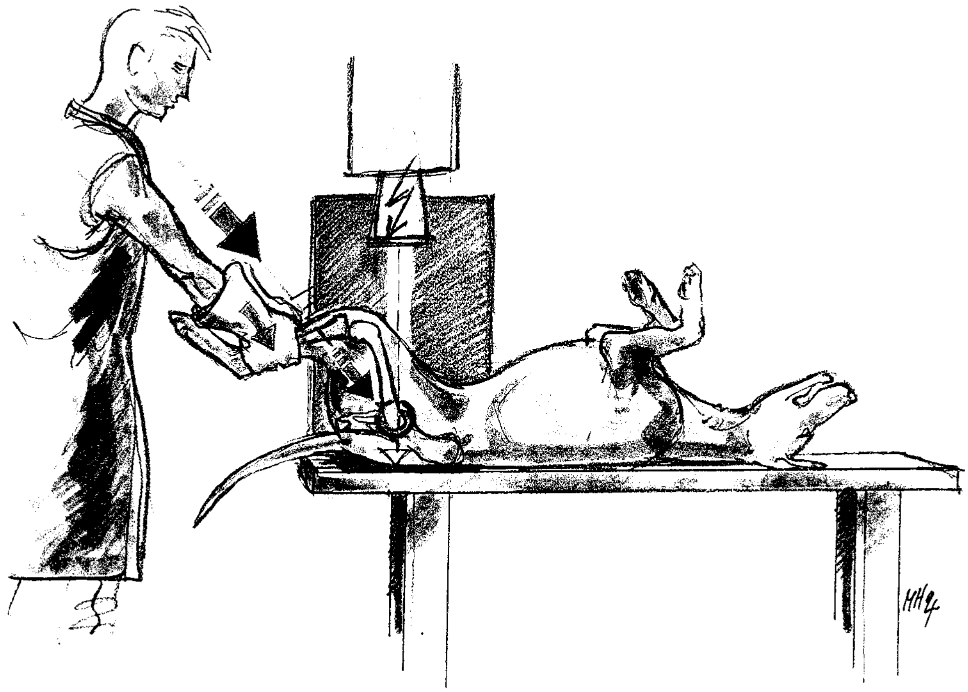

Fig 2. Radiographic stress technique for subluxation of femoral heads. Femurs are angled at 60° to the table top and manually pushed craniodorsally.

were assigned to CHD group C1, those with a score of 10 to 12 were assigned to CHD group C2. The point score method is described in detail elsewhere.[46] Based on the distribution of the plotted data, two critical SI values, 0.3 and 0.5, could be defined, classifying dogs into three groups (Fig 4 and Table 5).

Evaluating the relationship between the degree of subluxation and the CHD grade of those dogs with an SI 0.3 or less, 77% were assigned grade A or B, 92% were assigned grade A to C1, and 99% were assigned grade A, B, or C. Dogs with SI values of 0.3 to 0.5 were assigned all CHD grades, from normal to highly dysplastic. Of these, 88% were classified as B, C, or D. Of the dogs with an SI value greater than 0.5, 95% were graded CHD C to E.

Evaluating the relationship between the CHD grade and the degree of subluxation in dogs graded A or B, 71% of the dogs had an SI value 0.3 or less, 99% were 0.5 or less, and slightly more than 1% of the dogs had an SI value greater than 0.5. In dogs graded C, 82% had a maximal SI value of 0.5; SI values ranged from 0.15 to 0.69. In dogs classified C2 or worse, 89% had an SI value 0.3 or greater. In dogs graded D or E, 98% had an SI greater than 0.3; 36% had an SI greater than 0.5.

