Evaluation of a method for experimental induction of osteoarthritis of the hip joints in dogs

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Objective—To evaluate a method for experimental induction of osteoarthritis in the hip joints of dogs.

Animals—12 mixed-breed dogs.

Procedure—A unilateral triple pelvic osteotomy was performed. In 6 dogs, the iliac osteotomy was repaired with 45° of internal rotation, reducing coverage of the femoral head by the acetabulum. In the other 6 dogs, the fragments were repaired in anatomic alignment. Radiography, force plate evaluations, and subjective lameness evaluations were performed before and after surgery. Dogs were euthanatized 7 months after surgery, and samples of cartilage and joint capsule were examined histologically.

Results—Subjective lameness scores, radiographic appearance of the hip joints, and Norberg angles were not significantly different between groups; however, force plate evaluations did reveal significant differences in vertical ground reaction forces. Femoral head coverage was significantly decreased with rotation of the acetabulum. Mild inflammatory changes were discernible in the joint capsule and articular cartilage of some dogs in both groups.

Conclusions and Clinical Relevance—Results suggest that 45° internal rotation of the acetabulum does not consistently induce biologically important osteoarthritic changes in the hip joints of dogs. (*Am J Vet Res* 2000;61:484–491)

In 1991, Inerot et al[1] described a method for experimental induction of osteoarthritis in the hip joints of dogs. They performed a stepped osteotomy of the ilium, along with an osteotomy of the ischium, and then stabilized the iliac osteotomy with a single screw in such a way that the acetabular segment was rotated inward, decreasing coverage of the femoral head by the acetabulum. Dogs were euthanatized between 15 and 153 days after surgery, and development of osteoarthritis was evaluated by use of histologic (eg, examination of H&E-stained sections) and biochemical (eg, determination of proteoglycan content and glycosaminoglycan ratio) analyses. An advantage of this method of inducing osteoarthritis is that the joint capsule is not incised, thereby avoiding the confounding effects of synovial incision and ensuing inflammation that occur with the Pond-Nuki method of inducing osteoarthritis of the knee joint. However, the study by Inerot et al did not include force plate analyses of changes in ground reaction forces or detailed descriptions of radiographic changes induced by this method, and information on such changes would potentially be important to researchers using this model to study responses to various treatments for osteoarthritis.

The purpose of the study reported here, therefore, was to modify the method of Inerot et al so that a standard bone plate could be used for stabilization of the iliac osteotomy and to evaluate radiographic and histologic changes, changes in ground reaction forces, and changes in subjective assessments of degree of lameness associated with this method of experimentally inducing osteoarthritis.

Materials and Methods

Dogs—Twelve adult mixed-breed dogs ranging from 19.1 to 31.8 kg in weight were used. All dogs were judged to be healthy on the basis of results of routine physical examinations and laboratory analyses (PCV, total protein concentration, and estimated blood urea nitrogen concentration[a]). Additionally, none of the dogs had evidence of pre-existing orthopedic disease, as determined by means of physical examination and radiographic examination of the pelvis and knee joints. All dogs were housed in 1.5 × 3- m runs and exercised outside on a leash at a trot for 15 minutes 6 d/wk, except on days when force plate analyses were performed and for the 2 weeks immediately following surgery. All procedures and evaluations were approved by the Animal Care and Use Committee of Virginia Tech.

Surgery—Dogs were paired on the basis of body weight, and dogs in each pair were randomly assigned to an experimental or control group. Dogs were sedated with acepromazine maleate (0.02 mg/kg, IV) and butorphanol tartrate (0.1 mg/kg, IV) and anesthetized with thiopental sodium (15 mg/kg, IV, to effect). Anesthesia was maintained with isoflurane delivered via an endotracheal tube. Preservative-free morphine (0.15 mg/kg) was administered epidurally to minimize the concentration of isoflurane required and provide postoperative analgesia. The left hind limb and pelvis were prepared for aseptic surgery.

In all dogs, osteotomies of the pubis, ischium, and ilium were performed through separate incisions, as described.[2] For dogs in the experimental group, a right 45° pelvic osteotomy plate[b] was contoured and applied to the left ilium, resulting in internal rotation of the acetabular segment (**Fig 1**). The plate manufacturer's recommendations for plate size were followed, and 3.5-mm bone plates were applied in 5 dogs, and a 2.7-mm bone plate was applied in 1. For dogs in the control group, a 6-hole dynamic compression plate[c] was used to maintain the iliac segments in anatomic align-

