Abstract

Micromechanics of the Cement-Bone Interface and Its Consequences on Failure of the Complete Cemented Hip Reconstruction

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In cemented total hip arthroplasty, the cement-bone interface can be considerably degraded in less than one year in-vivo service (Figure 1). This makes the interface much weaker relative to the direct post-operative situation. Retrieval studies show that patients do, to a certain extent, not suffer from the degraded cement-bone interface itself. It is, however, unknown whether the degraded cement-bone interface affects other failure mechanisms in the cemented hip reconstruction. A good understanding of the mechanics of the cement-bone interface is therefore essential. The aim of this study was to investigate the mechanics of the cement-bone interface in the direct post-operative and degraded situation by the utilization of finite element analysis (FEA) and laboratory experiments. It was subsequently analyzed how the mechanics of the cement-bone interface affect failure of the cement mantle in terms of crack formation.

In order to investigate the mechanical response of the cement-bone interface, laboratory prepared (direct post-operative state) and postmortem (degraded state) specimens were loaded in various directions in the laboratory and FEA environment. From all specimens, multiple interface morphology parameters were documented, which were related to the interfacial response and subsequently converted to a numerical cohesive model. As a validation, this cohesive model was implemented into two FEA models of transverse sections of cemented hip reconstructions with distinct mechanical characteristics (Figure 2). Finally, the differences in fatigue crack formation in a complete hip reconstruction were determined by varying the cement-bone interface compliance (Figure 3).

When loaded in multiple directions, the interface compliance could not be related to the cement interdigitation depth ($r^2=0.08$). However, compliance did correlate to the gap thickness between the bone and cement ($r=0.81$) and the amount of interfacial contact ($r=0.50$). Surprisingly, for the same amount of contact, the interface was more compliant in degraded state than in the direct post-operative state. The mechanical response of the experimental and FEA cement-bone interface tests could, independent on the direct post-operative or degraded state, successfully be described by a cohesive model. The cohesive model was even more confirmed by the successful reproduction of the mechanics of the retrieved transverse sections. When the cohesive model was implemented in a complete reconstruction, we found that a compliant cement-bone interface resulted in considerably more fatigue cracks in the cement mantle than a very stiff interface.
This study showed that an increased compliancy of the cement-bone interface results in an increase of cement cracks in the cement mantle. It is therefore crucial to minimize the interfacial gaps and, as a result, increase the amount of contact between the bone and cement to generate a stiff cement-bone interface. It is, unfortunately, unknown how this well fixed interface can be maintained. We finally conclude that the derived cohesive model of the cement-bone interface can be used for multiple applications in orthopaedics, including pre-clinical of implants and patient specific studies of failed cemented reconstructions.