TITLE:

Subluxation During Development Alters Femoral Head Shape in a Canine Model of Hip Dysplasia

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INTRODUCTION:

Developmental dysplasia of the hip (DDH) is characterized by joint malformation, subluxation, and early onset osteoarthritis in adults. Subluxation results in focal, eccentric loading of the femoral head. Little is known about the effect of chronic subluxation on the course of shape development in the early postnatal hip. During development, the cartilage anlage of the femoral head is replaced by the secondary center of ossification (SCO). Bone is a self-organizing tissue; the morphology of developing joints reflects adaptation to the loading environment. The objective of this research was to quantify the evolving shape of the femoral head secondary center of ossification and to test for associations between SCO shape, hip subluxation, and degeneration.

MATERIALS AND METHODS:

Femoral head SCO shape was evaluated for 34 hips in 17 Labrador retrievers (9 female, 8 male) at 14 and 32 wk. DDH in this dog model shares the characteristic morphological and biochemical features of DDH in humans and is naturally occurring. 1 mm thick CT scans of the hips were acquired with a minimum in-plane resolution of 0.78 mm. SCOs were segmented from surrounding tissue. SCO principal axes were aligned with the image coordinate axes. Right hips were reflected in the sagittal plan to standardize anatomical handedness. SCOs were uniformly scaled to a unit volume so measures of shape would not be confounded with size. [Image 1] A medial representation (m-rep) method was used for shape analysis because bending and local thickness of an object can be evaluated separately (1). An m-rep is based on the center-point **p** and radius *r* of a set of inscribed bi-tangent spheres (eqn 1, Fig. 1a). Upper and lower boundary point locations $\mathbf{b}^{\pm 1}$ are defined by unit vectors $\mathbf{U}^{\pm 1}$ (eqn 1). Crests $\mathbf{b}^0$ are defined by an additional unit vector $\mathbf{U}^0$ and a scale factor η. The m-rep model was composed of 42 center-points arranged in a 6 row by 7 column mesh. The model was deformed to fit each SCO (Fig. 1b). A mesh regularity penalty and user-selected landmarks established spatial correspondence among models. SCO thickness at each center-point was represented by the sphere radius; bending of the m-rep mesh was measured by the z-axis height. 16- and 32-wk femoral head coverage, a measure of subluxation, and a degeneration score were available from previous research (2). No hips were dislocated. 9 hips had no femoral head cartilage biochemical abnormality (score 0); 7 had mild changes (score 1); 12 had moderate changes (score 2); 6 had a macroscopic lesion (score 3). The association of thickness and bending measures with subluxation was evaluated using hierarchical linear models. A proportional odds model was used to estimate the effect of shape on the probability of a lesion.

RESULTS:

The fitted m-rep models resulted in close approximations of the individual SCO boundaries (Fig. 1b). Greater hip subluxation at 32 wk was associated with an SCO that was thinner (smaller radius) in the ligament perifoveal region at 14 and 32 wk (p=0.015, p=0.003, respectively) (Fig. 2). An SCO that was thinner in this location also had a higher probability of a lesion at 32 wk (14 wk p=0.051, 32 wk p=0.004). Greater hip subluxation at 32 wk was associated with greater bending (greater z-axis height) of the medial mesh at 32 wk (p=0.007) (Fig. 3). An SCO with greater bending lateral to the perifoveal region also had a higher probability of a lesion at 32 wk (p=0.012). Greater subluxation resulted in greater shape changes. [Image 2][Image 3]

DISCUSSION:

The common m-rep model enabled evaluation of SCO bending and local thickness changes at corresponding spatial locations. SCO thinning occurred in the perifoveal region, which is characteristic for focal loading and lesion formation in dysplastic hips. The bend in the m-rep model mesh for subluxated hips occurred lateral to the site of SCO thinning. Our analyses show that chronic subluxation during development alters the adult morphology of the femoral head in what appears to be dose-response pattern. Measurement of SCO shape during development may improve our ability to detect hips at risk of early onset osteoarthritis.

REFERENCES:

(1) Siddiqi K, Pizer SM. Medial representations: mathematics, algorithms and applications. Klewer Academic Publishers, 2007 (2) Vanden Berg-Foels WS et al. Pediatr Res 60:549-554, 2006.

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FIGURE 1

$$m = \{\mathbf{p}, r, \mathbf{U}^{\pm 1}, \mathbf{U}^{0}\} \text{ where}$$
$$\mathbf{b}^{\pm 1} = \mathbf{p} + r\mathbf{U}^{\pm 1} \text{ and } \mathbf{b}^{0} = \mathbf{p} + \eta r \mathbf{U}^{0} \quad (1)$$

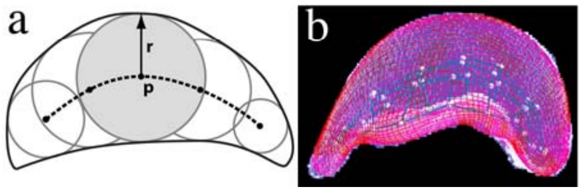

FIGURE 2

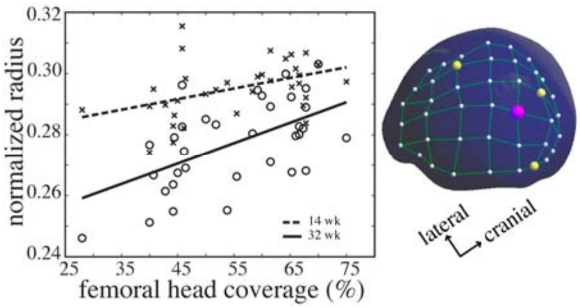

FIGURE 3

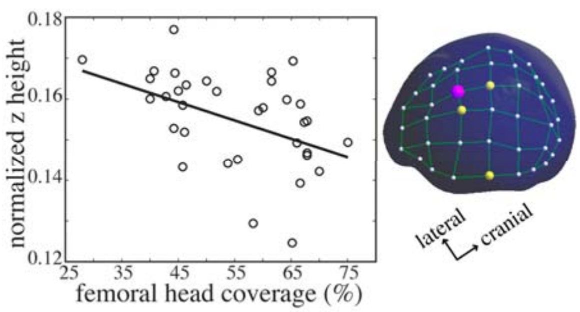

FIGURE CAPTIONS:

Fig. 1 2D schematic of m-rep model (a). SCO image with model overlay (mesh) (b).

Fig. 2 Size-normalized radius. Center-points at 32 wk with $p \leq 0.05$ are highlighted with larger colored spheres; the plotted radius is magenta. Lower femoral head coverage corresponds to greater subluxation.

Fig. 3 Size-normalized z-axis height at 32 wk. Center-points with $p \leq 0.05$ are highlighted with larger colored spheres; the plotted radius is magenta. Lower femoral head coverage corresponds to greater subluxation.