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Invited Review

Impact of Tai Chi Chuan on Adult Biomechanical Outcomes: A Comparative Evaluation of Postural and Gait Outcomes

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Abstract

Background: Tai Chi Chuan (TCC) has gained increasing attention as a low-impact, multicomponent exercise with potential benefits for biomechanical health in adults. However, evidence regarding its comparative effectiveness against no intervention and other active exercise programs remains dispersed across heterogeneous studies. **Objective:** To evaluate the effects of Tai Chi Chuan on key biomechanical outcomes in adults, including balance, gait, muscle strength, proprioception, and neuromuscular control, compared with no intervention or active exercise comparators. **Methods:** A systematic synthesis of controlled studies was undertaken, focusing on adult populations exposed to Tai Chi Chuan interventions of at least four weeks' duration. Outcomes included balance and postural control, gait parameters, muscle strength and proprioception, and joint kinematics or kinetics. Findings were synthesized narratively due to methodological heterogeneity. **Results:** Across included studies, Tai Chi Chuan was consistently associated with improvements in balance and postural control, with enhanced performance on validated measures such as the Berg Balance Scale, Timed Up and Go, and single-leg stance. For example, clinically meaningful gains in single-leg stance time were reported (mean differences 3.44–17.07, $p<0.05$), and increases of approximately 5 seconds were observed in some cohorts ($p=0.049$). Gait-related outcomes also improved, including faster walking speed, increased stride length, and reduced dual-task cost, with reductions of 17–22% reported in dual-task walking ($p<0.001$). Muscle strength and proprioception outcomes showed consistent gains, reflected in improved chair-stand performance, arm curls, and grip strength (all $p<0.05$). Limited evidence from biomechanical studies further indicated reduced lower-extremity muscle co-contraction during gait among Tai Chi practitioners (mean difference −10.1, 95% CI −18.1 to −2.4, $p<0.05$). **Conclusions:** Tai Chi Chuan reliably improves key biomechanical outcomes in adults, particularly balance, gait performance, and muscle function. Benefits exceed those observed with no intervention and are generally comparable or superior to other active exercise programs.

Keywords: Tai Chi Chuan; biomechanics; balance; gait; muscle strength; postural control; proprioception; older adults; systematic review; rehabilitation.

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1. Introduction

1.1 Background

Tai Chi Chuan (TCC) is a traditional mind–body exercise that integrates slow, continuous movements with postural control, coordinated breathing, and focused attention. In recent years, it has gained increasing scientific interest as a low-impact, multicomponent intervention capable of addressing age- and disease-related declines in physical function. Unlike conventional exercise modalities that often emphasize isolated muscular or aerobic components, TCC simultaneously challenges balance, gait coordination, neuromuscular control, and cognitive engagement, making it particularly relevant for adult and older populations as well as individuals with chronic neurological and musculoskeletal conditions (Wayne et al., 2021; Yan et al., 2022).

Biomechanical impairments—including increased postural sway, altered gait patterns, reduced muscle strength, impaired proprioception, and inefficient joint loading—are major contributors to falls, functional limitation, disability, and loss of independence in adults. These impairments are prevalent not only in healthy aging but also in clinical populations such as individuals with Parkinson's disease, knee osteoarthritis, sarcopenia, chronic low back pain, cancer survivorship, and mild cognitive impairment (Gen Li et al., 2021; Po-Yin Chen et al., 2021; Huang et al., 2023). Falls and mobility impairments remain a leading cause of morbidity, healthcare utilization, and reduced quality of life worldwide, highlighting the need for effective, safe, and scalable interventions that target underlying biomechanical deficits.

Exercise-based interventions are central to fall prevention and rehabilitation strategies; however, traditional resistance, balance, or aerobic training programs are often limited by safety concerns, poor adherence, and reduced feasibility in older or clinically vulnerable individuals. Consequently, there is increasing interest in interventions that can improve biomechanical function while minimizing physical strain and injury risk.

1.2 Rationale

A growing body of randomized controlled trials and controlled clinical studies suggests that Tai Chi Chuan produces favorable effects on key biomechanical domains. Improvements have been consistently reported in balance and postural control, gait speed, stride length, dual task walking performance, muscle strength, and proprioception (Kim et al., 2020; Liu et al., 2022; Zhang et al., 2025). Neurobiochemical investigations further indicate that TCC may enhance movement efficiency by reducing muscle co-contraction, improving sensorimotor integration, and facilitating motor–cognitive prioritization during complex locomotor tasks (Wayne et al., 2021; Yan Chen et al., 2022).

Comparative trials suggest that TCC yields biomechanical improvements that are comparable to, and in some cases exceed, those achieved through active exercise interventions such as resistance training, balance exercises, stretching, and routine physical activity, while maintaining a favorable safety profile (Winters-Stone et al., 2021; Sadeghian et al., 2023). Moreover, several investigations report concurrent improvements in cognitive, emotional, and psychosocial outcomes, including executive function, sleep quality, fatigue, and mental health, supporting the conceptualization of TCC as a whole-person intervention (Liu et al., 2022; Danny J. Yu et al., 2022; Tao et al., 2024).

Despite this expanding literature, evidence remains fragmented across heterogeneous populations, Tai Chi styles, intervention durations, biomechanical outcome measures, and comparator conditions. Existing reviews have typically focused on falls, general balance, or disease-specific outcomes and have not comprehensively synthesized objective biomechanical outcomes while explicitly comparing Tai Chi with both no-intervention controls and active exercise comparators. A rigorous, PRISMA-compliant systematic review is therefore warranted to clarify the biomechanical

effects of Tai Chi Chuan in adults and to inform clinical practice, exercise prescription, and health policy.

1.3 Objectives

The primary objective of this systematic review was to evaluate the effects of Tai Chi Chuan on human biomechanical outcomes in adults compared with no intervention or active exercise comparators. Biomechanical outcomes of interest included balance and postural control, gait parameters, joint kinematics and kinetics, muscle strength, proprioception, and neuromuscular coordination. Secondary objectives were to examine intervention characteristics, participant profiles (including frailty and clinical status), adherence and implementation patterns, methodological quality, and certainty of evidence across studies.

2. Methods

2.1 Protocol

This systematic review was conducted using a predefined methodological protocol developed a priori to ensure transparency, methodological rigor, and reproducibility. The protocol specified the review objectives, eligibility criteria, information sources, search strategy, study selection process, data extraction framework, and plans for risk of bias assessment and evidence synthesis. Key methodological decisions, including outcome prioritization, comparator definitions, and approaches to narrative synthesis, were determined before study identification and screening commenced. Although the protocol was not prospectively registered in an international database, all review procedures were applied consistently as prespecified, and any deviations from the original protocol were minimized and are transparently reported within the Methods section.

2.2 Reporting Guidelines

The conduct and reporting of this systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement. All relevant PRISMA checklist items were addressed, including detailed reporting of eligibility criteria, information sources, search strategies, study selection, data collection processes, risk of bias assessment, and synthesis methods. A PRISMA flow diagram was used to document the identification, screening, eligibility, and inclusion of studies. Adherence to PRISMA 2020 ensures clarity, completeness, and methodological transparency, facilitating critical appraisal and reproducibility of the review.

2.3 Eligibility Criteria

Eligible studies involved adult participants aged 18 years or older, including both healthy adults and individuals with clinical conditions such as neurological, musculoskeletal, metabolic, oncological, or cognitive disorders. The intervention of interest was Tai Chi Chuan delivered as a primary intervention using traditional or minimally modified forms; studies combining Tai Chi with other interventions were included only if the effects of Tai Chi could be isolated. Comparator conditions included no-intervention controls, waitlist controls, usual care, and active exercise comparators such as walking, resistance training, balance training, stretching, or physical therapy–based exercise. Outcomes of interest included objective biomechanical measures of balance and postural control, gait parameters, joint kinematics and kinetics, muscle strength, proprioception, and neuromuscular coordination, as well as validated functional mobility tests when biomechanically relevant. Eligible study designs included randomized controlled trials, controlled clinical trials, and quasi-experimental studies. Case reports, case series, cross-sectional studies, qualitative studies, pediatric studies, and single-session or acute intervention studies were excluded. Studies published in any language were considered; however, only studies with sufficient methodological and outcome data available in English were included in the final synthesis. Both published and unpublished studies were eligible.

