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Dorsolateral Subluxation of Hip Joints in Dogs Measured in a Weight-Bearing Position With Radiography and Computed Tomography

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Objective—To develop a radiographic procedure to measure dorsolateral subluxation (DLS) of the femoral head in canine coxofemoral (hip) joints in a weight-bearing position.
Study Design—DLS measured on a radiographic projection was compared with DLS measured on computed tomography (CT) images of hip joints in a weight-bearing position.
Animals—A total of 24 dogs of varying ages were examined including Labrador retrievers, greyhounds, and Labrador-greyhound crossbreeds.
Methods—Anesthetized dogs were placed in sternal recumbency in a kneeling position in a foam rubber mold. The stifles were flexed and adducted with the femora perpendicular to, and in contact with, the table. To test for DLS, dogs were imaged in this weight-bearing position (DLS test) with routine radiography and CT. For each hip, the DLS score was determined by measuring the percentage of the femoral head medial to the lateralmost point of the cranial acetabular rim on the dorsoventral radiographic projection and the lateralmost point of the central, dorsal acetabular rim on the CT image. Higher DLS scores indicated better coverage of the femoral head by the acetabulum. DLS scores were compared with the distraction index (DI) by grouping joints according to their probability of developing osteoarthritis (OA) as predicted by the DI.
Results—The DLS score in the new position ranged from 29% to 71% for radiography and 15% to 59% for CT. Joints classified as OA unsusceptible had a mean score of 64% ± 1.5% for radiography and 55% ± 0.8% for CT (n = 10); hip joints having a high probability of developing OA had a score of 39% ± 2.6% for radiography and 26% ± 1.9% for CT (n = 8). When the DLS test was repeated on the same dogs at a different time, the intraclass correlation coefficient for the DLS score on the radiographs was 0.85 (left hip) and 0.89 (right hip). There was a strong correlation ($r = .89$ for both hips) between the DLS score measured on the weight-bearing radiograph and the CT image. A strong correlation also was observed between the DLS score and the DI ($r = -.87$). The DLS scores for OA unsusceptible joints and joints with a high probability of developing OA were significantly different ($P < .05$).
Conclusions and Clinical Relevance—The DLS test can be performed with CT or routine radiography to measure variable amounts of DLS in weight-bearing hip joints oriented similarly to those of a standing dog. After additional long-term follow-up studies evaluating the development of OA and breed effects are performed, the DLS method may prove useful in studies of normal and abnormal hip joint development related to canine hip dysplasia.

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CANINE HIP DYSPLASIA (CHD) is a common, heritable developmental disease characterized by subluxation and incongruity of the hip joint resulting in osteoarthritis (OA).[1] Early diagnosis (ie, less than 1 year of age) of CHD is important for identifying affected dogs and initiating treatment.[2] The conformation of coxofemoral (hip) joints in dogs is assessed by radiographic examination. The positions currently used include the hindlimb-extended position standardized by the Orthopedic Foundation for Animals (OFA),[3] and a position in which the femoral heads are forcibly displaced laterally from the acetabulum during radiography (PennHip, Malvern, PA).[2,4] The hindlimb-extended procedure is used to assess the absence or presence of femoral head subluxation indicative of CHD.[3] The PennHip method measures joint laxity, which is considered a risk factor for OA.[2,4]

Some dogs considered disease free (OA unsusceptible) in the hindlimb-extended projection exhibit tight coxofemoral joints in the distraction procedures, but others have laxity. Recent data suggests that dogs with no subluxation or laxity are likely to be disease free whereas dogs with subluxation and high degrees of laxity are likely to develop OA.[2,5] The outcome for a dog with no subluxation on the hindlimb-extended projection but with moderate laxity is uncertain, but all these dogs are considered at risk for OA.[2] Given this uncertainty, radiographic evidence of OA has been used as the cardinal sign that hips were dysplastic.

The stress methods, done under heavy sedation or general anesthesia, elicit what has been called passive laxity, which is represented by the maximal lateral displacement of the femoral heads that occurs when force is used to distract the hip joint.[4] It seems reasonable that a distinction should be made between passive and functional laxity,[2] which can be described as subluxation of the femoral heads during ambulation. Smith et al[4] used an adjustable device (called a distractor) to reveal passive laxity and quantitated lateral displacement of the femoral head by a measurement called the distraction index (DI). Belkoff et al[6] used a machine to elicit hip joint laxity and quantitated laxity by measuring the percentage of the femoral head that is medial to the cranial rim of the acetabulum. Passive laxity, as measured by the DI, is a reliable predictor of the development of OA in Labrador retrievers when the DI is greater than 0.7 (loose hips) or less than 0.3 (tight hips).[5] As the DI increases from 0.3 to 0.7, the probability of OA increases; however, the outcome for Labradors, for example, within this range cannot be reliably predicted.[2,5] It is possible that other components of the hip joint structure, such as acetabular and femoral head conformation, contribute to functional joint stability and prevent the conversion of intermediate degrees of passive laxity into hip subluxation during ambulation. If this concept has validity, an estimate of functional laxity should be a good predictor of OA.[2] Although measurement of functional laxity is conceivable (possibly with fluoroscopy) it would be very difficult to do and would not be practical.

There has been ongoing interest in the radiographic examination of hip joints in a weight-bearing position. A technique has been described that obtains a view of the hips in a standing, awake dog, with the x-ray tube located beneath the dog and pointing upward to the hip joints.[7] Although this may be a better assessment of standing (not ambulating) functional laxity, it is difficult to reproduce and is impractical. Another method simulates weight bearing by placing the dog in dorsal recumbency, with the femora positioned between 45° and 60° to the longitudinal axis of the pelvis, and subluxating the hip joints by applying craniodorsal forces on the femora.[8] This method has not been evaluated widely, but variation may occur with positioning and the amount of force being applied to the hips. The test requires a person to stress the joints during the radiographic procedure.

Clinically, laxity and dorsolateral subluxation (DLS) of the femoral head can be detected by eliciting an Ortolani sign during palpation.[9] The initial maneuver during this test that induces the subluxation is called the Barlow maneuver.[10] This is performed by adducting a hindlimb, orienting it perpendicular to the longitudinal axis of the pelvis, and subluxating the hip joint by forcing the femoral head in a dorsolateral direction. The Ortolani sign is the "click" that occurs after the abduction of the limb and reduction of the subluxation. A positive Ortolani sign is thought to be a risk factor for the development of hip joint disease, but the significance of its presence or absence has not been evaluated in long-term studies.

The objective of this study was to develop a practical radiographic method that positions the hip joints similar to a standing dog and provides an objective measurement of femoral head subluxation under near neutral weight-bearing conditions. Comparisons were made to other common methods of evaluating hip laxity and conformation.

MATERIALS AND METHODS

Dogs

A total of 15 Labrador retrievers (13 8-12-month olds, 1 1.5-year old, and 1 4.5-year old), 3 Greyhounds (5-year olds), and 6 Labrador-greyhound crossbreeds (11-12-month olds) were examined. The 8 to 12-month-old Labrador retrievers were from dysplastic-dysplastic matings (OFA evaluation), whereas one 10-month old and the 4.5-year-old Labrador were from normal-normal matings. The crossbreeds were offspring of dysplastic Labrador retrievers and normal racing greyhounds; the Greyhounds were obtained as adults. Physical examination included the Ortolani test.[9] The presence or absence of the Ortolani sign was determined for all of the dogs under general anesthesia.

