

Gait analysis of a kinematic retaining implant for Total knee replacements during walking and running

Background

The analysis of gait analysis is an important tool in evaluating postoperative outcomes of a Total Knee Replacement (TKR). There are few studies which have evaluated the gait parameters of a Kinematic retaining (Kr) prosthesis. This study therefore aims to investigate the kinetic and kinematic differences of running and walking, in the ankle, knee and hip joints in patients who underwent a Kr TKR.

Methods

This study assessed the gait of 12 patients with physical limb Kr TKRs at 1 year follow up and 8 healthy controls using 3D video analysis. Data was collected on the kinetics and kinematics of walking and running at the ankle, knee and hip. Comparison was made between the operated and non-operated limbs of the patients, and between the operated and control limbs.

Results

Gait analysis showed no statistically significant difference in the hip, ankle and knee angles or moments between the non-operated and operated legs during walking and running.

However, there was a statistically significant difference between the knee angles of initial contact, maximum flexion during stance and swing in the TKR knees vs controls in walking and running. Similarly, there was also a statistically significantly higher max knee flexion moment between operated knees and controls in both walking and running.

Conclusion

This study has shown that a quadriceps avoidance gait persists in patients after TKR, and that there was symmetry and reciprocated gait parameters in non-operated limbs. These findings

suggest that Kr TKRs could be capable of replicating normal knee kinematics when running and walking

1.1 Introduction:

Osteoarthritis (OA) is a degenerative condition causing varying degrees of pain and disability. The incidence of knee OA in UK adults is approximately one in ten, with a recent increase in cases among 35-44-year olds^{1,2}. A Total Knee replacement (TKR) is the definitive surgical management of end stage arthritis in the knee³.

TKRs relieve arthritic pain and can improve patients function in activities of daily living⁴. The traditional mechanically aligned TKRs whether Cruciate Retaining (CR) or Posterior Sacrificing (PS) have similar outcomes in terms of gait parameters, range of motion, electromyographic waveforms, and isokinetic muscle testing parameters⁵. Mechanically aligned PS and CR knees also generates similar values of maximum knee flexion angles and flexion moments during loading⁶. However, literature on the assessment of gait parameters in a Kinematic retaining (Kr) prosthesis are sparse⁷.

Previous studies on gait analysis post TKR have focused solely on assessing walking⁸⁻¹². Some studies, although infrequent have assessed more challenging activities such as lunging, squatting and sit-to stand¹³⁻¹⁶. There are also some studies which have assessed walking at an 'elevate speed'^{12,17,18}, but to our knowledge there have been no studies performed looking at gait analysis of running post TKR.

This study therefore aims to investigate the kinetic and kinematic differences of running and walking, in the ankle, knee and hip joints in patients who underwent a kinematic retaining TKR.

2.1 Materials & Methods:

This study involved assessing patients who had undergone TKRs using the Physica KR (LimaCorporate, Italy) knee implant. Regional ethical committee approval has been sought for this study (IRAS ID 172937, REC reference 15/SC/0725).

Participants

This study was prospective and recruited sixteen patients who had undergone unilateral TKRs using the Physica KR prosthesis and were at minimum 1-year post-op. Exclusion criteria were as follows: a) musculoskeletal or neurological disorders that may affect gait, b) previous surgery on the contra-lateral leg, c) back pain, and d) patients who were unable to perform the gait testing sessions unassisted. Eight healthy control patients who did not suffer from musculoskeletal disorders were also recruited.

Data Acquisition

Three-dimensional video analysis was used to perform and assess gait, with ten cameras (Oxford Metrics, VICON, Oxford Metrics) synchronised with two Kistler force platforms (Hampshire, Kistler Instrument Ltd) to assess the kinetic and kinematic parameters of gait. Thirty-nine retro reflective spherical markers of 14mm size were placed on landmarks following the VICON plug-in-gait guidelines. Force platform and marker data was performed at 2000Hz and 250Hz respectively.

The Helen- Hayes plug-in-gait model was followed for application of the markers to the patient. A calibration trial for both dynamic and static movements was performed and evaluated to ensure there were no blind spots.

Running and Walking Gait:

Participants were asked to warm up initially for the walking gait analysis.

Subjects were then requested to ambulate in straight line, with three successful trials recorded. Subsequently, for the running analysis, participants were asked to trial and simulate laboratory environment running, before three successful trials of running were obtained.

Data Processing and analysis:

Three successful trials for walking and running were performed and recorded. Data was processed and assessed using Nexus 2.0. (VICON, Oxford Metrics, England).

The gait cycle was plotted, and time normalised to consecutive heel strikes of the same leg. Data was then evaluated and computed using MATLAB®, for the ankle, knee, and hip joints.

