

## Comments on application of optimization in bone mechanics

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a) Bone-mechanics is a very important subject which must be subjected to intensive research for many years to come. We should attack the problems with all the up-to-date tools available, i.e. extensive FEA (finite element analysis), advanced experimental technique at the micro-level, optimization formulations and tools, identification techniques, long term observations. There is no meaning in abandoning some of these tools.

b) The modelling for FEA must be three dimensional, due to the fact that two dimensional models are too restrictive. In the light of improved computer facilities extensive 3D modelling is possible.

c) Static FEA are necessary to obtain homogenized material quantities and study the influence of micro-structures.

d) Long term simulations by FEA are necessary to model the re-modelling of bone, to be tested against experimental observations. With this tool and improved modelling, the response to change in load or reactions to implants might then be estimated.

e) In relation to these simulations and observations, interesting identification (estimation) of parameters can be solved using optimization procedures. Find the parameters (the model) that minimize the difference between observations and simulations.

f) Like 3D is a must, so is a formulation in time. Loads and bone are time dependent, and it make little sense to deal with combinations of loads. At any time there is one and only one load situation. The re-modelling at any time may however also depend on the history (recent history) of loads, In a similar manner the sensing may also be non-local. However, models for time history influence as well as space non-local influence can be formulated.

g) With non-isotropy, a local measure of energy density must be more reasonable than a measure of strain or stress. Note, that stiffness and strength are independent quantities, although sometimes good stiffness also give good strength. However, in certain cases good strength can be obtained by actually removing material and decreasing the stiffness.

h) Optimization formulations in bone-mechanics has a broad range of applications, in particular in relation to re-modelling. So at any time step in a simulation, an optimization model is formulated and solved. Note, that advanced optimization models must include a number of constraints, and learning by doing the models must be improved.

i) These phenomenological models, that are tested against observations, will also be influenced by the increasing understandings obtained on the micro levels, from FEA analysis and

experiments.

j) Optimal re-modelling can be formulated as shape optimization (surface) as well as size optimization (density), and combination of these. In addition the orientational re-modelling is important, either in a macro sense controlled by principal stresses or in a micro sense by changes in homogenization results.