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Regional load bearing of the canine acetabulum

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Abstract

Objective: To determine the load bearing areas of the canine acetabulum.
Materials and methods: A kinematic study of four healthy dogs was used to determine the orientation of the femur to the pelvis at mid-stance. Femora and pelves from 10 canine cadavers were loaded with the physiological canine hip reaction force and angle being replicated. Impression material placed within the acetabulum was extruded from areas of load bearing. Digital images before and after loading were used to assess if six different regions of the acetabulum were fully, partially or non-load bearing.
Results: All areas of the acetabulum were partially or fully load bearing. The cranial and caudal thirds of the acetabulum were 7.9 and 13.1 times more likely to be fully load bearing than the central third, respectively. There was a significant difference in load bearing between the axial, middle and abaxial thirds of the acetabulum in all tests, with the middle and abaxial thirds 72.4 and 351 times more likely to be fully load bearing than the axial third, respectively.
Conclusion: The cranial and caudal thirds and the middle and abaxial thirds of the canine acetabulum are fully load bearing.
Clinical relevance: The caudal third of the canine acetabulum is loaded and therefore recommendations that fractures in this area be managed conservatively need to be reconsidered.

Keywords: Canine; Acetabulum; Load bearing; Fracture

1. Introduction

Pelvic fractures constitute approximately 25% of all fractures in dogs (Brinker, 1978). Acetabular fractures occur in 14–30% of dogs sustaining pelvic fractures (Denny, 1978; Braden and Prieur, 1986; Messmer and Montavon, 2004) and have previously been treated conservatively or surgically. A theoretical analysis of the canine hip has stated that the main load to the hip in the running dog is in the horizontal plane and directed forwards (Prieur, 1980). This has led some authors to suggest that fractures not involving the cranial third or two-thirds of the acetabulum may be more amenable to conservative (i.e. non-surgical) treatment based on the assumption that these are not regions where the majority of force is directed (Butterworth et al., 1994; Dyce and Houlton, 1993). A recent cadaveric study in domestic cats demonstrated that the load bearing regions of the acetabulum in that species are the central and caudal thirds (Beck et al., 2005). The aim of this study was to evaluate the load bearing regions of the acetabulum of normal canine cadavers by use of an in vitro coxofemoral model simulating conditions during the mid-stance phase of the gait cycle. Our hypothesis was that there would be no difference in load bearing between different regions of the acetabulum.

2. Materials and methods

2.1. Kinematic study

Four clinically normal greyhounds (median weight 30.2 kg, range 28.7–31.8 kg) with no evidence of orthopaedic disease on physical

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examination were selected. Retroreflective adhesive markers were placed on the skin over bony landmarks on the right side of the dog—the dorsal iliac crest, the greater trochanter of the femur and the lateral femerotibial joint (between the lateral femoral epicondyle and the fibular head). Dogs were filmed trotting on a motorised treadmill at 2.2–2.4 m/s using a single 60 Hz video camera. Data from this part of the study have previously shown that treadmill familiarisation had occurred (Owen et al., 2004).

Data from multiple gait cycles were used to determine the iliofemoral angle and the angle of the femur to the horizontal in the sagittal plane at mid stance. Mid-stance was defined as the limb position when the paw was immediately below the greater trochanter and in contact with the ground.

2.2. Loading study

Eleven skeletally mature ex-racing greyhound cadavers euthanized for reasons unrelated to this study were obtained. The femora, pelves and sacra were harvested and specimens with evidence of orthopaedic disease were rejected. All soft tissues, including the ligament of the head of the femur, were removed to allow impression material to be displaced from the acetabulum during loading. The distal third of the femur was removed. The specimens were stored at −20 °C and thawed to room temperature prior to biomechanical testing. Samples were kept moist with saline-soaked sponges during testing.

A standardised digital image of each acetabulum was obtained prior to experimental testing to visualise and record the acetabular cartilage (Coolpix S4 digital camera, Nikon, Surrey, UK).

