EXPLORING THE MECHANISMS OF GROWTH PLATE DEVELOPMENT AND DISEASE PROGRESSION THROUGH A DYNAMIC TRABECULAR BONE MICROSTRUCTURE MODEL

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Introduction

Growth plate biomechanics is a growing field of research that examines the mechanisms that regulate bone growth and development. The growth plate, found at the end of long bones, is responsible for longitudinal growth and is crucial for proper musculoskeletal development, and depends on mechanical and biological factors. However, growth plate injuries and diseases can disrupt normal bone growth and lead to severe complications and diseases such as slipped capital femoral epiphysis (SCFE), Legg-Calve-Perthes disease (LCPD), or Hip dysplasia (HD). This may alter the mechanical loading state in the region of the growth plate, affecting the process of endochondral growth. Advances in imaging and computational modeling provide valuable insights into the biomechanical forces and microstructural changes in the growth plate during normal growth (Moncayo-Donoso et al. 2019) and disease progression (Wilkinson and Zeggini 2021). This work presents a new model for endochondral growth that focuses on the role of trabecular groups in growth plate development. This model can aid in understanding the mechanisms of growth plate diseases and developing more effective treatments focusing on the mechanical factors involved in each developmental stage.

Methods

We developed a dynamic finite element model for growth plate development based on a bone remodeling approach that uses strain energy density as the main stimulus that controls the bone formation and resorption (Nackenhorst 1997). For the cartilaginous zones, the evolution law is based on the osteogenic index (OI) (Carter and Wong 2003) which will determine the strain ($\dot{\varepsilon}$) related to proliferation (d^p) and hypertrophy (d^h) due to endochondral growth in the growth plate. Following the evolution law shown in Eq. 1.

$$\dot{\varepsilon} = d^p + d^H = k_2 OI \qquad (1)$$

For the simulations, the domains are adopted from µCT scans and a linear isotropic model is implemented for its simplicity and under the assumption of small displacements due to the growing strains.

Results

Our model shows the evolution of the growth plate according to the mechanical action of the main trabecular groups. The evolution of the growth plate shown in mice µCT scans at different stages of development is used for validation of the dynamic model. Furthermore, the CT scans are used to test the proposed method in a 3D environment on a voxel-based domain.

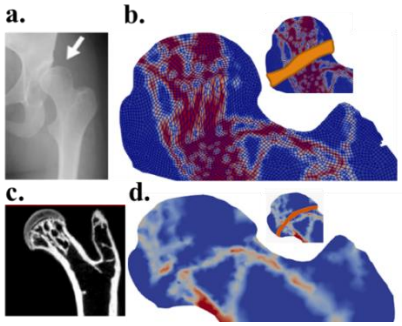

Figure 1: a) HD in a skeletally mature individual (Wilkinson et al. 2021) *b) 2D Growth plate deformation due to the action of trabecular groups. c) Model validation in mice. d) Healthy growth plate development.*

Discussion

These findings have important implications for the understanding of diseases that affect the growth plate. For example, conditions such as congenital pseudarthrosis, which is characterized by a failure of the bone to heal properly, have been linked to abnormal trabecular patterns in the growth plate in addition to SCFE, LCPD or HD. By studying the trabecular patterns of the growth plate in a dynamic model, researchers may be able to identify early markers of these diseases and develop more effective treatments for patients. Furthermore, the understanding of the trabecular patterns of the growth plate in healthy development can provide insight into the optimal mechanical environment for bone growth. For instance, by investigating the optimal trabecular patterns in healthy growth plates, clinicians may be able to develop new surgical techniques or physical therapy protocols to promote bone growth and healing in patients with growth plate disorders. Further studies will provide valuable insights into the optimal mechanical environment for bone growth and healing.

References

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