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Computational strategies for modeling bone fracture healing: a tool for the design of osteosynthesis implants

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ABSTRACT

Bone fracture healing is one of the most fascinating regenerative processes in biology, which is mainly regulated by the mechanical factors. Indeed, this process is normally selected as one of the best examples in medicine for explaining the concept of mechanobiology. Therefore, mechanical stabilization of the fracture gap plays a relevant regulative role on the final outcome of the bone healing. Hence, the effect of different mechanical conditions have been analysed in multiple experiments. Computational simulations are a very useful tool to unravel the mechanical influence on bone healing and also define the best mechanical conditions for patient-specific bone fractures. In fact, the authors of this work proposed in a previous work [1] the application of an external mechanical stimulus in the fracture gap, based on a high-frequency and low-magnitude cyclical displacement. This stimulus was defined by means of numerical simulations based on a mechanobiological modelling approach, where tissue differentiation is regulated by means of fluid flow and deviatoric strain. This stimulus was later applied in-vivo in tibia fractures of sheep, clearly, achieving a significant acceleration of the bone healing process. Therefore, in silico modeling has demonstrated its potential as a tool for designing a specific treatment. Two predominant approaches have been developed to simulate bone fracture healing: the phenomenological and the mechanobiological. The phenomenological strategy is a simplified approach that fits specific modes of regeneration under simple controlled mechanical conditions through mathematical laws, that later can be extrapolated to more complex conditions. However, mechanobiological approaches try to incorporate all the main components that comprise the new tissue, particularly the solid phase of the extracellular matrix, the fluid phase, the cells and the biochemical molecules. In the case of mechanobiological models, two approaches are normally used: continuum or multiscale, depending on the length scale on which these components are acting. In any case, the mechanobiological approach is normally used to understand how the cells sense the mechanical stimuli and adjust their response in order to restore the mechanical function of the broken bone. However, these models are not yet affordable for the simulation of realistic bone fractures, which present very different shapes of the fracture line, complicated anatomical locations and several number of fracture fragments. Therefore, the use of computational simulations for the design of osteosynthesis implants requires the development of novel numerical strategies that combine phenomenological simplicity and mechanobiological detail of both approaches.

REFERENCE

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