Large Variations of Patello-Femoral Joint Contact Forces During Highly Demanding Activities: Simulations and in vivo Measurements

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SUMMARY
The patello-femoral (PF) joint plays an essential role for the function of the knee joint, especially during activities with high knee flexion, which pose a challenge to many TKR patients. The loading conditions in the knee were calculated using a computational model, which was validated against simultaneously in vivo measured tibio-femoral (TF) forces. The peak PF forces showed significant variability depending on the activity and ranged from less than 1 body weight (BW) during walking to 4BW during high flexion activities, in contrast to the in vivo peak TF forces that where less variable for all activities (3 - 3.5BW). In high flexion activities the PF forces were found to be larger than the TF forces. The results suggest that the in vivo loading conditions of the knee can only be fully understood if the TF and the PF joints are considered together.

INTRODUCTION
The recent literature suggests that total knee replacement (TKR) is not consistently achieving restoration of function, one of the procedures primary goals [1]. Limited satisfaction with the outcome of TKR has specifically been related to the ability to perform functionally demanding activities. Whilst it is known that the patello-femoral (PF) joint plays an important role for knee joint function, knowledge of the in vivo PF joint forces during demanding functional activities remains limited. The aim of this study was therefore to assess the joint contact forces at both the tibio-femoral (TF) and the PF joints during demanding activities using a musculoskeletal model validated against in vivo measured TF forces.

METHODS
Gait analysis was performed on 2 male TKR patients (aged 64 & 78y; 19 & 8m post-op), who were implanted with telemetric knee implants [2], during walking, stair climbing, sit-to-stand and knee bend. 3D kinematics were measured using reflective markers attached to the skin, tracked at 100 Hz using a 10-camera motion capture system (Vicon, Oxford, UK). The external loads were measured using two 6 DoF force plates (AMTI, Watertown, MA, USA), while the TF contact forces were simultaneously measured using the instrumented tibial component [2]. The marker data was processed to reduce soft tissue artifacts [3] before the hip, knee and ankle joint positions were identified using a functional approach [4]. The patient specific anatomy was then fitted to the joint positions for the entire motion cycles, including an adaptation of the muscle lines of actions. The kinematics of the PF joint were determined using a previously validated model [5]. Muscle and joint contact forces at the PF and TF joints were calculated using an inverse dynamics and optimization approach to minimize the squared muscle stresses. To validate the model’s predictions, the calculated TF forces were compared to the in vivo measured data for all activities of the TKR subjects.

RESULTS AND DISCUSSION
The predicted resultant TF contact forces of both subjects showed good agreement with the in vivo measured data for all activities (Fig. 1). The difference between the predicted peak TF contact force and the in vivo measured peak TF force in each trial was approx. 15% averaged over both subjects and the four activities. While PF contact forces of less than 1BW were determined during walking (20° max. knee flexion), significantly larger PF forces were found for the activities requiring active knee extension from a more flexed position (Fig. 2): 2.9BW during stair climbing (50° max. flex.), 4BW

Figure 1: Example comparisons of tibio-femoral(TF) forces measured in vivo (dashed line) with model predictions (solid)
during sit-to-stand (88° max. flex.), and knee bend (87° max. flex.), averaged over all trials of both subjects for each activity.

![Comparison of tibio-femoral forces and patello-femoral forces, during a range of activities of 2 TKR subjects.](image)

**CONCLUSIONS**

This is the first study to demonstrate good agreement between calculated and in vivo measured TF forces during demanding activities of daily living in 2 subjects. Furthermore, this study has shown that the magnitudes of PF forces are much more activity-dependent than the TF forces. The large PF-forces may explain the general experience that many TKR patients have difficulties to rise from a chair or climb stairs, although the TF contact forces are lower or in the same range as during normal walking. By providing access to the loading condition at both the TF and PF joint, the presented model provides the essential basis for a better understanding of the loading conditions of the knee structures and identifying potential reasons for poor functional outcome of TKR procedures.

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**REFERENCES**

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