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Effect of "Xuling DingJin" in Tai Chi on Lumbar Spine Biomechanics during Walking

Background: Low back pain is a common condition. The Tai Chi posture of "Xuling Dingjin" may help alleviate lower back pain, but its biomechanical characteristics are not yet fully understood. This study aims to explore the effects of the "Xuling Dingjin" posture on the biomechanics of the lumbar spine during walking, and verify its potential benefits for its application in injury prevention and rehabilitation.

Methods: 12 experienced Tai Chi practitioners participated in the study. The VICON motion capture system, AMTI force measurement platform, and OpenSim software were used to collect lumbar biomechanical data, including activation of the paravertebral muscles and the bending angles of the L4-L5 segment of the lumbar spine.

Results: Walking with "Xuling Dingjin" posture significantly increased the activation levels of all target muscles ($P < 0.05$), especially the deep stabilizing muscles (multifidus and longissimus). The forward flexion angle of the L4-L5 segment in the sagittal plane decreased and the trend of asymmetric lateral flexion in the coronal plane was corrected, while there was no significant difference in the bending angle in the horizontal plane.

Conclusion: Maintaining the "Xuling Dingjin" posture during walking may enhances the dynamic stability of the spine and reduces the risk of unilateral overload.

Keywords: Tai Chi, Walking, Lumbar, Biomechanics, Opensim, Muscle activation, Balance control, Xuling Dingjing

Introduction

Low back pain (LBP) is now the leading cause of disability worldwide. According to the World Health Organization (WHO), about 80% of adults will experience at least one episode of LBP during their lifetime [1]. In an aging society, the incidence of lumbar degenerative disorders is rising sharply and the age of onset is becoming younger. This situation highlights the urgent need to develop novel strategies for preventing and treating LBP.

Walking is the most fundamental human activity. During gait, the lumbar spine must absorb ground-reaction forces and dynamic trunk loads; any biomechanical imbalance can disrupt disc pressure distribution and accelerate facet-joint wear. In a normal gait cycle, the lumbar spine flexes, extends, and laterally bends to accommodate shifting body weight. Coordinated contraction of the core muscles—erector spinae, transversus abdominis, and others—is essential for spinal stability. Compared with healthy individuals, people with low back pain show more in-phase coordination between thoracic and lumbar/pelvic motion and exhibit higher activation levels in the lumbar muscles [2]. These findings suggest that altered gait patterns in individuals with low back pain may perpetuate or even exacerbate their symptoms.

A range of treatments exists for low back pain, including pharmacologic and surgical interventions, yet these options are costly and carry inherent risks. In recent years, exercise therapy—particularly Pilates and core-strengthening programs—has gained popularity [3]. Walking, a simple and accessible intervention, has also shown promise; increased walking volume is associated with a reduced risk of developing LBP [4], and randomized trials demonstrate that it lowers pain by improving back-muscle endurance [5]. Mindfulness-based walking has been examined, but mindfulness alone did not yield additional pain relief [6]. Tai-chi research suggests it can elevate pressure-pain thresholds in the lumbar region [7] and may further improve hip range of motion and neuromuscular coordination.

Tai Chi, a traditional Chinese martial art, has been shown to alleviate lumbar strain and prevent lumbar disc herniation [8-9]. The posture "Xuling Dingjin" central to Tai Chi practice, emphasizes spinal elongation and stabilization, thereby enhancing the strength and stability of the lumbar muscles [10]. Biomechanically, this posture treats the spine as a flexible chain: the cervical spine serves as a relatively fixed fulcrum, while the lumbar spine is allowed to extend and undergo sequential adjustment. Such alignment is believed to lengthen the spine and optimize vertebral positioning [11]. However, most studies on the physiological effects of "Xuling Dingjin" remain at the level of subjective experience, and experimental evidence validating its biomechanical benefits is still lacking.

