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Hemiarthroplasty of hip joint: An experimental validation using porcine acetabulum

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ABSTRACT

Biphasic properties of articular cartilage allow it to be an excellent bearing material and have been studied through several simplified experiments as well as finite element modelling. However, three-dimensional biphasic finite element (FE) models of the whole joint are rare. The current study was carried out to experimentally validate FE methodology for modelling hemiarthroplasty. Material properties such as equilibrium elastic modulus and permeability of porcine acetabular cartilage were initially derived by curve-fitting an experimental deformation curve with that obtained using FE. These properties were then used in the hemiarthroplasty hip joint modelling. Each porcine acetabular cup was loaded with 400 N using a 34 mm diameter CoCr femoral head. A specimen-specific FE model of each acetabular cup was created using μCT and a series of software processes. Each model was analysed under conditions similar to those tested experimentally. Contact stresses and contact areas predicted by the model, immediately after loading, were then compared with the corresponding experimentally measured values. Very high peak contact stresses (maximum experimental: 14.09 MPa) were recorded. A maximum difference of 12.42% was found in peak contact stresses. The corresponding error for contact area was 20.69%. Due to a fairly good agreement in predicted and measured values of contact stresses and contact areas, the integrated methodology developed in this study can be used as a basis for future work. In addition, FE predicted total fluid load support was around 80% immediately after loading. This was lower than that observed in conforming contact problems involving biphasic cartilage and was due to a smaller local contact area and variable clearance making fluid exudation easier.

1. Introduction

The hip joint experiences high levels of contact stress during activities of daily living which play an important role in the tribology of the cartilage (Hodge et al., 1986; Katta et al., 2009) and its degradation (Hadley et al., 1990; Maxian et al., 1995; Mavcic et al., 2002). These stresses can be so high that they have the potential to induce several complications in the joint such as excessive wear of the cartilage (Katta et al., 2009; McCann et al., 2009). Moreover, under-loading can also have an adverse effect on the cartilage (Harrison et al., 1953). The contact stresses also show the load distribution within the articulating surfaces which may give an indication of the areas of cartilage that are most susceptible to breakdown. Moreover, when contacting cartilages move against each other, frictional shear stresses are induced and this may increase contact stresses and/or the coefficient of friction. In spite of this, cartilage displays remarkable tribological properties with a very low coefficient of friction and wear, and usually survives the lifetime of a person.

Usually, when only the femoral head cartilage breaks down, hemiarthroplasty can be performed (Ilfeld, 1953; Devas and Hinves, 1983; Phillips, 1987). However, any changes to the natural joint due to interventions such as hemiarthroplasty can have an adverse effect on the contact mechanics and tribology of the joint and may affect the survivorship of the cartilage.

Several clinical (Hodge et al., 1986; Catani et al., 1995; Krebs et al., 1998; McGibbon et al., 1999; Morrell et al., 2005) and laboratory (Brown and Shaw, 1983; Afoke et al., 1987; Macirowski et al., 1994; von Eisenhart-Rothe et al., 1997) studies have addressed cartilage contact mechanics in the hip joint. Such studies face several challenges; the scarcity of human cadavers and unwillingness of human subjects to be implanted with instrumented prosthesis. Moreover, it is impractical to conduct parametric studies using an experimental or clinical approach.

Analytical and finite element (FE) methods are thus used. Although, they are excellent non-invasive tools for understanding the mechanical and functional aspects of the joint and are

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