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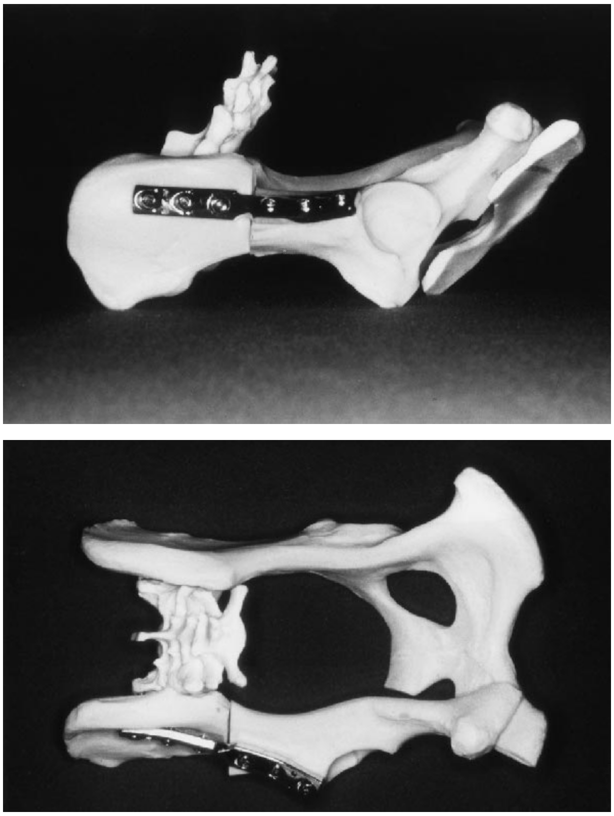

Figure 1—Lateral (top) and dorsal (bottom) views of the pelvis of a dog illustrating application of a right 45° pelvic osteotomy plate to the left ilium, resulting in internal rotation of the acetabular segment.

ment. The plate manufacturer's recommendations for plate size were followed, and 3.5-mm bone plates were applied in 5 dogs, and a 2.7-mm bone plate was applied in 1. Incisions were closed routinely. All dogs were given cefazolin sodium (22 mg/kg, IV) 20 minutes prior to surgery; additional doses were given every 2 hours until the completion of the surgery.

Immediately after surgery, while dogs were still anesthetized, pelvic radiography was performed. Dogs were then allowed to recover from anesthesia and were returned to their runs when ambulatory. All dogs were monitored for evidence of discomfort, and additional pain medication was administered if needed. Dogs were given acetaminophen (5 mg/kg, PO, q 8 h) and codeine (1 mg/kg, PO, q 8 h) for 3 days after surgery and were not exercised for 2 weeks after surgery. Dogs were then returned to their regular exercise schedule.

Radiographic evaluation—Pelvic radiography was performed before, immediately after, and 4, 8, 12, 16, 20, and 24 weeks after surgery. Except for radiographs obtained immediately after surgery, dogs were sedated with atropine (0.02 mg/kg, IM), xylazine hydrochloride (0.05 mg/kg, IV), and butorphanol (0.1 mg/kg, IV). A left lateral radiographic view was obtained, along with a ventrodorsal radiographic projection with the hip joints extended and a ventrodorsal radiographic projection with the femurs positioned perpendicular to the long axis of the pelvis and the hip joints abducted (frog-legged projection). Particular attention was given to ensure symmetric, parallel positioning of the femurs and symmetric alignment of the iliac wings to ensure accurate and consistent placement.

Radiographs were evaluated for evidence of degenerative joint disease (eg, osteophytes, remodeling of the femoral head or neck, and shallow acetabula). Norberg angle was measured on the hip-extended ventrodorsal radiographic projection as described.[3] The frog-legged radiographic projections were evaluated with a computerized digital image analysis system[d] to determine percentage of acetabular coverage of the femoral head. Coverage on radiographs after surgery was compared with the preoperative value to determine percentage change.

Evaluation of lameness—Severity of lameness was evaluated subjectively and objectively 2, 4, 6, 8, 12, 16, 20, and 24 weeks after surgery. For the subjective lameness evaluations, dogs were walked on a leash, and a lameness severity score (**Appendix 1**), adapted from a published scoring system,[4] was assigned. All subjective lameness evaluations were performed by a single board-certified surgeon who was not otherwise associated with the project, and who was not aware of group assignments of the dogs.

For the objective lameness evaluations, force plate analyses were performed, as described.[5-12] Briefly, dogs were trotted on leash along a 40-ft walkway that contained a force plate[e] mounted in the center of the walkway, flush with the surface. Three photoelectric timing devices were used to measure the dogs' speed. The photoelectric timers and the force plate were connected to a dedicated computer and software.[f] A video camera was used to record all trials.

Dogs were trotted along the walkway until 5 acceptable trials were obtained for each hind limb, and data for the 5 trials were averaged. An acceptable trial was defined as a pass across the force plate that included a distinct foot strike by the left or right forelimb and the ipsilateral hind limb that was within predetermined ranges for speed (1.6 to 1.9 m/s) and acceleration (–0.5m/s/s to 0.5 m/s/s). As a handler trotted each dog across the platform, an observer indicated whether each trial was acceptable. Videotapes of all trials were later reviewed to confirm the observer's assessment.

Dogs were evaluated 3 times prior to surgery, with no less than 3 days between evaluations, and data were averaged to obtain baseline values. Data obtained from the force plate evaluations included peak vertical force, vertical impulse, peak braking force, braking impulse, peak propulsion force, and propulsion impulse.