Existing research is largely cross-sectional, with few studies investigating the biomechanical mechanisms of the lumbar spine during walking [12] and none examining the biomechanical impact of the "Xuling Dingjin" posture of Tai Chi on the lumbar spine during gait. Our study aims to determine whether this posture enhances the safety of walking by imposing lower biomechanical demands on the lumbar spine. We hypothesize that (1) "Xuling Dingjin" improves lumbar stability, and (2) maintaining this posture while walking provides a safer mode of locomotion.

Methods and materials

Twelve asymptomatic adults (six males: 41.3 ± 8.8 years, 173.7 ± 5.2 cm, 74.7 ± 8.2 kg; six females: 54.3 ± 3.2 years, 162.2 ± 2.8 cm, 58.3 ± 8.2 kg) with ≥ 5 years of uninterrupted Tai Chi experience were enrolled. Volunteers were excluded if they reported any recent surgical intervention or acute illness, or if their movement execution was deemed inaccurate by a certified Tai Chi instructor. All participants were proficient in the "Xuling Dingjin" stance. Anthropometrics (height, body mass, leg, arm, shoulder, elbow, wrist and ankle breadth) and training history (age, sex, years of practice) were documented prior to data collection. Written informed consent was obtained from each volunteer, and the protocol received approval from the local institutional review board.

The laboratory was equipped with two AMTI force plates (Optima HPS, AMTI, USA) to collect kinetic data at 1000 Hz. Kinematic data were captured at 100 Hz by a Vicon motion-capture system consisting of eight infrared cameras (Vicon V5, Oxford Metrics, UK) and synchronized with the force plates. In accordance with the Vicon Plug-in-Gait full-body marker set, 39 reflective markers were placed on anatomical bony landmarks. Surface electromyographic (sEMG) activity of the multifidus and iliopsoas muscles was recorded at 1 500 Hz using a Noraxon sEMG system (Fig. 1).

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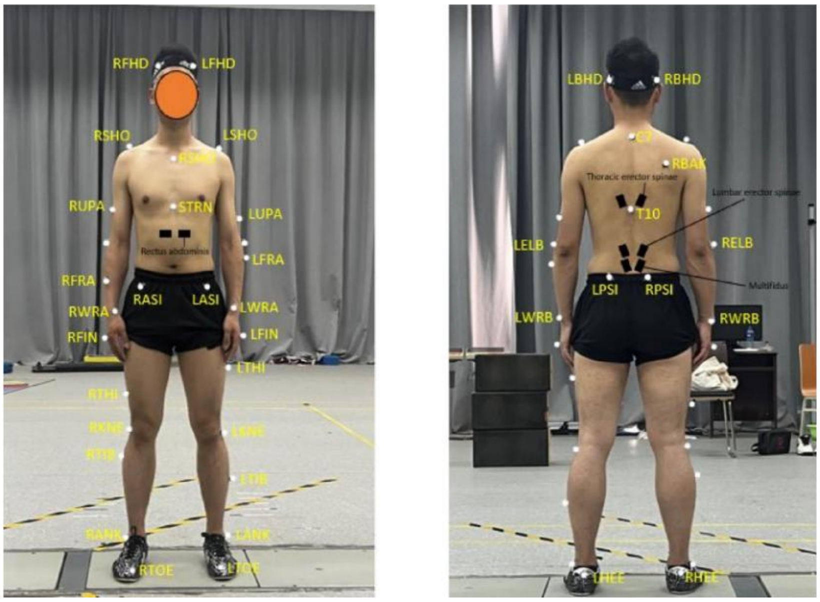

Figure 1. 39 markers on the body joints and surface electromyography locations

Subjects stood at the center of the force plate for static data collection, which was used to build each individual’s VICON model. Dynamic data were then recorded while participants walked along the X-axis (the direction of travel) at a pace controlled by a metronome. They started walking 1.5 meters in front of the force plate and continued until they had walked 1.5 meters past it. A valid gait cycle was defined from the instant the right heel first contacted the plate until the right toe left the plate. Five valid trials were collected for both normal walking and Tai Chi walking.

