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Nanoscale topographical characterizations and biomechanical properties of bone-cartilage unit during the spontaneous osteoarthritis

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***Abstract*—This study aims to obtain the nanoscale variations of topographical and mechanical properties of articular cartilage (AC) and subchondral bone (SB) in the knee joint of guinea pigs from the early to moderate osteoarthritis (OA) and to investigate how the mechanical properties and topographical parameters in AC and SB relates to OA level. Male Dunkin Hartley strain guinea pigs were grouped according to age (1, 3, 6, and 9 months, with 10 rats in each group). The topographical characterizations and mechanical properties of the AC and SB in the tibial plateau of the guinea pigs were determined through atomic force microscopy and nanoindentation. In addition, the structure of collagen in AC was observed by histological and Immunofluorescence analyses. Our findings indicated that the indentation moduli and hardnesses of the subchondral bone plate (SP) and subchondral trabecular bone (ST) in the tibial plateau of 3-, 6-, and 9-month-old guinea pigs increased compared with those of 1-month-old guinea pigs. There was no significant difference between the 1- and 3-month groups in the mean roughness of the ST. The roughness of AC exhibited a higher correlation with OA score than those of SP and ST. The moduli of SP and ST had significant correlations with OA score (r = 0.6610, r = 0.7390, respectively; $P < 0.001$). This study indicated that the quantitative surface characterization results may be utilized to develop an objective OA assessment method for clinical application and assist in the cartilage tissue engineering.**

***Clinical Relevance*— Quantitative surface characterization may supply new perspectives for the development of an objective OA assessment method for clinical application and assist in cartilage tissue engineering. However, deeper insight into the mechanism of interaction between bone and cartilage is required for additional future clinical investigation. Although the mechanical properties of AC were not determined in this study, promising results were obtained for the nanoscale surface topography and mechanical properties of the SB.**

I. INTRODUCTION

Surface topography and mechanical property of articular cartilage (AC) play an important role in its lubricating property and the capacity of resisting compressive loads during the process of joint movement. Clinically, topographical variation of AC at the macroscale has been used for osteoarthritis (OA) assessment and diagnosis based on the fact that the earliest pathological variations in cartilage appear on the articular surface caused by the deterioration of cartilage solid matrix. Besides AC, studies suggested that the subchondral bone (SB) might also be involved in the pathogenesis of OA since the increases in SB thickness causes bone sclerosis in late-stage OA[1-2]. However, to the best of our knowledge, the understanding of nanoscale mechanical properties across the osteochondral region was limited, which restricts the ability to understand the disease progression and engineering replacement materials. Therefore, the objective of our study was to assess topographical and mechanical characterization variations in AC of DH guinea pig knee in relation to OA stages, specifically focusing on the surface roughness. Another aim was to relate the changes observed in the surface topography and mechanical characterization of the cartilage to variations in those of SB.

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II. METHODS

Forty male DH strain guinea pigs aged 1, 3, 6, and 9 months (n = 10/each age group) were sacrificed via intraperitoneal injection of 100 mg/kg pentobarbital. Left knee joints were fixed in 4% paraformaldehyde (PFA) for 24 h and prepared for histological and Immunofluorescence analyses. Right knee joints were stored at −20 °C prior to the atomic force microscopy (AFM) and nanoindentation tests.

The mean roughnesses of the SP in the tibial plateau of 3-, 6-, and 9-month-old guinea pigs were found to significantly increase compared with that of 1-month-old guinea pigs ($p < 0.001$). There was no significant difference between the 1- and 3-month groups in the mean roughness of the ST. In addition, the mean roughnesses of the ST in the tibial plateau of 6-, and 9-month-old guinea pigs were found to increase compared with that of 1-month-old guinea pigs ($p < 0.001$). The moduli and hardnesses of SP had significant correlations with OA score (r =0.6610, r = 0.3870, respectively; $P < 0.001$). The increased OA score was significantly correlated with the modulus of ST (r = 0.7390, $P < 0.001$). The roughnesses of SP, ST and AC were significantly correlated with OA score (r = 0.5200, r = 0.5210, r = 0.8800, respectively; $P < 0.001$).

III. DISCUSSION & CONCLUSION

Surface topographies and mechanical characterizations of bone-cartilage unit were characterized at nanoscale in guinea pigs during the progression of spontaneous OA. The quantitative surface characterization results may be utilized to develop an objective OA assessment method for clinical application and assist in the cartilage tissue engineering. Moreover, the contribution of altered biomechanical changes may be more significant than those of increased bone matrix roughnesses of SP and ST, which may finally influence the composition of AC.

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