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KNEE JOINT LOADS AND SURROUNDING MUSCLE FORCES OF SELECTED KNEE UNFRIENDLY MOVEMENT ELEMENTS IN 42-FORM TAI JI

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INTRODUCTION

Tai Ji, as a mind-body therapy, is a traditional Chinese martial art that includes natural postures as well as gentle and smooth movements [1]. The American College of Rheumatology recommended Tai Ji as one of the non-pharmacologic treatments for knee osteoarthritis (OA) [2], but it remains unclear if all Tai Ji movements would be suitable and beneficial for knee OA patients.

Tai Ji movements often require bending the knee to a squatting position, which may place high loads on the knee joint. In addition, repetitions of some Tai Ji deep knee flexion movements (e.g., twisting and single-leg stance) may further increase loading to harmful levels at the knee. A previous study showed a greater knee flexion range of motion (ROM) in Tai Ji gait caused a higher knee extension (rectus femoris) muscle activity compared to normal speed walking [3].

Musculoskeletal modeling and simulation provides an efficient way to estimate joint loading and corresponding muscle forces during a movement. However, no study has utilized musculoskeletal simulations to investigate knee joint loading in Tai Ji movements. Therefore, the purpose of this study was to investigate the knee joint loading of selected unfriendly Tai Ji movement elements performed in high-pose position compared to slow walking.

METHODS

A male subject (23 yrs, 1.78 m, 73.3 kg) with two months of Tai Ji experience participated in this study. He performed three trials of level walking at 0.8 m/s and each of four identified knee unfriendly Tai Ji movement elements: lunge, pushdown and kick performed in high-pose position (35 ± 5°) and pseudo-step[4].

Three dimensional (3D) kinematic data were collected using a nine-camera infrared motion capture system (120 Hz, Vicon Motion Analysis, Inc., Oxford, UK). Anatomical and tracking reflective markers were placed bilaterally on the trunk, pelvis, thighs, shanks and feet. Three force platforms (1200Hz, Advanced Mechanical Technology, Inc., USA) were used to collect ground reaction forces (GRF) with the 3D kinematic data simultaneously using Vicon Nexus software. Maximum knee flexion angle was monitored using an electrogoniometer (Biometrics Inc., Newport, UK) placed on the lateral side of the right knee joint. Visual 3D (C-Motion Inc., USA) was used to compute 3D kinematics and kinetics. Kinematic and GRF data were smoothed at cutoff frequencies of 4 and 50 Hz, respectively, using a fourth-order zero-lag Butterworth low-pass filter. All joint moments were computed as internal moments.

The processed individual trials of each movement condition were exported to OpenSim (version 3.2, SimTK, Stanford, CA, USA) to perform musculoskeletal simulations. A generic 12-segment, 19-degree of freedom, and 92 muscle-actuated OpenSim musculoskeletal model (Gait 2392 Model), originally developed by Delp, et al. [5], was scaled to the height and weight of the subject to generate subject-specific models. Muscle forces were estimated using static optimization minimizing the sum of squared muscle activations. Knee joint reaction forces (JRF) were computed using the joint reaction analysis tool with the muscle forces from static optimization as inputs. The compressive force was the vertical component of the JRF along the long axis of the tibia and the anterior-posterior shear component of the JRF was orthogonal to the axial component.

RESULTS AND DISCUSSION

Lunge, pushdown and kick demonstrated similar peak knee compressive JRF compared to slow walking. Pseudo-step showed higher compressive JRF than other Tai Ji movement elements. In addition, Tai Ji movement elements showed greater peak knee anterior shear JRF than slow walking. Pushdown showed the greatest peak anterior shear JRF among the Tai Ji movement elements. The peak muscle forces of vastus medialis, vastus lateralis and vastus intermedius, and sum of knee extensor forces were greater for Tai Ji movement elements compared to slow walking. Kick showed the smallest peak muscle forces of vastus medialis, vastus lateralis and vastus intermedius, and sum of knee extensor forces compared with other Tai Ji movement elements. Tai Ji movement elements showed smaller peak sum of knee flexor forces than slow walking. Peak knee extension moments were higher in lunge, pushdown and pseudo-step than slow walking.

Our results are supported by the previous study of Tai Chi gait [3] which demonstrated rectus femoris had a significant higher activity level than semitendinosus. Xu et al. [6] also reported higher rectus femoris muscle activity level than semitendinosus in Brush Knees and Twist Steps, popular Tai Ji movements which include lunges.

Our results showed that the anterior shear JRF is relatively high in lunge, pushdown and pseudo-step as knee extensions are more heavily involved in maintaining flexed knee postures.

CONCLUSION

The high-pose lunge, pushdown and kick Tai Ji movement elements demonstrated similar knee compressive JRF as slow walking. Thus, these movements may be suitable for Tai Ji participants with knee OA and other knee pathological conditions to practice. However, high shear loading was found in all of the Tai Ji movement elements and there is cause for serious concerns. Future investigations are necessary to find ways of reducing the shear JRF during Tai Ji and other knee OA treatments.

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Table 1. Peak knee muscle forces (N), peak JRF (N) and knee extension moment (Nm/kg) of the selected Tai Ji movement elements and slow walking: Mean ± SD.

Variable		Lunge	Pushdown	Kick	Pseudo-step	Slow Walking
Knee extensor muscles	Rectus Femoris	748.1 ±112.9	865.2 ± 90.0	998.0 ± 96.0	1211.2 ±34.1	907.6 ± 81.7
	Vastus Medialis	454.9 ± 133.7	552.9 ± 108.9	241.0 ± 57.6	376.6 ± 22.5	101.5 ± 32.0
	Vastus Intermedius	526.5 ± 157.7	648.1 ± 126.9	279.9 ± 66.8	438.5 ± 25.2	118.0 ± 36.8
	Vastus Lateralis	963.9 ± 278.1	1191.1 ± 215.2	528.4 ± 121.7	815.9 ± 44.9	213.7 ± 73.0
	Sum	2233.6 ± 517.9	2928.1 ± 330.9	1910.4 ± 145.7	2563.1 ± 153.0	915.8 ± 92.7
Knee flexor muscle	Sum	608.1 ± 34.6	134.6 ± 126.0	417.6 ± 22.7	305.2 ± 135.5	1132.0 ± 41.4
Peak Anterior Shear JRF		1927.7±619.5	2281.5±86.9	1368.1 ± 221.1	2101.3±59.7	643.9 ± 24.2
Peak Compressive JRF		-2369.2±386.7	-2541.0±43.7	-2495.5±103.5	-2905.9±58.3	-2640.8 ± 139.7
Peak knee extension moment		1.04±0.21	1.01±0.28	0.48±0.41	1.46±0.26	0.38±0.19