

Knee Kinematics and Kinetics During Level and Downhill Walking in Total Knee Arthroplasty Using a Robotic Ligament Tensioner

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INTRODUCTION: Total Knee Arthroplasty (TKA) is a definitive treatment procedure for severe knee osteoarthritis. To achieve high functionality, it is important to restore the native knee biomechanics as much as possible. Robotic-assisted TKA holds promise in reliable ligamentous balancing through bony resection that may improve patient function, including during a more normal daily activity such as gait. This observational study aimed to capture functional parameters after robotic-assisted TKA and compare them with already recorded data of patients who had received a manually implanted TKA. In addition, we also used data from a healthy elderly subject group to see whether the gait of TKA patients with well-balanced ligaments had normalized.

METHODS: Three groups (n=13 each) were included. The rTKA (robotic single radius CR TKA) group consisted of 2/11 male/female, 68.4 ± 6.8 years, 27.6 ± 3.8 body mass index (BMI), 8/5 right/left. All subjects received a primary, unilateral TKA with single radius CR implants in a robotic-assisted procedure within 8 to 14 months after surgery and had BMI <35. All subjects were recruited from a single surgeon's clinic for this ongoing IRB-approved study. For comparison, a data repository was assessed to obtain the mTKA (Manually implanted single radius CR TKA) comparison group which consisted of 1/12 male/female, 66.5 ± 6.8 years, 29.5 ± 6.8 BMI, 5/8 right/left. The third group was an elderly "Healthy" comparator group consisting of 4/9 male/female, 60.5 ± 6.1 years, 25.3 ± 4.0 BMI, 7/6 right/left. The point cluster marker set (PCT) was used to obtain knee joint kinematics and kinetics. Passive reflective markers were placed on the skin and tracked with a multi-camera system. Subjects were instructed to walk at their usual pace on level and downhill walkways outfitted with force plates. (Fig.1). Knee kinematics and external moments were calculated and normalized to %bodyweight x height using inverse dynamics. One-way ANOVA with post-hoc Games-Howell analyses was performed on selected gait parameters. Statistical nonParametric Mapping (SnPM) of the waveforms was also performed (Fig 2).

RESULTS: The TKA groups were similar but approximately 8 years older than the Healthy. Sex distribution was the same in all three groups. The final laxity of the robotic cohort as measured under a constant ligament tension of 80-90N/side was, on average, within 1.2mm of the insert thickness medially and laterally throughout flexion, and the final mediolateral balance was within 0.5mm on average with the medial side slightly tighter than the lateral throughout flexion. All gait outcome parameters are tabulated in Table 1. There were slight differences in preferred walking speeds. The Healthy group walked faster than the mTKA both on the level and downhill surfaces (p=.012, p=.022, respectively). The range of motion (ROM) during walking was similar in the rTKA and the Healthy in both conditions. In contrast, the mTKA displayed a smaller ROM than the Healthy in both level and downhill walking (p=.004, p<.001, respectively). Conversely, during the midstance phase of the gait cycle, the knee of rTKA stayed significantly more flexed (10.9°, SE=1.5) compared to the Healthy (0.34°, SE=1.5) and mTKA (5.3°, SE=1.5) in level walking (p<.001, p=.044, respectively). A similar trend was also observed in downhill walking using SnPM. (Fig. 2A) The tibial anterior displacements of the rTKA were significantly smaller than the Healthy and mTKA in level (p=.040, p=.002, respectively) and downhill walking (p=.011, p<.001, respectively) (Fig. 2B). The peak flexion moment, which occurs during the first half of the stance in the sagittal plane, was higher in the rTKA and the Healthy (p<.001, p=.017 in level walking, p<.001, p=.003 in downhill, respectively) than the mTKA which may suggest the normal quadriceps use. On the contrary, the peak extension moment, occurring in the second half of the stance, was significantly lower in the rTKA than the Healthy and mTKA. (p<.001, p=.002 in level walking, p=.002, p=.003 in downhill, respectively) (Fig. 2C, D) In the frontal plane, there were no statistical differences among the 3 groups in adduction peaks in both level and downhill walking.

DISCUSSION: This study is one of the first to objectively compare manual and robotic ligament balancing techniques in TKA and report a difference in level walking as well as during a mid-flexion activity such as downhill walking. Some but not all of the gait parameters appear normalized after robotic surgery. The rTKA subjects demonstrated healthy quadriceps use during the stance phase under both conditions, suggesting that proper ligament tensioning may help the extensor mechanism, which is often compromised after TKA. On the other hand, the low extension moment during the swing phase suggests underutilization of the hamstrings, a feature that needs more study and could be related to implant design. One limitation of this study was that TKA implants for the manual and robotic groups were not the same. Future work will take this into account and identify the reason for the difference in kinetics.

SIGNIFICANCE/CLINICAL RELEVANCE: TKA with robotic-assisted ligament balancing suggests normalization of some, but not all, gait parameters and healthier quadriceps use during level and downhill walking when compared to manual TKA.