Necropsy—Dogs were euthanatized with an overdose of pentobarbital-phenytoin[g] after final evaluations were performed 28 weeks after surgery. Muscles and implants were carefully removed from each pelvis, and the left hip joints were removed by separating along the original osteotomies. Synovial fluid was carefully aspirated from the hip joint and replaced with formaldehyde using a syringe and 22-gauge needle. Hip joints were submerged in formaldehyde at a volume-to-volume ratio of approximately 9-to-1. The formaldehyde in the joint was changed after approximately 10 days.

Histologic evaluation—Isolated hip joints were trimmed to include a coronal section of the hip joint at the level of the ligament of the femoral head. A piece of joint capsule was harvested at the same level. Bone samples were placed in decalcifying solution,[h] processed with an automated tissue processor,[i] and embedded.[j] Samples were sectioned to a thickness of 5 µm and stained with alcian blue and with H&E. Sections were examined and assigned a score on the basis of histologic appearance of a representative region of the acetabular cartilage, using a modified Mankin scoring system[13] (**Appendix 2**). Joint capsule samples were sectioned, and sections were stained with H & E and examined. A score was assigned on the basis of histologic appearance (**Appendix 3**). Histologic evaluations were done by an individual (HPV) who was unaware of group assignment of the dogs.

Statistical analyses—At each time interval, force plate data, Norberg angles, and measurements of femoral head coverage were compared between groups and between the left and right limbs, and values for each time interval were compared with baseline values. Because subjective lameness scores did not include an evaluation of each limb, these scores were only compared between treatment groups at each time interval, and scores for each interval were compared with baseline scores. Histologic scores were compared between groups and between the left and right limbs within each group. Data were analyzed by use of ANOVA. Values of $P < 0.05$ were considered significant.

Results

Clinical observations—Dogs recovered from surgery without complications and were weight-bearing during the course of normal activity for the duration of the study. All dogs were willing to exercise readily by the second week after surgery.

Radiographic evaluation—Evidence of movement of the acetabular segments was not seen during the study. Most dogs had radiographic evidence of bridging callus by 12 weeks after surgery, and a lucency at the fracture line was no longer visible by 16 weeks after surgery, although fractures in some dogs healed without callus formation. Several dogs had radiographic evidence of screw loosening without gross displacement of the bone plates. Evaluation of the hip-extended ventrodorsal radiographic projections did not reveal evidence of osteoarthritis of the hip joints in any dogs at any time during the study.

Table 1—Mean ± SD percentage change in coverage of the femoral head by the acetabulum on pelvic radiographs from dogs that underwent a left triple pelvic osteotomy and in which the acetabulum was internally rotated 45° (experimental group; n = 6) and in dogs that underwent a left triple pelvic osteotomy and in which the fragments were stabilized in anatomic alignment (control group; n = 6)

	Experimental group		Control group	
Time after surgery (wk)	Left hip joint	Right hip joint	Left hip joint	Right hip joint
0	28 ± 9* †	−8 ± 11	−10 ± 17	1 ± 12
4	27 ± 14* † ‡	−2 ± 7	−11 ± 15	1 ± 13
8	22 ± 28†	−6 ± 5*	−13 ± 15	3 ± 9
12	21 ± 18* † ‡	−6 ± 6	−10 ± 17	3 ± 9
16	29 ± 19* † ‡	−7 ± 13	−16 ± 8	5 ± 12
20	27 ± 16* † ‡	−22 ± 11	−13 ± 14	2 ± 9
24	29 ± 16* † ‡	0 ± 5	−8 ± 13	2 ± 7
28	29 ± 17* † ‡	−6 ± 8	−7 ± 15	4 ± 6

Percentage change was calculated by subtracting the amount of coverage at each time after surgery from the amount of coverage prior to surgery and dividing by the amount of coverage prior to surgery. Therefore, positive numbers indicate a decrease in femoral head coverage and negative numbers indicate an increase.

*Significantly ($P < 0.05$) different from 0. †Significantly ($P < 0.05$) different from value for the right hip joint. ‡Significantly ($P < 0.05$) different from value for the control group.

For dogs in which the acetabular segment was internally rotated, the percentage change in femoral head coverage was significantly different from 0 at all times, except 8 weeks after surgery (**Table 1**). Percentage change in femoral head coverage was also significantly different from 0, 8, and 16 weeks after surgery for the left hip joints of dogs in the control group and 8 weeks after surgery for the right hip joint of dogs in the experimental group. Percentage change in femoral head coverage was significantly different between groups from 4 weeks after surgery to the end of the study. Similarly, percentage change in femoral head coverage was significantly different between the right and left hip joints for dogs in the experimental group, but not for dogs in the control group. Frequently, placement of the bone plate in dogs of either treatment group was such that the plate was found to impinge slightly on the radiographic projection of the acetabular margins. When this occurred, the margin was estimated to allow calculation of femoral head coverage.

For dogs in which the acetabular segment was internally rotated, Norberg angles for the left hip joints were significantly different from presurgical values at all times except 4, 16, and 28 weeks after surgery (**Table 2**). For control dogs, Norberg angles for the left hip joints were significantly different from presurgical values 12 and 20 weeks after surgery. Additionally, 4 weeks after surgery, Norberg angles for the right hip joints of control dogs were significantly different from presurgical values. When Norberg angles were compared between groups, angles for the left hip joint were significantly different between groups at all times from 12 weeks until the conclusion of the study. When the bone plate obscured the radiographic appearance of the rim of the acetabulum, Norberg angle was not measured. For this reason, Norberg angles were not measured in 1 dog in each group. Additionally, 5 measurements were not made in 1 dog, and 1 measurement was not made in each of 3 dogs.