The comparisons performed were the following:

- 1) TKR operated leg kinematics and kinetics vs non-operated leg
- 2) TKR operated leg kinematics and kinetic vs control legs

3.1 Results

Patient Demographics

Twelve patients with unilateral KrTKRs were evaluated at a minimum of one year follow up.

The mean age of the patients was 66 ± 5 years, with an age range of 57-75. There were six females and six males, and the mean weight was 84 ± 9 kg and 1.72 ± 0.1 m

3.2 Walking

There was no statistically significant difference between the non-operated and operated knees for the knee, hip or ankle angles (see table 1). Additionally, there was no statistically significant difference between the moments of the ankle, knee or hip between the operated and non-operated knees (see table 2).

Comparing the knee angles for the operated knee vs controls there was a statistically significant increase in the angle on initial contact 1.79 vs 6.93 ($p=0.031$), maximum flexion during stance 10.85 vs 19.54 ($p=0.005$), and maximum flexion during swing 42.72 vs 57.29 ($p<0.0005$). There was no statistically significant difference between the operated knees and the control hip angles. Due to significant scatter and data capture issues, the control ankles values were not included in this analysis.

When comparing the moments of the operated knees and the controls, there was a statistically significant difference between the knee moment in extension of 902.76 vs 2046.76 ($p=0.023$), and the hip extension moment -1412.21 vs -3255.82 ($p=0.011$).

3.3 Running

There was no statistically significant difference between the operated and non-operated knees for the knee, hip or ankle running angles (see table 3). Additionally, there was no statistically significant difference between the running moments of the hip, knee or ankle between the operated and non-operated knees (see table 4).

Comparing the knee angles for the running operated knee vs controls there was a statistically significant increase in the angle on initial contact 7.89 vs 14.73 ($p=0.011$), maximum flexion during stance 22.92 vs 33.98 ($p=0.005$), and maximum flexion during swing 61.88 vs 75.48 ($p=0.010$). There was no statistically significant difference between the running angles of the operated knee, hip or ankle compared to controls.

When comparing the moments of the operated knees and the controls, there was a statistically significant difference between the knee moments in extension of 942.78 vs 1884.67 ($p= 0.042$) (see Table 4).

4.1 Discussion

Currently, TKRs are the modality of choice for end stage OA in the knee. However, one in five patients post TKR are unsatisfied with their outcomes, compared to one in twenty for Total Hip Replacements^{19,20}. TKRs have therefore been assessed radiologically, clinically, and mechanically to identify and address this discrepancy. Implant design and surgical technique have evolved as a result of this. The Physica KR prosthesis is designed with a concave medial articulating surface, and a saddle-like lateral surface to allow greater flexion. This study compared the kinetics and kinematics of a KrTKR limb to the non-operated and control limbs, at the ankle, knee, and hip. Additionally, this study assessed the gait during both walking and running for operated, non-operated, and control limbs.

4.2 Walking

Gait analysis in this study showed no statistically significant difference in the knee angles between the operated and non-operated legs during walking. However, there was a statistically significant difference between the knee angles of initial contact, max-flexion during stance, and max-flexion during swing in the operated knees vs controls. Similarly, there was also a statistically significantly higher max knee flexion moment between TKR knees and controls. The severity of knee OA has been associated with reduced flexion angles of the knee and show some improvement in patients post TKR⁹. However, multiple studies have shown persistence of decreased knee flexion angles and peak flexion moments between TKR and control patients post operatively²¹. This has been attributed to the development of a ‘quadriceps avoidance gait’, which is often present in patients with OA of the knee to reduce pain in the affected limb^{9,21}. A reduction in the force of the quadriceps in the opposition of the knee flexion moment results in reduced compression of the joint, which is advantageous in a painful knee²¹. Although the painful stimulus has been removed post TKR, the persistence of these elements highlights the difficulties in changing a patient’s gait pattern post procedure. Interestingly, the non-operated limb also had a reduced knee flexion angle and peak knee flexion moment, with no statistically significant differences seen between the operated and non-operated limbs. There was also a high level of symmetry between the operated and non-operated knees. The development of OA in the contralateral limb is well documented²², with the incidence of bilateral knee OA and TKRs being relatively high²³. Given the symmetrical nature of gait, it is possible that the abnormal gait which develops in the OA knee is reciprocated in the other limb as a compensatory mechanism²¹. This could provide an altered mechanical loading environment in contralateral limb joints and lead to the development of OA.