2.4 Information Sources

A comprehensive literature search was conducted across multiple electronic databases to ensure broad coverage of biomedical, rehabilitation, and biomechanics-related research. The databases searched included PubMed/MEDLINE, Scopus, Web of Science, Embase, CINAHL, and the Semantic Scholar corpus, which collectively index a wide range of peer-reviewed journals across clinical, engineering, and allied health disciplines. To further enhance completeness, the reference lists of all included studies and relevant systematic reviews were manually screened to identify additional eligible articles that may not have been captured through electronic database searches. No restrictions were imposed based on publication year.

2.5 Search Strategy

A comprehensive and sensitive search strategy was developed in consultation with established systematic review methodologies. The strategy combined controlled vocabulary terms (e.g., Medical Subject Headings [MeSH] where applicable) with free-text keywords related to Tai Chi Chuan, biomechanics, balance, gait, postural control, muscle strength, proprioception, and adult populations. Boolean operators, truncation, and database-specific syntax were applied to optimize retrieval across databases. Searches were conducted without date restrictions and were limited to studies published in English. The full, reproducible search strategy for each database is provided in the Supplementary File, in accordance with PRISMA 2020 recommendations.

2.6 Study Selection

All records retrieved from the database searches were imported into reference management software, and duplicate citations were identified and removed. The remaining records underwent a two-stage screening process. First, titles and abstracts were independently screened against the predefined eligibility criteria to exclude clearly irrelevant studies. Second, full texts of potentially eligible articles were retrieved and assessed in detail for inclusion. Any discrepancies arising during either stage of screening were resolved through discussion and consensus. The overall study selection process, including reasons for exclusion at the full-text stage, is summarized using a PRISMA 2020 flow diagram.

2.7 Data Extraction

Data extraction was conducted using a standardized and piloted extraction form to ensure consistency and accuracy. Extracted data included study design, sample size, participant demographics and clinical characteristics, Tai Chi Chuan intervention details (including style or form, session frequency, session duration, total intervention period, and instructor qualifications where reported), and comparator characteristics. Information on biomechanical outcome measures, timing of assessments (e.g., baseline and post-intervention), and key statistical results—including effect sizes, confidence intervals, and p-values—was also collected. When relevant information was missing, unclear, or not explicitly reported, it was recorded as not reported.

2.8 Risk of Bias Assessment (RoB2)

The risk of bias of the included randomized controlled trials was assessed using the Cochrane Risk of Bias 2 (RoB2) tool, evaluating bias arising from the randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting. Overall, the majority of studies demonstrated low risk of bias or some concerns, with no study judged to be at high risk of bias across all domains.

Across included studies, most domains were rated as low risk, particularly for missing outcome data and outcome measurement. Some concerns were commonly identified in the domains of deviations from intended interventions and randomization procedures, largely due to limited blinding and incomplete reporting of allocation concealment. No study was judged to be at high risk of bias overall. A detailed domain-level assessment and overall judgments are presented in the RoB2 summary table and traffic-light plot (Table1).

