MRI Analysis of Anteroposterior Stability in the Normal Human Knee

INTRODUCTION:
During activities the knee experiences compressive forces caused by the weight of the body and muscle forces. However, there is also an anterior shear force pushing the femur forwards on the tibia. It is likely to be important to the feeling of stability that the shear force is resisted so as to limit the anterior femoral displacement. The dished bearing surface of the medial tibial compartment in combination with the medial meniscus may well perform this function. In contrast, the lateral tibial surface is convex in the sagittal plane and the meniscus is too mobile to offer any anteroposterior (AP) restraint. Therefore, we hypothesize that if an anterior force is applied to the femur relative to the tibia, AP stability is provided by the medial side, while the lateral side allows for femoral rollback to facilitate a high range of flexion. At any flexion angle, rotational laxity will occur about a point on the medial side.

Most previous in vivo MRI studies of AP stability have been conducted in unloaded conditions, with compressive loading only or with both a compressive and shear force in a low resolution MRI. We aimed to analyze the AP stability of the normal human knee when both a compressive and shear load was applied while maintaining a high resolution image through the use of a 7 Tesla (T7) MRI.

METHODS:
We investigated this using MRI on living subjects. Subjects were placed in a plastic rig with the knee at approximately 15 degrees of flexion, which is the angle of the knee at heel strike in level walking and in descending stairs (Figure 1). A compressive force of 150 lbs was applied along the tibial long axis. A similar approach to loading the knee was used in a previous study conducted by Shefelbine et al. A Siemens Research 7 Tesla MRI machine was used with sagittal three dimensional (3D)-T1-weighted non-fat suppressed fast low angle shot (FLASH) with isotropic resolution (0.6x0.6x0.6 mm). Upon completion of this scan, a weight was applied to the anterior tibia just below the receiving coil so that the shear force at the joint was 8 lbs. It has been shown that the most important shear force direction in flexion during function, is an anterior force of the femur on the tibia (such that the PCL would be stretched). After the shear force was applied, a second scan was taken. The forces applied were derived from studies by D’Lima and Colwell on an instrumented total knee where the compressive and shear force data from the instrumented total knee was used in a previous study conducted by Shefelbine et al. for comparison. The forces applied were derived from studies by D’Lima and Colwell on an instrumented total knee where the compressive and shear force data from the instrumented total knee was used in a previous study conducted by Shefelbine et al. for comparison. However, there is also an anterior shear force pushing the femur forwards on the tibia. It is likely to be important to the feeling of stability that the shear force is resisted so as to limit the anterior femoral displacement. The dished bearing surface of the medial tibial compartment in combination with the medial meniscus may well perform this function. In contrast, the lateral tibial surface is convex in the sagittal plane and the meniscus is too mobile to offer any anteroposterior (AP) restraint. Therefore, we hypothesize that if an anterior force is applied to the femur relative to the tibia, AP stability is provided by the medial side, while the lateral side allows for femoral rollback to facilitate a high range of flexion. At any flexion angle, rotational laxity will occur about a point on the medial side.

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RESULTS:
The scans of 8 male subjects (average age 28; ranging from 21-32) with healthy knees were obtained. Analysis of these scans showed all results to be consistent with the hypothesis. A typical example shows the lateral femoral condyle had a maximum anterior displacement of 1.00mm, while the medial femoral condyle had a maximum posterior displacement of 0.5mm (Figure 3).

DISCUSSION:
The above data stresses the importance of the role the menisci and bearing surfaces play in controlling the movement of the medial side of the knee. A damaged medial meniscus can have a major effect on the stability of the knee so that the total AP displacements during activities are increased. In addition to a feeling of instability, such repeated abnormal displacements are likely to cause a deleterious effect on function and long-term damage to the cartilage.

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