A direct comparison of telemetered in-vivo hip joint contact forces with those calculated using a 3D mathematical model of the lower limb.

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Introduction
In-vivo force data from instrumented hip implants can be used to assess the validity of hip joint contact force calculations. There are few examples in the literature of the direct comparison between in-vivo measured and calculated hip joint contact forces (Lu et al., 1998, Duda et al., 1999, Brand et al. 1994). Such direct comparisons have been made in two patients during many different activities. This paper reports results for walking.

Methods
Two subjects with instrumented femoral prostheses undertook 3D motion analysis with simultaneous recording of force plate data. Forces from the instrumented femoral prostheses were recorded using radio telemetry equipment (Graichen et al., 1999). Walking at normal, fast and slow speed was evaluated for this study.

A 3D model of the lower limb (Stansfield, 2000) was used to calculate the hip joint contact forces in femoral co-ordinates:
- Y axis from mid epicondyles to femoral head
- Z axis in the plane of the femoral epicondyles and hip joint centre, perpendicular to the Y axis, pointing laterally
- X axis perpendicular to both Y and Z axes, pointing ventrally

47 muscle elements (Brand et al., 1982) were used in the model and wrapping procedures were used to ensure that muscles did not pass through underlying structures. 3D representations of the femoral-tibial joint and the tibial-fibular-talus joint were included. A double linear optimisation approach was used to distribute forces in the muscles of the lower limb; first the maximum muscle stress was minimised then within this solution the sum of muscle and joint forces was minimised.

Results & Discussion
For each of the two subjects, HS and KW, normal, fast and slow walking results are illustrated in Figure 1. Telemetered and calculated forces are shown together for each component of the hip joint contact force (/BW) over the gait cycle (%) from initial foot contact to next initial same foot contact. Subject details are included in Table 1.

The calculated X and Z components of the hip joint contact force for KW exhibited closer agreement with telemetered forces than those of HS. These components were critically dependent on the alignment of the axes systems, possibly indicating that the axes set used for calculations in HS were not aligned with those of the joint replacement.

In general calculated results exhibited an earlier rise in early stance and earlier fall in late stance than the telemetered results. These characteristics were also present in the work of Duda et al, whose subjects were fitted with similar telemetry equipment.
The model of the lower limb employed produced results that were of the same general pattern and order of magnitude as the directly measured telemetered hip joint contact forces. The use of a 3D model of the hip, knee and ankle ensured that muscle force profiles were compatible with hip, knee and ankle joint equilibrium, however, there remained evidence of differences between calculated and telemetered hip joint contact forces.

Comparison of calculated results and those recorded from the subjects will allow refinement of the model particularly in respect of the definition of the criteria used by the body to distribute forces in the muscles.

**References**

**Acknowledgements**
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<table>
<thead>
<tr>
<th>Subject</th>
<th>HS</th>
<th>KW</th>
</tr>
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<tbody>
<tr>
<td>Sex</td>
<td>Male</td>
<td>Male</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>92.3</td>
<td>75.1</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>170.4</td>
<td>163.5</td>
</tr>
<tr>
<td>Age (years)</td>
<td>58</td>
<td>64</td>
</tr>
<tr>
<td>Instrumented side</td>
<td>Right side</td>
<td>Right and left sides replaced. Right tested Right 36 months Left 30 months</td>
</tr>
<tr>
<td>Months post-operative</td>
<td>Right 36 months</td>
<td></td>
</tr>
<tr>
<td>Walking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed (m/s)</td>
<td>1.32</td>
<td>1.92</td>
</tr>
<tr>
<td>Cadence (steps/s)</td>
<td>1.83</td>
<td>2.18</td>
</tr>
<tr>
<td>Step Length (m/s)</td>
<td>0.72</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Table 1 Subject characteristics and walking speed, cadence and step length.
Figure 1 Calculated and telemetered hip joint contact forces (/BW) for two subjects, HS and KW, during the gait cycle (%) from initial foot contact to next initial same foot contact.