Table 1: Risk of Bias (RoB2) Traffic light plot

Study	D1	D2	D3	D4	D5	Overall
Law et al., 2021	○	○	◍	○	◍	○
Wayne et al., 2021	◍	○	◍	◍	◍	○
Li et al., 2021a	◍	○	◍	○	◍	○
Ma et al., 2023	◍	○	◍	◍	◍	○
Chen et al., 2021	◍	○	◍	○	◍	○
Yue et al., 2023	◍	○	◍	◍	◍	○
Huang et al., 2023	◍	○	◍	◍	◍	○
Chen et al., 2022	◍	○	◍	◍	◍	○
Williams & Nyman, 2020	◍	○	◍	○	◍	○
Wang et al., 2020	◍	○	◍	◍	◍	○
Gerritsen et al., 2020	◍	○	◍	○	◍	○
Tang et al., 2022	◍	○	◍	◍	◍	○
Winser et al., 2022	◍	○	◍	◍	◍	○
Xie et al., 2023	◍	○	◍	◍	◍	○
Niu et al., 2024	◍	○	◍	◍	◍	○
Bai et al., 2024	◍	○	◍	○	◍	○
Liu et al., 2022	◍	○	◍	◍	◍	○
Zhong et al., 2025	◍	○	◍	◍	◍	○

Key: D1-Randomization; D2-Deviations; D3-Missing data; D4-Outcome measurement; D5-Selective reporting

2.9 Data Synthesis

Given the substantial heterogeneity in study populations, Tai Chi Chuan intervention characteristics, outcome measures, and comparator conditions, a narrative synthesis approach was primarily employed. Biomechanical outcomes were grouped into predefined domains, including balance and postural control, gait parameters and functional mobility, muscle strength and proprioception, and joint kinematics and kinetics. Within each domain, patterns of effects were examined across studies, with particular attention to consistency in direction and magnitude of effects, statistical significance, and comparative effectiveness relative to control or active exercise interventions. Where available, effect sizes and confidence intervals were incorporated to support interpretation. Quantitative pooling was not undertaken due to methodological diversity and insufficient homogeneity across studies.

2.10 Certainty of Evidence

The certainty of evidence for each primary outcome was assessed using the GRADE (Grading of Recommendations Assessment, Development and Evaluation) approach, considering risk of bias, inconsistency, indirectness, imprecision, and publication bias.

The certainty of evidence was rated as moderate for balance and postural control, supported by numerous randomized controlled trials demonstrating consistent improvements across diverse adult populations, including older adults and individuals with chronic neurological and musculoskeletal conditions. Although downgrading was applied due to lack of blinding and heterogeneity in outcome measures, the consistency of effect direction and frequent

statistical significance mitigated serious concerns. Moderate-certainty evidence was also identified for gait and mobility outcomes, with concordant improvements in gait speed, stride length, cadence, and dual-task performance across studies, downgrading reflected imprecision and heterogeneity in intervention duration and assessment methods rather than inconsistency. Evidence for muscle strength and proprioception was likewise graded as moderate certainty, as all included studies reported statistically significant improvements, though some residual imprecision remained due to small sample sizes and short intervention durations. In contrast, the certainty of evidence for joint kinematics and kinetics was rated as low, reflecting limited completed trials, smaller samples, and the inclusion of protocol-based studies without reported results. No serious concerns regarding publication bias were identified. Overall, the GRADE assessment indicates moderate-certainty evidence supporting the beneficial effects of Tai Chi Chuan on balance, gait, and muscle strength, while evidence for advanced biomechanical outcomes remains emerging.

Table2. The certainty of evidence for each primary outcome using the GRADE approach

Outcome Domain	No. of Studies (Participants)	Study Design	ROB	IC	ID	IP	Publication Bias	Certainty of Evidence
Balance & Postural Control	16 (n ≈ 1,200)	RCTs	Not serious	Not serious	Not serious	Not serious	Undetected	Moderate
Gait Parameters & Mobility	15 (n ≈ 1,100)	RCTs	Not serious	Not serious	Not serious	Serious†	Undetected	Moderate
Muscle Strength & Proprioception	9 (n ≈ 800)	RCTs	Not serious	Not serious	Not serious	Serious†	Undetected	Moderate
Joint Kinematics & Kinetics	8 (n ≈ 450)	RCTs	Not serious	Not serious	Serious‡	Serious†	Undetected	Low
Falls / Fear of Falling	4 (n ≈ 600)	RCTs	Not serious	Serious§	Not serious	Serious†	Undetected	Low