Table 2—Mean ± SD Norberg angles for dogs that underwent a left triple pelvic osteotomy and in which the acetabulum was internally rotated 45° (experimental group) and in dogs that underwent a left triple pelvic osteotomy and in which the fragments were stabilized in anatomic alignment (control group)

	Experimental group		Control group	
Time	Left hip joint	Right hip joint	Left hip joint	Right hip joint
Before surgery	103.33 ± 5.46	101.83 ± 5.32	102.33 ± 3.07	102.17 ± 3.3
After surgery (wk)				
0	99.00 ± 1.83*	100.8 ± 5.23	101.92 ± 5.44	102.67 ± 3.31
4	102.00 ± 4.9	103.42 ± 5.3	105.6 ± 2.38	104.00 ± 2.88*
8	100.30 ± 3.67*	104.1 ± 6.11	106.00 ± 3.92	103.58 ± 3.76
12	99.50 ± 2.92* †	101.92 ± 6.43	109.63 ± 3.35† ‡	102.5 ± 2.3
16	99.70 ± 3.46†	103.50 ± 5.71	110.38 ± 5.79* † ‡	102.92 ± 2.75‡
20	99.00 ± 4.7* †	102.92 ± 8.14	111.90 ± 4.25* † ‡	102.83 ± 2.58‡
24	98.80 ± 3.77* †	101.17 ± 1.63	109.13 ± 4.37† ‡	102.67 ± 3.61‡
28	99.40 ± 6.13†	102.17 ± 3.7	111.00 ± 5.71† ‡	103.17 ± 4.05‡

*Significantly ($P < 0.05$) different from value obtained before surgery. *See* Table 1 for remainder of key.

Table 3—Lameness scores ± SD for dogs that underwent a left triple pelvic osteotomy and in which the acetabulum was internally rotated 45° (experimental group) and in dogs that underwent a left triple pelvic osteotomy and in which the fragments were stabilized in anatomic alignment (control group)

Time	Experimental group	Control group
Before surgery	5.33 ± 0.52	5.17 ± 0.41
After surgery (wk)		
2	12.67 ± 3.88*	10.00 ± 2.53*
4	7.33 ± 0.82*	7.00 ± 1.79*
6	6.00 ± 1.67	7.00 ± 2.76
8	6.00 ± 1.5	5.67 ± 0.52
12	5.17 ± 0.41	5.00 ± 0.00
16	5.17 ± 0.41	5.00 ± 0.00
20	5.33 ± 0.52	5.50 ± 0.55
24	5.17 ± 0.41	5.00 ± 0.00

See Table 2 for key.

Lameness evaluation—For dogs in both groups, lameness scores 2 and 4 weeks after surgery were significantly different from preoperative scores (**Table 3**). Significant differences between groups were not detected at any time during the study.

For dogs in the experimental group, vertical impulse of the left hind limb was significantly different from presurgical values at all times during the study (**Table 4**); whereas, for dogs in the control group, vertical impulse was significantly different from presurgical values only 2, 4, and 6 weeks after surgery. For dogs in the experimental group, peak vertical force of the left hind limb was significantly different from presurgical values only 2 and 4 weeks after surgery, and for control dogs, peak vertical force of the left hind limb was significantly different from presurgical values only 2 weeks after surgery, indicating mild lameness. The right hind limb had a significant compensatory increase in vertical impulse 2 weeks after surgery in both groups. Surprisingly, the right hind limb in control dogs had a significant increase in peak vertical force 2, 4, 8, and 12 weeks after surgery.

When the vertical ground reaction forces were compared between groups, vertical impulse for the left hind limb was significantly different between groups from 6 weeks after surgery until the conclusion of the study. However, peak vertical force was not significantly different between groups at any time.

Peak braking force and braking impulse were significantly increased, compared with presurgical values, at various times throughout the study (**Table 5**). However, a pattern to the significant changes could not be identified. Peak braking force and braking impulse were not significantly different between groups at any time.

Peak propulsion force and propulsion impulse for the right hind limbs were not significantly different from presurgical values at any time during the study (**Table 6**). Propulsion impulse of the left hind limb was significantly decreased, compared with presurgical values, 2 and 4 weeks after surgery for both groups and 6 weeks after surgery for the control group. Peak propulsion force of the left hind limb was significantly decreased, compared with presurgical values, 2 and 4 weeks after surgery for both groups and 6 and 8 weeks after surgery for the experimental group. Six weeks after surgery, dogs in which the acetabular segment was rotated had a significantly smaller propulsion impulse for the left hind limb than did control dogs, but other differences between groups were not detected.

Necropsy findings—Gross examination of the left and right hip joints did not reveal any severe erosions or osteophytes. In some joints, thinning and yellowing of the cartilage was observed, and the femoral head appeared flatter than normal in a few dogs. However, these changes were evident in dogs from both groups.

