Effect of Bearing design in Cruciate Retaining Total Knee Arthroplasty on Knee Joint Kinematics and Ligament Tension during Knee Extension-flexion Movements.

Yohei Okada[1], Keitaro Yamamoto[2], Shogo Kawaguchi[2], Kazushi Horita[1], Yuta Mori[1], Kota Watanabe[3], Hiromichi Fujie[4], Atsushi Teramoto[1]
[1]Department of Orthopedic Surgery, Sapporo Medical University, Sapporo, Japan, [2]Teijin Nakashima Medical Co., Ltd., Okayama Japan, [3]Second Division of Physical Therapy, Sapporo Medical University School of Health Sciences, Sapporo, Japan, [4]Tokyo Metropolitan University, Tokyo, Japan,
Email of Presenting Author : yokada@sapmed.ac.jp
Disclosures: Y. Okada (N), K. Yamamoto (N), S. Kawaguchi (N), K. Horita (N), Y. Mori (N), H. Fujie (N), K. Watanabe (N), A. Teramoto (N)

INTRODUCTION: Cruciate retaining (CR) total knee arthroplasty (TKA) has been reported to exhibit joint motion different from that of the normal knee. Typically, in TKA knees, the tibia is reported to be more anterior and medial in extension than in normal knees, and to exhibit paradoxical motion, i.e., backward movement of the tibia during extension-to-flexion motion. Various implant designs and surgical techniques have been devised to bring this motion closer to the normal knee, but the actual changes in motion and ligament tension in the knee that occur when implant design is changed are not known. We hypothesized that by shifting the geometry of the bearing surface of existing TKAs in the anterior, medial or a combination of directions, knee joint motion and tension in the posterior cruciate ligament (PCL), medial collateral ligament (MCL) and lateral collateral ligament (LCL) would approach normal knee conditions. The purpose of this study was to biomechanically investigate the effect of TKA bearing design on knee joint kinematics and ligament tension during knee extension-flexion movements using fresh-frozen cadavers.

METHODS: Six fresh-frozen human cadaveric knees with a mean age of 81.5 ± 2.6 years were evaluated. The knees were tested using a six-degrees of freedom (6-DOF) robotic system consisting of a 6-axis manipulator with a 6-DOF universal force-moment sensor (UFS). The knee joint coordinate system proposed by Grood and Suntay was fixed to the knee joint. TKA procedure with a measured resection technique was done on each knee using FINE CR (Teijin Nakashima Medical Co., Ltd., Okayama Japan). We set a standard CR bearing which enables CR-TKA to extend 0 degree with 1.5 Nm extension moment as with intact knee state. The following knee states was evaluated in sequence in the same specimen: (1) intact knee, (2) CR-TKA, (3) bearing surface profile shifted 5mm anterior (A5), (4) bearing surface profile shifted 3mm medial (M3), (5) bearing surface profile shifted 3mm medial and 5mm anterior (M3A5). Bearing surface was changed by using specially made bearings without any additional bony cuts or ligament releases. At each state of the knees, passive flexion-extension (FE) movements from 0 to 120 degree with 10 N axial load was applied. The 6-DOF motion and force-moment of the knees were recorded throughout the examination. After transection of the PCL, the recorded knee motions of each state of the knees were reproduced to calculate the *in situ* force of the PCL under the principle of superposition [5]. Furthermore, we determined the *in situ* force of the MCL and LCL in the same way by reproducing the motion after transection of the MCL and LCL. The two-factor repeated measures analysis of variance (ANOVA) with post hoc pairwise comparisons with Tukey correction was adopted to compare the knee joint kinematics and *in situ* forces in the PCL, MCL and LCL of each group. A value of $p < 0.05$ was considered significant. This study was approved by the Institutional Review Board of the author's University.