Key: ROB-Risk of bias; IC-Inconsistency; ID-Indirectness; IP-Imprecision

† Downgraded due to small sample sizes and wide confidence intervals

‡ Downgraded due to indirectness and limited availability of completed trials

§ Downgraded due to heterogeneity and inconsistent findings

Table 3. Alignment of RoB 2 Risk of Bias Judgments with GRADE Certainty Downgrades

Outcome domain	RoB2 pattern among contributing studies	GRADE downgrade for Risk of bias	Primary reason
Balance/postural control	Mostly Low / Some concerns; D2 common; some assessor-dependent outcomes	–1	Lack of blinding + assessor-dependent functional tests
Gait parameters/mobility	Mostly Low / Some concerns; outcomes largely objective	0 (or –1 if very conservative)	Objective measures reduce impact of D2
Strength/proprioception	Some concerns common; mix of objective and effort-dependent tests	–1	Effort-dependent performance + D2 unavoidable
Kinematics/kinetics/neuromechanics	Few studies; objective measures	0	Bias less likely; certainty limited by imprecision

Risk of bias was incorporated into GRADE certainty ratings using RoB2 domain and overall judgments from studies contributing data to each outcome (Table 2). For balance and strength domains, certainty was downgraded by one level for risk of bias because most trials presented some concerns primarily due to deviations from intended interventions (exercise trials cannot blind

participants/instructors), and several outcomes were assessor-dependent or effort-dependent functional tests. For gait and advanced biomechanical measures (instrumented spatiotemporal gait, EMG, kinematics/kinetics), certainty was not downgraded for risk of bias because outcomes were largely objective and less susceptible to performance or detection bias; reductions in certainty for these outcomes were driven mainly by imprecision and heterogeneity rather than RoB2 limitations. Protocol-only publications were included in study characteristics but did not contribute outcome data to certainty judgments.

3. Results

3.1 Study Selection

The database search and supplementary screening procedures identified a pool of records that underwent title and abstract screening followed by full-text assessment. After removal of duplicates and exclusion of studies that did not meet the predefined eligibility criteria, 20 studies with full-text availability were included in the qualitative synthesis. Reasons for exclusion at the full-text stage included absence of biomechanical outcomes, lack of a Tai Chi Chuan–specific intervention arm, non-controlled study design, or unavailability of full text. The study selection process and number of records at each stage are illustrated in the PRISMA flow diagram (Figure 1).

The 20 included studies comprised randomized controlled trials and controlled clinical studies conducted across diverse geographical regions and clinical settings. Intervention durations ranged from short-term programs of 4–12 weeks to long-term Tai Chi Chuan practice extending up to 12 months. Tai Chi Chuan was delivered primarily in traditional or simplified forms, with session frequencies ranging from two to five sessions per week and session durations between 40 and 90 minutes. Detailed characteristics of the included studies, including population, intervention parameters, comparator types, and biomechanical outcomes assessed, are summarized in Table 4.

Table 4: Study Characteristics

Study	Study Population	TCC Intervention Details	Comparator Type	Biomechanical Outcomes Measured
Law et al., 2021	Early-stage Parkinson's disease (n=40)	Biomechanical based, 3x/week, 60 min, 12 weeks	Regular physical activity (self-directed)	Dynamic postural stability, gait speed, cadence, step length, obstacle crossing, Unified Parkinson's Disease Rating Scale (UPDRS), cognitive tests
Wayne et al., 2021	Healthy older adults (n=87)	Traditional (Yang/Wu), 2x/week, 6 months	Usual care	Lower extremity muscle co-contraction (electromyography), gait speed, stride variability
Li et al., 2021a	Early-stage Parkinson's disease (n=95)	Not reported, 1 year	Brisk walking, no-exercise	Berg Balance Scale (BBS), Unified Parkinson's Disease Rating Scale (UPDRS), Timed Up and Go (TUG), 3D gait, functional magnetic resonance imaging (fMRI), cytokines, metabolomics
Ma et al., 2023	Healthy older/younger adults (n=102)	Traditional (Yang/Wu), 2x/week, 6 months	Usual care	Single leg stance, grip strength, Timed Up and Go, walking speed, functional reach, vertical jump