Radiography

Dogs were evaluated by 3 radiographic procedures during the same episode of general anesthesia. All dogs were premedicated with acepromazine (0.02 mg/kg, intramuscular [IM]) and glycopyrrolate (0.01 mg/kg, IM). General anesthesia was induced with thiopental (10 mg/kg, intravenous [IV], veterinary penthothal) in the Labradors and crossbreeds, and propofol (6 mg/kg, IV, diprivan) in the greyhounds. After intubation, inhalant anesthesia (halothane) was used in the greyhounds to maintain a deep plane of anesthesia so that palpebral and hind limb withdrawal reflexes were absent. Anesthesia in the Labradors and crossbreeds was maintained by IV thiopental and depth of anesthesia was based on the same criteria.

For the DLS test, the hindlimbs of the anesthetized dogs were fixed in an adducted position with medical tape, proximal to the stifles. The hocks were adducted and held together with tape. The dogs were placed in sternal recumbency in a kneeling position on a foam pad, with their hock joints extended and the stifles flexed and placed through a cut-out opening in the pad (Fig 1). Cotton was placed within the cut-out opening between the pad and the thighs of the dog to help stabilize the hind end. The hole in the pad allowed both stifles to have direct contact with the table and transmit force along the longitudinal axis of the femur to the hip joints, permitting DLS. The hips were slightly extended so that the diaphyses were nearly perpendicular to the table but not superimposed over the femoral heads or acetabulae (Fig 2). Although the stifles were obscured by the pad, the operator could palpate the greater trochanter and distal lateral femoral epicondyle before radiography to check for slight caudal displacement of the stifles relative to the trochanter. The hocks, hind paws, and trochanters were checked for symmetry from the lateral and caudal aspects. The image was evaluated for positioning and symmetry on the dorsoventral radiographic projection. To standardize the radiographic image, care was taken to ensure that the distal femoral diaphyses superimposed the caudolateral aspect of the obturator foramina, and that the ischiae were superimposed on the distal femoral condyles.

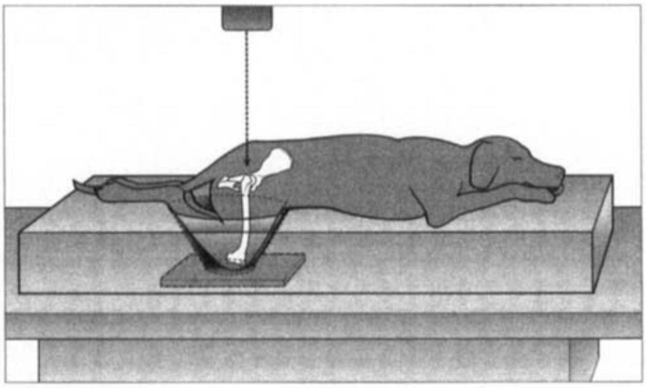

Fig 1. Illustration of a dog in sternal recumbency on a foam rubber mold for the dorsolateral subluxation (DLS) test. The stifles are adducted and bound with tape. The distal tibiae are also bound with tape. The distal lateral femoral epicondyle is palpated to ensure its slight caudal displacement relative to the greater trochanter. The hocks, hind paws and trochanters are checked for symmetry as viewed from the lateral and caudal aspects. This initial positioning decreases the chance of superimposition of the stifles over the hips which necessitates repeating the radiograph. The pad height is approximately 5 in. A shorter pad height may be necessary with smaller dogs to ensure stifle weight bearing.

For the hip-extended view, the dogs were radiographed in dorsal recumbency. Proper positioning was determined by examining the ventrodorsal projection for alignment and symmetry.[3]

The distraction radiographic method of measuring hip joint laxity (PennHip) as described by Smith et al[4,5] was performed under the same anesthetic episode by one of our investigators (Todhunter).

Computed Tomography

Computed tomography (CT) images were obtained in the DLS test and hindlimb-extended positions approximately 1 month before radiography. Induction of anesthesia was performed with the same protocol as for radiography. All dogs were maintained by inhalant anesthesia. Positioning was evaluated by examination of the pilot CT

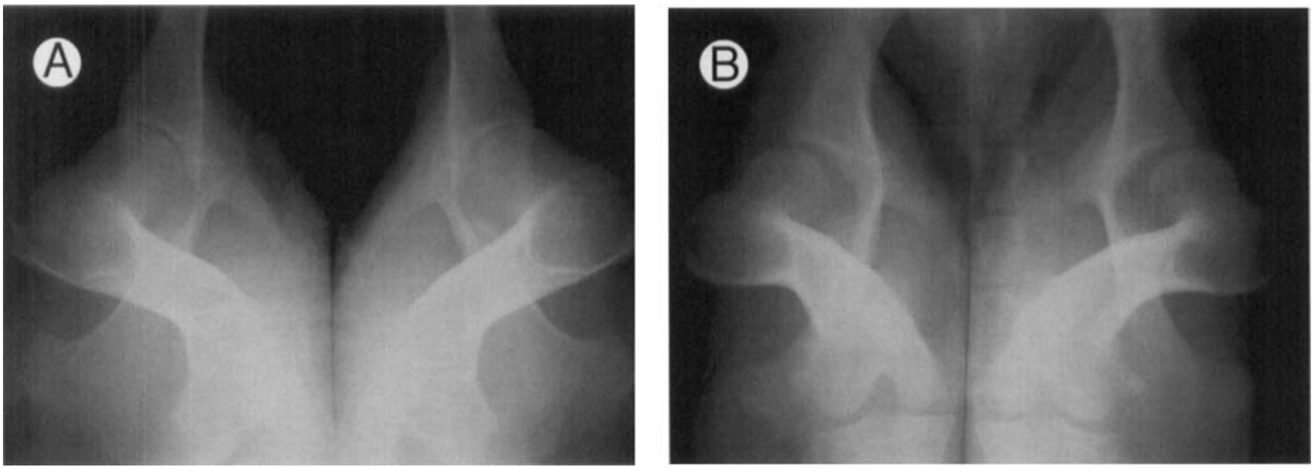

Fig 2. Photographs of dorsoventral radiographs of the weight-bearing position (described in Fig 1) used for the DLS test. The DLS score was determined on plastic overlays with these radiographs and is shown in Fig 4. (A) Radiograph of a greyhound (dog 4). This dog had a DLS score of 63% for the left hip and 67% for the right hip. (B) A dysplastic Labrador retriever (dog 18, E56). This dog had a DLS score of 44% for the left hip and 41% for the right hip.

scans by using the same criteria that were used for the DLS test and hip-extended radiographs. The same foam pad was used to hold the patients in the weight-bearing position.