The right distal femur was potted in a hard-setting polyester filler paste (U-Pol Extra, W. David and Sons Ltd., Wellingborough, UK**)** and attached to the crosshead of the materials testing machine in a custom made jig which allowed the femur to be positioned with six degrees of freedom and held rigid. The pelvis was mounted inverted (such that the acetabulum was open upwards) in a custom made jig which allowed the position of the pelvis to be tilted in the sagittal and frontal planes and held rigid, but allowed free movement of the jig in the horizontal plane. The jigs were mounted in a materials testing machine (Dartec 50 kN, Dartec, UK) with the relative orientation of the pelvis to the femur being equal to the mean orientation measured in the kinematic study at midstance. Bones were first mounted with a pelvis to femur angle of 106° and femur to the horizontal angle of 72° in the sagittal plane (group 1). Loading was repeated with equivalent angles of 120° and 70° (group 2). The long axis of the femur to the ischium in the frontal plane (i.e. the abduction angle) was 105° based on data from instrumented total hip arthroplasty prostheses in the dog (Page et al., 1993). As well as being inverted, **t**he pelvis–femur construct was positioned in the jig such that the hip reaction force direction was parallel with the vertical displacement of the materials testing machine's crosshead. Hip-joint-reaction force direction was replicated at 20° to the vertical in the frontal plane and 0° to the vertical in the sagittal plane based on data from instrumented hip prostheses in dogs and from a three-dimensional model of the canine pelvic limb (Page et al., 1993; Bergmann et al., 1999; Shahar and Banks-Sills, 2002).

Fast-setting alginate impression material (Surrey Precision Dental, Southampton, Hampshire, UK) was mixed and poured into the acetabulum in its liquid phase. Based on previous studies (Page et al., 1993; Shahar and Banks-Sills, 2002), hip joint-reaction force loads of 1.0 times bodyweight and 1.65 times bodyweight were each applied to groups 1 and 2. Compression was applied via the testing machine with the free movement of the pelvis in the horizontal plane ensuring that the femoral head seated centrally in the acetabulum. Compression was maintained until the impression material had set. The load was removed and the femur and acetabulum separated with care being taken that impression material was not dislodged from the acetabulum (von Eisenhart et al., 1999). The impression material was extruded from the regions of load bearing, whereas unloaded regions remained covered. Regions where cartilage had thin remnants of adherent impression material that had stuck to the acetabulum were classified as load bearing. As a preliminary study the femur of dog 7 (25 kg) was mounted in the acetabulum of dog 10 (30 kg) and load applied at 1.0 and 1.65 times the bodyweight of dog 7 for groups 1 and 2 to confirm that this model could detect non-load bearing regions associated with coxofemoral incongruity.

Pre-loading and post-loading digital images of the acetabulae were compared (Paint Shop Pro 5.01, Corel, Maidenhead, Berkshire, UK). Each acetabulum was divided into cranial, central and caudal thirds and then into axial, middle and abaxial thirds (Figs. 1 and 2). Each region was categorised as: fully load bearing if $<10\%$ of the area of cartilage was covered with impression material, partially load bearing if 11–89% of the area of cartilage was covered with impression material and non-load bearing if $>90\%$ of the area of cartilage was covered with impression material (Fig. 3).

