Abstract

Failure mechanisms, such as implant-induced adverse bone remodelling, excessive implant-bone interface stresses and lack of primary stability, are known to affect the outcome of cementless Total Hip Arthroplasty (THA). These failure mechanisms are reported to be influenced by the design of femoral implant. Employing shape optimization as pre-clinical design tool, stem geometries can be evaluated based on these failure objectives. However, the biomechanical causes of failure may sometimes be mutually conflicting. Therefore, it is necessary to implement multi-objective shape optimization scheme to tackle the design conflict and subsequently, attain trade-off designs by compromising on the design objectives. An experimental study using digital image correlation (DIC) was first carried out in order to develop and validate reasonably accurate 3-D finite element (FE) models of intact and implanted femurs. The FE models of the intact and implanted femurs were developed by replicating the orientation, loading and boundary conditions of the tested specimens. A close agreement between measured and predicted strains confirmed the suitability of the FE model generation procedure. Using a patient-specific femur and an initial design of TriLock (DePuy) hip stem, a fully-automated 3-D multi-objective shape optimization scheme, comprising of a parameterized CAD module, FE analysis and genetic algorithms (GA) was developed, based on minimization of bone remodelling and interface stresses. The optimal stem geometries (OSGs) were found to be narrower and more bone preserving as compared to the initial (TriLock) design. A back-propagation neural network (BPNN) was developed for faster prediction of primary stability of cementless implants based on implant geometry. Using the BPNN-predicted output as the objective function, a GA-based search was performed to minimize post-operative implant-bone relative micromotion. The study favoured lateral-flared designs having rectangular proximal transverse sections and greater stem-sizes for improved stability. Further compromised designs of femoral implants were sought in a multi-objective optimization study by introducing a novel hybrid intelligent framework for simultaneous minimization of bone remodelling, interface stresses and micromotion. The trade-off stem geometries (TSGs) predicted favourable load transfer and more improved fixation as compared to the TriLock and OSGs. Finally, a comparative assessment between a trade-off model and the TriLock stem was carried out, based on the combined effect of bone ingrowth and remodelling. The trade-off model predicted reduced proximal remodelling as compared to the TriLock stem. The bone ingrowth configurations were found to be similar for both designs, although the trade-off design predicted slightly superior bone ingrowth at immediate post-operative stage.

Keywords: femoral implant, cementless, digital image correlation, *in vitro* testing, finite element analysis, shape optimization, multi-objective optimization, stress shielding, bone remodelling, interface stresses, genetic algorithm, neural network, implant-bone micromotion, osseointegration.