KNEE JOINT LOADS AND SURROUNDING MUSCLE FORCES DURING STAIR ASCENT IN TOTAL KNEE REPLACEMENT PATIENTS AND HEALTHY CONTROLS

[1]Songning Zhang, [1]Robert Rasnick, [1]Tyler Standifird, [2]Jeffrey A. Reinbolt, [3]Harold E. Cates
[1]Biomechanics/Sports Medicine Lab, The University of Tennessee, Knoxville, TN, USA
[2] Mechanical, Aerospace, and Biomedical Engineering, The University of Tennessee, Knoxville, TN, USA
[3]Tennessee Orthopedic Clinics, Knoxville, TN, USA
email: szhang@utk.edu, web: web.utk.edu/~sals/resources/biomechanics_laboratory.html

INTRODUCTION

Total knee replacement (TKR) is commonly used to correct end-stage knee osteoarthritis (OA) of the knee joint. Unfortunately, difficulty with stair climbing often persists and prolongs the challenges of TKR patents. Stair climbing is a common activity of daily living and utilized in all clinical recovery assessments after a TKR.

Experimental studies of stair ambulation after TKR reported that peak knee extension moment appears to be reduced following TKR compared to healthy subjects during stair ascent [6]. Studies utilizing an instrumented TKR have shown that compressive loads at the knee during stair ascent were ranged between 2.5 and 3.1 bodyweight (BW) in stair ascent [2, 3]. Only a limited number of studies have utilized musculoskeletal simulations to investigate knee joint loading in stair negotiation in healthy subjects. However, no studies have investigated the knee joint loading and muscle forces in TKR patients during stair ascent using musculoskeletal simulation. Therefore, the purpose of this study was to determine if the knee joint reaction force (JRF) following TKR are recovered to the level of healthy individuals, and determine the differences in muscle forces causing those loadings during stair ascent.

METHODS

Five patients (63.6 ± 8.7 yrs, 1.7 ± 0.1 m, 87.0 ± 8.9 kg, 14.6 ± 3.4 months post-surgery) who received a posterior stabilized TKR and five healthy participants (57.8 ± 10.0 yrs, 1.8 ± 0.1 m, 89.0 ± 6.6 kg) participated in the study. A 9-camera motion analysis system (240 Hz, Vicon Motion Analysis), and two force platforms and an instrumented staircase (1200 Hz, AMTI) were used to obtain 3D kinematic and ground reaction force data for five trials during stair ascent at a self-selected speed.

Kinematic and kinetic data were initially processed in Visual3D (C-Motion, Inc.) and then exported to OpenSim (3.0.1, SimTK, Stanford, CA, USA) to perform musculoskeletal simulations. A generic musculoskeletal model (Gait 2392 Model) was scaled to the height and weight of each individual participant to generate subject-specific models. In order to improve the accuracy of the simulations a residual reduction algorithm (RRA) was used to minimize virtual residual forces added to the model to account for dynamic inconsistency. Kinematic changes from RRA were all kept below 5.5 cm of translation and 3.5 degrees of rotation. Peak residual forces and moments were each kept below 14% of body weight and 1.6 Nm/kg, respectively. Individual muscle excitations and resulting muscle forces were calculated using computed muscle control to drive simulations of the stair ascent trials. Joint reaction forces were computed using the JRF Tool in OpenSim.

In order to compare differences between TKR patients and healthy individuals, a paired samples t-test was used for each variable (21.0, IBM SPSS, Chicago, IL) with an alpha level set at 0.05 a priori.

RESULTS AND DISCUSSION

Peak knee extensor moment was reduced in TKR patients compared to healthy controls (Table 1), which is consistent with findings reported in the literature [1, 5]. Although no differences of both earlier and late peak knee joint compressive forces were found, the late-stance peak compressive knee contact force showed a trend of elevated compressive JRF for TKR patients compared to controls ($p = 0.051$). The magnitudes for compressive JRF seen in this study were elevated slightly over those seen in the literature for stair ascent [2, 3, 4].

The late stance peak rectus femoris muscle force was reduced while the late stance peak vastus medialis force was greater in TKR patients compared to healthy controls (Table 1). No differences were found for the late stance peak hamstring muscle forces. However, the peak late stance medial gastrocnemius muscle force was smaller and the late stance peak lateral gastrocnemius muscle force was greater in TKR patients compared to controls.

It appears a different strategy was utilized by TKR patients to produce similar levels of muscle forces compared with to healthy controls. It can be seen that the majority of muscle force during the push-off phase is from the rectus femoris in healthy individuals. However, TKR patients utilized the vastus medialis more during push-off than healthy controls. Similarly, TKR patients utilized the medial and lateral gastrocnemius differently than healthy individuals. The underlying biomechanical factors causing these differences and the influence they have on JRF remain unclear. TKR patients may be utilizing the muscles differently as a compensatory strategy for the reduced knee extensor strength that remains after rehabilitation. It is possible that gait compensation strategies seen in knee OA patients to relieve pain linger after the TKR rehabilitation is completed.

CONCLUSION

TKR patients showed a trend of having higher late stance peak compressive JRF. Some muscle force compensatory strategies appear to be present in the push-off phase; however, the differences in muscle forces do not clearly explain the trend present in compressive JRF during the second half of stance. Future research utilizing musculoskeletal modeling and simulation is necessary to investigate differences in muscle forces dependent on rehabilitation strategies and differences existing at the ankle.

REFERENCES

1. Berti, L., et al. (2006). *Clin Biomech*, **21**, 610-616.
2. D'Lima, D. D., et al. (2005). *Clin Orthop Relat Res*, **440**, 45-49.
3. D'Lima, D. D., et al. (2006). *J Arthroplasty*, **21**, 255-262.
4. Heinlein, B., et al. (2009). *Clin Biomech*, **24**, 315-326.
5. Mandeville, D., et al. (2007). *Clin Biomech*, **22**, 787-794.
6. Standifird, T. W., et al. (2014). *J Arthroplasty*, **29**, 1857-1862.

Table 1. Peak knee extensor moment and late stance joint contact forces and related muscle forces: mean ± SD.

Variable	Healthy	TKR	P-value
Peak Extensor Moment (Nm)	119.9 ± 25.9	77.1 ± 16.5	**0.014**
Late Stance Peak Compressive JRF (N)	-2774.3 ± 456.5	-3560.6 ± 609.6	0.051
Rectus Femoris (N)	730.7 ± 127.2	322.3 ± 310.4	**0.026**
Vastus Medialis (N)	92.6 ± 45.6	722.3 ± 415.5	**0.027**
Vastus Intermedius (N)	102.5 ± 53.5	63.1 ± 23.6	0.186
Vastus Lateralis (N)	184.8 ± 112.5	76.6 ± 29.3	0.098
Total Quadriceps (N)	996.3 ± 227.2	1091.0 ± 271.2	0.566
Semimembranosus (N)	359.6 ± 57.6	439.2 ± 116.3	0.207
Semitendinosus (N)	42.2 ± 18.5	43.4 ± 15.0	0.913
Bicep Femoris Long Head (N)	148.5 ± 77.1	129.7 ± 31.3	0.628
Bicep Femoris Short Head (N)	322.3 ± 45.8	398.4 ± 100.3	0.177
Medial Gastrocnemius (N)	847.5 ± 207.2	244.7 ± 296.7	**0.006**
Lateral Gastrocnemius (N)	242.7 ± 76.0	906.9 ± 446.8	**0.028**
Total Flexor Force (N)	1367.3 ± 214.1	1587.5 ± 272.0	0.193