SIGNIFICANCE OF THE EXTENSOR MUSCLE FORCE IN DEEP KNEE FLEXION AS PART OF ACTIVITIES OF DAILY LIVING

INTRODUCTION
The knee extensors play an essential role in human movement. However, the function of the lower limb muscles in deep flexion is not well studied. Previous analyses of muscle activity have been limited to flexion below 100 degrees or rehabilitation exercise such as squat. Information about muscle activity such as extensor/flexor forces and the amount of muscle co-contraction during activities of daily living are required to predict the overall force at the knee acting upon the articular cartilage. In particular, the muscle forces used in recent in vitro studies [1,2] seem to be insufficient to simulate the muscle forces in deep flexion. The aim of this study was to investigate the extensor muscle force acting at the knee during routine deep flexion activities.

METHODS
The subjects were 7 women and 9 men (age: 32 ± 4 yrs, 1.7 ± 0.1m, 597 ± 120 N) who had no history of knee pain or injury. After an approved informed consent, four different activities including level walking, stair-climbing, rising from kneeling and rising from deep kneeling, were captured using four opto-electronic cameras in a protocol previously reported [3]. The knee was flexed to approximately 90° during the rise from kneeling, and 150° during rise from deep kneeling. A four channel surface EMG was used for collecting the muscle activities from vastus medialis, rectus femoris, hamstrings and medial head of gastrocnemius. The EMG signal levels were normalized to the signal during maximum voluntary contractions. Inter-segmental moment about the knee was calculated using an inverse dynamics approach. A statically determinant knee model [4] was used to calculate the muscle force and the joint reaction force. In particular, the extensor muscle force was calculated by the following basis; 1) normalized EMG signals of the quadriceps, hamstring and gastrocnemius were used to determine ratio of extensor/flexor activity level (the level of muscle co-contraction) during the motion, 2) the net extensor/flexor muscle moments were determined as to balance the inter-segmental flexion/extension moments, 3) the muscle force was calculated by the muscle moment and the moment arm which was known in the knee model. Since the extensor (the quadriceps) was the dominant agonist for the activities included on this study, the analysis was focused on extensor dominant phase in each motion. Analysis of variance (ANOVA) with a single factor for two groups (α=0.05) was used to compare different activities and sex.

Table 1. Relative knee flexor activity to knee extensor activity during the motions (mean, SD).

<table>
<thead>
<tr>
<th>Hamstrings (%)</th>
<th>Gastrocnemius (%)</th>
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<tr>
<td>Level Walking</td>
<td>8.8 (4.4)</td>
</tr>
<tr>
<td>Stair Climbing</td>
<td>21.7 (16.6)</td>
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<tr>
<td>Kneeling</td>
<td>18.1 (8.4)</td>
</tr>
<tr>
<td>Deep Kneeling</td>
<td>17.6 (5.1)</td>
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</tbody>
</table>

RESULTS
The level of knee flexor muscle co-contraction activities during the extensor dominant phase varied in each activity (Table 1). The gastrocnemius muscles had the primary co-contraction activity to the knee extensors during walking and stair climbing. However, the activity levels of the gastrocnemius muscles were substantially reduced during the deep flexion activities.

Peak extensor muscle force and the joint reaction forces occurred immediately after the beginning of the motion, and then decreased with knee extension during the deep flexion activities (Fig.1 and Fig.2). The peak extensor forces during the deep flexion activities were larger than those during walking (p<0.001). Differences in the extensor force were seen between female and male subjects during deep kneeling, while there was no difference in the force during walking. During deep kneeling male subjects had larger peak extensor forces (average 5.0BW) than female subjects (average 3.9BW, p<0.05).

DISCUSSION
Extensor forces of higher than 4BW (2400N) were observed at flexion angles over 80°. This muscle force at high flexion increases joint reaction forces, causing peak forces higher than 7BW at flexion angles over 130°. These results demonstrate the significance of the extensor and joint reaction forces in deep flexion. The values observed in this study contradict in vitro results by Li et al [1,2], which showed lower mechanical forces at the knee joint at 150° than at 120°. Direct comparison of these results are hampered because of the difference in methods. However, the 400N extensor force used in Li’s study, which is six times smaller than the force calculated in this study, may lead to underestimation of the joint force in deep flexion and differences in the angle at which peak forces occur.

The significant joint loads observed in this study support the epidemiological facts that indicate a strong relationship between deep knee bending and the occurrence of knee osteoarthritis [5]. The high forces in deep flexion are also an important consideration for total knee arthroplasty (TKA), since allowing deep flexion is a current focus of TKA design. The excessive loads to the joint at flexion angles greater than 120° may cause mechanical failure of the prosthesis in long term, and should be considered in future prosthetic development.

REFERENCES

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