Coronal gait kinematics was affected by the coronal inclination of the medial tibial plateau for varus osteoarthritic knees

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INTRODUCTION: The tibial varus inclination, defined as the tibial condylar plateau angle formed by the tibial anatomical axis and the tibial joint line, has been shown to be associated with knee osteoarthritis (OA) onset. Analysis of static alignment in advanced OA showed that the medial condylar plateau becomes more parallel to the ground (tibial parallel phenomenon) under weight-bearing conditions, depending on the tibial varus inclination. Varus thrust, i.e., the momentary sideways movement of the knee joint during gait, has also been shown to be associated with knee OA progression. Research on coronal gait kinematics can provide critical suggestions for clarifying the mechanism of alignment change and varus thrust in knee OA. The common gait analysis applied by skin markers or markerless devices cannot directly evaluate bony motion; however, the new unique motion analysis system, by combining the motion capture system and the three-dimensional (3D) lower extremity alignment assessment system via biplanar long-leg X-rays, can directly evaluate dynamic bony angular changes relative to the ground based on the coordinate system during walking (Fig. 1, 2). The aims of this study were to (1) directly measure the bony kinematics relative to the ground during walking, focusing on the coronal plane, and (2) determine the correlation between the kinematics and inclination of the medial condylar plateau in healthy, early, and advanced varus osteoarthritic female knees. The hypotheses were as follow: in all groups, (1) the tibia would show a plateau area, the femur would slowly tilt laterally, and the dynamic alignment would show a varus angular change during the loading response phase, and (2) one of the dominant factors determining the kinematics would be the medial condylar plateau angle.

METHODS: The ethical review board of Niigata Institute for Health and Sports Medicine approved this study. Subjects with medial knee OA or no knee complaints associated with other diseases were randomly selected from the 3505 subjects who visited the clinic from September 2008 to August 2013. This study involved 37 female participants (43 knee joints), including 8 healthy adults (9 knees) and 29 patients with medial knee OA (34 knees). The average age was 58 years (range: 21–80 years), and the average body mass index (BMI) was 24.5 kg/m2 (range: 17.3–35.8 kg/m2). In this study, grade 0 occurred in 2 knees (4.7%), grade 1 occurred in 7 knees (16.3%), grade 2 occurred in 13 knees (30.2%), grade 3 occurred in 13 knees (30.2%), and grade 4 occurred in 8 knees (18.6%). The knees were divided into three groups: non-OA (KL 0,1: 9 knees, 20.9%), early OA (KL 2: 13 knees, 30.2%), and advanced OA (KL 3,4: 21 knees, 48.8%).

A 3D lower extremity alignment assessment system (Knee CAS, LEXI Inc., Tokyo, Japan) using biplanar long-leg X-rays (0°, 60°) was developed to evaluate lower extremity alignment and bone morphology (Fig. 1). The femoral and tibial coordinate systems in the 3D skeletal model were determined as described by Sato et al. The matching error of the 3D to 2D image registration technique was within a range of 0.7 mm in rotation and 0.5 mm in translation. In the gait analysis, the subjects walked along a 12.0 m flat lane at their preferred speed. The world coordinate system of a motion capture system (VICON612, Vicon Motion Systems Ltd., UK) was set at the center of the lane where the subjects reached a constant walking speed. The world coordinate system was defined as follows: the y-axis is the gait direction, the z-axis is the gravity direction, and the x-axis is the cross product of the y- and z-axes. Gaits were captured at a sampling rate of 120 Hz. Regarding accuracy, the detection error of the 3D position of the marker was less than 0.7 mm in static conditions under a capture space of 3.0 m × 4.0 m × 2.5 m with a retroreflective skin marker. The gait cycle was classified using the five time points: initial contact, foot flat, heel-rise, opposing initial contact, and toe-off. Biplanar X-ray images of the lower extremities with the markers were obtained immediately after gait capture. The 3D position was estimated from the 2D data of the markers on the X-ray image (Figs. 1, 2). As the kinematics parameters, the "femoral anatomical axis: FAA" and "tibial anatomical axis: TAA" dynamic positions during the stance phase of the gait cycle were calculated. Each bony position relative to the ground was defined as the position of the FAA and TAA relative to the z-axis of the world coordinate system in the coronal plane (lateral inclination, +). The kinematic parameter of the lower extremity alignment was presented as the "dynamic alignment," which was determined by the association between the FAA and TAA in the coronal plane of the world coordinate system. A positive dynamic alignment value indicates varus alignment (Fig. 2). In the static parameters, the femorotibial angle (FTA) and coronal angle of the medial compartment of the proximal tibia (MCT) that was, as the best fitting "approximation plane", determined by the least squares method, using ten points digitized on the MCT. The main parameters were the kinematics of the bony axes relative to the ground in the coronal plane during the stance phase of the gait. The differences in overall kinematics were assessed using repeated measures ANOVA with Tukey's post hoc test. The association between the kinematic parameters and coronal MCT was evaluated by multiple linear regression after univariate analysis.