Both the DLS and hip-extended CT scans were acquired during the same anesthetic episode with overlapping, transverse slices of the pelvis at the level of the coxofemoral joints (2-mm thickness, 1-mm index) (PQS ZAP 16 spiral CT Medical Imaging System; Picker International, Cleveland, OH). Images were reconstructed in a 512 × 512 matrix and viewed at bone windows (window [W] = 1,500, level [L] = 250 and W = 3,200, L = 300). Selected images were printed onto radiographic film (Kodak Ektascan Laser Printer, Model 1120 and Kodak EIR-7 laser imaging film; Kodak, Rochester, NY) and the entire study was archived to tape (Sony data cartridge QG54M 8-mm; Sony Corporation, Tokyo, Japan). Additional image viewing, manipulation, 3-dimensional image reconstructions, and measurements were made on a networked computer workstation (Voxel Q computer workstation; Picker International, St. Davids, PA).

A density phantom (Fig 3) was placed on the dog's pelvis to obtain data concerning bone density. This information is not reported here. In the weight-bearing position, the phantom was loosely secured over the pelvis with velcro straps. In the hip-extended position, the pelvis of the dog rested on the phantom. The phantom was 18 in long, 10 in wide, 1¾ in deep, and weighed 7 kg. The phantom was kindly provided by Dr Chris Cann of University of California at San Francisco. Gel bags were placed between the phantom and the dog to improve contact with the phantom and reduce artifacts within the image. A total of 6 dogs were also secured without the density phantom to evaluate its effect on subluxation.

Evaluation of Radiographs

For each hip joint, the DLS score was determined in the weight-bearing projection by measuring the percentage of the femoral head diameter medial to the lateralmost point of the cranial rim of the acetabulum on plastic overlays as described by Belkoff et al[6] (Fig 4). Radiographs of dogs in the standard, hindlimb-extended position were evaluated as normal or dysplastic and graded for conformation as either excellent, good, or fair normal joints or as mild, moderate, or severe CHD.[3] Because 3 dogs had unilateral CHD based on the subjective, OFA-like radiographic evaluation, each joint was considered separately.

The PennHip distraction method, as described by Smith et al[4] was used to measure passive laxity as the DI. The DI is the current standard for measuring maximal passive laxity. DLS scores were compared with the DI by grouping the joints into 4 categories according to their probability of developing OA as predicted by the DI in young Labrador retrievers[5]: (1) group 1, OA unsusceptible (DI ≤ 0.3); (2) group 2, OA susceptible with a less than 50% chance of developing OA ($0.3 < DI \leq 0.5$); (3) group 3, OA susceptible with a greater than 50% chance of developing OA ($0.5 < DI \leq 0.7$); and (4) group 4, high probability for OA ($DI > 0.7$).

Evaluations of CT Scans

A variation of the technique of Belkoff et al[6] was used to measure the DLS score from the CT scans. This measurement was taken directly from the monitor at the computer workstation using the central, dorsal acetabular rim rather than the cranial rim that was used for the measurement on the radiographic projection (Fig 5).

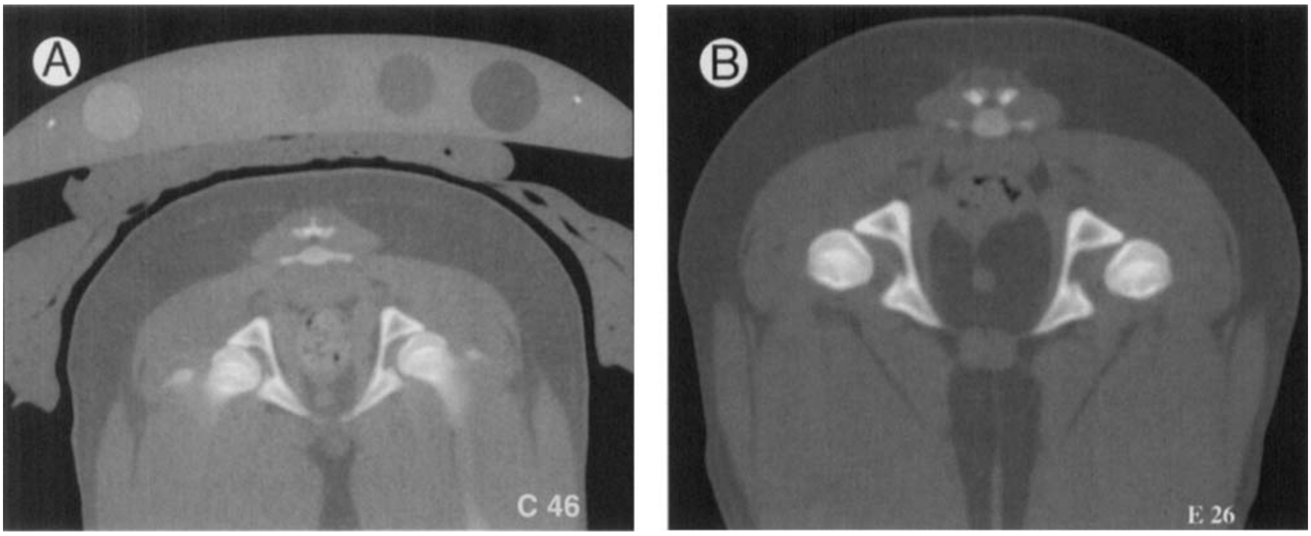

Fig 3. Central computed tomographic (CT) slice of dogs positioned as in Fig 1 for the DLS test. The density phantom was positioned dorsally on each dog. Gel bags are placed between the phantom and the skin to decrease artifact. (A) CT scan of a Labrador retriever (dog 9) with a DLS score on the CT slice of 54% for the left and 57% for the right hip. This dog was considered an OA-unsusceptible Labrador. Note the good congruency between the lunate surface of the acetabulum and the femoral head. The lunate surface of the acetabulum has a concave articular surface. The entire fovea (flattened part on medial femoral head) is medial to the acetabular articular surface. (B) The CT image of the pelvis from a dysplastic Labrador (dog 23) is shown. This dog was imaged without a phantom. There is severe subluxation of the femoral heads. The DLS score was 26% for the left and 24% for the right hip. Notice the focal perifoveal contact at the lateral edge of the acetabular articular surface. The lunate surface of the acetabulum has lost its concavity compared with dog 9 in Fig 3A.

Reproducibility of DLS Score

To assess the reproducibility of the DLS method, it was repeated 10 times in 7 dogs (once in 5 dogs; twice in 1 dog; three times in 1 dog) a few months after the first evaluation using the same protocol. To evaluate the consistency of the Belkoff et al method[6] for measuring the DLS score, radiographs from 6 of the dogs were measured twice. Because of financial constraints, we were not able to repeat the CT scans, but did remeasure the DLS score from 6 of the CT scans to evaluate the repeatability of our measurement technique.

Statistical Methods

To determine whether the DLS score in the weight-bearing radiograph and CT scan were similar, the Pearson product-moment correlation coefficient (r) for the relationship was calculated separately for each joint. The relationship between the DLS score measured from the weight-bearing radiograph and the DI was also evaluated by correlation analysis. Reproducibility of the DLS method and measurement was tested by intraclass correlation analysis. To determine whether there was a significant difference in DLS scores when grouped according to the susceptibility to OA based on the DI groupings, a one-way analysis of variance was used. A Tukey's multiple comparisons procedure was used to test for significant differences between groups at an experimentwise error rate of $P < .05$.