Continuous data from the kinematic study were graphically assessed for normality and expressed as mean and standard deviation when appropriate. All analyses were undertaken with a statistical programme (SPSS 14.0, Inc., Chicago, Illinois). Differences in load bearing between the cranial, central and caudal thirds, and between the axial, middle and abaxial thirds of the acetabulum, were evaluated with Fisher's exact test. In order to comply with the requirements of the Fisher's Exact test, that is,

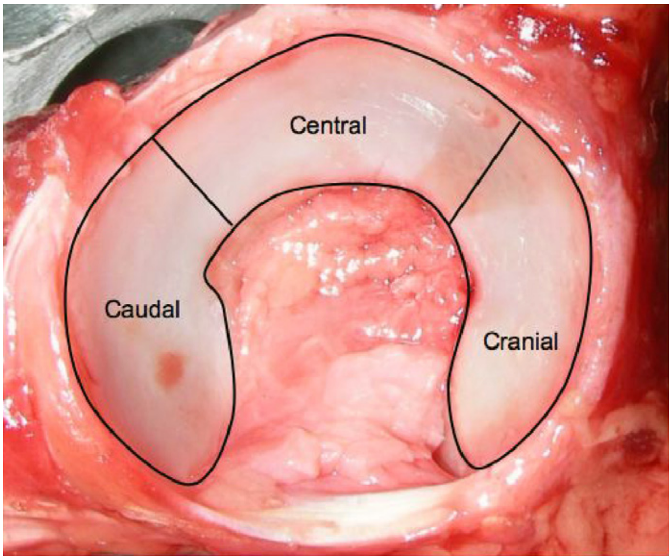

Fig. 1. A right acetabulum prior to loading showing the articular cartilage divided into cranial, central and caudal thirds.

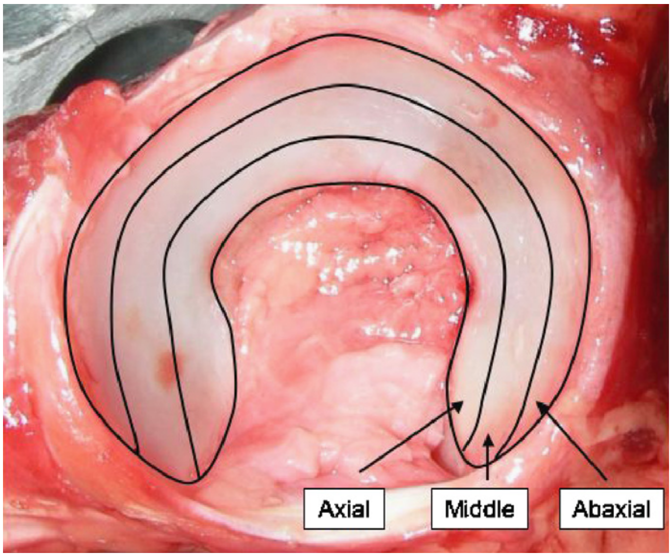

Fig. 2. A right acetabulum prior to loading showing the articular cartilage divided into axial, middle and abaxial thirds.

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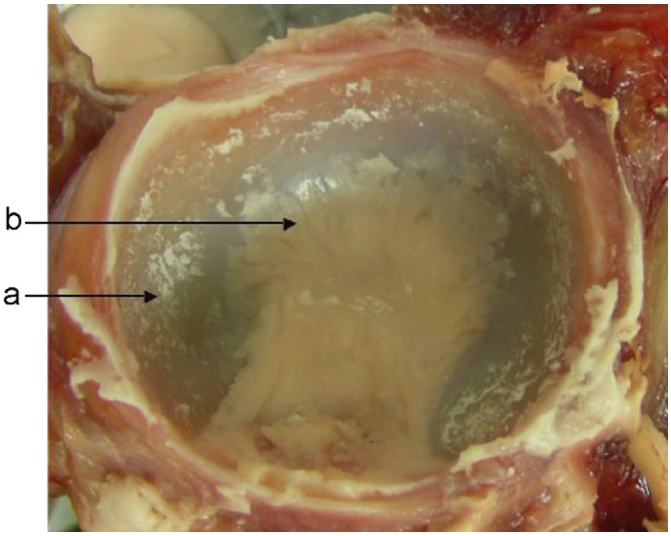

Fig. 3. Post-loading studies showing areas of full load bearing where there is no impression material on the articular surface (a) and partial load bearing where there is impression material on 11–89% of the articular surface (b).

each cell must contain a number greater than zero, any cells containing zero were nominally increased to one and the associated alternate cells were decreased by one. In this way the test criteria were satisfied although the altered values made it more difficult to demonstrate significance. The associations between load bearing and region of the acetabulum loaded, angle of loading and magnitude of load applied were assessed with logistic regression. Animal identity was treated as a random effect in a mixed model to take account of any clustering of outcome at this level. Model fit was assessed with the Hosmer–Lemeshow test (Hosmer and Lemeshow, 2000). The significance level was set at 5%.

