Introduction: Knee osteoarthritis (OA) is one of the most frequent orthopaedic diseases, leading to pain, high economical costs, and loss of quality of life. OA mostly affects the medial knee joint compartment [1,2] which transfers approximately 60-80% of the vertical force [3]. In order to decelerate OA progression and relieve pain, this medial knee joint force is aimed to be reduced. Several studies used the external knee adduction moment (EAM) as a surrogate measure for medial knee joint loading. The EAM is a product of the ground reaction force (GRF) and the perpendicular distance from the knee joint center to the GRF vector and can be reduced by lowering the total force magnitude or by shortening the lever arm. A common approach to lower the EAM is to modify gait. Several studies have investigated the effect of passive methods such as lateral wedged insoles or shoes with partially controversial results [4-5]. There is still no consensus about the mechanisms to reduce medial knee joint loading and it remains unknown how accurate the analytical models are. The aim of this study was therefore to determine the effect of walking with an active medial and lateral foot loading on the medial knee joint loading using instrumented implants which directly measure the contact loads. Based on theoretical considerations, we hypothesized that a lateral foot loading would lead to a reduction of the medial knee joint force due to a lateral shift of the GRF vector (Figure 2b).

Methods: The study was approved by the local ethics committee. Five subjects (4 male, 1 female, age 63-75) with instrumented knee implants [6] gave written informed consent to participate in this study. Each subject performed 3 series of 30 consecutive gait cycles on a treadmill at 2.5km/h, loading the foot either normally, medially, or laterally. To enforce the gait modifications, an acoustic feedback was given, using a resistive pressure sensor (Interlink Electronics, Type FSR 402, 18mm diameter) embedded in an insole under the fifth metatarsal head.

The patients first walked without instructions, loading their foot normally, and the pressure level was set as baseline. When this pressure threshold was exceeded, an acoustic feedback was caused. Then, the threshold was increased by 20% and the subjects were verbally instructed to roll the foot more laterally and thereby trigger the beep tone with every step. Subsequently, the threshold was decreased by 20% and the subjects were instructed to load their foot medially and thereby avoid the beep tone. The medial knee joint forces Fmed and the resultant force Fres were computed in percent of the patient’s bodyweight (%BW). The force distribution across the tibial plateau was determined as the ‘Medial Ratio’ MR = Fmed / 100*Fz. Fres, Fmed and MR were determined at the instants of the 2 maxima of Fres, acting during each gait cycle. The changes caused by lateral or medial foot loading were computed in percent of the corresponding values during normal walking. A student t-test for unpaired samples with alpha set to 0.01 was used to analyze the changes. Additionally, a 3D motion analysis was conducted to quantify the changes of gait parameters.

Results: Lateral foot loading increased Fmed and Fres by 16% with no significant changes in MR (Figure 1). The subjects achieved the lateral foot loading mainly by ankle inversion, in-toeing and a subtle lateral trunk lean. Some subjects also exhibited subtle in- or decreases in step width or hip adduction. Medial foot loading reduced Fmed significantly by 18% on average with a concomitant decrease in MR by 18% whereas Fres was not altered significantly. The medial loading was mainly realised by an increased step width, out-toeing of the foot, increased hip abduction and ankle eversion.

Discussion: Contrary to our hypothesis, lateral foot loading led to a significant increase of Fmed and Fres. As the force distribution was not altered significantly, biomechanical considerations suggest that lateral foot loading shifted the CoP, as hypothesized, laterally relative to the foot but tilted the GRF vector medially relative to the limb due to the kinematic adaptations (Figure 2c). This tilt counteracts a shortening of the lever arm. The increase of Fres indicates an increase of total force magnitude, perhaps caused by muscle co-contraction due to a smaller and more instable support base, and probably caused the increase of Fmed. Medial foot loading reduced Fmed and MR significantly, indicating a force shift from the medial towards the lateral knee compartment which implies a shortening of the EAM lever arm (Figure 3). As the CoP as well as the segment masses can be altered by kinematic gait adaptations, we propose that 1. not only a shift of the CoP, but also a tilt of the GRF vector changes the length of the EAM lever arm and 2. these changes are to be considered relative to the extremity in a local coordinate system. However, as this investigation was performed on a treadmill, GRF data could not be collected and further studies including determination of the EAM are needed to prove these theoretical assumptions.

Significance: With the ability to directly measure the in vivo knee joint loading, this study provides unique and novel in vivo data about the effects of gait modifications on the knee joint loading. Several methods used in the past to lower loading of the medial knee compartment seem to be obsolete. The findings support the development of effective intervention strategies to lower the
medial knee joint loading, prevent further progression of OA, and relieve pain.

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**References:**

**Figure 1** Changes of $F_{med}$ (green), $F_{res}$ (yellow), and MR (blue), during walking with lateral and medial foot loading, averaged for all subjects and both maxima.