DISCUSSION

CHD prevention programs have been applied for decades, but the disease is still common in many

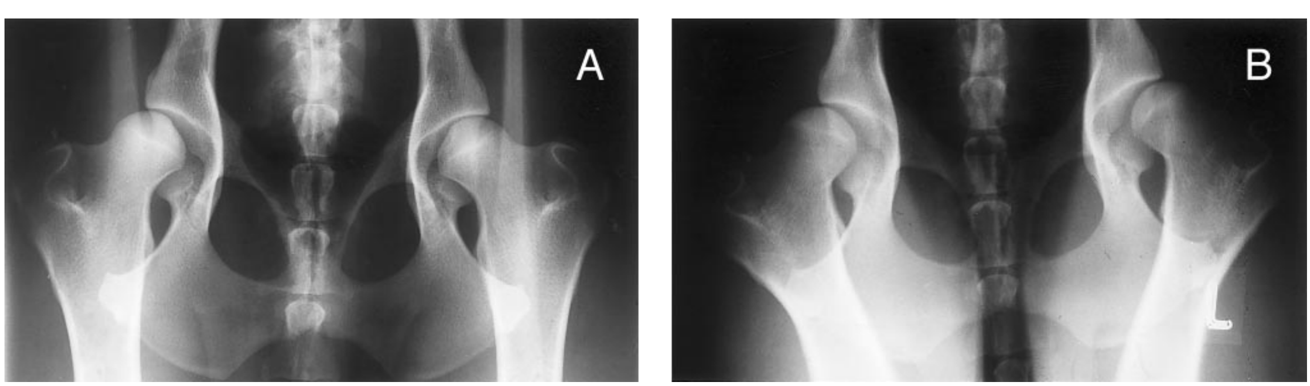

Fig 3. (A) Coxofemoral radiograph of a 1-year-old German Shepherd dog taken using the standard technique. The two femoral heads show differing degrees of laxity. (B) Coxofemoral radiograph, using the stress technique illustrated in Fig 2, taken from the same dog as in A. The SI was 0.54 on the right and 0.46 on the left.

Table 3. Average Total Canine Hip Dysplasia Score on the Standard View and Average Subluxation Index on the Standard and on the Stress Views for the Right (R) and Left (L) Hip Joint and for the Worse (W) Joint for Each Dog*

Value	$\bar{x}$	S_x	Median	25-75% Range	0-100% Range
R point score	7.1	4.5	6	4 -10	0 -22
L point score	6.6	4.9	6	3 -9	0 -21
R SI standard	0.17	0.09	0.15	0.11 -0.21	0.00 -0.60
L SI standard	0.14	0.08	0.13	0.09 -0.17	0.00 -0.52
R SI stress	0.29	0.15	0.29	0.18 -0.39	0.00 -0.84
L SI stress	0.29	0.15	0.28	0.17 -0.41	0.00 -0.71
W point score	7.8	4.8	6	4 -11	0 -22
W SI standard	0.19	0.09	0.17	0.13 -0.22	0.00 -0.60
W SI stress	0.34	0.14	0.32	0.22 -0.43	0.04 -0.84

* Point score: sum of scores on the six parameters evaluated on the standard view. SI standard, SI on the standard view; SI stress, SI on the stress view.
$\bar{x}$ = mean.
S_x = standard deviation.

breeds. In the early 1990s, CHD was diagnosed in 42% of the purebred dogs screened for CHD in Switzerland.[3] The incidence of severe CHD has decreased slightly worldwide over the past 30 years, but no steady decrease in the frequency of CHD has been noted.[2,3,51] Therefore methods for CHD evaluation must be reevaluated critically.

The cause of CHD remains unknown, and the cause of joint instability, widely viewed as a precursor of coxarthrosis, has not been determined.[20,52,53] A developmental disorder of connective tissue has been postulated as the cause of hip joint laxity, leading to a pathologically high elasticity of the articular capsule and ligaments.[43] This argument is supported by the finding that the ratio of collagen III and I in CHD-free Greyhounds differs significantly from breeds commonly affected by CHD.[54]

Assuming that a lax hip joint tends to promote coxarthrosis, laxity should be quantified more reliably.[20] Although secondary degenerative changes can be identified quite readily, the standard radiographic positioning with hindlimbs pulled caudally does not demonstrate coxofemoral instability reliably because of the nonphysiological tensioning of the pelvic muscles,[24] and twisting of the joint capsule.[25,27,37,55] Various distraction techniques have been developed for the radiographic quantification of hip joint laxity.[22,24-31,34,36] In all these techniques, femoral heads were distracted only laterally, which does not accurately replicate force vectors present during locomotion. In an unstable hip joint, the femoral head usually subluxates craniodorsally and laterally when loaded, and the first radiological changes of CHD are therefore visualized at the craniodorsal acetabular edge.[23,33] The concerns about the validity of these techniques were the stimulus to develop a stress technique that replicated the multiple forces acting on the hip joint during locomotion.

