INTRODUCTION
Cycling is a recommended activity after total knee arthroplasty (TKA) and it has been shown that up to 50 % of the TKA patients are riding a bike and 25 % think that cycling has an important place in their life. In a recent in vitro study [1], which investigated the contact pressures in TKA components for common recreational activities (cycling, power walking, downhill walking, jogging), it has been concluded that cycling produces relatively low contact forces and therefore is a safe activity for TKA patients. The explored quasi-static approach, however, bears certain limitations which need to be considered. Cycling is an activity with relatively high flexion demand. Sagittal plane angles of 110 degrees and more are typical. The combination of high flexion together with antero-posterior motion and/or internal/external rotation may cause unfavorable conditions at the artificial articulation leading to constraint forces and subsequent wear (even though external forces are low). The purpose of this study was to analyze the three-dimensional motion pattern of the knee joint during cycling for a group of TKA patients compared with a normal control group. In addition, kinetic boundary conditions were obtained to better describe the biomechanical situation.

SUBJECTS
Nineteen subjects gave informed consent to participate in this study, which had been approved by the institutional review board. Nine of those subjects (age 61.2 ± 7.6 years) were TKA patients and were implanted with a fixed bearing posterior stabilized high flexion prosthesis (NexGen, Zimmer, Inc.) and 22 months post-op on average. Three of those patients had bilateral implants. An age-matched, asymptomatic control group (age 56.8 ± 7.6 years) consisted of 10 subjects. All subjects were physically examined, and WOMAC index and knee society score were taken.

METHODS
In order to investigate the kinetic conditions under which the knee was functioning, three-dimensional pedal forces were recorded. The force measurement system was integrated into the crank shafts and is based on strain gauge technology. Forces were calculated in a global coordinate system and the impulse introduced to each leg was determined.

Motion analysis was performed using a technique called “point cluster technique” [2]. Twenty-one reflective markers were placed on the thigh and shank creating two cluster groups. Marker motion was observed with a four-camera optoelectronic system. Subjects were instructed to cycle at a self-selected speed at a preset resistance. Based on the determined eigenvalues the rigid body motion of thigh and shank was calculated and the relative joint motion was computed. For graphic representation of the data, the medio-lateral axis of the coordinate system was fixed to the epicondylar axis of the knee joint.

RESULTS
TKA patients had a knee society score of 93 ± 6 (compared to 100 ± 8 in the control group). Resultant pedal forces and generated impulse showed no significant differences between TKA patients and Normals. No significant differences for force and impulse values were found comparing left/right, dominant/non-dominant and operated/non-operated knee. Patients with contra-lateral osteoarthritis (OA), as defined by the clinical examination and the knee society score, showed higher forces and impulses at the operated leg (Tab. 1).

<table>
<thead>
<tr>
<th></th>
<th>TKA Side (Mean ±SD)</th>
<th>OA Side (Mean ±SD)</th>
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</thead>
<tbody>
<tr>
<td>Knee Society Score</td>
<td>95 ± 2</td>
<td>78 ± 6</td>
</tr>
<tr>
<td>Force [N]</td>
<td>193 ± 29</td>
<td>149 ± 26</td>
</tr>
<tr>
<td>Impulse [Ns]</td>
<td>498 ± 139</td>
<td>385 ± 121</td>
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Table 1: Three patients with TKA and remaining osteoarthritis on the contralateral side.

The motion analysis showed the following mean values ±SD for TKA patients / Normals: maximum flexion angle 132.5 ° ± 16.0 °/131.5 ± 18.3 °, minimum flexion angle 41.4 ° ± 12.0 °/40.3 ° ± 15.7 °, range of rotation in transversal plane 12.6 ° ± 4.7 °/9.9 ° ± 3.6 ° and range of anterior-posterior translation 5.3 mm ± 5.1 mm/2.7 mm ± 0.4 mm. There were no significant differences between study groups.

DISCUSSION
Interestingly, in this study, force and impulse of TKA patients with contemporary prostheses were comparable to healthy subjects indicating functional restoration of the joint. Contralateral osteoarthritis may cause higher forces at the operated leg and thus, relatively higher stresses at the artificial articulation. As expected, the generated forces at the bike pedal were low (20 - 25% body-weight) calling for little muscle activity and low compressive joint forces. However, with a mean maximum flexion angle of 131.5°, the observed motion ranges were higher than expected. Prostheses not designed for high flexion activities could lose tibio-femoral contact during cycling with detrimental effects on wear. According to manufacturer, the implanted high flexion prosthesis of this study allows flexion up to 155 ° with minimal loss of contact area and therefore should be no problem. Still, the measured range of rotation in the transverse plane indicates that despite its posterior-stabilized design rotation is taking place with approximately the same amount as it occurs in normal subjects. This may have detrimental effects on the post at the tibial plateau and could explain the previously observed rotational damage patterns on retrieved posterior stabilized TKA specimens [3].

In summary, data are suggesting that leisure activities should be considered to determine the appropriate TKA design. This study will provide useful data for future design and wear testing scenarios.

REFERENCES

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Figure 1: Motion pattern of one TKA subject showing flexion vs. rotation in the transverse plane during 4 consecutive cycles