

# 太极拳训练对膝骨性关节炎患者登梯活动时下肢关节间协调性的影响

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**摘要:** **目的:** 人类运动本身就是不稳定的, 因此需要一个复杂的姿势控制系统来有效地激活下肢肌群, 进而产生髋、膝、踝关节的协调运动, 以保持人体重心在其支撑面内。膝骨性关节炎 (knee osteoarthritis, KOA) 患者的下肢感觉运动功能发生变化, 导致关节间协调性和姿势稳定性受损, 增加了日常生活中跌倒的风险。对于 KOA 患者来说, 登梯是一项常见但困难且危险的运动任务。与平地步行相比, 登梯任务需要通过下肢关节更协调的配合以达到更强的姿势控制能力。研究表明 KOA 患者在上楼梯时膝关节屈曲角度减小, 同时髋关节屈曲角度增大, 踝关节背屈角度减小。下楼梯时可观察到他们在开始下台阶时重心前移, 同时在站立初期膝关节角度和髋关节角度减小, 踝关节则无明显变化。太极拳是一种中国传统的有氧运动, 其可以提高下肢肌肉力量和平衡能力。然而, 有关太极拳训练对 KOA 患者下肢关节间协调性影响的研究很少。循环图作为一种反映关节间协调性的方法, 已被用于研究 KOA 患者平地步行时的下肢协调模式, 但其只研究了矢状面的髋-膝循环图。本研究旨在探讨 KOA 患者接受太极拳训练后, 在登梯过程中, 髋-膝、髋-踝和膝-踝关节在矢状面上的协调表现, 并探究太极拳训练是否比平衡训练能更有效地改善下肢关节间的协调性。**方法:** 28 名太极拳组的 KOA 患者和 24 名对照组的 KOA 患者最终完成了干预。太极拳组采用杨氏太极拳十式进行训练, 由起势、卷肱式、搂膝拗步、野马分鬃、云手、金鸡独立、蹬脚、揽雀尾、十字手、收势组成。而对照组则进行平衡训练, 包括单腿站立、向前走、倒退走、侧向行走和单脚轻触地面。训练为期 12 周, 每周两次, 每次 1 小时。在干预前后, 对参与者进行基线特征、相关量表 (如 WOMAC、Berg 等)、三维步态分析的评估。在大学的步态实验室中, 使用一个 1.8 米长的平地走道和一个定制的八级楼梯 (高: 20 厘米, 踏板深度: 30 厘米) 来模拟日常的登梯活动。在楼梯的顶端, 有一个长 1 米、宽 2.5 米的平台, 平台周围有护栏以保证安全。根据校准系统技术协议, 75 个反射标记物被贴在每个受试者相应的体表解剖位置上。标记物的运动轨迹由配备了 10 台红外摄像机的三维运动捕捉系统 (Oqus7+, Qualisys AB, 瑞典) 以 100 Hz 的采样频率记录。受试者被要求以舒适的速度上楼梯到顶端并下楼梯回到平地。然后使用 Visual3D (V6, C-motion Inc., Germantown, MD, USA) 分

