ANCHORAGE OF ORTHOPAEDIC PROSTHESES:

Influence of bone properties and bone-implant mechanics

L. R. RAKOTOMANANA, A. TERRIER N. A. RAMANIRAKA, P.-F. LEYVRAZ
Hôpital Orthopédique de la Suisse Romande, Lausanne - Laboratoire de Génie Médical, EPFL, 1015 Lausanne, Switzerland

1. Introduction

1.1. FAILURE MECHANISMS AT BONE-IMPLANT INTERFACES

After cemented THR, failures at stem-cement interface and at bone-cement interface mainly resulted from the occurrence of abnormally high cement stresses and excessive micromotions (e.g. Jasty et al., 1991, Gardiner and Hozack, 1994). High compressive stress was source of cement fracture and enhanced the stem subsidence (e.g. Phillips et al., 1990) while excessive slipping enhanced the creation of cement debris (e.g. Rothman and Cohn, 1990). Bone-cement slipping led to a necrosis of bone that inter-digitize with the cement while the stem-cement debonding might induced the stem loosening (e.g. Harris, 1992) and peri-prosthetic osteolysis (e.g. Burke et al., 1991). The coupling effects between the two interfaces are complex. Increasing the stem roughness influence not only the shear friction at the stem-cement interface but also promotes the bone-cement failure (e.g. Gardiner and Hozack, 1994). In parallel, evidence of the effects of cement thickness has been observed either clinically or experimentally (e.g. Ebramza-deh et al., 1994).

After cemented TKR, aseptically loosening of the tibial component remains one of the failure causes in Total Knee Replacement (TKR) (e.g. Windsor et al., 1989). Analysis of interfacial membranes surrounding aseptically loose tibial component pointed out the presence polyethylene, metallic and cement debris (e.g. Chiba et al., 1994). These debris were mainly produced by wear between femoral component and articulating tibia and by wear and fragmentation of cement. Loosening generally occurred either at the bone-cement interface for the cemented prostheses (e.g. Walker, 1977). Among different factors, the non symmetrical distribution of stress transfer (e.g. Hsu et al., 1989) between the implant and tibia constitutes the major cause of aseptic loosening.
1. **BONE PROPERTIES AND QUALITY OF ANCHORAGE**

It is well established that varying degrees of bone density result in varying elastic moduli and strength of both the compact and spongious bone (e.g. Carter and Hayes, 1976). Indeed, porotic spongious bone cannot be relied upon to well support orthopaedic prosthesis for loading joints as knee and hip. After cemented THR, the stress shielding (understressing of proximal femur following the femoral stem implantation) is recognized to induce proximal bone resorption (Korovessis et al., 1994) and is thought not limiting directly the longevity of cemented femoral stems. However, analysis of stress and micromotions in presence of bone remodelling has shown the coupling effects between stress shielding and stem instability (e.g. Terrier et al., 1997).

After TKR, bone properties has been shown to play an important role in the biomechanics of tibial component anchorage. The seek of bone quality for implant leaning is pursued by the care of tibial component positioning (e.g. Lemaire et al., 1997) and the tibial resection (e.g. Bloebaum et al., 1994). Porotic spongious bone could accelerate the sinking and tilting of tibial plateau. In parallel, accounting for continuously varying bone density and anisotropy is important. Magnitude of compressive stress under the tibial component for anisotropic bone model may be four times higher than stress magnitude when bone is assumed to be isotropic (e.g. Rakotomanana et al., 1994). This may lead to wrong conclusion for stress analysis. Therefore, the accuracy of numerical analysis of tibial component anchorage depend sensibly on the bone model assumption.

1. **GOALS OF THE STUDY**

From this brief review, a model of cemented anchorage should account for the bone quality and interface properties. Despite numerous numerical models on cemented interfaces (e.g. Harrigan and Harris, 1991; Verdonchot and Huiskes, 1996-1997) and bone remodelling around implants (e.g. Weinans et al., 1994), the study of the coupling effects of the interface mechanics and long term bone properties seems to be missing. The purpose of this work was to develop a model to investigate the short term and long term fixation of various cemented orthopaedic implants. The model is based on a bone constitutive law including inhomogeneity, anisotropy and bone adaptation; and an interface model based on unilateral contact mechanics for the two interfaces (bone-cement; cement-implant).

2. **Basic theory**

2. **MODELLING OF CEMENTED INTERFACE: CONTACT MECHANICS**

For cemented implants, two interfaces should be considered (bone-cement, cement-prosthesis). For each of them, the local relative micromotion is usually decomposed in a normal micromotion (debonding) and in shear micromotions (slipping). The contact stress vector from implant to bone is split into contact pressure and frictional