RESULTS: The TAA showed acute angular changes at the loading response (0-20% of the stance phase) and plateau area at the subsequent phase (Fig. 3). The femur gradually inclines laterally (lateral inclination) until the terminal stance phase (Fig. 3). The dynamic alignment changed acutely during the loading response (0-20% of the stance phase) (Fig. 3). In the overall kinematics, there were statistically significant differences in the TAA ($p < 0.001$), FAA ($p < 0.001$), and dynamic alignment ($p < 0.001$) between the advanced group and the other groups (non-OA and early OA groups). The change in dynamic alignment showed significant correlations for static parameters in terms of the changes in kinematic parameters ($p < 0.05$). The coronal MCT was more dominant than the K-L grades in the linear regression analysis used to identify the factors determining the dynamic alignment change ($p = 0.003$).

CONCLUSION: For women, in all groups, the tibia tilted laterally during the loading response phase, and a plateau area subsequently appeared until the terminal stance phase (tibial parallel phenomenon). The femur slowly tilted laterally until the terminal stance phase, and the dynamic alignment showed a relatively large varus angular change during the loading response phase. In terms of the factors determining the change in dynamic alignment, the coronal MCT was the more dominant factor than the K-L grades.

SIGNIFICANCE: In terms of clinical relevance, this study may imply that the acute change in the dynamic alignment itself is a possible varus thrust, which is strongly associated with the inclination of the MCT.

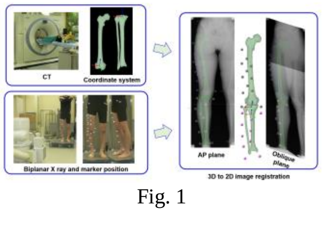

Fig. 1

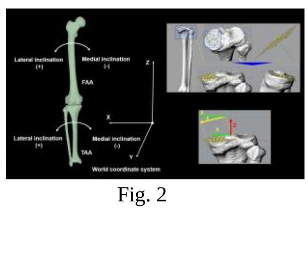

Fig. 2

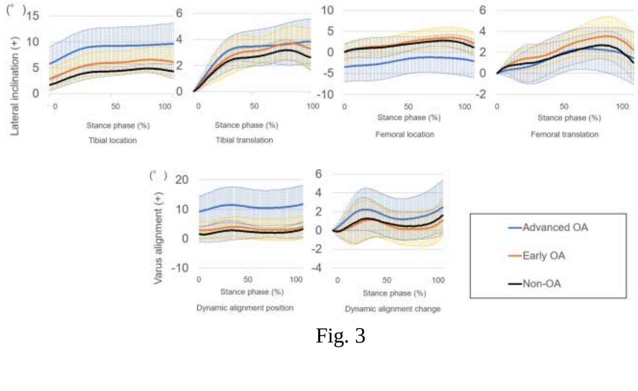

Fig. 3