MECHANOBIOLOGY OF CONGENITAL HIP DYSPLASIA

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Introduction: Congenital dysplasia of the hip (CDH) occurs in utero when the head of the femur is displaced from the acetabular socket. During normal endochondral ossification the growth front progresses from the diaphysis towards the proximal end of the femur. The growth front is flat in the diaphysis and becomes convex around the metaphysis (Figure 1a). In the proximal femur of a child with CDH, the growth front progresses more on the medial side than on the proximal side, resulting in coxa valga. Many factors are attributed to the development of CDH including: ligamentous laxity, breech position in the womb (causing extreme flexion of the hip), a shallow acetabulum, and unbalanced muscle development. All of these conditions alter the loading on the head of the femur. When a child is young and bone growth is rapid, the developing bone is particularly responsive to mechanical loads. For nearly a century pediatric orthopedists have understood the importance of treating CDH as soon as possible to avoid deformed bone growth. Splinting is often used to ensure the head of the femur stays in the acetabulum during the early stages of growth.

Previous studies have proposed that endochondral growth and ossification is promoted by intermittent octahedral shear stress and inhibited by intermittent hydrostatic compression. Using a finite element model of the proximal femur, we examined the stresses that resulted from both normal and CDH loading conditions. From mechanobiological principles we calculated growth rates in the developing cartilage. We compared the normal and CDH cases to determine how loading conditions may predict altered bone morphology in CDH.

Methods: A 2D plane strain finite element model of the proximal femur was created and loads were applied to simulate hip joint loading for both the normal and CDH loading conditions (Figure 1). The model was composed of single phase, isotropic, homogenous cartilage hybrid elements (G=2 MPa, ν=0.49).

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\frac{d\varepsilon}{dt} = \frac{d\varepsilon_s}{dt} + a\frac{\varepsilon_m}{dt} + aMax\sigma_s + b\varepsilon_m\sigma_s
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In this analysis the biological contribution to growth was assumed constant. Octahedral shear stress (\(\sigma_s\)) is always positive and increases the specific growth rate. Hydrostatic compressive stress (\(\sigma_c\)) is negative and decreases the specific growth rate, whereas hydrostatic tension increases the growth rate. The maximum octahedral and minimum hydrostatic stress over the three loading cases was used to represent the loading history. The constants \(a\) and \(b\) were determined so that the maximum mechanobiological contribution to growth was 50% of the biological growth.

Results: Stress contours for the normal and CDH load histories are shown in Figure 2. In the normal loading condition, hydrostatic compression is fairly even across the metaphysis of the femur, while octahedral shear is maximum in the middle. This results in higher predicted growth rates in the middle of the metaphysis relative to the medial and lateral edges. In the CDH loading condition, hydrostatic compression is greater on the lateral side and hydrostatic tension in greater on the medial side. In addition, octahedral shear is greater on the medial side of the metaphysis, resulting in higher growth rates on the medial side relative to the lateral side.

Discussion: The general trend in predicted growth rates in the normal and CDH proximal femurs compared favorably with clinical observations. In a normal hip, the growth front is slightly convex when it reaches the metaphysis, with endochondral growth and ossification proceeding faster in the middle than on the medial and lateral edges. When the head of the femur is displaced from the acetabulum, the developing cartilage experiences greater shear stresses due to the altered loading. These shear stresses promote growth on the medial side and result in coxa valga. On going studies will expand these principles to a 3D model and examine the effects of altered loading conditions on anteversion angle.

Results from this study are consistent with other studies that predict the patterns of secondary ossific center formation, the effects of loading conditions on growth front morphology in the phalanx, and development of the bicondylar angle of the distal femur during bipedal gait. Understanding the role of mechanics in growth and development may lead to more efficient and effective clinical treatments for preventing bony deformities.


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