There was no statistically significant difference between peak adduction moments in TKR limbs vs non-operated limbs, or in TKR limbs vs controls. This suggests that there is similar medial loading of the KrTKR patients compared to controls and non-operated limbs. The knee adduction moment is used to assess mechanical loading of the medial compartment during gait⁹. A higher knee adduction moment, has been linked to both the severity of and progression of OA^{24,25}. This restoration of knee adduction moments similar to controls highlights the efficiency of the KR implant in maintaining low medial compartment forces.

There was no statistically significant difference in hip or ankle angles and moments in the operated vs non-operated legs. There was however a statistically significant difference between the max hip extension moment between TKR limbs and controls.

4.3 Running

This study is unique in its assessment of running for patients post TKR. Running is characterised by a decreased stance phase and an increased swing phase²⁶. There is often an increase in joint excursion, and an increase in eccentric muscle contraction²⁷. Running is not a common activity performed after a TKR, often due to multiple factors, including lack of motivation, medical comorbidities, and precautions over implant survival.

In this study, the symmetry of gait present with walking between the operated and non-operated limbs was also mirrored in running. There was no statistically significant difference in the knee, hip or ankle angles between the operated and non-operated legs during running. However, there was a statistically significant difference between the knee angles of initial contact, maximum flexion during stance, maximum flexion during swing, as well as the max knee moment in TKR limbs vs controls. This suggests that the quadriceps avoidance gait persists during running in patients who underwent Kr TKR.

Interestingly, even at heightened speed, the TKR group had similar knee adduction moments compared to both controls and non-operated limbs. This suggests that the levels of medial compartment stress during running in TKRs does not rise despite an increase in the forces acting across the knee. Given that high knee adduction moments have been attributed to enhanced poly wear, KrTKRs may be less susceptible to wear²⁸.

Limitations of this study include patient numbers, as well as lack of gait analysis prior to TKR surgery. Additionally, the laboratory environment has inherent limitations with respect to assessing for normal walking and running. It must also be noted that this is an overall assessment, and there is likely to be some scatter at the individual level.

5.1 Conclusion

Overall, this study has shown that a quadriceps avoidance gait may persist in patients post TKR (in both walking and running) and that there is significant symmetry and reciprocated gait parameters in non-operated limbs. Additionally, compared to control subjects, the Kr TKR patients still had lower flexion knee angles in both running and walking. Similarly, the knee adduction moments for Kr TKRs are comparable to control subjects, suggesting that they have a sustained decrease in medial compartment loading, which could suggest that they have some resistance to wear. These findings suggest that Kr TKRs could be capable of replicating normal knee kinematics when running and walking.

References

1. Swain S, Sarmanova A, Mallen C, et al. Trends in incidence and prevalence of osteoarthritis in the United Kingdom: findings from the Clinical Practice Research Datalink (CPRD). *Osteoarthritis Cartilage*. 2020;28(6):792-801. doi:10.1016/j.joca.2020.03.004
2. Yu D, Peat G, Bedson J, Jordan KP. Annual consultation incidence of osteoarthritis estimated from population-based health care data in England. *Rheumatology (Oxford)*. 2015;54(11):2051-2060. doi:10.1093/rheumatology/kev231
3. Skou ST, Roos EM, Laursen MB, et al. A Randomized, Controlled Trial of Total Knee Replacement. *N Engl J Med*. 2015;373(17):1597-1606. doi:10.1056/NEJMoa1505467
4. Loughhead JM, Malhan K, Mitchell SY, et al. Outcome following knee arthroplasty beyond 15 years. *Knee*. 2008;15(2):85-90. doi:10.1016/j.knee.2007.11.003