析受试者在上下楼梯时的运动学数据。使用截止频率为 6 Hz 的零滞后的四阶低通巴特沃斯滤波器对标记物运动轨迹进行滤波,并对相位、患侧关节的运动范围 (range of motion, ROM) 等步态参数进行滤波。在获得相关步态参数后, MATLAB 根据步态周期中矢状面上的髌、膝和踝关节角度来绘制髌-膝、髌-踝和膝-踝的循环图。本研究使用的循环图是按顺时针方向绘制的,从站立期到摆动期,以脚跟着地和脚趾离地为分界点。然后,我们得到了站立期、摆动期和整个步态周期所有循环图周长和面积的平均值。对周长、面积以及显示的循环图进行综合分析,可以反映下肢关节间的协调性。统计方法上,采用重复测量方差分析组间效应、时间效应和交互作用效应。**结果:** 两组在年龄、性别、身高、体重、BMI 和 K/L 分级方面无明显差异。与干预前相比,经过 12 周的太极拳训练和平衡训练后, WOMAC 评分降低, Berg 评分升高。矢状面上的髌-膝、髌-踝和膝-踝循环图见摘要正文末尾。无论是上楼梯还是下楼梯,干预后两组的髌关节 ROM 均有所下降。与干预前相比,两组膝关节和踝关节的 ROM 仅在下楼梯时下降。太极拳组的膝关节 ROM 大于对照组。在上楼梯过程中,太极拳组和对照组的髌-膝、髌-踝和膝-踝循环图摆动期周长和总周长与干预前相比明显减少。太极拳组的髌-膝、髌-踝和膝-踝循环图的站立期面积明显大于对照组。在下楼梯过程中,显著的时间主效应表明干预后太极拳组和对照组髌-膝循环图中的所有周长参数、髌-踝循环图的总周长、膝-踝循环图摆动期周长和总周长均有所减少。两组的髌-膝和髌-踝循环图总面积也变小。在髌-踝和膝-踝循环图中,站立期的周长在时间和组别之间具有显著的交互效应。简单效应分析结果表明,太极拳组在干预后站立期周长减少,而对照组没有变化。干预后,太极组站立期髌-踝循环图周长明显小于平衡组。此外,对交互效应显著的所有循环图站立期面积和膝-踝循环图总面积参数进行简单效应分析,结果表明干预后只有太极拳组的循环图面积有所减少。**结论:** 12 周的太极拳训练和平衡训练都改善了 KOA 患者的症状和平衡功能。干预后 KOA 患者在上楼梯时,从脚趾离地到下一级楼梯的过程中,髌关节屈曲、膝关节屈曲和踝关节背屈角度都有所增加,能够更快地过渡到下一次足跟着地,因此表现出周长减少的趋势。此外,干预后两组患者髌关节的 ROM 减小可能是由于患者平衡能力和肌肉力量的提高导致代偿策略的改变,其并不需要通过增加髌关节角度来提高足廓清能力以防止跌倒。在站立期,太极拳组的髌膝循环图面积明显大于对照组,这可能是由于两组间膝关节的 ROM 本身就存在差异。从下楼梯阶段的循环图可以看出, KOA 患者在站立期和摆动期的髌屈曲角度均大于干预前,从而影响了循环图周长和面积的变化。此外,太极拳组干预后,站立期髌关节屈曲角度的增加伴随着膝关节屈曲角度的减小,使得膝关节的负荷减小,因此站立期髌膝循环图的面积显著减小。这一变化与太极拳训练中 "松腰落胯"、"逼胯以坚膝" 的理念

相符。此外，太极拳组的髌-踝循环图和膝-踝循环图显示，站立期踝关节的跖屈角度减小，改善了 KOA 患者从足跟着地到最大踝背屈的延迟。两组的髌关节、膝关节和踝关节 ROM 均减小，这可能表明 KOA 患者的姿势控制得到改善，重心移动范围减小，无需通过代偿性增加关节活动范围来提高稳定性。综上所述，太极拳训练和平衡训练均改善了 KOA 患者在登梯活动时的下肢关节间协调性，且太极拳干预在改善下楼梯时的下肢协调性方面效果更显著。此外，干预后 KOA 患者的症状和平衡功能均得到改善，干预后循环图的周长和面积也有减少的趋势。因此，循环图可以作为后续判断 KOA 患者感觉运动系统功能是否改善的客观依据，也是研究运动模式和关节间协调性的有效方法。

**关键词：** 膝骨性关节炎；太极拳；关节间协调性；循环图

## **The effects of Tai Chi Chuan training on lower limb inter-joint coordination during stair negotiation in patients with knee osteoarthritis**