For the stress technique described by Smith et al,[27] a special tool and a fee-associated training seminar are required.[56] Belkoff et al[25] also used a custom-designed distractor. With Badertscher's technique,[24] dislocation is achieved using a simple wooden lath. The latter technique has never been published in a scientific journal, and thus is not widely known. Our technique does not require any special equipment and can be learned quickly. Smith et al's[27] proposal for quantifying the degree of femoral laxity on a radiograph is considered to be optimal because it is not influenced by the absolute size of the dog, by slight pelvic malpositioning, or by the radiographic magnification of the hip joint on the x-ray film.

Exact positioning of the pelvis and femurs is often difficult to achieve in the standard radiographic view. Insufficient inward rotation of the femurs and pelvic tilting over its long axis are common. Our stress technique, too, carries the risk of tilting the pelvis because the femurs are pushed craniodorsally. Therefore pelvic positioning was verified by fluoroscopy. The SI was not significantly influenced by slight malpositioning or by the tester.

The relationship between the magnitude of forces acting on the coxofemoral joints and the degree of femoral head laxity is not linear. A small force of 2 N per hip joint is sufficient to effect nearly maximal subluxation of the femoral head.[25,57] Results of our stress simulation test suggest that the force exerted on

Table 4. Results of the Variance Analysis of Tester-Induced Bias and of Pelvic Positioning on the Larger Subluxation Index*

Source	Degrees of Freedom	Type III Sums of Squares	Mean Square	F Value	$P >$
Tester (T)	2	0.0179	0.0089	0.70	.50 (ns)
Pelvic positioning (P)	2	0.0446	0.0223	1.74	.18 (ns)
Combination (T+P)	4	0.0403	0.0101	0.78	.54 (ns)
Error	66	0.8466	0.0128		
Corrected total	74	0.9223			

* Abbreviation: ns, nonsignificant ($P > .05$).
F Value = ratio of variances.

