“骨正”太极拳与“骨不正”太极拳下肢生物力学特征的比较

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摘要：目的：膝骨关节炎（knee osteoarthritis，KOA）导致患者关节疼痛、活动受限等，严重影响生活质量。太极拳能够有效缓解 KOA 患者的关节疼痛、僵硬、活动受限等症状，改善身体功能活动。但同时，也有报道太极拳初学者在练习时会出现膝关节疼痛，KOA 患者则不少在练习太极拳后出现疼痛加重的情况，可能与 KOA 患者下肢异常的力学负荷增加有关。下肢力线、关节力矩、关节接触力等是与关节疼痛有关的常见力学负荷因素。下肢力线齐体现为股骨、胫骨和髌骨三者良好对位对线。结合现代康复理念，“骨正”主要表现为骨髓坚固、关节清利，即保持关节良好的对线对位并保持正常的骨代谢平衡，“骨不正”表现包括关节对线不良和骨代谢的异常，影响下肢的活动度、稳定性及其控制能力。KOA 患者由于病变导致筋骨代谢的失衡，基本存在“骨不正”的情况，常表现为下肢关节动静态力线不齐，导致膝关节内外侧间室负荷分布不均，软骨磨损增加，加速 KOA 的发生和发展，影响关节稳定性。选择太极拳长期练习者为“骨正”参照，因其下肢力线及其骨代谢正常，规范的太极拳动作确保练习过程中下肢关节对线正常，长期练习改善下肢肌肉力量和协调性，增强关节稳定性，也体现了太极拳的“骨正”原则。因此，比较“骨正”与“骨不正”太极拳练习过程中的生物力学特征，分析不同招式练习时下肢运动学、动力学及肌肉力的差异，有助于后续康复训练中加以针对性指导，更好地提高太极拳对 KOA 的康复效应，减少学习过程中的可能不利影响。**方法：**运用三维运动分析系统（Qualisys，瑞典）采集 10 例 KOA 患者太极拳初学者（“骨不正组”）和 10 例太极拳长期练习者（“骨正组”）八式太极拳的运动学与动力学数据，借助 OpenSim 平台构建 KOA 患者“骨不正”与长期练习者“骨正”模型，通过肌肉骨骼仿真模拟分析，观察骨不正太极拳与骨正太极拳练习过程中下肢运动学、动力学、肌肉力特征的差异。**结果：**太极拳招式生物力学特征：①卷肱式：骨不正组髋关节最大伸展力矩和最大外展力矩显著小于骨正组；骨不正组臀中肌平均肌肉力大于骨正组（$P<0.05$），股二头肌、胫前肌平均肌肉力小于骨正组（$P<0.05$）；膝关节垂直轴接触力峰值时刻，骨不正组胫前肌肌肉力小于骨正组（$P<0.05$）。②搂膝拗步：骨不正组下肢各关节各方向的最大力矩，包括髋关节伸展、外展、内旋，膝关节屈曲均小于骨正组（$P<0.01$），踝关节跖屈力矩也小于骨正组（$P<0.05$）。③野马分鬃：骨不正组髋关节最大伸展力矩（$P<0.05$）、外展力矩、内旋力矩和膝关节最大屈曲力矩均小于骨正组（$P<0.01$）；膝关节垂直轴接触力峰值时刻骨不正

