The Effect of Component Placement on Joint Loading and Contact Stress of Resurfacing Arthroplasty of the Hip

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Introduction
Precise biomechanical reconstruction of the hip joint by a hip replacement is essential for the success of the procedure. Whether this can be best achieved with surface replacement arthroplasty (SRA) remains a topic of debate. High socket inclination has been associated with edge loading thereby causing increased wear of the articulating surfaces with high blood and urine ion levels as a result. However, in vivo joint loading is also affected by reconstruction of the femoral biomechanics as restoration of the femoral offset will restore the abductor moment arm of the gluteus medius. However, no 3D-evaluation of the moment arm changes of the anterior, middle and posterior part of the gluteus medius following hip replacement has been reported yet.

Muscle moment arms and contact forces can be estimated with generic musculoskeletal models. However, these models do not fully account for anatomical differences between subjects and patient specific models have been shown to lead to more accurate calculations of the hip joint loading following hip replacements.

It was the purpose of this study to evaluate the biomechanical changes (abductor moment arms, contact forces and contact stresses) that occur after optimal and non-optimal component placement of both components of a hip resurfacing, by using a subject specific musculoskeletal model based on CT-scan data.

Materials and Methods
Nineteen hips (9 left and 10 right) from 11 cadavers were resurfaced with a Birmingham Hip Resurfacing (Smith & Nephew, UK) using a femoral navigation system (Kolibri, Brainlab). Nails were used to mark the insertion sites of the posterior, middle and anterior part of the gluteus medius on the femur and pelvis. CT images of the pelvis and both femurs were acquired before and after the surgery. Grey-value segmentation in Mimics (Materialise, Belgium) produced contours representing the bone geometry and identifying the outlines of the 3 parts of the gluteus medius. The anatomical changes induced by the procedure were characterised by the translation of the hip joint center (HJCR) with respect to the pelvic and femoral bone. This translation was determined by locating the HJCR in the pre- and postoperative bone meshes and linking both meshes by registration.

Biomechanical parameters were evaluated pre- and postoperatively for normal gait. The orientation of the femur with respect to the pelvis, given in Euler angles, originated from a normal gait pattern from a lower limb musculoskeletal model provided by OpenSim. The contact forces resulting from the changed moment arms were calculated with the body weight at the center of the pelvic bone. The contact stresses were calculated by dividing the total contact force by the projected surface of the acetabular component in the direction of the force.

The contact forces during normal gait with 'optimal' component placement were calculated for a femoral cement mantle thickness of 3 mm, a socket inclination and anteverision of 45° and 15°. The biomechanical effect of 'non-optimal placement' was simulated by varying the positioning of the femoral component on the femoral neck in combination with different socket inclination and anteverision angles.

The paired Student’s T-test with a CI of 95% and a significant p-value of p<0.05 was used.

Results
The abduction moment arm decreased by a mean of 1.5%, 2.5% and 3.2% respectively for the anterior, middle and posterior muscle compartments with the 'optimal' component placement in comparison to the pre-operative status. There was a significant (p<0.01) shortening of the muscle length for all parts of the gluteus medius with the largest shortening of the posterior part by 6mm (= 4.2%). This was caused by a significant shortening of the femoral offset by 2.3mm (p<0.01). Because of a significant (p<0.01) medialisation of the HJCR by 4 mm, there was no significant increase in contact force.

The abduction moment arm of the 3 parts of the gluteus medius decreased by 0.2 to 0.4 mm in an average 6mm lateralisation of the femoral HJCR. As a consequence, the hip joint contact forces increased by 0.5% per mm HJCR displacement. Each millimeter of cranial and lateral displacement of the femoral HJCR increased the contact force by 0.5% and 1%, respectively.

The abduction moment arms were not influenced by an increased inclination or anteverision of the socket. However, the contact stresses changed significantly by 0.8% and 0.2% per degree of inclination and anteverision respectively. The contact force increased 1% per mm lateral displacement of the acetabular HJCR.

Discussion
Optimal placement of the SRA components did not completely restore the biomechanics of the native hip joint, however the differences were small. The contact forces were not increased due to the compensatory effect of the medialisation of the acetabular HJCR. This suggests that reaming to the acetabular floor should be conducted in SRA.

Hip resurfacing was used as a model to evaluate the biomechanical effects of non-optimal component placement in hip replacement. Femoral component displacement in the cranial and lateral direction significantly increased hip joint loading. Errors of socket placement in the coronal and sagittal plane significantly increased the contact stresses. Accumulative errors of both component displacements could lead to increased contact stresses of 18% to 23% with socket inclinations of 50° and 55° respectively.

This study evaluated the interplay of the biomechanical effect of surgical errors of femoral and acetabular component displacement in comparison to the native biomechanics and the 'optimal' component positioning. Not only acetabular but also femoral component aberrations will lead to increased loading of the articulating surfaces, thereby potentially leading to increased wear and failure rates. Surgeons should reconsider continuing the resurfacing procedure if a neck length loss and lateralisation of the HJCR by >5 mm is anticipated based on the pre-operative templating as this would increase the contact stresses by >12%.

The most important limitation of this cadaver study is that only the effect of the gluteus medius moment arm changes was modelled. However, the abductors are accepted to be the most important contributors to hip joint loading.

References