Comparison of the 3D Orientations in Lower Limb Alignment and Loading Axis

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INTRODUCTION:
Lower limb alignment (LLA) has been a principal predictor of the progression of osteoarthritis (OA) of the knee. Progression of articular cartilage and subchondral bone degeneration is believed to be induced by abnormal alignment such as a varus or valgus deformity since it may alter loading distributions within the knee joint. Currently, LLA is assessed by a two dimensional (2D) anteroposterior radiograph despite its three dimensional (3D) nature. In this study, 3D LLA was obtained by an image registration technique using bi-planar radiography and 3D geometric models of femur and tibia. The 3D LLA was compared with the loading axis simultaneously measured with a force plate in double-limb standing, single-limb standing to understand the actual weight-bearing condition of lower extremity.

METHODS:
After institutional review board approval, three healthy male subjects (23-39 years old) with no previous history of knee injury signed informed consent and participated in this study. Each subject’s lower limb was CT scanned with a resolution of 640 x 512 pixels and 1.5 mm intervals. Three dimensional geometric models of the femur and tibia were created with solid modeling software.

A bi-planar radiograph system with a rotation table was used to take frontal and oblique images of entire lower limb. The table positioned at 0 deg and 60 deg relative to the optical axis of an x-ray source. The x-ray source to object distance was 2.7 m and the object to cassette distance was 0.3 m. The contours of the femur and tibia in both radiographs and the projected outlines of the 3D models were matched to recover six-degree of freedom parameters of each bone [1]. The 3D LLA was a line drawn from the center of the femoral head to the center of the ankle. A surface proximity map was created between the distal femoral articular surface and the proximal tibial articular surface.

A force plate (A9261, Kistler, Switzerland) was positioned on the rotation table. The subjects stood on the force plate with a measured limb on the spacer and the other on the shield (Fig.1). Bi-planar radiographs were taken in double-limb standing, double-limb standing with toe up in the measured leg, and single-limb standing, without being assisted by any supportive device. The toe up posture was intended to minimize postural sway during the time interval between the two x-ray exposures. The force plate data were captured at a sampling frequency of 50 Hz and averaged over 1 second around the instances in time of two x-ray exposures.

RESULTS:
Figure 2 shows the separation distance mapping and passing points of 3D LLA and the loading axis on the proximal tibia in all subjects. For all subjects the passing points of the 3D LLA were almost in the middle of the joint width in lateral direction. Compared to the 3D LLA, the loading axis passed through the anterior region in double-limb standing and single-limb standing, and anterior and medial region in single-limb standing. The separation distance tended to decrease in the medial compartment in single-limb standing, and to increase in toe up in the entire region. The anterior and medical deviations of the loading axis from the 3D LLA normalized by the joint width in anteroposterior direction and by the joint width in lateral direction were shown in Fig.3. The anterior deviation was significantly smaller in toe up than in single-limb standing. The medial deviation was significantly greater in single-limb standing than in double-limb standing (Fisher’s PLSD).

REFERENCES: