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FOUR DECADES OF FINITE ELEMENT ANALYSIS OF ORTHOPAEDIC DEVICES: WHERE ARE WE NOW AND WHAT ARE THE OPPORTUNITIES?

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Abstract

Finite element has been used for more than four decades to study and evaluate the mechanical behaviour total joint replacements. In Rik Huiskes seminal paper "Failed innovation in total hip replacement: Diagnosis and proposals for a cure", finite element modelling was one of the potential cures to avoid poorly performing designs reaching the market place. The size and sophistication of models has increased significantly since that paper and a range of techniques are available from predicting the initial mechanical environment through to advanced adaptive simulations including bone adaptation, tissue differentiation, damage accumulation and wear. However, are we any closer to FE becoming an effective screening tool for new devices? This review contains a critical analysis of currently available finite element modelling techniques including: i) development of the basic model, the application of appropriate material properties, loading and boundary conditions ii) describing the initial mechanical environment of the bone-implant system iii) capturing the time dependent behaviour in adaptive simulations iv) the design and implementation of computer based experiments and v) determining suitable performance metrics.

The development of the underlying tools and techniques appears to have plateaued and further advances appear to be limited either by a lack of data to populate the models or the need to better understand the fundamentals of the mechanical and biological processes. There has been progress in the design of computer based experiments. Historically, FE has been used in a similar way to in vitro tests, by running only a limited set of analyses, typically of a single bone segment or joint under idealised conditions. The power of finite element is the ability to run multiple simulations and explore the performance of a device under a variety of conditions. There has been increasing usage of design of experiments, probabilistic techniques and more recently population based modelling to account for patient and surgical variability. In order to have effective screening methods, we need to continue to develop these approaches to examine the behaviour and performance of total joint replacements and benchmark them for devices with known clinical performance.

Finite element will increasingly be used in the design, development and pre-clinical testing of total joint replacements. However, simulations must include holistic, closely corroborated, multi-domain analyses which account for real world variability.