Integrated analysis system of trabecular bone considering micro/nano scale characteristics

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A diagnosis of osteoporosis is now performed by the measurement of bone mineral density. To consider the bone strength, however, it is important to analyze the microscopic stress accurately under macroscopic loading condition considering furthermore micro/nano scale characteristics, which include the trabecular architecture at microscale and biological apatite (BAp) crystallite orientation at nanoscale. They are supposed to determine the bone quality.

Hence, in this study, the microstructure model is obtained by μCT images by means of the image-based modeling technique. It is analyzed by the homogenization method considering the BAp crystallite orientation to obtain the equivalent macroscopic material properties. The microscopic stress in trabeculae is analyzed by the mesh superposition method using the above macro and micro models under macroscopic boundary conditions. The originality lies in the use of the mesh superposition method together with the conventional homogenization method to overcome its theoretical limitation. Especially, a new microstructure modeling method with insulation elements whose material properties are the calculated equivalent macroscopic ones is proposed and its theoretical validity is shown. This leads to the microscopic stress analysis under arbitrary macroscopic loading condition. In addition, the microscopic modeling based on the morphology analysis that evaluates the heterogeneity and periodicity is proposed. In the evaluation of microscopic stress, a three-dimensional visualization method of principal stress vector within the model and a new histogram that quantifies the stress distribution are proposed.

An integrated analysis system has been developed with the above morphology analysis, multi-scale stress analysis and also new customizable GUI, so that the medical doctors can easily use to fit for the purpose of analysis or medical specialty.

The developed system has been applied to quail's bone, pig's bone and human vertebra, and its effectiveness has been shown.