Functional Alignment in Robotic-Assisted Total Knee Arthroplasty Enhances Function, Posture, and Patient Satisfaction

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Introduction: Robotic-assisted total knee arthroplasty (R-TKA) is rapidly evolving, offering unmatched precision and standardization that may enhance clinical outcomes. While radiographic accuracy and patient-reported outcome measures (PROMs) are well-established indicators, achieving a pain-free, physiological gait remains a critical marker of success from the patient's perspective. This study aims to evaluate whether robotic-assisted TKA facilitates a more physiological gait and standing posture, and whether gait analysis can serve as an objective tool for postoperative assessment and monitoring. Furthermore, it investigates whether functional alignment in R-TKA provides superior functional and postural outcomes compared to traditional mechanical alignment, potentially supporting more individualized and patient-specific alignment strategies.

Methods: A total of 50 patients (male and female) undergoing robot-assisted total knee arthroplasty (R-TKA; Mako, Stryker, USA) were prospectively enrolled after obtaining informed consent and approval from the institutional review board. Assessments were conducted preoperatively (T0) and at 3, 6, and 12 months postoperatively (T1–T3). Patients were subgrouped preoperatively according to their leg axis into valgus (HKA > 3°), neutral (HKA –3° to 3°), or varus (HKA < –3°) using the mechanical femorotibial angle, mechanical distal medial distal femoral angle, mechanical proximal tibial angle, joint line convergence angle, and hip–knee angle. The same method was applied postoperatively, creating two alignment groups: neutral mechanical alignment (HKA –3° to 3°) and functional varus alignment (HKA < –3°). Outcome measures included the Knee Injury and Osteoarthritis Outcome Score (KOOS) for clinical evaluation and posture and gait analysis using a light-optical motion analysis system (4D Motion Lab, Diers International GmbH, Germany), focusing on kyphotic angle, trunk inclination, surface rotation, pelvic inclination, and knee axis alignment.

Results: At the 6-month follow-up, patients showed a progressive normalization of knee joint mobility and a significant improvement in KOOS scores in both the postoperative neutral and functional varus subgroups. The functional varus group demonstrated even greater improvements in KOOS Pain (+67% vs. +55%), KOOS Symptoms (+58% vs. +25%), and KOOS Activities of Daily Living (ADL) (+44% vs. +36%), while improvements in KOOS Quality of Life (LQ) were identical in both groups (+137%). Only in KOOS Sport and Recreation did the neutral group slightly outperform the functional varus group (+80% vs. +70%). Posture and gait analysis revealed distinct differences between neutral and functional varus subgroups. The kyphotic angle (ICT–ITL max) and pelvic inclination normalized exclusively in patients with a functional varus alignment (kyphotic angle: 49.9° ±11.8° vs. 65.4° ±10.6°; pelvic inclination: 23.4° ±8.3° vs. 13.0° ±12.3°). In contrast, the lordotic angle (ITL–ILS max) and surface rotation RMS normalized in both groups, while pelvic torsion remained stable in the functional varus group (1.7°→1.8°) but improved in the neutral group (3.2°→0.7°). In the gait analysis, stride length increased in both subgroups, with a greater enhancement in the functional varus group (+43% vs. +34%), and stride velocity improved markedly in functional varus patients (+64% vs. +30% in neutral patients). Swing time, stance time, single support time, and double support time all demonstrated similar positive trends across both subgroups. Regarding dynamic posture, kyphotic and lordotic angles as well as surface rotation were comparable between the neutral and functional varus groups. However, trunk inclination and pelvic inclination displayed much greater variability in neutrally aligned patients, suggesting a higher degree of heterogeneity in postural control compared to the functional varus subgroup.

Discussion: Robotic-assisted total knee arthroplasty enables reproducible and standardized implantation, with clear improvements in both clinical outcomes and patient-reported outcome measures (PROMs). Importantly, gait and posture analysis proved to be a sensitive and objective tool for quantifying functional recovery, complementing conventional radiological and clinical follow-up. This innovative approach supports individualized recommendations and offers an objective evaluation of therapeutic success, which is particularly valuable for an increasingly geriatric patient population. In subgroup analyses, patients with functional varus alignment demonstrated higher PROM scores and more physiological postural indicators. In contrast, patients with neutral-aligned implants showed a wider range of trunk and pelvic inclination, indicating increased compensatory movements of the hip and trunk to adapt to the less physiological alignment. In summary, these findings suggest that maintaining the patient's natural physiological varus leg axis—rather than overcorrecting to a neutral alignment—results in better functional outcomes, improved posture, and greater patient satisfaction.

Significance / Clinical relevance: Up to 10–20% of patients remain dissatisfied after total knee arthroplasty, often experiencing persistent pain or requiring assistive devices for walking and mobility. This study addresses this challenge by leveraging robotic-assisted total knee arthroplasty (R-TKA) to investigate the impact of preserving pre-arthritic knee alignment versus overcorrection to a neutral axis on the restoration of a physiological gait and stance pattern. Our findings demonstrate that robotic-assisted implantation with functional varus alignment results in more physiological gait mechanics, improved posture, better functional outcomes, and higher patient satisfaction, highlighting the importance of precision and individualized alignment strategies in modern TKA.