RESULTS

The DLS test revealed passive subluxation of the hip joint of dogs under general anesthesia with radiography and CT (Figs 2B and 3B, respectively). It elicited DLS of the femoral head with respect to the acetabulum, simulating the malarticulation of the hip joint that presumptively occurs in weight-bearing dogs with CHD. Figure 3B shows the focal contact of the perifoveal area of the femoral head with the dorsal acetabular rim that we think is the mechanical initiator of OA in dogs with CHD. The perifoveal area is the location of the earliest osteoarthritic cartilage lesions in 8 to 12-month-old Labradors with CHD.[11] The degree of DLS was estimated for each hip joint in this weight-bearing position by measuring the amount of the femoral head medial to the cranial acetabular rim and is reported here as the DLS score. The position was easy to use and is

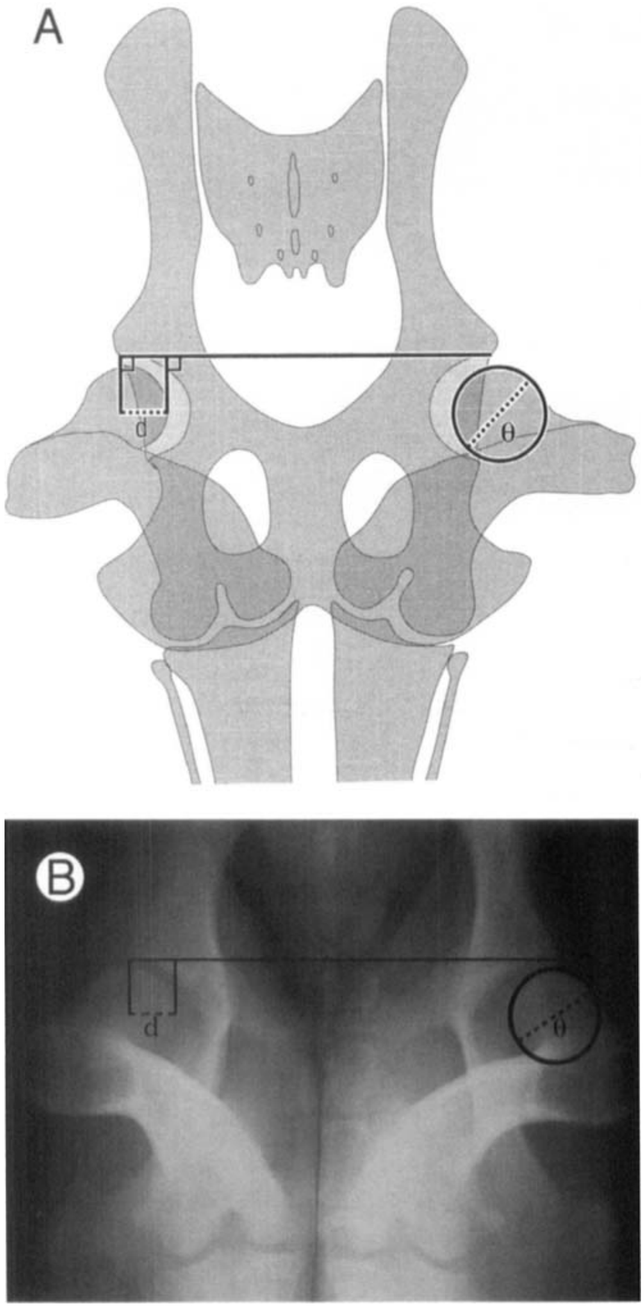

Fig 4. (A) Illustration showing how the DLS score is derived from a dorsoventral radiograph. A straight line joins the cranial acetabular lateral margin. A perpendicular line is dropped from this line at the most medial edge of the femoral head and from the lateral margin of the cranial acetabulum. The distance between these two perpendicular lines is measured in millimeters (d). The DLS score (percentage of the femoral head medial to the cranial acetabular rim) was determined by dividing d by the widest diameter (mm) of the femoral head (θ) from the same hip (DLS score = $d/\theta \times 100\%$). (B) Photograph of a radiograph taken to determine the DLS score.

reproducible. Because subluxation was facilitated by the weight of the hind end of the dog, it did not require that a person stress the joints while the radiograph was taken.

Radiographic Evaluations

The DLS score measured on the radiographic projection ranged from 29% to 71% (Table 1). Joints considered OA unsusceptible (group 1) had a mean DLS score of 64%. Joints considered OA susceptible with a less than 50% chance of developing OA (group 2) had a mean DLS score of 61%. Those with a greater than 50% chance (group 3) had a mean DLS score of 48%. The group considered to have a high probability for OA (group 4) had a mean DLS score of 39%. The mean DLS scores for groups 1 and 2 were not significantly different from each other. All other group comparisons of mean DLS scores were significantly different (Table 2).

The results of the subjective evaluations of the hip-extended radiographic views are listed in Table 1. A total of 3 Labrador retrievers (2 1-year-olds and 1 8-month old) had evidence of OA (femoral neck remodelling and new bone at joint capsule attachments). In this population of dogs, the lowest DLS score that was considered to be OA unsusceptible was determined by examining all of the hips that had a DI less than or equal to 0.3 and selecting the one with the lowest DLS score (56%). All of the hips considered OA unsusceptible in the DLS view (DLS score $\geq$ 56%) were considered normal in the subjective, OFA-like evaluation of the hip-extended projection. However, 5 of the Labradors considered normal in the hip-extended view had at least one joint with a DLS score ($\leq$ 48%) that placed them in the group considered OA susceptible with a greater than 50% chance of developing OA ($0.5 < \mathrm{DI} \leq 0.7$). This point is shown by dog 18, an 8-month-old Labrador retriever, which was considered normal in the subjective hip-extended evaluation, yet had passive subluxation in the DLS test (left hip DLS score of 44%, right hip 41%) and moderate passive laxity in the distraction view (left hip DI of 0.68, right 0.52) (Fig 6). This difference in femoral head subluxation between the DLS and hindlimb-extended positions is further illustrated by comparing 3-dimensional reconstructions of the CT scans of dog 20, an 11-month-old Labrador retriever, obtained in the two positions (Fig 7).