3. Results

3.1. Kinematic study (Table 1)

Data were obtained using 29–40 gait cycles per dog. The mean (and standard deviation) iliofemoral angle for each dog was 106° (±4.77°), 120° (±3.79°), 120° (±3.09°) and 107° (±2.50°). The mean angle for all dogs was 114° (SD 6.86°, range 102–126°).

Data for the angle of the femur to the horizontal (floor) were obtained as above. The mean (and standard deviation) angle for each dog was 72° (±2.86°), 70° (±4.44°), 69° (±3.41°) and 72° (±2.86°). The mean for all dogs was 70° (SD 3.50°, range 55–78°).

3.2. Loading study

One greyhound pelvis was rejected due to the presence of haemarthrosis and cartilage erosion of one hip joint. Of the remaining 10, the mean dead body weight was 32.9 kg (SD 4.67 kg, range 25–43 kg).

For the incongruent hip validation study, the widest diameter of the femoral head was 21.4 mm, compared to the diameter of the correct femoral head for the corresponding acetabulum, which was 23.6 mm. There was no extrusion of impression material from the abaxial third of the acetabulum, i.e. where the small head did not contact the larger acetabulum, thus demonstrating that this model of hip loading is able to detect areas of non-load bearing.

For the four test methods performed, full load bearing was noted in the cranial acetabulum in 2–7 hips tested, in the central acetabulum in 0–4 hips tested and in the caudal acetabulum in 3–6 hips tested (Table 2). In the remainder of the hips these areas were partially load bearing; no areas were non-load bearing in any hip for any test method. There was a significant difference in load bearing between the cranial, central and caudal areas in Group 1 at a load of 1.0 × bodyweight ($P = 0.019$), but no significant difference for Group 1 loaded at 1.65 × bodyweight or for Group 2 at both loads (Table 2). Logistic regression showed that the cranial and caudal thirds of the acetabulum were 7.9 and 13.1 times more likely to be fully load bearing than the central acetabulum, respectively, after adjusting for load applied and direction of load ($P < 0.001$), but there was no significant difference in loading between the cranial and caudal thirds of the acetabulum (Table 3). Hips loaded at 1.65 × bodyweight were 3.2 times more likely to be fully load bearing than those loaded at 1.0 × bodyweight. Hips were 0.2 times as likely to be fully load bearing when

Table 1
Hip joint angles from the kinematic study

Dog	Iliofemoral angle			Angle of femur to horizontal		
	Mean	SD	Range	Mean	SD	Range
1	106	4.77	90–122	72	2.86	68–78
2	120	3.79	105–125	70	4.44	55–74
3	120	3.09	114–126	69	3.41	63–76
4	107	2.50	102–112	72	2.86	68–78
All	114	6.86	102–126	70	3.50	55–78

Table 2
Load bearing in the cranial, central and caudal thirds of the acetabulum

	Group 1 (106°)		Group 2 (120°)		All
	1.0 × weight	1.65 × weight	1.0 × weight	1.65 × weight	
Cranial					
Fully	7	7	2	4	20
Partially	3	3	8	6	20
Central					
Fully	0	4	1	1	6
Partially	10	6	9	9	34
Caudal					
Fully	6	10	3	5	24
Partially	4	0	7	5	16
P-value	0.019*	0.080	0.085	0.228	

*Significant.