RESULTS: The kinematics of the TKA knee showed that the tibia was more anterior, medial, externally and internally rotated in extension than in the normal knee, and was also more anterior and medial in flexion. The *in situ* forces of the ligaments of the TKA knee were similar to those of the normal knee for the PCL and LCL, but the MCL was higher than the normal knee in all ranges of motion. The kinematics of the M3 bearing knee showed that the tibia moved 2.3-3.4 mm more laterally than the TKA knee in all ranges of motion, i.e., closer to the normal knee. The PCL, MCL, and LCL *in situ* forces of the M3 bearing knee were not significantly different from those of the TKA knee. The kinematics of the A5 bearing knee showed that the tibia moved 3.6 mm posteriorly in extension but 2.2 mm anteriorly in flexion compared to the TKA knee. The PCL *in situ* force of the A5 bearing knee was increased in mid-flexion compared to the TKA knee, the MCL *in situ* force was increased in all ranges of motion, and the LCL *in situ* force was not significantly different. The kinematics of the M3A5 bearing knee showed that the tibia moved 2.8 mm laterally and 3.7 mm posteriorly in extension compared to the TKA knee, but 3.5 mm laterally and 3.3 mm anteriorly in flexion. The PCL in situ force of the M3A5 bearing knee increased in the mid-flexion range, the MCL in situ force increased in all ranges of motion, and the LCL in situ force also showed an increasing trend compared to the TKA knee (Fig. 1-3).

DISCUSSION: The results of this study indicate that changing the bearing geometry alters the kinematics and ligament tension of the TKA knee. Shifting the bearing surface geometry inward generally produced the predicted changes in kinematics and no significant changes in ligament tension. Shifting the bearing surface shape anteriorly resulted in the predicted kinematics in extension, but the opposite was true in flexion. Furthermore, ligament tension in some ranges of motion of the PCL and in all ranges of motion of the MCL increased. The change in the positional relationship between the femur and tibia due to the change in bearing geometry also changed the distance between the ligament attachments, which may have caused this increase in tension. Therefore, when using a bearing with a shape that guides movement, it may be necessary to increase the amount of osteotomy and increase the gap. In addition, although the surface shape was shifted forward as it is in this case, it may be necessary to pay attention to the overall shape change in order to avoid kinematic conflicts.

SIGNIFICANCE: Although it was possible to bring the kinematics of the TKA knee closer to that of a normal knee by changing the shape of the bearing, it was also found to cause a change in ligament tension. It may be necessary to design geometry and surgical techniques that also take ligament tension into account.

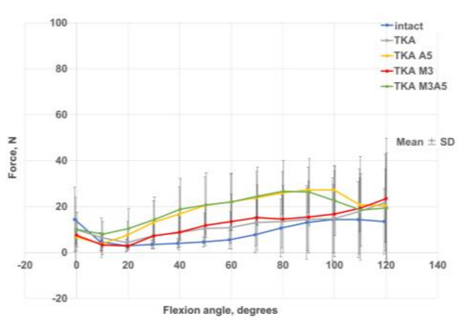

Fig. 1 *In situ* force in the PCL during passive flexion-extension.
TKA: Total Knee Arthroplasty, A5: 5mm anteriorly shifted bearing, M3: 3mm medially shifted bearing, M3A5: 3mm medially and 5mm anteriorly shifted bearing

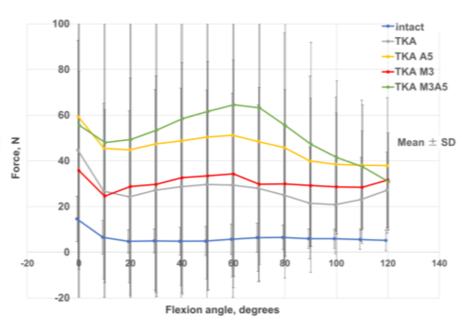

Fig. 2 *In situ* force in the MCL during passive flexion-extension.
TKA: Total Knee Arthroplasty, A5: 5mm anteriorly shifted bearing, M3: 3mm medially shifted bearing, M3A5: 3mm medially and 5mm anteriorly shifted bearing

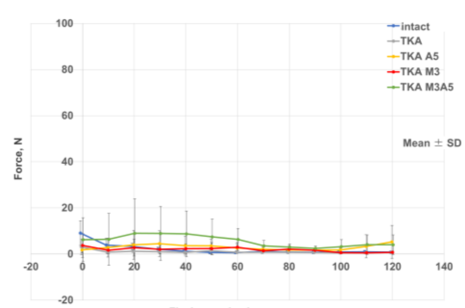

Fig. 3 *In situ* force in the LCL during passive flexion-extension.
TKA: Total Knee Arthroplasty, A5: 5mm anteriorly shifted bearing, M3: 3mm medially shifted bearing, M3A5: 3mm medially and 5mm anteriorly shifted bearing