5. Bolanos AA, Colizza WA, McCann PD, et al. A comparison of isokinetic strength testing and gait analysis in patients with posterior cruciate-retaining and substituting knee arthroplasties. *J Arthroplasty*. 1998;13:906-915. doi:10.1016/S0883-5403(98)90198-X.
6. van den Boom LGH, Halbertsma JPK, van Raaij JJAM, Brouwer RW, Bulstra SK, van den Akker-Scheek I. No difference in gait between posterior cruciate retention and the posterior stabilized design after total knee arthroplasty. *Knee Surgery, Sport Traumatol Arthrosc*. 2014;22:3135-3141. doi:10.1007/s00167-014-3215-y.
7. Blakeney W, Clément J, Desmeules F, Hagemester N, Rivière C, Vendittoli PA. Kinematic alignment in total knee arthroplasty better reproduces normal gait than mechanical alignment. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(5):1410-1417. doi:10.1007/s00167-018-5174-1
8. Abbass S, Abdulrahman G. Kinematic analysis of human gait cycle. *Al-Nahrain Journal for Engineering Sciences*. 2014;16(2):208-222. Retrieved from <https://nahje.com/index.php/main/article/view/289>
9. Hatfield GL, Hubley-Kozey CL, Astephen Wilson JL, Dunbar MJ. The effect of total knee arthroplasty on knee joint kinematics and kinetics during gait. *J Arthroplasty*. 2011;26(2):309-318. doi:10.1016/j.arth.2010.03.021
10. Alnahdi AH, Zeni JA, Snyder-Mackler L. Gait after unilateral total knee arthroplasty: frontal plane analysis. *J Orthop Res*. 2011;29(5):647-652. doi:10.1002/jor.21323
11. Pethes A, Kiss RM, Szendrői M. Variability of gait in the early postoperative period of total knee arthroplasty with different surgical technique. *Int Orthop*. 2014;38(3):517-523. doi:10.1007/s00264-013-2115-y
12. McClelland JA, Webster KE, Feller JA, Menz HB. Knee kinematics during walking at different speeds in people who have undergone total knee replacement. *Knee*. 2011;18(3):151-155. doi:10.1016/j.knee.2010.04.005
13. Boonstra MC, De Waal Malefijt MC, Verdonschot N. How to quantify knee function after total knee arthroplasty? *Knee*. 2008;15:390-395. doi:10.1016/j.knee.2008.05.006.
14. Byrne JM, Prentice SD. Swing phase kinetics and kinematics of knee replacement patients during obstacle avoidance. *Gait Posture*. 2003;18:95-104. doi:10.1016/S0966-6362(02)00164-9.
15. Mizner RL, Snyder-Mackler L. Altered loading during walking and sit-to-stand is affected by quadriceps weakness after total knee arthroplasty. *J Orthop Res*. 2005;23:1083-1090. doi:10.1016/j.orthres.2005.01.021.
16. Boonstra MC, Jenniskens AT, Barink M, et al. Functional evaluation of the TKA patient using the coordination and variability of rising. *J Electromyogr Kinesiol*. 2007;17:49-56. doi:10.1016/j.jelekin.2005.11.009.
17. McClelland JA, Webster KE, Feller JA. Variability of walking and other daily activities in patients with total knee replacement. *Gait Posture*. 2009;30:288-295. doi:10.1016/j.gaitpost.2009.05.015.
18. Okita Y, Tatematsu N, Nagai K, et al. The effect of walking speed on gait kinematics and kinetics after endoprosthetic knee replacement following bone tumor resection. *Gait Posture*. 2014;40:622-627. doi:10.1016/j.gaitpost.2014.07.012.
19. Bourne RB, Chesworth BM, Davis AM, et al. Patient satisfaction after total knee arthroplasty: who is satisfied and who is not? *Clin Orthop Relat Res*. 2010;468:57-63.
20. Fujita T, Hamai S, Shiimoto K, et al. Analysis of factors influencing patient satisfaction after total hip arthroplasty in a Japanese cohort: the significant effect of postoperative physical activity. *J Phys Ther Sci*. 2022;34(2):76-84. doi:10.1589/jpts.34.76
21. Milner CE. Is gait normal after total knee arthroplasty? Systematic review of the literature. *J Orthop Sci*. 2009;14(1):114-120. doi:10.1007/s00776-008-1285-8

22. Shakoor N, Block JA, Shott S, Case JP. Nonrandom evolution of end-stage osteoarthritis of the lower limbs. *Arthritis Rheum* 2002; 46:3185–9
23. Mont MA, Mitzner DL, Jones LC, Hungerford DS. History of the contralateral knee after primary knee arthroplasty for osteoarthritis. *Clin Orthop Relat Res* 1995(321):145–50.
24. Sharma L, Hurwitz DE, Thonar EJ, Sum JA, Lenz ME, Dunlop DD, Schnitzer TJ, Kirwan-Mellis G, Andriacchi TP. Knee adduction moment, serum hyaluronan level, and disease severity in medial tibiofemoral osteoarthritis. *Arthritis Rheum*. 1998;41:1233–1240
25. Miyazaki T, Wada M, Kawahara H, Sato M, Baba H, Shimada S. Dynamic load at baseline can predict radiographic disease progression in medial compartment knee osteoarthritis. *Ann Rheum Dis*. 2002;61:617–622.
26. Dugan SA, Bhat KP. Biomechanics and analysis of running gait. *Phys Med Rehabil Clin N Am*. 2005;16(3):603-621. doi:10.1016/j.pmr.2005.02.007
27. Ounpuu S. The biomechanics of walking and running. *Clin Sport Med* 1994;13(4):843–63
28. Collier MB, Engh CA, Jr, McAuley JP, Engh GA. Factors associated with the loss of thickness of polyethylene tibial bearings after knee arthroplasty. *J Bone Joint Surg Am*. 2007;89:1306–1314. doi: 10.2106/JBJS.F.00667