Paraspinal muscle (PL) activation was obtained via static optimization and time-normalization in OpenSim (v4.4, Stanford University, USA). To validate the OpenSim output, the multifidus was used as an example: raw sEMG signals were first processed with a 10–500 Hz Butterworth band-pass filter and a 50 Hz notch filter, then rectified, normalized, and smoothed with a 50 ms sliding window. Comparison between the sEMG-derived activation and the OpenSim-simulated activation confirmed the reliability of the muscle-activation modelling [13].

L4-L5 angular excursions in flexion/extension (X), lateral bending (Y), and axial rotation (Z) were computed with OpenSim inverse kinematics and subsequently normalized [14].

Results and Discussion

3.1 Muscle activations

In this study, the activation levels of five key lumbar-core muscles—psoas major (PS), multifidus (MF), iliocostalis lumborum (IL), longissimus thoracis (LT), and quadratus lumborum (QL)—were selected as evaluation indices, with activation expressed on a scale from 0 to 1.

In XW, the average activation levels of PS, MF, IL, LT, and QL were all significantly higher than those in normal walking ($P < 0.05$). In XW, the muscle activation curves of IL, LT, and MF all exhibited a biphasic activation pattern during the swing phase, whereas a single-peak activation pattern was observed in W. PS muscle activation under W conditions presented a single peak during the swing phase, whereas under XW conditions it displayed a sustained activation state. QL muscle activation under W conditions peaked in the mid-to-late single-leg stance phase, whereas under XW conditions a triphasic pattern appeared from the swing phase through the single-leg stance phase （Fig. 2) (Tab. 1).

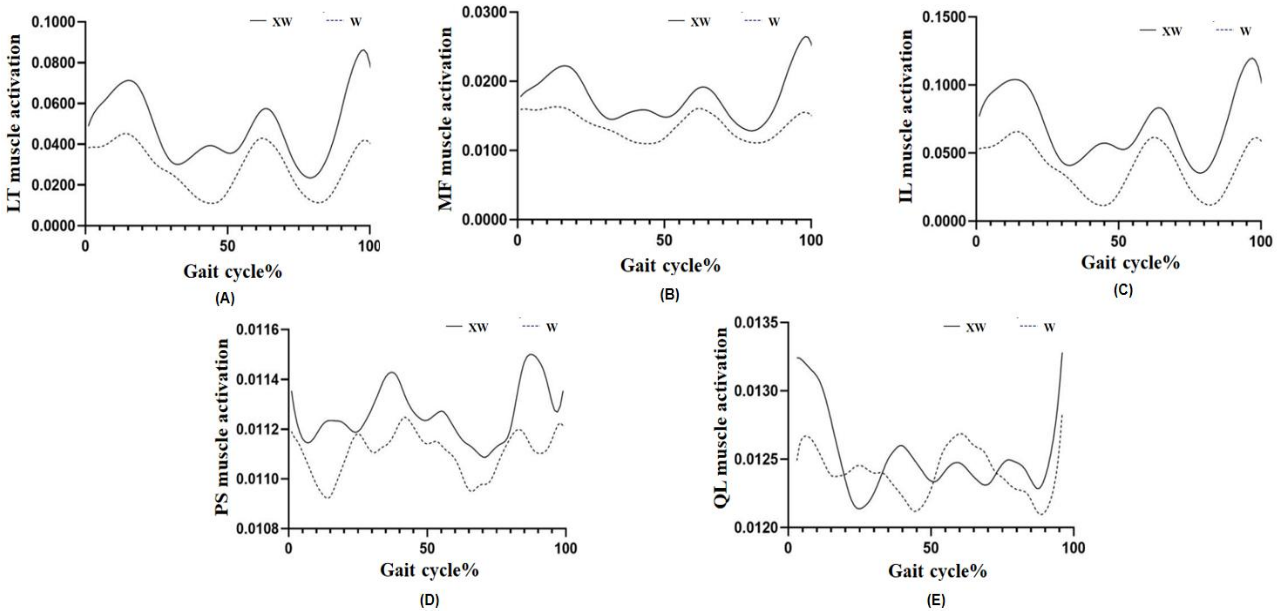

Figure 2. Comparison of muscle activation of the paraspinal muscles of walking in two conditions.
(A) LT, (B) MF, (C) IL, (D) PS, (E) QL