Histologic evaluation—Histologic evaluation of the articular cartilage demonstrated a wide range of lesion severity. Several samples did not have any histologic changes, whereas others had obvious osteoarthritic changes, including fissures in the cartilage, superficial cellular disruption and mild clustering, and decreased stain uptake. Tidemark integrity was not compromised in any of the dogs. Several dogs had mild changes in the cartilage of the right hip joint, which did not undergo surgery, and 1 dog in the experimental group had more severe changes in the right than in the left hip joint. Mean histologic scores for the left and right hip joints of dogs in the experimental

Table 4—Mean ± SD vertical impulse and peak vertical force for hind limbs of dogs that underwent a left triple pelvic osteotomy and in which the acetabulum was internally rotated 45° (experimental group) and in dogs that underwent a left triple pelvic osteotomy and in which the fragments were stabilized in anatomic alignment (control group)

	Experimental group				Control group			
	Impulse		Peak force		Impulse		Peak force	
Time	Left limb	Right limb	Left limb	Right limb	Left limb	Right limb	Left limb	Right limb
Before surgery	9.55 ± 0.84	9.72 ± 0.54	71.19 ± 7.37	71.02 ± 7.18	10.71 ± 0.53	10.18 ± 0.90	70.03 ± 4.44	67.89 ± 5.45
After surgery (wk)								
2	6.50 ± 1.45	11.02 ± 1.25	56.00 ± 11.13	75.33 ± 9.67	7.61 ± 0.65	11.08 ± 1.25	58.49 ± 4.74	72.91 ± 2.48
4	7.75 ± 1.15	10.11 ± 0.90	63.04 ± 9.79	70.56 ± 7.32	8.84 ± 0.37	10.30 ± 1.17	68.33 ± 5.15	71.26 ± 6.00
6	8.03 ± 1.23	10.08 ± 1.01	66.73 ± 9.28	73.45 ± 10.49	9.56 ± 0.35	10.26 ± 1.32	70.08 ± 5.19	70.80 ± 5.46
8	8.49 ± 0.83	9.93 ± 0.61	68.48 ± 7.68	72.57 ± 9.69	9.92 ± 0.37	10.31 ± 1.16	73.09 ± 4.93	73.44 ± 5.13
12	8.81 ± 1.10	9.66 ± 0.80	70.24 ± 8.69	70.85 ± 9.28	10.19 ± 0.41	10.26 ± 1.20	73.24 ± 7.04	72.27 ± 7.00
16	9.26 ± 0.95	9.66 ± 0.63	72.56 ± 8.94	70.44 ± 9.34	10.07 ± 0.54	10.15 ± 0.89	72.13 ± 6.96	70.96 ± 6.97
20	9.16 ± 0.77	9.57 ± 0.52	71.24 ± 10.00	68.80 ± 8.13	9.96 ± 0.41	9.96 ± 0.84	72.84 ± 8.25	71.75 ± 6.85
24	8.99 ± 0.82	9.51 ± 0.61	70.40 ± 8.88	69.20 ± 8.49	10.05 ± 0.62	9.86 ± 0.94	71.72 ± 7.18	69.74 ± 6.05
28	8.96 ± 0.95	9.42 ± 0.66	70.17 ± 6.80	69.70 ± 8.18	10.10 ± 0.55	9.94 ± 1.20	73.18 ± 7.17	70.38 ± 5.90

Table 5—Mean ± SD peak braking force and braking impulse for hind limbs of dogs that underwent a left triple pelvic osteotomy and in which the acetabulum was internally rotated 45° (experimental group) and in dogs that underwent a left triple pelvic osteotomy and in which the fragments were stabilized in anatomic alignment (control group)

	Experimental group				Control group			
	Impulse		Peak force		Impulse		Peak force	
Time	Left limb	Right limb	Left limb	Right limb	Left limb	Right limb	Left limb	Right limb
Before surgery	−0.19 ± 0.08	−0.18 ± 0.09	−5.62 ± 1.46	−5.71 ± 1.72	−0.13 ± 0.07	−0.18 ± 0.08	−4.80 ± 1.41	−5.04 ± 0.59
After surgery (wk)								
2	−0.24 ± 0.12	−0.30 ± 0.10	−6.43 ± 1.90	−8.49 ± 1.85	−0.21 ± 0.05	−0.18 ± 0.10	−6.53 ± 1.73	−7.50 ± 1.35
4	−0.23 ± 0.11	−0.25 ± 0.08	−7.20 ± 1.87	−8.36 ± 2.89	−0.16 ± 0.04	−0.19 ± 0.08	−6.39 ± 2.00	−6.69 ± 1.71
6	−0.19 ± 0.07	−0.20 ± 0.11	−6.65 ± 1.62	−7.33 ± 2.24	−0.13 ± 0.07	−0.15 ± 0.07	−5.92 ± 1.94	−6.39 ± 2.00
8	−0.21 ± 0.12	−0.24 ± 0.10	−6.57 ± 1.21	−7.91 ± 2.17	−0.13 ± 0.05	−0.15 ± 0.05	−6.49 ± 2.05	−6.34 ± 1.24
12	−0.18 ± 0.09	−0.27 ± 0.11	−5.35 ± 1.22	−7.54 ± 1.64	−0.14 ± 0.05	−0.19 ± 0.10	−5.62 ± 0.82	−6.12 ± 0.69
16	−0.16 ± 0.08	−0.25 ± 0.11	−5.00 ± 1.17	−7.09 ± 2.05	−0.12 ± 0.02	−0.17 ± 0.07	−5.66 ± 1.50	−5.90 ± 1.02
20	−0.18 ± 0.06	−0.27 ± 0.16	−4.94 ± 0.91	−6.47 ± 1.98	−0.16 ± 0.08	−0.15 ± 0.10	−5.30 ± 1.47	−5.06 ± 1.35
24	−0.17 ± 0.08	−0.23 ± 0.10	−4.82 ± 1.7	−6.46 ± 1.61	−0.10 ± 0.21	−0.20 ± 0.14	−4.96 ± 3.39	−5.70 ± 1.33
28	−0.19 ± 0.07	−0.25 ± 0.08	−5.46 ± 1.89	−6.75 ± 1.30	−0.18 ± 0.08	−0.20 ± 0.15	−5.80 ± 1.48	−5.76 ± 1.34

