INTRODUCTION: Surgical intervention of the knee joint routinely endeavors to recreate a physiologically normal joint loading environment. The loading conditions resulting from osteotomies, fracture treatment and arthroplasties of the knee are considered to have an impact on the long term clinical outcome. Knowledge regarding the in vivo loading conditions in the knee is limited. The goal of this study was to determine validated human tibio-femoral contact loads that occur during typical daily activities.

METHODS: A musculo-skeletal model of the human lower extremity was developed based on CT-data from the Visible Human (NLM, Bethesda, USA). Muscles were represented as straight lines spanning from origin to insertion, wrapped around the bones where necessary to approximate their real curved path. Muscles with large attachment areas were modeled by more than one line of action. In total, the muscle model included 95 lines of action. Data on the physiological cross-sectional area (PCSA) of the individual muscles was taken from the literature.

The tibio-femoral joint was modeled with three rotational degrees of freedom (DOF) while the patello-femoral joint was modeled with one rotational DOF around the medio-lateral axis, and two translational DOF in the sagittal plane. Tracking of the patella during gait analysis was not possible and its motion was therefore determined from an in vitro experiment during a complete flexion-extension cycle of the knee.

An instrumented femoral prosthesis was used to measure the in vivo hip contact forces in four patients (mean 61 years) as described in a previous study (Fig. 1, left). Clinical gait analysis was conducted for six trials of both walking and stair climbing and time dependent kinematics and kinetics data were gathered. The in vivo hip contact forces were measured during all activities. An optical system (Vicon, Oxford Metrics, UK) consisting of six infrared cameras and 24 reflective markers attached to the patients’ skin was used to determine movement of the lower limbs.

The musculo-skeletal model, including muscle origins, insertion sites and wrapping points, was then scaled to the individual patient anatomies using bony landmarks positions (Fig. 1, right). Muscle force distribution was then computed using numerical optimization techniques. From the muscle and the resultant intersegmental forces, joint contact forces were calculated for the ankle, knee and hip joints for the tested activities in all patients. Measured and calculated hip contact forces revealed good agreement in both pattern and magnitude for all activities in all patients.

RESULTS: The average resultant peak tibio-femoral contact force during walking was 3.6 times body weight (BW) across all four patients (Fig. 2). Compared to the variation of forces for each patient repeating the same task, inter-individual variation proved larger. During stair climbing, forces through the knee were considerably larger than during walking. The average maximum force for this activity was 5.9 BW although peaks of up to 6.8 BW were calculated for one particular patient (P4). Average anterior-posterior peak shear forces of 0.6 BW (0.4 to 0.8) were determined during walking and 1.3 BW (0.9 to 1.6) during stair climbing.

DISCUSSION: This study has evaluated the tibio-femoral contact forces that occur in humans during walking and stair climbing using validated musculo-skeletal analyses. The results demonstrate both intra-individual variation between repetitions of the same exercise but also inter-individual variations between different patients performing the same task.

The highest forces seen during stair climbing were consistently larger than those during walking, and occurred when the knee was under large angles of flexion. The corresponding shear forces during stair climbing were more than double those whilst walking. The calculated in vivo tibio-femoral contact loads were larger than the corresponding loads in the hip joint which were reported as up to 3.1 BW walking and 3.7 BW stair climbing.

The tibio-femoral contact forces calculated in this study were comparable to those seen in the literature (5.9 BW at 40° flexion), and demonstrate that the loading in the knee is considerably larger than in the hip. The magnitude of joint contact forces reported in this study illustrate the impact that muscle activity has on knee joint loading. In this respect, surgical intervention of the knee joint should attempt to conserve the soft tissues in order to maintain a physiologically balanced loading environment.

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Figure 1: (Left) Image of patient stair climbing. Reflective markers are attached to the skin in order to measure the positions of each limb throughout the gait cycle. Hip contact forces from an instrumented endoprosthesis were measured simultaneously. (Right) Musculo-skeletal model used for calculating muscle and joint contact forces.

Figure 2: Tibio-femoral resultant contact forces calculated throughout the gait cycle using the musculo-skeletal model shown together with the average knee flexion angle. All forces in body weight.