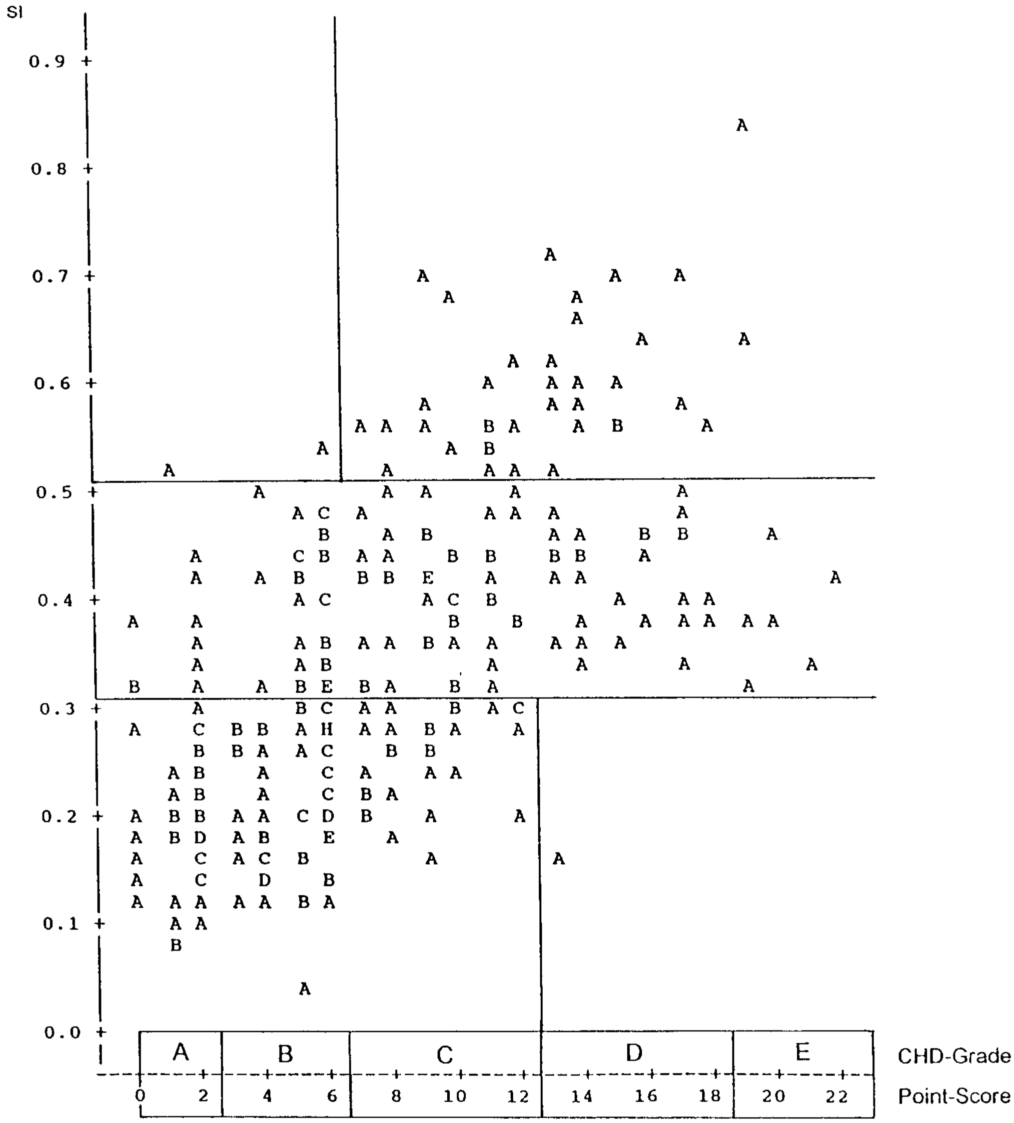

Fig 4. Bivariate diagram of the relation between the Canine Hip Dysplasia (CHD) point score derived from the standard view and the subluxation index (SI) derived from the stress view in 302 dogs. The horizontal lines represent the critical SI values of 0.3 and 0.5, and the vertical lines the gradations from CHD grade B to C, as well as from C to D. Key: A, one animal; B, two animals; C, three animals; D, four animals; E, five animals.

the hip joints by the tester is high enough to yield reliably a maximal subluxation.

Applying our stress technique to dogs with different CHD grades, femoral subluxation reached an average SI of 0.34, identical to the DI compiled by Smith et al.[27] Their result was based on data from 49 German Shepherd dogs, whereas the data from 10 Borzois that they had also examined were excluded. Our result is based on the data from 302 dogs, representing 63 breeds, including some with excellent coxofemoral conformation (eg, Huskies and Belgian Shepherd dogs). When the Borzoi data are included Smith et al's[27] calculations, their DI drops to 0.31, lower than our value.

In our study, the SI value on stress views averaged 1.8 times that on standard radiographic views. The 2.6-fold increase noted by Smith et al[27] was not seen, but they did not specify the CHD grade evaluated on the standard view. It therefore remains undetermined which of the two stress techniques quantifies femoral laxity more reliably.

On angled limb stress views, Badertscher's SI

Table 5. Relation Between Canine Hip Dysplasia Grade and Subluxation Index (Indexing) in 302 Dogs

SI	CHD-Grade, Corresponding Number of Dogs: A	B	C1	C2	D	E	Total
≤0.3	40	67	21	10	1	0	139
>0.3-0.5	9	33	25	23	28	6	124
>0.5	1	1	6	11	18	2	39
Total	50	101	52	44	47	8	302

increases by 0.17 on average compared with extended limb standard view and slightly exceeds ours, reading 0.15. Badertscher[24] noted a twofold increase in the degree of subluxation between the stress technique with extended pelvic limbs and the stress technique with angled pelvic limbs when compared with the degree of subluxation on standard technique films. Of the three radiographic techniques (standard, stressed with extended hindlimbs, and stressed with angled hindlimbs), the stress technique with angled pelvic limbs was most reliable for demonstrating maximal coxofemoral laxity.