组髋关节外展角度大于骨正组（$P<0.05$）。④云手：骨不正组髋关节最大外展力矩和内旋力矩小于骨正组（$P<0.01$）。⑤金鸡独立：骨不正组髋关节旋转关节活动度大于骨正组（$P<0.01$）。⑥蹬脚：整个招式中髋关节旋转活动范围与膝关节屈伸活动范围，骨不正组显著大于骨正组（$P<0.01$）；膝关节垂直轴接触力峰值时刻，骨不正组膝关节屈曲角度小于骨正组（$P<0.05$），臀中肌和臀大肌的肌肉力也小于骨正组（$P<0.05$）。⑦揽雀尾：骨不正组髋关节最大伸展力矩、内旋力矩小于骨正组（$P<0.01$），膝关节最大屈曲力矩小于骨正组（$P<0.05$），股二头肌平均肌肉力小于骨正组（$P<0.05$）。⑧十字手：骨不正组最大髋关节伸展力矩（$P<0.05$）、内收力矩、外旋力矩和膝关节最大屈曲力矩均小于骨正组（$P<0.01$）；股四头肌平均肌肉力显著小于骨正组（$P<0.01$）；膝关节垂直轴接触力峰值时刻，骨不正组髋关节屈曲、膝关节屈曲、踝关节屈曲角度均小于骨正组（$P<0.05$），而股二头肌、胫前肌肌肉力大于骨正组（$P<0.05$）。**结论：**"骨不正"与"骨正"太极拳各招式练习中存在下肢各关节最大力矩、关节活动范围、下肢肌群平均肌肉力等方面的差异。KOA 患者因异常的神经肌肉激活模式其下肢力线不齐可能不会对膝关节的接触力造成影响。对 KOA 者进行太极拳训练时，应针对性指导，需根据其能力循序渐进地选择动作。KOA 太极拳初学者应重视基本功练习，建立正确的神经肌肉激活模式，逐渐结合正确的招式指导以达到更好的康复效果。

关键词：膝骨关节炎；太极拳；骨正；仿真分析；关节负荷

Comparison of the biomechanical characteristics of the lower limb between " normal alignment " and "abnormal alignment" TaiChi

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Abstract: Objective： Knee osteoarthritis (KOA) causes subjects to suffer from joint pain and limited mobility, which seriously affects the quality of life. TaiChi can effectively relieve joint pain, stiffness, limited mobility and improve functional activities in individuals with KOA. However, it has been reported that TaiChi beginners experience knee pain during practice, while many individuals with KOA experience increased pain after practicing TaiChi, which may be related to the increased abnormal mechanical loads on the lower limbs of individuals with KOA. Lower extremity force lines, joint moments, and joint contact forces are common mechanical loading factors associated with joint pain. Lower extremity force line alignment is reflected in

good alignment of the femur, tibia and patella. Combined with modern rehabilitation concepts, "normal alignment " is mainly manifested as strong bone marrow and flexible joints, maintaining good alignment of joints and normal bone metabolism balance, while "abnormal alignment " is manifested as poor alignment of joints and abnormal bone metabolism, which affects mobility, stability and control of the lower limbs. Due to the imbalance of tendon and bone metabolism caused by the disease, individuals with KOA essentially show " abnormal alignment ", which is often exhibited as uneven dynamic and static force lines of the joints of the lower limbs, resulting in uneven load distribution of the knee joints' medial and lateral compartments, and accelerating the occurrence and development of KOA.Long-term TaiChi practitioners are chosen as " normal alignment " references because their lower limb force line and bone metabolism are normal, their standardized TaiChi movement ensures that the lower limb joints are aligned normally in the process of practice. In addition, long-term practice improves the lower limb muscle strength and coordination, enhances the joint stability, and also embodies the " normal alignment " principle of TaiChi. Therefore, comparing the biomechanical characteristics of " normal alignment " and " abnormal alignment " TaiChi exercises and analyzing the differences in lower limb kinematics, dynamics, and muscular force during the practice of different stances will help to provide targeted guidance for subsequent rehabilitation training and better improve the effectiveness of TaiChi on KOA. This will help to reduce the possible adverse effects during the learning process for beginner.**Method**： Ten Tai Chi beginners with KOA ("abnormal alignment group") and ten long-term Tai Chi practitioners ("normal alignment group") were recruited, and their kinematic and kinetic data during the eight-form Tai Chi were collected using a 3D motion analysis system (Qualisys, Sweden). KOA patients' "abnormal alignment" and long-term practitioners' "normal alignment" models were constructed using OpenSim platform, and the differences in lower limb kinematics, dynamics, and muscle forces during Tai Chi practice between the two groups were observed using musculoskeletal simulation analysis.**Result**：Biomechanical characteristics of each stance: ①Forearm rolling: the maximum extension moment and the maximum abduction moment of the hip joint were significantly lower in the abnormal alignment group than in the normal alignment group. The average muscle forces of gluteus medius was greater in abnormal alignment group than that in the normal alignment group ($P < 0.05$), while the average muscle force of biceps femoris and tibialis anterior was smaller in the abnormal alignment group than in the normal alignment group ($P < 0.05$). At the peak vertical contact force of the knee joint, the muscle force of tibialis anterior in the abnormal alignment group was smaller than that in normal alignment group ($P < 0.05$). ② Brush knee and twist step: The maximum moments in all directions of the lower limb joints, including hip extension, abduction, and knee flexion, were all significantly lower in the abnormal alignment group than in the normal alignment group ($P < 0.01$) and the ankle plantar flexion moments were also lower than in the normal alignment group ($P < 0.05$).③Wild Horse Parts Its Mane: The maximum hip extension moment ($P < 0.05$), abduction moment, internal rotation moment and maximum knee flexion moment were all significantly lower in the abnormal alignment group than in the normal alignment group ($P < 0.01$). At the hip abduction angle of the normal alignment group was larger than that of the normal alignment group at the moment of peak knee vertical axis contact force ($P < 0.05$). ④ Cloud hands: The maximum hip abduction moment and internal rotation moment of the hip joint in the abnormal alignment group were significantly smaller than those in the normal alignment group ($P < 0.01$).