Table 1

Comparison of average muscle activation of paraspinal muscles in two walking modes

Muscle	Average muscle activation（W）	Average muscle activation（XW）	Z	Z	P	Cohen's d
LT	0.0279（0.0129, 0.0415）	0.0423（0.0325, 0.0648）	-8.530	-8.530	0.000	1.39
MF	0.0137（0.0118, 0.0155）	0.0169（0.0150, 0.0198）	-17.418	-17.418	0.000	1.46
IL	0.0399（0.0158, 0.0592）	0.0620（0.0483, 0.0973）	-8.525	-8.525	0.000	1.47
PS	0.0111（0.0109, 0.0113）	0.0112（0.0110, 0.0114）	-2.639	-2.639	0.008	1.99
QL	0.0113（0.0110, 0.0120）	0.0122（0.0116, 0.0129）	-6.253	-6.253	0.000	0.43

3.2 Lumbar Spine Kinematics

In both walking conditions, the mean spinal-curvature angles in the X and Y axes differed significantly ($P < 0.05$); no significant difference was observed in the Z axis. In the X axis, L4–L5 exhibited a biphasic pattern throughout the gait cycle under both conditions. In the Y axis, the neutral spinal position occurred at 50 % of the gait cycle in XW, but earlier in W. In the Z axis, the mean curvature in XW was flatter than in W (Fig. 3) (Tab. 2).

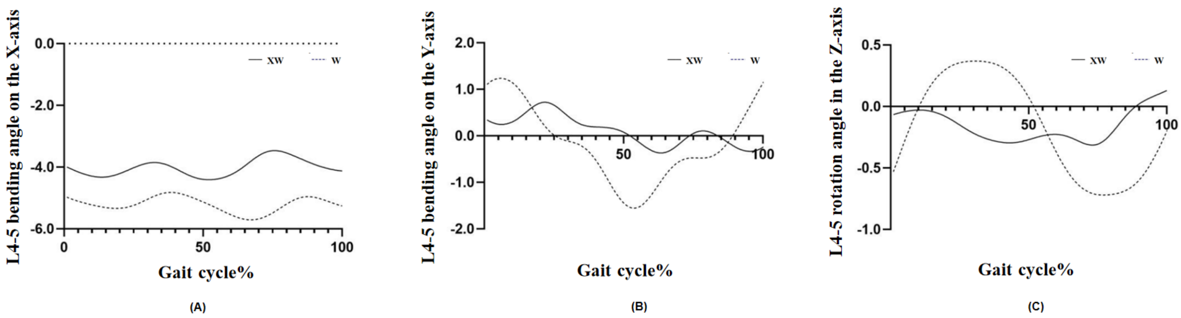

Figure 3. L4-5 motion comparison during XW and W.
(A) Flexion/extension (X-axis), (B) Lateral bending (Y-axis), (C) Axial rotation (Z-axis)

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Table 2

L4-5 motion comparison in X, Y, Z between two walking modes

Axis	Average angle（W）	Average angle（XW）	Z	P
X	-5.1916（-4.9877，-5.3733）	-4.0796（-4.3017，-3.8285）	-8.725	0.000
Y	-0.2015（-0.6455，0.4948）	0.1629（-0.2146，0.2392）	-2.736	0.006
Z	-0.1911（-0.6031，0.2955）	-0.2157（-0.2705，-0.033）	-0.073	0.942

Previous studies on Tai Chi have mostly been limited to intervention studies, with little discussion of its internal mechanisms. In this study, we focused on exploring the most important part of Tai Chi—the state of “Xuling Dingjing”—and quantified its biomechanical effects on the spine. Our results indicate that walking while maintaining this posture improves spinal stability and reduces the risk of injury more than normal walking.