Table 6—Mean ± SD peak propulsion force and propulsion impulse for hind limbs of dogs that underwent a left triple pelvic osteotomy and in which the acetabulum was internally rotated 45° (experimental group) and in dogs that underwent a left triple pelvic osteotomy and in which the fragments were stabilized in anatomic alignment (control group)

	Experimental group				Control group			
	Impulse		Peak force		Impulse		Peak force	
Time	Left limb	Right limb	Left limb	Right limb	Left limb	Right limb	Left limb	Right limb
Before surgery	0.85 ± 0.31	0.80 ± 0.18	9.74 ± 1.62	10.05 ± 1.47	0.91 ± 0.10	0.89 ± 0.27	10.24 ± 0.72	9.73 ± 1.55
After surgery (wk)								
2	0.46 ± 0.10	0.82 ± 0.20	6.06 ± 1.04	9.52 ± 1.61	0.56 ± 0.12	1.01 ± 0.25	6.63 ± 1.51	10.53 ± 1.84
4	0.56 ± 0.09	0.80 ± 0.22	7.13 ± 1.26	9.37 ± 1.81	0.65 ± 0.14	0.97 ± 0.22	8.10 ± 1.87	10.28 ± 1.37
6	0.63 ± 0.07	0.86 ± 0.24	8.18 ± 1.10	10.15 ± 1.52	0.79 ± 0.16	0.92 ± 0.21	9.06 ± 1.86	9.94 ± 1.08
8	0.64 ± 0.11	0.75 ± 0.17	8.38 ± 1.32	9.38 ± 1.21	0.82 ± 0.19	0.97 ± 0.17	9.85 ± 1.36	10.40 ± 0.84
12	0.75 ± 0.06	0.74 ± 0.17	9.63 ± 1.13	9.22 ± 0.95	0.87 ± 0.16	0.86 ± 0.23	10.08 ± 1.50	9.84 ± 1.23
16	0.81 ± 0.10	0.81 ± 0.25	10.10 ± 1.32	9.69 ± 1.82	0.92 ± 0.25	0.88 ± 0.24	10.33 ± 1.39	10.13 ± 0.89
20	0.78 ± 0.16	0.82 ± 0.25	9.64 ± 1.57	9.60 ± 2.00	1.13 ± 0.45	0.93 ± 0.17	10.45 ± 1.45	10.62 ± 1.25
24	0.80 ± 0.11	0.80 ± 0.20	10.02 ± 1.21	9.83 ± 1.45	0.84 ± 0.23	0.86 ± 0.19	8.66 ± 3.66	9.83 ± 0.92
28	0.79 ± 0.13	0.83 ± 0.24	10.00 ± 1.28	10.05 ± 1.95	0.91 ± 0.20	0.86 ± 0.14	10.60 ± 1.59	9.87 ± 0.90

group (3.67 and 2.17, respectively) were not significantly different from scores for the left and right hip joints of control dogs (3.00 and 1.67, respectively).

Histologic evaluation of the joint capsules revealed a wide range of lesions. For dogs in which the acetabular segment was internally rotated, mean score for the left hip joint (0.97) was significantly higher than mean score for the right hip joint (0.42). However, mean scores for dogs in the experimental group were not significantly different from mean scores for the left and right hip joints of control dogs (0.83 and 0.50, respectively).

Discussion

Results of the present study suggest that 45° internal rotation of the acetabulum does not consistently induce biologically significant osteoarthritic changes in the hip joints of dogs. Minimal or no changes were seen radiographically and during lameness examinations. These results suggest that this method would be a poor choice for studying osteoarthritis, and that more sensitive evaluation techniques or longer evaluation times would be necessary to use this method for osteoarthritis research.