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loaded at an angle of 120° than at 106°. The model showed that clustering was not significant at the patient level ($P = 0.16$) and was not retained in this model. The model fit was good as assessed by the Hosmer–Lemeshow test ($P = 0.67$).

For the four test methods performed, full load bearing was noted in the axial acetabulum in 0–1 hips tested, in the middle acetabulum in 8–10 hips tested and in the abaxial acetabulum in 3–6 hips tested (Table 4). In the remainder, these regions were partially load bearing; no areas were non-load bearing. There was a significant difference in load bearing between the axial, middle and abaxial areas for both groups at both loads (Table 4). Logistic regression showed that the middle and abaxial areas of the acetabulum were 72.4 and 351 times more likely to be fully load bearing than the axial area, respectively (Table 5). There was a trend for increased loading at 1.65 × bodyweight compared to 1.0 × bodyweight and at a loading angle of 106° compared to 120° though these were not significant and were not retained in the logistic regression model. Clustering at the patient level was not significant ($P = 0.15$) and was not retained in this model. The model fit was good ($P = 1.0$).

Table 3
Multivariable logistic regression model of the odds of full load bearing of the acetabulum by cranial to caudal acetabular area

Variable	Odds ratio	95% Confidence interval	*P*-value
Cranial acetabulum	7.9	3.9–44.2	<0.001*
Central acetabulum	1.0 (reference)		
Caudal acetabulum	13.1	2.4–26.0	
1.0 × bodyweight	1.0 (reference)		0.009*
1.65 × bodyweight	3.2	1.3–7.7	
106° angle	1.0 (reference)		<0.001*
120° angle	0.2	0.1–0.5	

*Significant.

4. Discussion

Retrospective clinical studies of acetabular fractures in dogs have speculated that load bearing occurs mainly through the cranial third of the acetabulum and that fractures of other parts of the acetabulum can be treated conservatively (Butterworth et al., 1994). However, other studies have reported that conservative management of caudal acetabular fractures in dogs commonly results in lameness and hip pain (Boudrieau and Kleine, 1988). A previous study of load bearing in a cadaveric model in cats showed that the cranial third of the acetabulum was less likely to be load bearing than either the central or caudal thirds. To the authors' knowledge, the distribution of load bearing in the canine hip has not been previously reported.

Greyhounds were utilised in this study as the incidence of hip disease, specifically hip dysplasia and incongruency, is rare in this breed. Furthermore, placement of retroreflective markers is easier than in other breeds due to the prominence of bony landmarks. Inaccuracies in the placement of retroreflective markers and movement of skin overlying joints has been reported but the methods of placement by a single-trained investigator has been shown to minimise inaccuracies (Kadaba et al., 1989). To ascertain whether this model of hip loading could determine areas of non-load bearing, a small femoral head was loaded in a large acetabulum. Impression material remained present along the abaxial edge of the acetabulum

Table 5
Multivariable logistic regression model of the odds of full load bearing of the acetabulum by axial to abaxial acetabular area

Variable	Odds ratio	95% Confidence interval	*P*-value
Axial acetabulum	1.0		<0.001*
Middle acetabulum	72.4	9.0–584.6	
Abaxial acetabulum	351.0	37.5–3288.4	

*Significant.

Table 4
Load bearing in the axial, middle and abaxial thirds of the acetabulum

	Group 1 (106°) 1.0 × weight	Group 1 (106°) 1.65 × weight	Group 2 (120°) 1.0 × weight	Group 2 (120°) 1.65 × weight	All
Axial					
Fully	0	1	0	0	1
Partially	10	9	10	10	39
Middle					
Fully	7	8	3	8	26
Partially	3	2	7	2	14
Abaxial					
Fully	10	9	8	9	36
Partially	0	1	2	1	4
P-values	<0.001*	<0.001*	0.008*	<0.001*	

*Significant.

