Impaction Loads During Insertion Of Hip Resurfacing Implant: A Finite Element Study

Michael C. Hogg¹, Lawrence Kohan², Richard Appleyard³, Ronald M. Gillies¹-²

¹WorleyParsons Advanced Analysis, Sydney, NSW, Australia; ²Orthopaedics & Traumatic Surgery, University of Sydney, Royal North Shore Hospital, Sydney, NSW, Australia; ³Joint Orthopaedic Centre, Sydney, NSW, Australia
dane.dabirrahmani@worleyparsons.com

Introduction: Hip resurfacing (HR) using metal-on-metal bearings was largely abandoned in the 1980s because of disappointing early results due, in part, to poor machining tolerances. With the increasing numbers of younger patients undergoing hip replacement, the focus of recent studies has been shifted to developing bearings that operate near the fluid film end of the mixed lubrication regime or within the fluid film lubrication regime. Such implants have much lower wear rates due to the lower friction associated with these lubrication regimes. It has been shown both experimentally and theoretically that hard bearing surfaces, such as metal-on-metal implants, do operate in the mixed and possibly the fluid films during normal gait [1]. The parameters of such implants responsible for achieving fluid film lubrication are a large femoral head diameter, small radial clearances and accurate manufacturing processes to achieve good sphericity and smooth surface finishes. The ability to now improve the manufacturing tolerances has lead to a resurgence in the use of metal-on-metal HR implants. The Australian National Joint Registry (2004) states, in the years 2002-December 31st 2003, that 3703 hip resurfacing procedures were performed. The revision rate was 1.9%, of which 67% were due to femoral neck fracture [2]. A better understanding of implant insertion procedure may help in understanding the early femoral neck fractures that have occurred. This study has investigated the impact loads associated with hip resurfacing surgery at the hammer, implant impactor and implant using the finite element method with comparison to experimental data acquired during surgery.

Materials and Methods: A model consisting of the hammer, impactor and reconstructed femur was created as shown in Figure 1. The native femur geometry was generated from computed tomography (CT) images using commercially available software. The hip resurfacing implant was placed on the native femur which was also cut distal to the lesser trochanter such that only the proximal femur was modeled. A finite element mesh was then generated using this geometry. The implant and implant were both meshed with first order reduced integration hexahedral elements and the femur was meshed using second order tetrahedral elements. The hammer was represented by a point mass weighing 1.5kg tied to the face of the hammer which was modeled as a rigid surface. The impactor consisted of a stainless steel handle (E=200GPa, ν=0.3, ρ=7850kg/m³) and UHMWPE head (E=1GPa, v=0.45, ρ=940kg/m³). The resurfacing implant was titanium alloy (E=115GPa, v=0.34, ρ=4500kg/m³). The femur was locally isotropic with linear-elastic material properties based on the Hounsfield unit (HU) values from the CT images. This involved mapping the HU values to the element centroid using an apparent bone density range of 0.1-1.8g/cm³ divided into 100 discrete density bands. All elements in the bone were grouped according to these density bands and subsequently assigned elastic modulus values calculated from the apparent bone density using the relationship suggested by Carter & Hayes [3] with a strain rate of 1.0s⁻¹ [4]. Poisson’s ratio of ν=0.3 was used for the femur for all density value bands. The general contact formulation available in ABAQUS/Explicit was used on all surfaces with the exception of the contact between the implant and impactor head where a pure master-slave surface-to-surface contact formulation was used. A friction coefficient of μ=0.1 was specified for contact between the implant and impactor head, μ=0.9 between the implant and bone and μ=0.3 elsewhere. The proximal femur was fixed distal to the lesser trochanter to prevent translations. All parts of the model were initially touching and the hammer was given an initial velocity of 1m/s directed along the axis of the impactor. The analysis was run for a period of 5ms using ABAQUS/Explicit (ABAQUS, Inc., Providence, RI, USA).

Results: The main outputs included the force between the hammer and impactor, the force between the impactor head and implant, and the reaction force at the base of the femur. These results, shown in Figure 2, indicate that contact between the hammer and impactor occurs four times for a single hammer swing. The peak magnitude of this hammer force was approx 34.1kN. Due to energy losses in the system, the forces between the other components were much less, with a maximum of 1.93kN between the impactor head and implant and 1.4kN at the base of the femur.

Discussion: The peak force on the hammer was approx 36% higher than the 25kN force measured experimentally by Kohan et al [5], which may be attributed to the simplified representation of the hammer. Forces on the bone may be overestimated by the omission of soft tissue layer and the short length of femur considered. Nonetheless, forces experienced by the bone are much lower than those occurring in regular daily activities such as walking and stair climbing. Consequently the insertion procedure is unlikely to cause bone damage leading to future femoral fracture.