Changes in the Functional Properties of Collagen and Proteoglycan Matrix during Rabbit Maturation: A Study Utilizing Mechanical Indentation and Finite Element Analysis

INTRODUCTION: Articular cartilage has a specific function in joints between articulating bones. External loads control its structure and composition [1,2]. The mechanical function of cartilage tissue is also closely related to tissue composition and structure [3]. These mechanical properties of articular cartilage change over age, presumably due to structural, compositional and functional adaptation to external factors, as well as due to biological phenomena.

In the present study, our objective was to assess the mechanical role of specific cartilage constituents (i.e. collagen and proteoglycans (PGs)) for the development and maturation of cartilage and its function. For this, we combined mechanical tests of articular cartilage and finite element (FE) analysis.

METHODS: Samples were harvested from tibial (n=89) and femoral (n=91) medial condyle of female New Zealand white rabbits. Seven different age groups were studied; newborn, 11 days, 4 weeks, 6 weeks, 3 months, 6 months and 18 months. Samples were tested mechanically under indentation (0-0.544mm) loading with 2-step creep compression. Step-wise creep-load of 0.04N was applied after a pre-load of 0.01N with 15μm/s ramp loading rate and equilibration time of 1800s per step. From the indentation tests, isotropic instantaneous (E_{iso}) and equilibrium modulus (E_{eq}) were determined [4]. When computing E_{iso}, Poisson’s ratio of 0.15 was assumed [5], and when computing E_{eq}, assuming tissue incompressibility, Poisson’s ratio of 0.5 was used [6]. A needle probe technique was used for measurement of cartilage thickness (b) [7].

Results: We found that significant (p<0.001) development in the mechanical properties of rabbit articular cartilage occurred during maturation (Fig. 2). The development in functional tissue properties exhibited similar behavior in both joint locations. The equilibrium mechanical properties, mostly resulting from the effects of PGs, increased linearly and significantly (p<0.001) over age. In the early age, the instantaneous mechanical properties increased as well. However, between 6 weeks and 3 months age in the rabbits, there was a significant decrease (p<0.001) in the instantaneous modulus of the tissue. Through FE analyses, this result was found to be related to fibril network modulus.

DISCUSSION: We found that significant alterations occur in the dynamic (instantaneous) mechanical properties at between 6 weeks and 3 months age in rabbit articular cartilage. FE analyses indicated that these changes in the functional properties of the tissue were related to the changes in the mechanical properties of the collagen network. We hypothesize that these mechanical changes occur due to remodeling of the collagen network architecture, which highly affects the mechanical properties of the bulk tissue [9]. However, this still requires verification with the polarized light microscopy, a technique capable to assess the collagen network orientation. The present findings are important for understanding the mechanical adaptations that occur in the cartilage structure during maturation.

REFERENCES: