

Optimisation Algorithms in Biomechanics

A contribution to discussion on

by

R. Contro and P. Vena

Laboratory of Biological Structure Mechanics (LaBS) and Department of Structural Engineering
Politecnico di Milano
Piazza Leonardo da Vinci, 32 – 20133 Milano - Italy

Multidisciplinary optimisation is an important source of concepts and methods which can be extended successfully to biomechanics and to other closely related fields, like biomaterials and tissue engineering. The optimisation theories can be considered under different points of view, characterized by similar mathematical tools but leading to techniques often denoted or known with different locutions. Each of these theories are able to solve specific problems in the field of biomechanics. Among some aspects of the optimisation theories, already put in evidence as relevant and effective for biomechanics, such as the issue of the relationship between optimisation and modelling an remodelling of biological tissues, according to our experience we would like to draw the attention of the optimisation and biomechanical communities on particular approaches of certain common interest.

The most important of these approaches, for the wide role played in several biomechanical problems, is known as **inverse problem**. Very often in biomechanics not only material parameters are unknown because, differently from usual solid mechanics, they cannot be measured, but also boundary conditions, both static and kinematical, can be defined only as a part of the living body system to which they belong. This kind of **identification problems** is crucial if we want that the results obtained by refined finite element analyses be appreciated by medical doctors, because they are able to realize that the accuracy of a computational model can be vanished by inaccuracy of the boundary conditions of certain physiological environment. If parameter identification techniques are to be used a particular care must be assumed in designing the laboratory tests which are more suitable to identify unknown parameters. Seeking objective functions which exhibit significant sensitivity to the design variables is not trivial because of complexity of phenomena involved, difficulty to model them and the random properties, depending on the patient and on the state of health, on the natural tissues. These are characterized by very complicate physical and geometrical arrangements of microstructural components, non uniform density distribution, ‘inter-subjects’ variations, strong temperature and time dependences usually combined. Constitutive nonlinearity and viscosity are mandatory features to taken into account absolutely.

Optimisation as frame mathematical for **optimal design** concerns both **prostheses and biomaterials**. When designing a prosthetic device one should consider that the human part to be replaced was optimal in the natural healthy conditions. This means that to reproduce its natural functions as much as possible a new optimal design has to be searched for under constraints which simulate the desired functionality allowed by the artificial materials used, namely biomaterials that in turn should be designed.

The increased capability to manufacture biomaterials with a refined control at the smallest length scale (macro- or nanotechnology), gives to the concept of material design new and very promising perspectives. For designing biomaterials their required performances are suggested by biomechanical, clinical and biological considerations.

For example, the required performance for the artificial ligament concerns mainly the mechanical stiffness, strength and fatigue. These properties have to be similar to those of the natural ligaments to replace. An artificial ligaments made of composite material has been considered by the Authors in one of their recent research. The device consists of a tube of polymeric matrix reinforced with PLLA fibers helically oriented. Mechanical properties of each component and the 3D distribution of

the reinforcement have been investigated and the resulting overall mechanical property were compared to that of natural ligaments. This is relatively simple problem due to the simplicity of the structure under consideration.

A more sophisticated problem can be the case of the graded coatings. The required performance for the graded coating can be the mechanical strength and the wear resistance whereas the constraint of the design problem are given by biocompatibility considerations. The design of the graded properties in terms of distribution of material components along the thickness of the coating could in principle be obtained by optimising the material properties in a such a way to satisfy the requirements and the constraints.

A common feature to these problems is the complexity of the models needed to reproduce the physical systems. In particular for mechanical systems, the complexity is given by the constitutive laws and by the complex anatomical configurations (consider for example to the complex geometry of a cruciate ligament in the knee). These features makes the problem a demanding task in terms of computational resources and modelling efforts. In this case the optimisation approach to the material and device design can be undertaken only if an efficient and versatile algorithm is available able to handle complex systems and time consuming models.

Design problems of biomaterials even more difficult to formulate in form of explicit objective functions, state equations as process constraints and related sensitivities, occur when design variable have to be determined as parameters that influence chemical-physical processes.

Let us give just two examples of this kind, which we are dealing with.

1) Drugs delivery materials are porous materials whose time of delivering is prescribed by the therapeutic action of the pharmaceutical species and depends on the material porosity and on its chemical physical interaction with the above pharmaceuticals. So which porosity, eventually modified by barriers given by polymeric hydrogels, should be designed to guarantee the prescribed delivering time?

2) One technique to produce Functional Graded Materials, strongly recommended for certain articulating prostheses where biocompatibility and low friction must given on the opposite sides, is *tape casting*. By means of this technique several thin strips of different ceramics embedded in a polymeric matrix are overlapped and then sinterized at high temperature to get a unique graded material without internal discontinuities as it happens into traditional composites. Again which process parameters should be selected to obtain the desiderated material properties?

This last research, performed in collaboration with Researchers of the University of Trento, expert in technology of ceramic materials, as all the above ones, relies on three phases: correct understanding of the phenomenon to be modelled, their modelling and related optimum problem formulation, as identification or design problem, development of efficient and robust optimisation algorithms able to be linked to the complex models required by biomechanics and related branches of biomaterials and biological tissues and related scaffolds.