Kinematic Analysis Of Stair-climbing In Cruciate-retaining And Posterior-stabilized Total Knee Arthroplasties

Satoshi Hamai¹, Ken Okazaki¹, Hideki Mizu-uchi¹, Hiroyuki Nakahara¹, Takeshi Shimoto², Hidehiko Higaki³, Yukihide Iwamoto¹.
¹Kyushu University, Fukuoka, Japan, ²Fukuoka Institute of Technology, Fukuoka, Japan, ³Kyushu Sangyo University, Fukuoka, Japan.


Introduction: Stair-climbing is a fundamental, common activity of daily living. Improved stair-climbing ability following cruciate-retaining (CR) TKA compared to TKA without posterior cruciate ligament (PCL) or a compensatory mechanism has been observed in several studies. However, controversy still exists as to whether CR TKA provides reproducible knee kinematics during knee flexion-extension activities including stair-stepping. Posterior-stabilized (PS) TKA was designed to improve posterior stability, range of motion, and stair-climbing ability with engagement of the post-cam mechanism to substitute for the PCL. Different PS knee systems have different post shape and locations (i.e. early or late engagement of the cam and post), allowance of hyperextension, and their subsequent intended functions. However, little information about the influence of the post-cam mechanism on knee kinematics during stair-climbing has been published.

Methods: A total of twenty four knees in nineteen patients following CR or PS TKA were included in the study. A study of these patients was approved by the Institutional Review Board, and they were informed of the risk involved with radiation exposure. Twelve knees in ten subjects received CR TKA (Foundation knee, Encore Medical Co.) and 12 knees in eleven subjects received PS TKA (NexGen Complete Knee Solution Legacy Posterior Stabilized Knee, Zimmer Inc.).

Clinical outcome has been evaluated by knee score based on the Knee Society Clinical Rating System. The overall alignment of the limb was evaluated in terms of hip-knee-ankle (HKA) angle, which was defined as the angle between the mechanical axis of the femur and the mechanical axis of the tibia. A radiological assessment of the flexion angle of the femoral component and the posterior tibial tilt angle on the lateral view was performed according to the Knee Society Roentgenographic Evaluation.

Continuous sagittal radiological images were obtained during stair-climbing for each patient using a large flat panel detector (Clavis, Hitachi, Tokyo, Japan). AP tibiofemoral position, implant flexion, and axial rotation angles were determined in three dimensions using radiographic-based image-matching techniques [3].

Results: Results: The average postoperative extension/flexion angle was -1 ± 2°/119 ± 11° after CR TKA and -3 ± 3°/125 ± 7° after PS TKA. The Knee Society score (knee score/function score) was 93 ± 6/78 ± 15 for CR TKA and 93 ± 6/75 ± 14 for PS TKA. The average HKA angle in CR/PS TKA was significantly (p < 0.01) improved from 9.2 ± 46.2°/9.8 ± 6.2° preoperatively to 1.0 ± 2.3°/0.1 ± 2.5° post-operatively. The average post-operative alignment of the femoral and tibial components on the lateral radiograph in CR/PS TKA was 3.2 ± 2.1°/2.6 ± 2.2° of flexion relative to the distal half of the axis of the femoral shaft
and 5.4° ± 2.6°/5.0° ± 2.9° of posterior tilt relative to the proximal half of the axis of the tibial shaft. All of the parameters were not significantly different between CR and PS TKAs.

In CR TKA, anterior sliding of the femur on the tibia at mid-flexion was not observed. Stair-climbing produced consistent anterior femoral roll-forward in all knees. However, five knees (42%) demonstrated paradoxical femoral translation (2.4 ± 1.5 mm) at 12.0 ± 7.8° of knee flexion and seven knees (58%) demonstrated reverse axial rotation (3.8 ± 2.8°) at 21.3 ± 15.4° of knee flexion (total nine knees: 75%, 16.7° of knee flexion on average). The average of the minimum distance between the intercondylar notch of the femoral trochlea and the intercondylar eminence of the tibial insert at foot strike/toe off was 26.9 ± 1.6 mm/4.6 ± 2.4 mm. No knees demonstrated impingement of the femoral trochlea on the tibial insert (Fig. 1). In PS TKA, anterior sliding of the femur on the tibia (4.1 ± 2.8 mm) without engagement of the post-cam mechanism at mid-flexion was recognized in four knees (33%). The average of the minimum post-cam and femoral trochlea-anterior post distances at foot strike/toe off were 4.0 ± 1.9 mm/18.2 ± 4.1 mm and 19.3 ± 2.1 mm/1.6 ± 2.9 mm. No knees demonstrated post-cam engagement, but four knees demonstrated anterior tibial post impingement from -0.5 ± 3.0° of implant flexion (Fig. 2). A more anterior position of the femur on the tibia at toe off was demonstrated in four knees with impingement of the anterior post compared to seven knees without impingement (2.8 ± 1.9 mm vs. -1.1 ± 1.1 mm, p = 0.02). The average post-operative sagittal alignment of the femoral and tibial components in PS TKA with/without anterior post impingement was 3.6 ± 2.2°/1.9 ± 2.0° of flexion and 7.5 ± 2.0°/2.8 ± 2.2° of posterior tilt. Significant differences (p = 0.004) were found in post-operative sagittal alignment of the tibial component between patients with and without anterior post impingement.

Discussion: This study characterized knee kinematics during stair-climbing after two different types of total knee prostheses. Mid-flexion AP stability during stair-climbing was demonstrated in all knees after CR TKA, suggesting that the retained PCL was functioning. Restored physiological posterior femoral rollback in flexion is preferable to the longer extensor moment arm, because it requires less quadriceps force to extend the knee under load and decreases patellofemoral contact force. However, due to deficiency of ACL, paradoxical femoral translation occurred at 12° of knee flexion in 42% of knees. It can be assumed that this symmetrical type of CR TKA, even with a functional PCL, might not reproduce physiological knee kinematics at low flexion. Improved sagittal profile of femoral component and medial pivot design could diminish paradoxical knee movements in knees with CR TKA.

In PS TKA, non-function of the post-cam mechanism caused 4.1 mm of anterior femoral sliding at mid-flexion in 33% of knees. Anterior tibial post impingement was recognized at knee extension in 33% of knees, providing anterior femoral position. Although there was no evidence of component malpositioning on radiological analysis of the knees, PS knees with anterior post impingement demonstrated significantly larger posterior tibial slope than those without anterior post impingement (7.5° vs. 2.8° on average, p = 0.004). Anterior tibial post impingement did not prevent further hyperextension and resulted in significantly more anterior displacement of the femur relative to the tibia with sudden change of direction compared to knees without impingement. Repetitive anterior impingement can lead to wear or fracture of the polyethylene post, which may be a concern regarding the long-term prognosis following PS TKA. Therefore, in order to avoid anterior post impingement in PS TKA, surgeons are not recommended to cut the proximal tibia around 7° posterior tibial slope to its anatomical axis in the sagittal plane.
Significance: Further attention must be given to the sagittal alignment of the tibial component at surgery of PS TKA and the timing and location of the post-cam mechanism when designing prostheses.