In the original description of this experimental model,[1] radiographs were obtained at various times after surgery and only 1 example was used to demonstrate decreased coverage of the femoral head by the acetabulum. However, change in percentage of femoral head coverage was not quantified, and descriptions of other radiographic changes were not included. Seven months after surgery, dogs in the present study did not have radiographic evidence of osteoarthritis, suggesting that degenerative processes that were induced by this procedure were mild. Given that some gross and histologic changes were detected, radiographically detectable changes may have developed if a longer postoperative evaluation period had been allowed.

In the present study, coverage of the femoral head by the acetabulum was reported as the percentage change from preoperative values. Thus, this value was negative if coverage had increased, and positive if coverage had decreased. Not surprisingly, for dogs in which the acetabular segment was internally rotated, femoral head coverage in the left hip joint was significantly decreased, compared with presurgical values, values for the control dogs, and values for the contralateral hip joint. Isolated instances of statistically significant changes in femoral head coverage for hip joints in control dogs and for the right (unoperated) hip joint in experimental dogs were likely a result of limitations of the method used to outline bone structures on radiographs or of inaccuracies stemming from superimposition of the bone plate on the joint outline.

The Norberg angle is a measure of hip subluxation. In general, higher numbers are associated with less subluxation, although the correlation between Norberg angle and development of degenerative joint disease has been questioned.[14] In the present study, Norberg angle for the left hip joint was significantly different between groups. This difference resulted partially from higher values in control dogs and partially from lower values in dogs in which the acetabular segment was internally rotated. For dogs in the experimental group, Norberg angles for the left hip joints were not significantly different from angles for the right hip joints. To some extent, the lack of significant differences was a result of the high SD for the left hip joints. Acetabula were rotated around an axis roughly parallel to the midline of the ilium, and the point of reference on the acetabular rim may have changed, making assessment of Norberg angles difficult.

We did not detect any significant differences between groups in regard to lameness scores at any time in this study. This was not surprising, in that all dogs appeared clinically normal by the sixth or eighth week after surgery, and osteoarthritic changes that were evident histologically were mild enough or developed late enough in the study to not cause an appreciable degree of discomfort. In their study, Inerot et al[1] reported that dogs did not bear weight on the limbs for 1 to 2 days after surgery and had a slight limp for 2 to 4 weeks.

In this study, results of force plate evaluations were consistent with those expected for dogs recovering from surgery. Dogs in both groups were noticeably lame during the first 2 force plate evaluations after surgery, and data for ground reaction forces supported this impression. After this time, changes were less frequently seen in control dogs, and significant changes, compared with presurgical values, after this time in control dogs and the right hind limbs of experimental dogs may have been attributable to variations in the dogs' gait. These inconsistent findings were most evident for braking peak forces and impulses, which may not be as important as other objective measurements of lameness.[9] The consistent decrease in vertical impulse for the left hind limb of dogs in which the acetabular segment was internally rotated suggests some degree of lameness. Impulse reflects both the force generated by the limb and the time that the paw is in contact with the ground[5] and, therefore, may provide more information than the peak vertical force. Because there was not a corresponding decrease in peak vertical force by the sixth week after surgery, we assume that changes in vertical impulse were a result of changes in the time the dogs kept their paws in contact with the ground and speculate that the differences between groups represented a subtle lameness.

Inerot et al[15] described a variety of subjective histologic findings in dogs that underwent acetabular rotation but did not attempt to quantify their histologic findings. Changes in cartilage specimens from dogs in their study ranged from loss of stain uptake and chondrocyte clustering to deep erosions and subchondral bone atrophy. In contrast, dogs in the current study did not have histologic evidence of deep erosions or subchondral bone atrophy but did have evidence of decreased stain update. In addition, only mild disruption of cartilage architecture was seen, although some fissures were evident. In general, findings for dogs in the present study were similar to mild degenerative changes in the study by Inerot et al.

There are several possible explanations as to why dogs in the present study did not develop more profound cartilage lesions. The most plausible explanation is that alterations to joint biomechanics that were created were mild and any laxity that developed was insignificant, so that arthritic changes were slow to develop. Even though most dogs with hip dysplasia first have clinical signs of pain and joint laxity between 4 months and 1 year of age, radiographic changes may not appear until after 6 months of age,[16] and many dogs with naturally occurring hip dysplasia do not have radiographic evidence of osteoarthritis until after 2 years of age.[14]

Prior to this study, we believed that internally rotating the acetabular segment 45° in dogs would have altered hip joint biomechanics sufficient to cause mechanical trauma to the joint. Clinical experience during triple pelvic osteotomy surgery has shown that excessive external rotation of the acetabulum can cause interference dorsally between the acetabulum and the femur, and we believe that additional internal rotation would have caused a similar situation ventrally. In addition, we would have had to use plates that were twisted by hand. We chose to use manufactured 45° plates in the present study, because we thought that we could achieve a greater degree of standardization between dogs in this manner and because, although to the authors' knowledge studies have not been performed, hand bending plates may cause them to be weaker, so that some of the applied twist could be lost. The degree of rotation achieved in dogs in the present study was likely greater than that achieved by Inerot et al.[1] In their study, the pubis was not cut, and the caudal aspect of the ilium was placed medial to the cranial portion via a stepped cut.