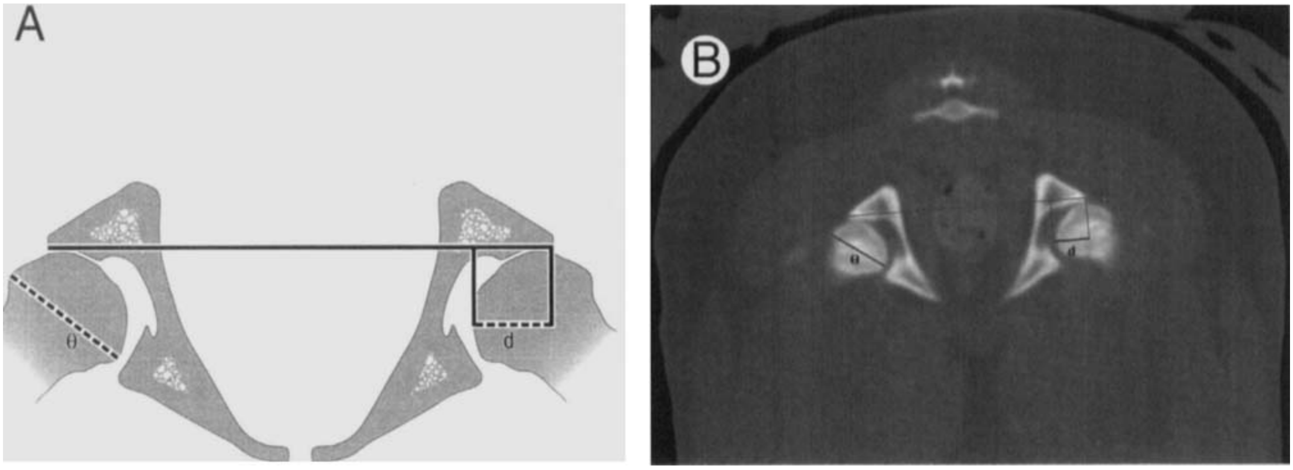

Fig 5. **(A) Illustration of the method of measuring the DLS score on a central CT slice. Instead of drawing a line connecting the cranial acetabular rims as for the radiographic method, a line was drawn connecting the lateralmost point of the central, dorsal, and acetabular rims. Two lines were then drawn perpendicular to this line; one at the lateral aspect of the dorsal acetabular rim and one at the medial aspect of the femoral head. (B) This was done individually for each hip joint by scrolling though the CT slices until the one containing the medial-most aspect of the femoral head was found. The DLS score was determined by measuring (in millimeters) the distance between these perpendicular lines (d) and dividing that distance by the widest diameter of the femoral head (θ) from the same hip (DLS score = $d/\theta \times 100\%$).**

CT

The DLS score measured at the center of the acetabulum from the CT slice ranged from 15% to 59% (Table 1). There was a strong positive correlation between the DLS score in the radiographic projection and the CT slice (r = .89 for both the left and right hips, $P < .05$) (Fig 8). Joints considered OA unsusceptible (group 1) had a mean DLS score of 55%. Joints considered OA susceptible with a less than 50% chance of developing OA (group 2) had a mean DLS score of 48%; those with a greater than 50% chance (group 3) a mean DLS score of 35%. The group considered to have a high probability for OA (group 4) had a mean DLS score of 26%. The mean DLS scores of the 4 groups for the central CT slice were all significantly different from each other (Table 2).

Relationship of the DLS Score to the DI

The DLS score correlated with the DI ($r = -.87$ for both hips; $P < .05$) (Fig 9). The DI ranged from 0.15 to 0.91 (Table 1). Each hip joint with a DI of 0.3 or less (n = 14) had a DLS score of 56% or more. Three hips that had a DLS score of 56% or more had a DI that placed them in the OA-susceptible group with a more than 50% chance of developing OA ($0.5 < \text{DI} \leq 0.7$); nine hips that had a DLS score of 56% or more had a DI that placed them into the OA-susceptible group with a less than 50% chance of developing OA ($0.3 < \text{DI} \leq 0.5$). This is shown in dog 7, a 4.5-year-old Labrador retriever (Fig 10). This mature dog did not show OA on the hindlimb-extended projection, did not subluxate in the weight-bearing position (left hip DLS score 68%, right hip 59%), yet it had some passive laxity on the distraction view (left hip DI of 0.40, right hip of 0.44). Similar results were seen in dogs 8, 10, 11, and 12, in which hips with DLS scores of 56% or more had moderate degrees of passive laxity.

Reproducibility of DLS Score

The intraclass correlation coefficient (r_I), a measure of repeatability, for the DLS test was .85 for 16 left hips and .89 for 14 right hips. The group standard deviations for the radiographic DLS scores ranged from 0 to 6.4. For repeat measurements of the same radiograph, r_I for the left hip was .96 and for the right hip was .93 for 12 hips. The group standard deviations for the CT DLS scores ranged from 0 to 2.8. For repeat measurements of the CT image, r_I was 0.95 for the left hip and was 0.97 for the right hip for 12 hips.

Table 1. DLS Scores for Radiographs and CT Scans, DI, OFA Scores (subjective hip-extended evaluations), OA, and Ortolani Sign for 24 Dogs

Dog No*	Signalment	Hip	DLS Scores (%) Radiograph	DLS Scores (%) CT Scan	DI	OFA-Like Score	OA	Ortolani Sign
1	5 yr female Greyhound	L	71	59	.15	2	–	–
		R	71	51	.15		–	–
2	1 yr male Crossbreed	L	68	51	.38	1	–	–
		R	64	49	.42		–	–
3	11 mo male Crossbreed	L	64	52	.26	1	–	–
		R	66	53	.30		–	–
4	5 yr male Greyhound	L	63	57	.21	2	–	–
		R	67	58	.21		–	–
5	5 yr male Greyhound	L	63	53	.26	2	–	–
		R	62	53	.30		–	–
6	11 mo male Crossbreed	L	61	45	.33	1	–	–
		R	67	56	.33		–	–
7	4.5 yr male Labrador Retriever	L	68	51	.40	3	–	–
		R	59	44	.44		–	–
8	1 yr female Crossbreed	L	58	41	.49	2	–	–
		R	56	45	.49		–	–
9	10 mo female Labrador Retriever	L	58	54	.28	2	–	–
		R	56	57	.28		–	–
10	10 mo male Labrador Retriever	L	57	42	.58	2	–	–
		R	56	40	.54		–	–
11	1 yr male Crossbreed	L	59	35	.52	2	–	–
		R	55	37	.48		–	–
12	11 mo female Crossbreed	L	59	53	.48	1	–	–
		R	55	54	.32		–	–
13	1 yr male Labrador Retriever	L	50	34	.52	6	+	–
		R	50	33	.63		+	–
14	11 mo female Labrador Retriever	L	48	43	.61	3	–	+
		R	54	44	.57		–	+
15	8 mo male Labrador Retriever	L	52	33	.71	2	–	+
		R	48	38	.67		–	+
16	1.5 yr male Labrador Retriever	L	48	37	.67	5	–	+
		R	50	39	.67		–	+
17	8 mo female Labrador Retriever	L	54	40	.65	2	–	+
		R	46	37	.65		–	+
18	8 mo male Labrador Retriever	L	44	29	.68	3	–	+
		R	41	33	.52		–	+
19	1 yr male Labrador Retriever	L	43	31	.81	6	+	+
		R	41	26	.88		+	+
20	11 mo male Labrador Retriever	L	40	26	.60	5	–	+
		R	46	29	.56		–	+
21	8 mo male Labrador Retriever	L	40	26	.80	5	–	+
		R	37	24	.76		–	+
22	10 mo male Labrador Retriever	L	34	29	.68	3	–	+
		R	42	23	.60		–	+
23	8 mo female Labrador Retriever	L	30	26	.83	5	–	+
		R	36	29	.78		–	+
24	8 mo female Labrador Retriever	L†	29	15	.91	7	+	+

NOTE. Ages reflect time when radiographs were taken. DLS score represents % of femoral head medial to the cranial acetabular rim for the radiographs and central acetabular rim for CT scans. OFA-like score 1-7 (normal: 1, excellent; 2, good, 3, fair; 4, borderline; 5, mild dysplasia; 6, moderate displasia; 7, severe displasia). The score is provided for the dog and is based on the hip with the worst conformation.

Abbreviations: DLS, dorsolateral subluxation; CT, computed tomography; DI, distraction indices; OFA, Orthopedic Foundation for Animals; OA, osteoarthritis; +, presence; – absence; L, left; R, right; crossbreed, Labrador × greyhound cross.

