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

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INTRODUCTION:

Robotic-assisted Total Knee Arthroplasty (TKA) holds promise in reliable ligamentous balancing through bony resection that may improve patient outcomes, including 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 cruciate retaining (CR) 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 has normalized.

METHODS:

Three groups (n=13 each) were included. The rTKA (robotic single radius CR TKA); 2/11 male/female, 68.4 ± 6.8 years, 27.6 ± 3.8 body mass index, 8/5 right/left. Subjects were included if they 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; 1/12 male/female, 66.5 ± 6.8 years, 29.5 ± 6.8 body mass index, 5/8 right/left, as well as an elderly "Healthy" comparator group; 4/9 male/female, 60.5 ± 6.1 years, 25.3 ± 4.0 body mass index, 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. Simultaneously, ground reaction forces were collected during level and downhill walking (Fig.1, 2). Subjects were instructed to walk at their usual pace, Level walking trials were completed over a horizontal surface with embedded force plates. Downhill walking trials were performed on a ramp with a 12.5% slope and an embedded force plate, and five trials were recorded for each activity. 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.

RESULTS:

The TKA groups were similar but approximately 8 years older than the Healthy group. Sex distribution was the same in all three groups. All gait outcome parameters are tabulated in Table 1. There were slight differences in preferred walking speeds. The Healthy group was 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 Healthy groups in both conditions. In contrast, the mTKA displayed a smaller range compared to the Healthy group both in 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. 3) The tibial anterior displacements of the rTKA were significantly lower than the Healthy and mTKA in level ($p=.040$, $p=.002$, respectively) and downhill walking ($p=.011$, $p<.001$, respectively). The peak flexion moment, which occurs during the first half of the stance phase in the sagittal plane, was higher in the rTKA and Healthy group ($p<.001$, $p=.017$ in level walking, $p<.001$, $p=.003$ in downhill, respectively) compared to 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 compared to the Healthy and mTKA. ($p<.001$, $p=.002$ in level walking, $p=.002$, $p=.003$ in downhill, respectively) In the frontal plane, there were no statistical differences among the 3 groups in adduction peaks in both level and downhill walking. 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.

DISCUSSION AND CONCLUSION:

Some but not all of the gait parameters appear normalized after robotic surgery; subjects demonstrated healthy quadriceps use, which is interesting because the extensor mechanism is often compromised after TKA. On the contrary, the low extension moment suggests underutilizing the hamstrings. This study is the first to objectively compare manual and robotic ligament balancing and report a difference in level walking as well as a mid-flexion activity such as downhill walking.

Fig.1 Level Walking

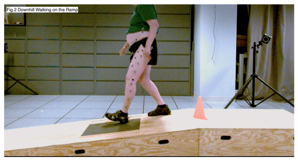

Fig.2 Downhill Walking on the Ramp

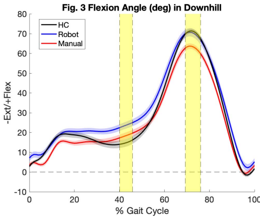

Fig. 3 Flexion Angle (deg) in Downhill

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]		
	Robot (rTKA)	Manual (mTKA)	Healthy	Robot (rTKA)	Manual (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), [-051, 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.