Another explanation for the lack of severe osteoarthritic changes among dogs in the present study, compared with dogs in the previous study, may be the differences in age and weight of the dogs used in these studies. Ages of dogs used in the present study were not known, but the dogs were considered to be adult on the basis of results of physical and radiographic examinations. Inerot et al[1] used dogs between 12 and 18 months old, which may have been more susceptible to the effects of altered joint conformation. The greater elasticity of the joint capsule and ligament of the femoral head in these dogs may have allowed laxity to develop more easily. Although weights of the dogs in the study by Inerot et al were not reported, all were Greyhounds or pointers. Dogs in the present study may have been smaller than those used in the previous study and, consequently, may have been less susceptible to arthritic changes.

In the present study, histologic scores for 2 control dogs and for the right hip joint from 1 dog in the experimental group were suggestive of osteoarthritis. These findings are difficult to explain. Although alignment of bone segments in the control dogs may not have been anatomic, it was obviously better than in dogs in which the acetabulum was internally rotated. It is possible that these dogs had mild osteoarthritis of the hip joints that was not detectable during physical or radiographic examinations.

In conclusion, results of the present study did not confirm the findings of Inerot et al, and this method did not consistently result in development of clinically detectable osteoarthritis within the first 7 months after surgery.

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[a] Azostix, Bayer Corp, Elkhart, Ind.
[b] Triple Osteotomy Plate 45°, Synthes (USA), Paoli, Pa.
[c] DCP Dynamic Compression Plate, Synthes (USA), Paoli, Pa.
[d] Cue-3, Olympus, Lake Success, NY.
[e] AMTI OR6-6, AMTI, Newton, Mass.
[f] VBEL, Sharon Software, Dewitt, Mich.
[g] Beuthansia-D Special, Schering-Plough Animal Health Corp, Kenilworth, NJ.
[h] TBD2, Shandon-Lipshaw, Pittsburgh, Pa.
[i] Miles Scientific VPI Automated Tissue Processor, Sakura, Torrence, Calif.
[j] Surgipath EM 400 Imbedding Medium, Surgipath Medical Industries, Richmond, Ill.

Appendix 1

Scoring system used for assigning subjective lameness scores in dogs*

Score	Criteria
Gait	
1	Stands and walks normally
2	Stands normally; slight lameness at walk
3	Stands normally; severe lameness at walk
4	Abnormal posture when standing; severe lameness at walk
5	Reluctant to rise and will not walk > 5 strides
Weight bearing	
1	Normal weight bearing on all limbs at rest and when walking
2	Normal weight bearing at rest; favors affected limb when walking
3	Partial weight bearing at rest and when walking
4	Partial weight bearing at rest; non-weight bearing when walking
5	Non-weight bearing at rest and when walking
Joint mobility	
1	< 15° limitation of hip joint extension
2	15 to 30° limitation of hip joint extension
3	30 to 45° limitation of hip joint extension
4	45 to 60° limitation of hip joint extension
5	> 60° limitation of hip joint extension
Elevation of contralateral limb	
1	Readily accepts elevation of contralateral limb; bears full weight on affected limb > 2 min
2	Offers mild resistance to elevation of contralateral limb; bears full weight on affected limb > 1 min
3	Offers moderate resistance to elevation of contralateral limb and replaces it in ≤ 30
4	Offers strong resistance to elevation of contralateral limb and replaces it in ≤ 10
5	Refuses to raise contralateral limb
Response to limb palpation	
1	No signs of pain during palpation of affected limb
2	Signs of mild pain (eg, turns head in recognition)
3	Signs of moderate pain (eg, pulls limb away)
4	Signs of severe pain (eg, vocalizes or becomes aggressive)
5	Will not allow limb palpation

*Overall lameness score was calculated by summing scores for each of the 5 categories.

Appendix 2

Modified Mankin scale used for grading histologic changes in articular cartilage*

Score	Criteria
Structure	
0	Normal
1	Irregular surface, including fissures into the radial layer
2	Pannus
3	Superficial cartilage layers (≥ 6) absent
4	Slight disorganization; cellular rows absent and some small superficial cell clusters
5	Fissures into calcified cartilage layer
6	Disorganization; chaotic structure, clusters, osteoclast activity
Cellular abnormalities	
0	Normal
1	Hypercellularity, including small superficial clusters
2	Clusters
3	Hypocellularity
Matrix staining	
0	Normal or slight reduction
1	Staining reduced in radial layer
2	Staining reduced in interterritorial matrix
3	Staining evident only in pericellular matrix
4	Staining absent

*Score was calculated by summing scores for each of the 3 categories.

Appendix 3

System for scoring histologic appearance of specimens of joint capsule

Score	Criteria
0	Normal; unremarkable
1	Slight increase in synovial membrane cellularity or reactive villar hyperplasia; slight increase in vascularity; mild inflammation
2	Moderate increase in synovial membrane cellularity or reactive villar hyperplasia; moderate increase in vascularity; moderate inflammation
3	Severe increase in synovial membrane cellularity or reactive villar hyperplasia; severe increase in vascularity; severe inflammation

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