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in an area of marked joint incongruency, thus demonstrating that the model can detect areas of non-load bearing.

Previous studies using an instrumented hip prosthesis have shown the mean hip angle in dogs to be 110° with the femur at a 70° angle relative to the horizontal in the sagittal plane (Page et al., 1993). In the greyhounds used for kinematics in this study the mean angle of 114° was similar to that reported by Page, but the angle in individual dogs was either 106° or 120°, hence loading studies were performed at both of these angles. Hips loaded at 106° were more likely to be fully load bearing than those loaded at 120°. It may be that an angle of 106° more closely approximates the angle of loading at midstance in greyhounds, but further studies would be required to verify this. It is likely that there is some variation in the angle of maximal hip loading in individual dogs. It is also suggested that if the entire gait cycle was evaluated all regions of the canine hip would be fully load bearing at some stage.

Peak hip joint force magnitude in walking dogs is 1.04–1.65 times body weight at mid stance (Page et al., 1993; Shahar and Banks-Sills, 2002). In this study increasing the load applied to the hip from 1.0 to 1.65 times body weight resulted in the acetabulum being more likely to be fully load bearing. Cartilage is a viscoelastic structure and will deform in response to constant compressive loading, and this may result in improved joint congruency, which would explain more uniform loading at the higher load.

In the previous study of load bearing in the cat (Beck et al., 2005), areas of load bearing and non-load bearing were clearly defined and only differences in the cranial, central and caudal thirds of the acetabulum were investigated. In this study visual inspection of the articular surface showed that there were large volumes of residual impression material along the axial third of the acetabulum in all hips and small areas of impression material in other areas. Impression material covering $<10\%$ of each region of the acetabulum was chosen to represent full load bearing, as complete loss of impression material from the articular surface rarely occurred. Further studies to quantify the magnitude of loading in different areas and at different loads could be performed using tactile array sensors or pressure sensitive film (Mason et al., 2005).

In this study, the cranial and caudal thirds of the acetabulum were more likely to be fully load bearing than the central third of the acetabulum. This is in contrast to the cat where the central and caudal thirds were more likely to be load bearing. As the study design was identical in both species, there is likely to be a difference in the regional load bearing between dogs and cats. However none of these three regions of the acetabulum were non-load bearing. Clinically this suggests that clinically, the surgical repair of acetabular fractures should not be dependent on their location in the cranial, central or caudal thirds of the acetabulum. Failure to surgically repair centrally and caudally located fractures may lead to morbidity due to displacement and incongruency of a load bearing surface and subsequent osteoarthritis (Matta et al., 1986). In order to avoid this morbidity and maximise postoperative joint function, the standard AO/ASIF principles of articular fracture management are that articular fractures should be anatomically reduced and rigidly stabilised.

The abaxial and middle thirds of the acetabulum were significantly more likely to be fully load bearing than the axial third. This is similar to load bearing in the human hip where the major load bearing area is along the anterior–superior edge. This may be clinically relevant during open reduction and fixation of acetabular fractures, where it may be more important to accurately reduce the abaxial and middle regions than the axial region.

Although trends in load bearing were noted, it was not possible to accurately determine if hip angle and magnitude of loading affected load bearing when assessing the abaxial, middle and axial thirds of the acetabulum, as sparse data was noted in some categories in the majority of specimens (i.e. most hips were partially load bearing in the axial third of the acetabulum). Increasing the number of hips loaded may not overcome this problem if similar patterns of loading are noticed in all specimens.

Limitations to this study include failure to assess joint loading at all stages of the gait cycle, use of a single breed of dog and failure to quantify the load distribution.

4.1. Clinical significance

Repair of acetabular fractures in dogs should ideally follow AO/ASIF principles of articular fracture fixation, namely accurate anatomic reduction and rigid internal fixation, regardless of the location of the fracture. Caudally located acetabular fractures should not be treated conservatively based on location alone.

Conflict of interest

None.

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