* Dogs listed in decreasing order of worst DLS score for each dog.

† Right hip not evaluated because of presumptive injury.

Table 2. DLS Scores, DI, OFA-like Scores, and Number of Dogs With OA and Ortolani Sign for 4 Groups of Dogs Grouped According to DI*

	DLS Score (%)				Number of Dogs	
Groups	Radiographs	CT Scan	DI	OFA-Like Score	With OA	With Positive Ortolani Sign†
1 (DI ≤ 0.3) OA-unsusceptible, n = 10 joints; 5 dogs	64 ± 1.5 range (56-71)	55 ± 0.84 range (52-59)	0.24 ± 0.02 range (0.15-0.30)	2.2 ± 0.50 range (1-2)	None	None
2 (0.3 < DI ≤ 0.5) OA-susceptible, <50% chance for developing OA, n = 11 joints; 6 dogs	61 ± 1.5 range (55-68)	48 ± 1.8 range (37-56)	0.41 ± 0.02 range (0.32-0.49)	1.7 ± 0.33 range (1-3)	None	None
3 (0.5 < DI ≤ 0.7) OA-susceptible, >50% chance for developing OA, n = 18 joints; 10 dogs	48 ± 1.5 range (34-59)	35 ± 1.4 range (23-44)	0.60 ± 0.01 range (0.52-0.68)	3.3 ± 0.47 range (2-6)	1 of 10 dogs	7 of 10 dogs
4 (DI > 0.7) High probability of developing OA, n = 8 joints; 5 dogs	39 ± 2.6 range (29-52)	26 ± 1.9 range (15-33)	0.81 ± 0.02 range (0.71-0.91)	5.0 ± 0.84 range (2-7)	2 of 5 dogs	5 of 5 dogs

NOTE. Groups were determined by distraction index ranges for each hip joint, which are based on the probability of the development of osteoarthritis in Labrador retrievers.[3] OFA-like score 1-7 (1, excellent; 2, good; 3, fair; 4, borderline; 5, mild dysplastia; 6, moderate dysplastia; 7, severe hip dysplasia).

* Data are expressed as the mean ± SEM.

† On at least one hip.

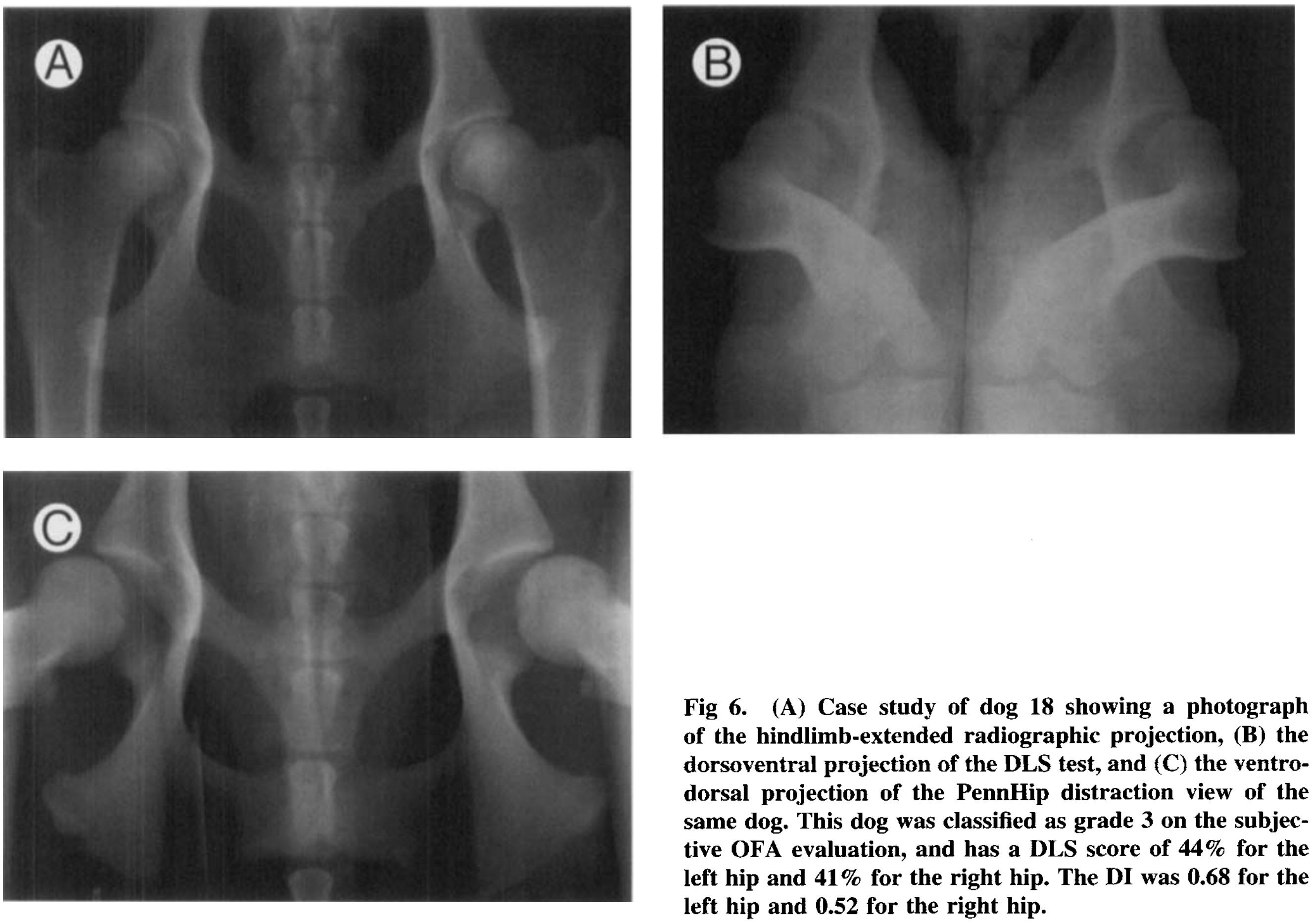

Fig 6. (A) Case study of dog 18 showing a photograph of the hindlimb-extended radiographic projection, (B) the dorsoventral projection of the DLS test, and (C) the ventrodorsal projection of the PennHip distraction view of the same dog. This dog was classified as grade 3 on the subjective OFA evaluation, and has a DLS score of 44% for the left hip and 41% for the right hip. The DI was 0.68 for the left hip and 0.52 for the right hip.

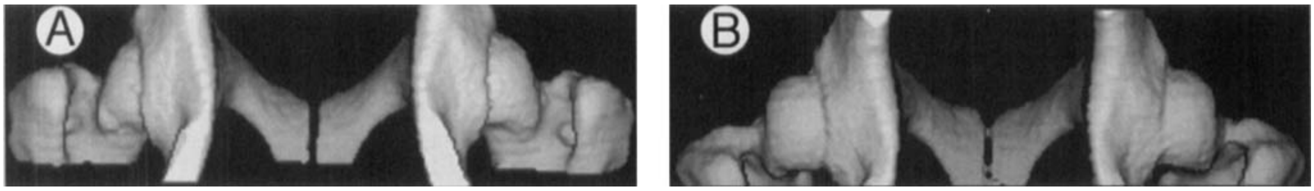

Fig 7. Photographs of 3-dimensional reconstructions of dog 20 created from serial overlapping, transverse slices of the pelvis at the level of the hip joints (2-mm thickness, 1-mm index) (A) in the hip-extended position and (B) in the DLS test position. Notice how the femoral heads subluxate much further in the DLS position (B) than in the OFA position (A).