In gait analysis, the activation patterns of core muscles are crucial for understanding how different walking styles influence spinal and pelvic stability. Comparisons between W and XW reveal marked differences in these activation patterns. During normal walking, these muscles typically exhibit a biphasic activation pattern aligned with specific phases of the gait cycle, such as swing and initial heel contact [15-16]. In contrast, the slower, controlled movements and emphasis on stability inherent in XW lead to earlier onset or prolonged activation. LT, essential for maintaining frontal-plane stability and controlling trunk rotation [17], shows higher activation in XW than in W through mechanisms such as extended activation duration and altered neural control strategies [18]. This finding aligns with LT’s established role [19] and with the Tai Chi principle of “moving the body with the waist”. IL and MF display activation patterns similar to LT in XW. Dysfunction of MF has been linked to low-back pain [20]; Tai Chi appears to selectively engage these smaller muscles not typically targeted by other exercises. Under the Tai Chi cue “contain the chest and draw up the back”, IL must isometrically maintain the lumbar lordosis during single-leg stance and, in early swing, coordinate with contralateral abdominal muscles to control axial trunk rotation. Psoas major, pivotal for hip flexion and lumbar stabilization, shows greater activation in single-leg stance during XW, indicating that “Xuling Dingjin” helps maintain spinal balance while standing on one leg. Quadratus lumborum, critical for frontal-plane spinal stability [21], exhibits multiple peaks throughout the XW gait cycle, reflecting sustained activation that minimizes lateral sway and preserves balance. Collectively, these findings demonstrate that XW enhances core-muscle activation and spinal stability, offering therapeutic potential for chronic low-back pain and degenerative spinal disorders. Moreover, Tai Chi’s emphasis on balance and coordination may improve proprioception and reduce fall risk.

During walking, the lumbar spine must continually flex, laterally bend, and rotate in the transverse plane to maintain balance and forward progression; these repeated motions increase anterior disc pressure and predispose unilateral paraspinal muscles to overuse. In contrast, the “Xuling Dingjin” (lightly lifting the crown while keeping the coccyx centered) induces axial elongation of the spine, markedly reducing compensatory lumbar flexion and anterior disc loading—reflected by a significant decrease in L4-L5 sagittal-plane curvature. Muscle activation data show that MF, LT, and other deep stabilizers are significantly more active during XW than during W, aligning with the reduced sagittal motion and demonstrating that “Xuling Dingjin” constrains excessive lumbar movement, allowing the L4-L5 segment to remain closer to a neutral position throughout the gait cycle. This minimizes disc degeneration risk and is particularly relevant for sedentary populations as a daily preventive strategy. In the frontal plane, Tai Chi’s “contain the chest and draw up the back” cue recruits the internal/external obliques and erector spinae symmetrically, correcting the asymmetric lateral trunk lean that typically accompanies alternating lower-limb advancement in normal walking. The resulting balanced activation attenuates uneven compressive loads on lumbar facets and discs, thereby reducing lateral-stress-related falls [22]. In the transverse plane, although L4-L5 axial rotation angles did not differ statistically between XW and X, “Xuling Dingjin” still imposed a subtle constraint on trunk rotation. Excessive lumbar rotation is associated with low-back pain and postural instability. By emphasizing “relax the waist and sink the hips” together with “alternating solid and void”, Tai Chi actively modulates rotational amplitude without adding torsional load to the lumbar spine. Collectively, XW confers clear biomechanical advantages by reducing sagittal-plane loading, correcting frontal-plane asymmetry, and preserving transverse-plane rotational stability, offering a safe and practical exercise strategy for low-back-pain prevention and management.

The small sample size of this study may affect the generalizability of the findings, and future studies will involve groups of different ages, genders, and years of exercise for more reliable statistical analysis. The walking action was chosen to more widely apply the “virtual collar and top strength” movement to daily life, and the research action will be expanded in the future.

Conclusions

Maintaining the “Xuling Dingjin” posture during walking significantly increases both the amplitude and duration of paraspinal muscle activation, thereby enhancing spinal dynamic stability. This postural cue also markedly reduces sagittal-plane flexion and frontal-plane lateral bending at the L4–L5 segment, lowering the risk of unilateral overload. Moreover, no significant change in transverse-plane curvature was observed during Tai Chi-style walking, indicating that it does not add torsional load to the lumbar spine and confirming its safety.

Funding

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