A positive correlation between the degree of femoral head laxity and the CHD grade derived from the standard view was demonstrated by Smith et al,[28] by Madsen and Svalastoga,[36] and by our results. No positive correlation, however, was found by Badertscher.[24] The reason for this discrepancy may be the different mode of hip joint assessment on the standard view. Correlation between standard and stress technique data was not calculated in the studies by Belkoff et al[25] and Madsen and Svalastoga.[30]

The first critical SI value in our study is 0.3. Virtually all dogs with distinct arthrosis (CHD grades D and E) showed an SI greater than 0.3. Of the dogs with normal or borderline normal hip joint conformation (CHD grade A or B), only 71% had an SI of 0.3 or less, 28% had an SI between 0.3 and 0.5, and 1% (two dogs) had an SI greater than 0.5. We therefore concluded that a substantial number of dogs may not develop coxarthrosis despite the presence of obvious femoral laxity. Several authors have observed hip joints free of arthrosis that subluxated under stress.[22,29,30,33,35,36] Passive laxity without evidence of arthrosis is a common finding in Bernese Mountain dogs and Labrador Retrievers but rarely seen in German Shepherd dogs.[28,36,43] Smith et al[38] hypothesized that two forms of subluxation exist: (1) a functional form, corresponding to subluxation of the femoral heads during locomotion, and (2) a passive form, corresponding to femoral head subluxation when manually forced out of the acetabulum under anesthesia. It remains unproven whether this passive laxity is ever present in the conscious dog because the degree of subluxation during locomotion has not been quantified. Nevertheless, functional laxity may induce coxarthrosis because articular malpositioning under load results in arthrosis.[10]

Our second critical SI value is 0.5. Roughly 95% of the dogs with an SI greater than 0.5 are dysplastic. Therefore one may conclude that for normal coxofemoral development, passive instability should not exceed an SI of 0.5.

Dogs with CHD grade A to C are accepted for breeding purposes by most breed clubs. Consequently, 82% of the evaluated dogs could be used for breeding. As a result, CHD prevalence has for many years not changed.[2,3,51,58] Assuming that coxofemoral instability and arthrosis are undesirable findings in breeding dogs, the breeding recommendation should be refined (Table 6). Combining the results of our radiographic stress technique with those of the standard technique, only those dogs scoring CHD grade A or B and a maximal SI of 0.3 should be accepted for breeding. Dogs assigned CHD grades D or E and those with an SI greater than 0.5 should be precluded from breeding. It also seems undesirable to breed dogs CHD graded C2 and having an SI less than 0.5 because they show distinct coxofemoral arthrosis. Dogs scoring CHD grade A to C1 and an SI between 0.3 and 0.5 and dogs scoring a CHD grade C1 and a maximum SI of 0.3 should be accepted for breeding only if their offspring can be closely screened for evidence of CHD. If the dysplasia incidence of their offspring happens to be above average for the breed, they should be excluded from breeding, as proposed by Willis.[59]

Consequently, 35% of the dogs evaluated in this study could be accepted for breeding without preconditions and 29% with preconditions, whereas 36% would be barred from breeding. This recommendation may seem to diminish the breeding population drastically and thereby impair the genetic variety of a breed. Depending on breed, however, only 10% to 40% of dogs born are ever examined for CHD, and less than half of these are used for breeding.

CONCLUSIONS

The degree of hip joint laxity can be uncovered reliably only when a radiographic stress technique is

Table 6. Proposal for Canine Breeding Guidelines Based on Radiographic Findings*

	CHD Grade					
SI	A	B	C1	C2	D	E
≤0.3	yes	yes	(yes)	no	no	no
>0.3-0.5	(yes)	(yes)	(yes)	no	no	no
>0.5	no	no	no	no	no	no

* Abbreviations: SI, subluxation index; CHD, canine hip dysplasia.

applied. Our technique can be performed without extensive training and without special equipment. Selecting phenotypically healthy breeding stock may be optimized by combining the results of the standard radiographic technique and those of a stress examination technique with hindlimbs angled.

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