Dynamic CT of patellofemoral and tibiofemoral kinematics before and after total knee arthroplasty: a pilot study

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INTRODUCTION: Total knee arthroplasty (TKA) is an effective treatment for end-stage osteoarthritis, but up to 20% of patients remain dissatisfied, often due to persistent anterior knee pain and functional limitations. These complaints have been linked to altered patellofemoral (PF) and tibiofemoral (TF) kinematics. However, research on PF joint dysfunction after TKA is limited, which is related to challenges in capturing in vivo dynamic joint motion. Dynamic CT has emerged as a feasible method for continuous in vivo motion capture with low radiation exposure. The objective of this pilot study was to develop and evaluate a dynamic CT-based protocol capable of quantifying six-degree-of-freedom PF and TF kinematics before and after TKA, and to characterize postoperative changes.

METHODS: This prospective study was approved by the local Institutional Review Board and subjects provided written informed consent. Ten participants with primary osteoarthritis (6 males, 4 females; mean age 65 ± 8 years) scheduled for cemented bicruciate-stabilized TKA were included between March 2022 and June 2023. Static and dynamic CT scans were acquired preoperatively and at one-year follow-up. Dynamic scans captured a ten-second flexion-extension-flexion cycle in a semi-seated position, yielding 41 frames per scan. Preoperatively, the femur, patella, and tibia were segmented using a convolutional neural network. Postoperatively, CAD models of femoral and tibial implants were aligned to CT data to determine the relative implant-bone orientation. Due to metal artifacts, patellar registration was performed manually by four operators, who aligned the preoperative meshes to the postoperative scans. The averaged positions were then used for analysis. Anatomical coordinate systems were assigned to bone meshes to calculate six-degree-of-freedom kinematics. PF motion was assessed via patellar flexion, tilt, proximal tip rotation, and mediolateral translation. TF kinematics focused on femoral condyle anterior-posterior (AP) translation. Analyses were restricted to the shared 14°–55° flexion range achieved by all participants. Descriptive statistics were used to compare pre- and post-TKA motion, and inter-operator reliability for patellar registration was assessed using intraclass correlation coefficients (ICCs).

RESULTS SECTION: Postoperatively, the patella exhibited trends toward increased flexion (median difference: 0.9°–3.9°), more medial proximal tip rotation (median difference: 1.5°–6.0°), increased lateral tilt (median difference: 2.7°–5.5°), and a lateralized position (median difference: 1.5–2.8 mm) compared to preoperative kinematics (Figure 1). Reliability of manual patellar registration was excellent, with ICCs ≥ 0.90 for all parameters. TF kinematics revealed approximately 2–4 mm AP translation of both medial and lateral femoral condyles (Figure 2). The lateral condyle occupied a more anterior position postoperatively compared to the preoperative position and exhibited reduced inter-subject variability. These findings suggest more constrained and uniform postoperative motion. Despite the small sample, largely consistent patterns across participants demonstrate that dynamic CT may effectively capture clinically relevant changes in knee kinematics after TKA.

DISCUSSION: This study demonstrates the feasibility of dynamic CT for detailed assessment of PF and TF kinematics before and after TKA. Postoperative changes were characterized by increased patellar flexion, medial proximal tip rotation, lateral tilt, and lateral shift, combined with a more anterior position of the lateral femoral condyle. These findings likely reflect differences between the prosthesis design and alignment, and the native knee morphology. Limitations include small sample size, use of a single implant design, labor-intensive postoperative patellar registration, long total analysis time, restriction to non-weightbearing movement, and limited analysis to the 14°–55° flexion range. Further advancements in automation and processing efficiency will be necessary to research post-TKA PF and TF kinematics in a larger sample size and confirm these exploratory findings.

SIGNIFICANCE/CLINICAL RELEVANCE: Dynamic CT may provide a practical tool for in vivo evaluation of knee kinematics after TKA with strong clinical potential due to the low radiation exposure and wide availability of CT scans in hospitals. By capturing patellar and femoral motion continuously, this method may help identify abnormal joint mechanics associated with persistent pain or dissatisfaction, support individualized surgical planning, and refine implant design.
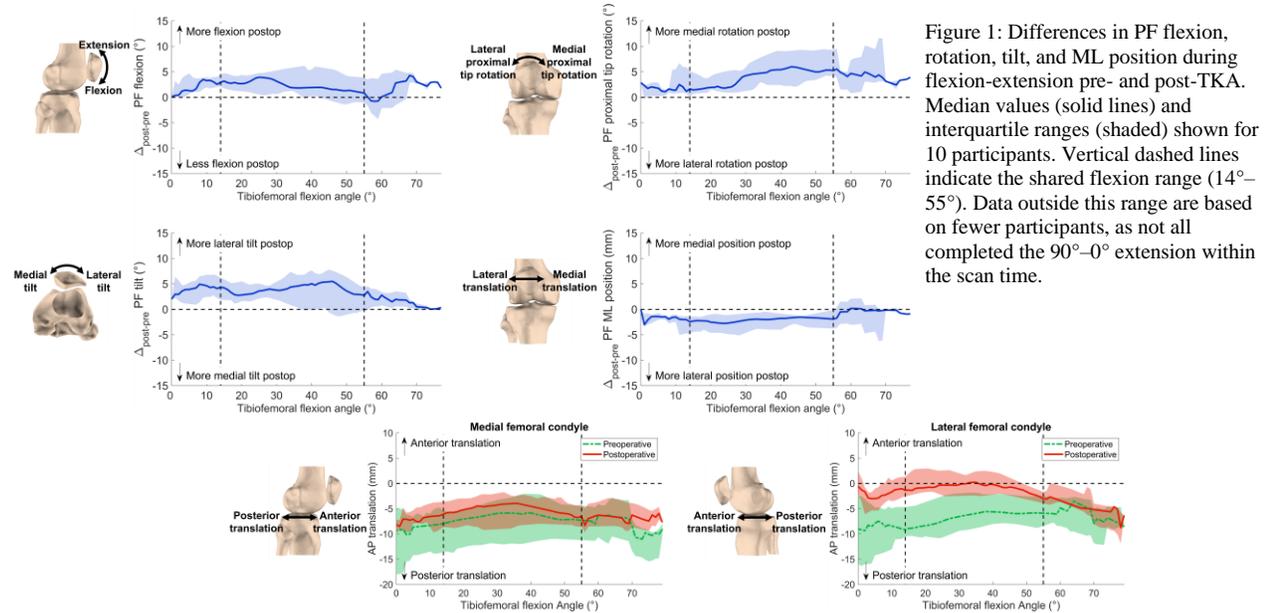

Figure 1: Differences in PF flexion, rotation, tilt, and ML position during flexion-extension pre- and post-TKA. Median values (solid lines) and interquartile ranges (shaded) shown for 10 participants. Vertical dashed lines indicate the shared flexion range (14°–55°). Data outside this range are based on fewer participants, as not all completed the 90°–0° extension within the scan time.

Figure 2: Medial (left) and lateral (right) femoral condyle AP translation during flexion-extension. Pre-TKA data shown with green dashed lines and shading (median, IQR); post-TKA with red solid lines and shading. Vertical dashed lines indicate the shared flexion range (14°–55°). Data outside this range are based on fewer participants, as not all completed the 90°–0° extension within the scan time.