Cortical bone development under the growth plate is regulated by mechanical load transfer

CORTICAL BONE DEVELOPMENT UNDER THE GROWTH PLATE IS REGULATED BY MECHANICAL LOAD TRANSFER

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INTRODUCTION

During growth, the cortex below the growth plate emerges from trabeculae, which gradually densify towards the diaphysis. In this study, we hypothesize that the development is governed by mechanical stimuli. We also hypothesize that trabecular and cortical bone share the same regulatory mechanisms for adaptation to mechanical loads.

METHODS

We monitored the 3D development of the tibial cortex in growing pigs from 6, 23 and 230 weeks old, using micro-computer tomography (µCT, Scanco). Specimens were sawn from the posterior cortex at three levels: just below the growth plate (GP), at metaphyseal level (M), and at diaphyseal level (D). To analyze if regulation mechanisms for trabecular bone adaptation could explain cortical bone development, the tendency of cortical bone development was simulated using our mechanical stimulation theory, which could explain bone modeling and remodeling of trabecular bone (Huiskes, 2000). We assume that local dynamic loading variables (SED-rate) activate osteocytes in the bone matrix to transfer osteoblastic bone-formation stimuli to trabecular surfaces, through the canalicular network. The stimulus received at the surface depends on osteocyte density, mechano-sensitivity and signal decay by distance. Bone is formed at trabecular surfaces, where and while the stimulus exceeds a threshold value. Osteoclasts are assumed to resorb bone that is (micro)damaged, the sites of which are determined at random per iteration. Coupling between osteoclastic and osteoblastic activities in remodeling is governed by stress concentrations around resorption cavities. This scheme was implemented in a 3D Finite Element Analysis for a section of cortical bone. This was loaded in longitudinal direction with a distributed load that increased from 0 MPa endosteally to 80 MPa periosteally.

RESULTS

At 6 weeks, at GP level, the cortex consisted of trabecular bone (fig 1A). At M level, a cortex was present, but could hardly be separated from trabecular bone (fig 1B). At D level, a cortex was clearly present (fig 1C); the endosteal surface was irregular due to trabeculae merging into the cortex. At 23 weeks, at GP level, the situation was similar to 6 weeks. At M and D levels, the endosteal surface had smoothened. At 230 weeks, a porous cortex was present at GP level, in which trabeculae merged. The inner and outer cortical surfaces at M and D levels were smooth. The computer simulation model showed the tendency of cortical bone development (fig 1D-F). At increment (inc) 10, the initial homogeneous distribution of bone had developed into trabecular bone, a situation comparable with 6 and 23 weeks at GP level. At inc 40, the structure corresponded with 6 weeks at M level, and at inc 80, the structure corresponded with 6 weeks at D level and with 230 weeks at GP level.

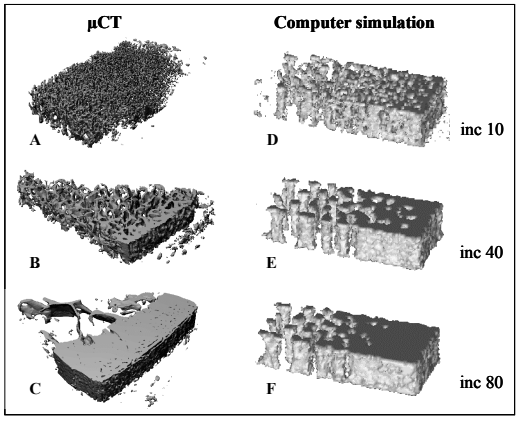

Figure 1: Results of µCT (A-C) and computer simulations (D-F) of cortical bone development.

DISCUSSION

The cortical structure changed significantly during growth. From the growth plate towards the diaphysis, the pores of the trabecular structure gradually filled in. Hence, cortex emerged from trabecular bone, suggesting that the regulation mechanisms of trabecular and cortical bone are similar. This was confirmed by the results of the computer simulation model, largely predicting this morphological development, using the same bone regulation theory that worked for trabecular bone (Huiskes, 2000). We conclude that merging of metaphyseal trabeculae under the growth plate into cortex is likely to be governed by mechanical stimuli. Further, diaphyseal cortex development of growing long bones can be explained as a form of trabecular bone adaptation, without need of different regulation mechanisms for cortical and trabecular bone.

REFERENCES

Huiskes *et al*, Nature 405:704-706, 2000.