⑤ Golden cock standing: The horizontal joint mobility of the hip joint of the abnormal alignment group was significantly greater than that of the normal alignment group ($P<0.01$). ⑥ Kick with heel: The range of hip joint rotation and knee joint flexion/extension in the whole stance was significantly greater in the abnormal alignment group than in the normal alignment group ($P<0.01$); the knee joint flexion angle in the abnormal alignment group was smaller than in the normal alignment group at the moment of peak contact force in the vertical axis of the knee joint ($P<0.05$), and the muscle force of the gluteus medius and gluteus maximus was also smaller than in the normal alignment group ($P<0.05$). ⑦Grasp the bird's tail: The maximum hip extension moment and internal rotation moment in the abnormal alignment group were significantly smaller than those in the normal alignment group ($P<0.01$), the maximum flexion moment of the knee joint was smaller than those in the normal alignment group ($P<0.05$), and the average muscle force of the biceps femoris was smaller than that in the normal alignment group ($P<0.05$).⑧Crossed hands: The maximum hip extension moment ($P < 0.05$), adduction moment, extorsion moment and maximum knee flexion moment were significantly smaller than those of the normal alignment group ($P < 0.01$); the average muscle force of quadriceps was significantly smaller than that of the normal alignment group ($P < 0.01$); At the moment of peak contact force of the vertical axis of the knee joint, the hip flexion, knee flexion and ankle dorsiflex angles of the

abnormal alignment group were smaller than those of the normal alignment group ($P < 0.05$), while the muscle force of biceps femoris and tibialis anterior was greater than that of the normal alignment group ($P < 0.05$). **Conclusion**： There are differences in the maximum torque of the joints of the lower limbs, the range of motion of the joints, and the muscular force of the lower limb muscles in the exercises of each movement of Tai Chi for “abnormal alignment” and “normal alignment”. KOA subjects with abnormal neuromuscular activation patterns may not have an impact on the contact force of the knee joint due to their uneven lower limb force lines. When training Tai Chi for those with normal alignment, you need to select the movements in a gradual manner according to their abilities. Beginner of Tai Chi for individuals with KOA should pay attention to basic exercises to establish the correct neuromuscular activation patterns and gradually combine them with the correct stance instruction to achieve better rehabilitation results.

Key words：knee Osteoarthritis；TaiChi；Gu Zheng；simulation analysis；joint loading