Ortolani Sign

All but 2 (dogs 14 and 16) of the 28 hips with DLS scores of 50% or more had no Ortolani sign. All of the hips (n = 15) with a DLS score of less than 50% had a positive Ortolani sign. The 3 dogs in group 3 (disease susceptible, high probability of developing OA) that had a negative Ortolani test also had DLS scores of 50% or more (Tables 1 and 2).

DISCUSSION

In this study we describe a stress method that we have termed the DLS test, which reveals hip joint subluxation in a weight-bearing position. We selected dogs that would show variable amounts of DLS with both routine radiography and CT. The DLS test was sensitive to hip conformation and resulted in a broad range of subluxation based on the presence or absence of CHD. It is important to relate the DLS score with the subsequent development of OA in the same hip joint. To date, the development of OA in a previously dysplastic joint has been the benchmark sign of CHD.[2,5]

There was a strong correlation between the DLS score (from the radiographs and CT scans) and the DI. With respect to the probability of developing OA in Labrador retrievers based on the DI,[5] the following proposal for scores in the DLS test (with routine radiography) can be offered: a DLS score

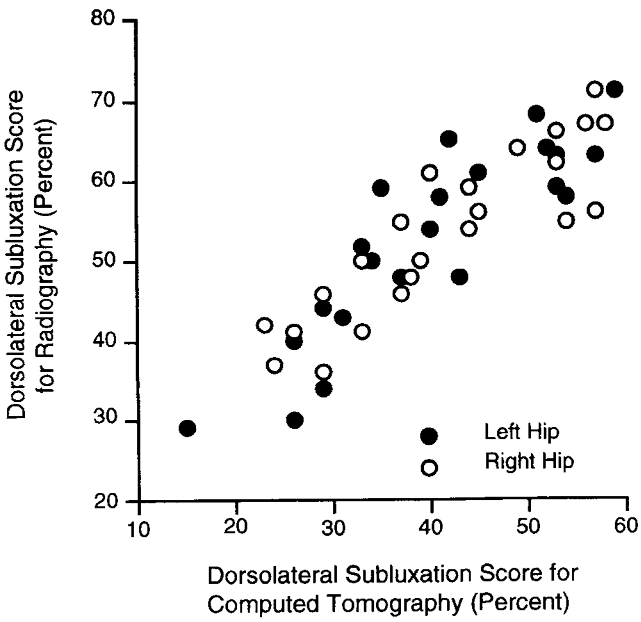

Fig 8. Graph showing the relationship between the DLS score on the radiograph and the central CT slice for each hip joint. The correlation coefficient (*r*) = .89 for both the left and right hips.

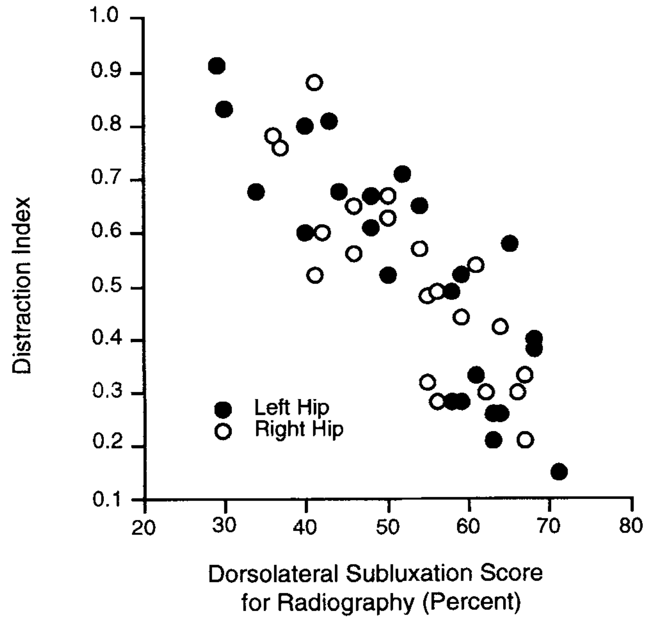

Fig 9. Graph showing the relationship between the DLS score on the radiograph and the DI for each hip joint. The correlation coefficient (*r*) = −.87 for both the left and right hips.