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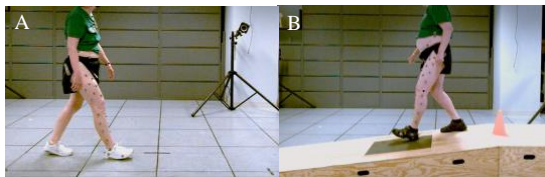


Figure 1. Gait Trials shown under two different conditions. (A) Level walking trials were completed over a horizontal surface. (B) Downhill walking trials were performed on a ramp with a 12.5% slope. Simultaneously, ground reaction forces were collected with an embedded force plate. Five trials were recorded for each activity.

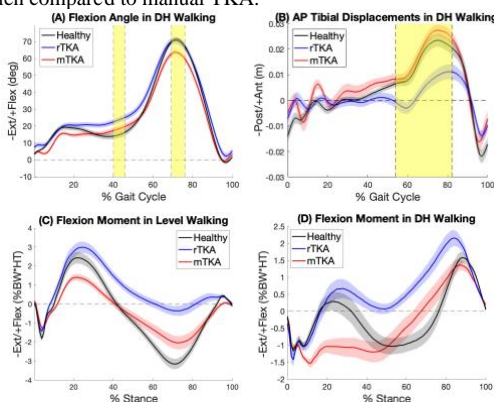


Figure 2. Knee Joint Kinematics and Kinetics (A) rTKA stayed more flexed during downhill walking in the midstance phase, while mTKA reached lower flexion angles during swing phase compared to Healthy and rTKA (B) Tibial AP displacement of rTKA was smaller than other 2 groups (C) (D) rTKA showed higher flexion moment in both conditions at the 1st half of the stance phase. rTKA showed lower extension moment at the 2nd half of the stance in both conditions.

Table 1. Peak Kinematics and Kinetics During Level and Downhill Walking

Variable (unit)	Level Walking, Mean (SE), 95% CI [Lower, Upper]			Downhill Walking, Mean (SE), 95% CI [Lower, Upper]		
	rTKA	mTKA	Healthy	rTKA	mTKA	Healthy
Speed (m/s)	1.28 (0.044), [1.19, 1.37]	1.17 (0.044), [1.08, 1.26]	1.35 (0.044), [1.26, 1.44]	1.14 (0.047), [1.05, 1.23]	1.01 (0.047), [0.92, 1.11]	1.20 (0.047), [1.11, 1.29]
Stride length (m)	0.79 (0.017), [0.76, 0.83]	0.76 (0.017), [0.73, 0.80]	0.84 (0.017), [0.81, 0.88]	0.71 (0.021), [0.66, 0.75]	0.68 (0.021), [0.64, 0.73]	0.77 (0.021), [0.72, 0.81]
Knee sagittal plane ROM (°)	64.2 (1.4), [61.3, 67.1]	61.5 (1.4), [58.7, 64.4]	68.7 (1.4), [65.8, 71.6]	69.9 (1.5), [66.8, 73.0]	65.5 (1.5), [62.4, 68.6]	74.0 (1.5), [70.9, 77.1]
Tibial Anterior displacement range (mm)	13.7 (2.4), [8.8, 18.7]	27.1 (2.4), [22.2, 32.1]	23.0 (2.4), [1.80, 2.79]	13.0 (2.5), [8.0, 18.0]	28.4 (2.5), [23.4, 33.4]	24.6 (2.5), [19.6, 29.6]
Flex. moment (%BW*HT)	3.08 (0.26), [2.55, 3.62]	1.49 (0.26), [0.96, 2.02]	2.52 (0.26), [1.99, 3.05]	0.78 (0.25), [0.27, 1.30]	-0.73 (0.25), [-1.24, -0.22]	0.55 (0.25), [0.04, 1.07]
Ext. moment (%BW*HT)	0.47 (0.29), [0.11, 1.06]	2.11 (0.29), [1.52, 2.69]	3.20 (0.29), [2.62, 3.78]	0.025 (0.24), [-0.51, 0.46]	1.27 (0.24), [0.78, 1.75]	1.14 (0.24), [0.65, 1.62]
Add. moment, peak 1 (%BW*HT)	2.36 (0.24), [1.88, 2.83]	2.36 (0.24), [1.88, 2.83]	3.18 (0.24), [2.70, 3.65]	2.08 (0.27), [1.54, 2.61]	1.44 (0.27), [0.91, 1.98]	2.19 (0.27), [1.65, 2.73]
Add. moment, peak 2 (%BW*HT)	1.82 (0.22), [1.37, 2.27]	1.55 (0.22), [1.10, 2.00]	1.70 (0.22), [1.32, 2.22]	1.49 (0.25), [0.99, 2.00]	1.38 (0.25), [0.87, 1.88]	1.51 (0.25), [1.01, 2.02]
Abd. moment (%BW*HT)	0.46 (0.12), [0.21, 0.71]	0.58 (0.12), [0.33, 0.83]	0.63 (0.12), [0.37, 0.88]	-0.041 (0.094), [-0.23, 0.15]	0.33 (0.094), [0.14, 0.52]	0.010 (0.094), [-0.091, 0.29]

BW*HT: bodyweight times height, ROM: range of motion, Ext.: Extension, Flex.: Flexion, Add.: Adduction, Abd.: Abduction