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**Aim:** Human locomotion is inherently unstable and thus needs a complex postural control system that activates the lower extremity muscles, producing related coordinated movements of the hip, knee, and ankle joints, to maintain the center of gravity within its base of support. Patients with knee osteoarthritis (OA) have changes in the lower limb sensorimotor function, resulting in impaired inter-joint coordination and postural stability, and increasing the risk of falls in daily life. Stair negotiation is a common but difficult and hazardous locomotor task for individuals with knee OA. Compare with walking, it requires greater postural control via highly coordinated joint movements. Studies have shown that individuals with knee OA demonstrated smaller knee flexion angles in conjunction with larger hip flexion angles and smaller ankle dorsiflexion angles during stair ascent. When descending the stair, they were observed to move their center of gravity anteriorly at the initiation of stepping down, accompanied by a decrease in knee angle and hip angle during the early stance phase, but no significant change in the ankle. Tai Chi Chuan (TCC), an ancient Chinese aerobic exercise can improve muscle strength and balance of lower limbs. However, there are few studies on the effects of TCC training on inter-joint coordination of the lower limb in individuals with knee OA. Cyclogram as a method of reflecting inter-joint

coordination, have been used to investigate coordination patterns during level walking in individuals with knee OA, but only the hip-knee cyclogram in the sagittal plane was studied. The study aimed to explore the performance of hip-knee, hip-ankle, and knee-ankle coordination in the sagittal plane during stair negotiation after TCC training in individuals with knee OA and to investigate if TCC training is more efficient than balance training for improving inter-joint coordination. **Method:** 28 participants with knee OA in the TCC group and 24 participants with knee OA in the control group eventually completed the intervention. The TCC group adopted Yang's Ten-form of Tai Chi Chuan training. It consists of commencement, repulsing the monkey, brushing the knee and twisting step, parting the wild horse's mane, waving hands like clouds, golden cock stands one leg, kicking with heel leading, grasping the peacock's tail, crossing hand and closing. Whereas the control group underwent balance training, which included single-leg standing, walking forward, walking backward, side stepping, and single-leg tapping. The training lasts for 12 weeks and twice a week, 1 hour each time. Participants were evaluated with baseline characteristics, relevant scales (such as WOMAC, Berg, etc.), and three-dimensional gait analysis before and after the intervention. A 1.8-m walkway and a customized eight-step staircase (height: 20cm, tread depth: 30 cm) with handrails on both sides were used to mimic daily stair negotiation in a university gait laboratory. At the top of the staircase, a 1-m long and 2.5-m wide platform with a fence around the platform was equipped for security. 75 reflective markers according to the calibrated systems technique protocol were attached to the anatomical landmarks of each subject. The marker trajectories were recorded at a sampling rate of 100 Hz by a 3D motion capture system equipped with ten infrared cameras (Oqus7+, Qualisys AB, Sweden). Participants were asked to ascend the stairs to the top and descend back to the floor at their comfortable speeds. Then, Visual3D (V6, C-motion Inc., Germantown, MD, USA) was used to analyze subjects' kinematic data during stair negotiation. The marker trajectories were filtered using a zero-lag fourth-order low-pass Butterworth filter with a cutoff frequency of 6 Hz, and gait parameters such as gait phase, and range of motion (ROM) on the affected side. After acquiring related gait parameters, the cyclograms in hip-knee, hip-ankle, and knee-ankle using MATLAB were generated by simultaneously plotting the hip, knee, and ankle joint angles in the sagittal plane throughout the entire gait cycle. The cyclograms used in this study were plotted in a clockwise direction from the stance phase to the swing phase, divided by the heel strike point and the toe-off