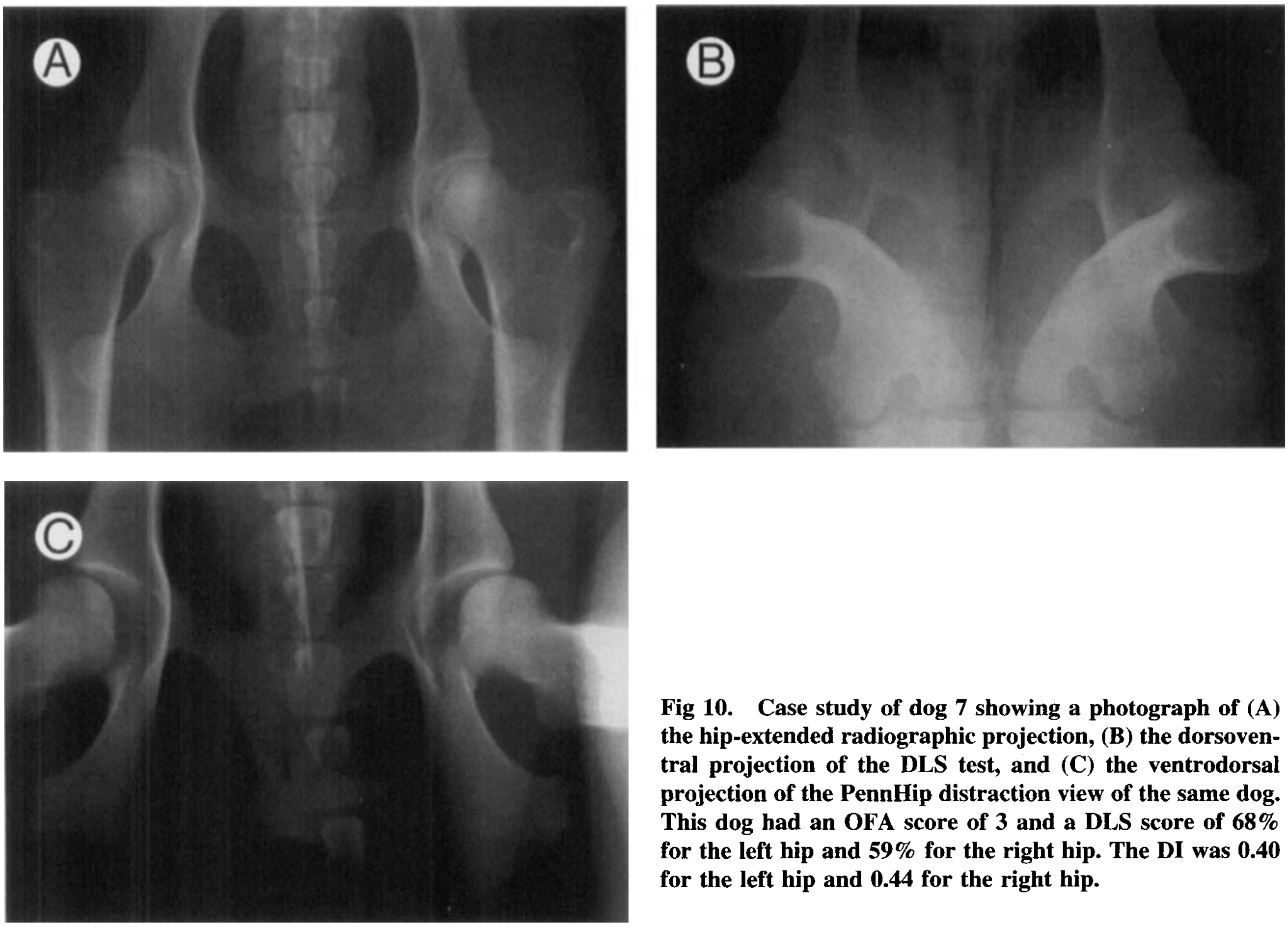

Fig 10. Case study of dog 7 showing a photograph of (A) the hip-extended radiographic projection, (B) the dorsoventral projection of the DLS test, and (C) the ventrodorsal projection of the PennHip distraction view of the same dog. This dog had an OFA score of 3 and a DLS score of 68% for the left hip and 59% for the right hip. The DI was 0.40 for the left hip and 0.44 for the right hip.

greater than 60% suggests that a dog is unsusceptible or has a low susceptibility for OA, less than 50% suggests a moderate susceptibility, and less than 40% suggests a high probability for OA. Given the variation of the DI in dogs with DLS scores between 50% and 60%, it is not possible at this time to offer a prediction of OA susceptibility (based on the DI in Labrador retrievers) for DLS scores within this range. Although the mean DLS score for hips with a DI of 0.3 or less was 64%, the low end of the range was 56%. It is believed, therefore, that (for this population of Labrador retrievers) a DLS score as low as 56% is a tolerable amount of femoral head coverage, because dogs with a DI value of 0.30 or less are considered OA unsusceptible.[2] It can be reasoned that when more than 50% of the femoral head diameter is within the acetabulum during weight-bearing, the tendency to subluxate is minimal. Conversely, when less than 50% is within the acetabulum during weight bearing, maintenance of reduction of the hip joint during ambulation would be more difficult. Until data from long-term follow-up studies support this contention, this hypothesis remains unproved.

A similar distribution was seen in the DLS score measured on the CT scans, however the mean DLS scores of the 4 groups were lowered by approximately 12%. This difference is likely a result of measuring the DLS score at the center of the acetabulum on the CT scans (as opposed to the more laterally located cranial acetabular rim on the radiographs). We considered the DLS score measured through the central CT image to be the best estimate of hip subluxation in the weight-bearing position short of using a boned-out specimen. The high correlation between the measurements of DLS score on the radiograph and the CT indicates that the scores from the two methods vary together and suggests that the landmarks chosen on the radiographs are reliable ones. It further shows that the weight-bearing position is reproducible because the radiograph and CT were performed on each dog on two separate occasions and the intraclass correlation coefficients for the DLS test method on the radiograph were high. For practical application, the DLS score from the radiograph is preferable. For experimental applications, quantitative CT offers the prospect of evaluating the contribution of hip geometry to coxofemoral reduction. Bone density and its distribution in the femoral head and acetabulum can also be determined.

Comparison of the DLS test and the subjective evaluation of the hip-extended view suggests that the DLS test can be used for earlier (ie, < 1 year of age) detection of dogs with DLS associated with CHD, and that the hip-extended view for the early diagnosis of CHD may lead to false negatives based on the subjective evaluation of subluxation. This concept was suggested previously by Smith et al[2] with reference to the PennHip method. The DLS reveals more subluxation than the hip-extended position because leg extension twists the hip joint capsule, thus shortening its tensile elements and forcing the femoral heads into the acetabulum.[4] Given the young age of some of the Labradors in this study, it is not surprising that the majority did not show radiographic evidence of OA on the hip-extended projection. It is well documented that the earliest lesions associated with OA in the hips of dysplastic dogs are perifoveal cartilage fibrillation, synovitis, and synovial effusion.[12,13] These early changes cannot be appreciated on a standard radiograph of the hip.

Because variation may exist between dogs in the contour of the dorsal acetabular rim (ie, at the center of the joint), measurement of the DLS score at the level of the center of the acetabulum on the radiograph (rather than at the cranial rim) may be a more accurate representation of functional acetabular coverage of the femoral head. However, the strong correlation between the DLS scores measured on the radiograph and CT (which is measured at the center of the joint in the frontal plane) indicates that variation in lateral acetabular contour may not be important in the measurement of the DLS score. A disadvantage of this DLS position is that the hips are positioned over the stifles, causing some superimposition and magnification and, thereby, less detail when compared with the distraction radiographic projections in which the pelvis is close to the radiographic film. The cranial acetabular rim is a clearer point of reference in the DLS position than the center of the dorsal acetabular rim and was, therefore, chosen to represent the most lateral point of the acetabulum in the radiographic projections.

A positive Ortolani sign for a given hip was rare above a DLS score of 50% (2 of 28 hips). Every hip joint with a DLS score less than 50% had a positive Ortolani sign. This suggests that when more than 50% of the femoral head is within the acetabulum and the hip joint is subjected to the Barlow maneuver, subluxation may not occur or, conversely, a subsequent reduction of the head into the acetabulum (Ortolani sign) may not be palpable. A total of 3 dogs that had a negative Ortolani test had DIs that placed them into group 3 (intermediate OA risk, >50% chance of developing OA). These same 3 dogs had DLS scores of 50% or more. This suggests that other factors, such as coxofemoral geometry, may influence the result of the Ortolani test. Further studies are needed to substantiate this hypothesis.

For the dogs examined in this study, there was a strong correlation between the DLS score and the DI. In fact, the coefficient of determination (r^2) for our data is .76 (r = .87), which means that 76% of the variation in the DLS score can be explained by variation in DI. Thus, it can be reasoned that passive laxity is a primary factor permitting passive subluxation in the DLS position. However, a few of the dogs in this study (dogs 7, 8, 10, 11, and 12) that had mild to moderate passive laxity appeared to be OA unsusceptible (DLS score ≥ 56%) in the DLS test. Also, there was no significant difference (with radiography) in the DLS scores of groups 1 and 2. An interpretation of this observation is that the DLS test is less sensitive when compared with the DI in detecting dogs at risk for hip OA. Alternatively, it may be suggested that despite the presence of passive laxity, other anatomic factors important for joint stability, such as joint conformation, may have prevented the laxity from being expressed as DLS in the weight-bearing position, allowing groups 1 and 2 to have similar DLS scores. If the latter concept is correct, fewer false positives (for development of OA) may be predicted by the DLS method than with the DI. Future studies addressing the relationship between DLS and DI and the intraarticular hip joint volume[13] (and possibly coxofemoral geometry) will help answer whether the DLS test and the DI assess the same or different parameters important in the pathogenesis of CHD and OA.

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