point. Then, we obtained the average value of all cyclograms parameters including perimeters and areas of the stance phase, swing phase, and total gait cycle. A comprehensive analysis of the perimeters, areas, and displayed cyclograms can reflect the coordination of the lower limb joints. Statistically, mixed between-within-subjects ANOVAs were used to analyze the intergroup effect, time effect, and interaction effect. **Result:** There were no significant differences in age, sex, height, weight, BMI, and K/L grade between the two groups. After 12 weeks of Tai Chi Chuan training and balance training, WOMAC scores were lower and Berg scores were higher than before intervention. Hip-knee, hip-ankle, and knee-ankle cyclograms in the sagittal plane are shown at the end of the body of the abstract. Whether ascending or descending the stair, the ROM of the hip decreased in two groups after the intervention. Compared with pre-intervention, the ROM of the knee and ankle in both groups only decreased during the stair descent. And the ROM of the knee was greater in the TCC group than in the control group. During stair ascent, the swing phase perimeters and total perimeters of hip-knee, hip-ankle and knee-ankle cyclograms in the TCC group and the control group were significantly reduced compared with pre-intervention. The stance phase area of the hip-ankle cyclogram of the TCC group was significantly greater than that of the control group. During stair descent, significant time main effects indicated decreased all perimeter parameters of hip-knee cyclogram, total perimeters of hip-ankle cyclogram, the swing phase perimeters, and total perimeters of knee-ankle cyclograms in both the TCC group and control group after intervention. There were also fewer total areas in the hip-knee and hip-ankle cyclogram in the two groups. In the hip-ankle and knee-ankle cyclograms, the perimeter of the stance phase had significant interaction effects between time and group. The results of simple effect analysis showed that the TCC group decreased after the intervention while it did not change the control group. And the perimeter of the hip-ankle cyclogram in the stance phase was significantly smaller in the Tai Chi group than in the balanced group after the intervention. In addition, the investigation of simple effects analysis of area parameters with significant interaction effects for the stance phase of all cyclograms and the total knee-ankle cyclogram. It shows that only the TCC group had a decrease in cyclograms' areas after the intervention. **Conclusion:** Twelve weeks of tai chi training and balance training both improved symptoms and balance function in participants with knee OA. Following the intervention, participants with knee OA during stair ascent from the toes off the ground to the next stair exhibited increased hip flexion,

knee flexion, and ankle dorsiflexion angles, were able to transition more quickly to the next heel strike, and therefore demonstrated a tendency for the cyclograms to decrease in perimeters. In addition, the reduction in the ROM of the hip in both groups after the intervention may be due to a change in the compensatory strategy of the patients due to their improved balance as well as muscle strength, which does not require increased foot clearance ability to prevent falls by increasing hip joint angle. The area of the hip-knee cyclogram during the stance phase was significantly larger in the TCC group than in the control group probably because of inherent intergroup differences in the ROM of the knee between the two groups. The cyclograms during the descending stair period observe that the hip flexion angle in patients with knee OA is greater than pre-intervention in both the stance and swing phase, thus affecting the change in cyclograms perimeters and areas. Moreover, the increase in hip flexion angle in the stance phase after the intervention in the TCC group was accompanied by a decrease in knee flexion angle, which led to a decrease in the knee joint load, and therefore a significant decrease in the area in the hip-knee cyclogram in the stance phase. This change is consistent with the concept of “loosening the waist and dropping the hips” and “forcing the hips to strengthen the knees” in TCC training. In addition, the hip-ankle cyclogram and knee-ankle cyclogram in the TCC group showed a reduction in the ankle plantarflexion angle during the stance phase, improving the delay from heel strike to maximum ankle dorsiflexion angle in patients with knee OA. And reduced ROM of the hip, knee, and ankle joints in both groups may indicate improved postural control and a reduced range of center of gravity movement in patients with knee OA, without the need for compensatory increases in joint range of motion to increase stability. In summary, both TCC and balance training improved the inter-joint coordination in the lower limb during stair negotiation in patients with knee OA, and the TCC intervention was more pronounced in improving lower limb coordination during stair descent. In addition, the symptoms and balance function of KOA improved after the intervention, and the perimeters and areas of the cyclograms tended to decrease after the intervention. Therefore, the cyclograms can be used as an objective basis for the subsequent determination of whether the sensorimotor system function of patients with KOA improves or not, as well as an effective method to study movement patterns and inter-joint coordination.

**Key words:** knee osteoarthritis; Tai Chi Chuan; inter-joint coordination; cyclogram