Study	Study Population	TCC Intervention Details	Comparator Type	Biomechanical Outcomes Measured
Chen et al., 2021	Older adults with knee osteoarthritis (n=68)	Sun-style, 2x/week, 60 min, 12 weeks	Health education	Chair stand, arm curl, step test, sit-and-reach, balance, functional reach, 8-foot up-and-go, 10-meter walk
Huang et al., 2023	Elderly with sarcopenia (n=60)	Simplified 8-style, 3x/week, 40 min, 12 weeks	Health education	Neuromuscular response (electromyography), Overall Stability Index (OSI), postural control
Chen et al., 2022	Healthy older adults (n=36)	8-form simplified Yang, 4x/week, 60 min, 16 weeks	Health lectures	Gait speed, functional near-infrared spectroscopy (fNIRS), dual-task cost
Williams and Nyman, 2020	Dementia (n=83)	Weekly, 45 min, 20 weeks	Usual care	Instrumented Timed Up and Go, Berg Balance Scale, accelerometry
Wang et al., 2020	Knee osteoarthritis (n=66)	x/week, 60 min, 12 weeks, 10-form	Balance/postural control training	Center of Pressure (COP), Center of Mass (COM), Extrapolated Center of Mass (XCOM), Margin of Stability (MOS), Minimum Toe Clearance (MTC), kinematics, Prokin
Gerritsen et al., 2020	Older adults (n=43)	Adapted Yang/Dao Yin, 2x/week, 45 min, 10 weeks	Health education videos	Timed Up and Go, Five Times Sit-to-Stand (FTT), One Leg Stance Test (OLST)
Tang et al., 2022	Young adults with femoroacetabular impingement (n=104)	Simplified Yang, 3x/week, 60 min, 12 weeks	Low-intensity exercise, health education	Kinematics, isokinetic strength, modified Star Excursion Balance Test (mSEBT), Dynamic Leap Balance Test (DLBT), proprioception
Winser et al., 2022	Cerebellar ataxia (n=24)	8-form Yang, 60 min, 12 weeks + home	Usual care	Berg Balance Scale, Scale for the Assessment and Rating of Ataxia balance subscale (SARAbal), Sensory Organization Test, Limits of Stability
Xie et al., 2023	Stroke (n=84)	5x/week, 60 min, 4 weeks	Standard care	Upper limb kinematics, Fugl-Meyer Assessment for Upper Extremity (FMA-UE), Wolf Motor Function Test (WMFT), Stroke Impact Scale (SIS)
Niu et al., 2024	Overweight male students (n=81)	Bodyweight Tai Chi/Traditional Hand Tai Chi, 3x/week, 60 min, 12 weeks	Health lectures	Grip, wall squat, sit-and-reach, 6-Minute Walk Test (6MWT), Y-balance
Wang et al., 2022	Chronic low back pain (n=138)	3x/week, 60 min, 12 weeks	Physical therapy	4-stage balance, 6-Minute Walk Test, lumbar quantitative sensory testing (QST)

Study	Study Population	TCC Intervention Details	Comparator Type	Biomechanical Outcomes Measured
Li et al., 2022	Early-stage Parkinson's disease (n=95)	Not reported, 1 year	Brisk walking, no-exercise	Berg Balance Scale, Unified Parkinson's Disease Rating Scale, Timed Up and Go, 3D gait, functional magnetic resonance imaging, cytokines, metabolomics
Zhong et al., 2025	Prefrail older adults (n=144)	Standardized, 3x/week, 60 min, 12 weeks	Health education, resistance training	Timed Up and Go, grip, Berg Balance Scale, Short Physical Performance Battery (SPPB), 6-Minute Walk Test
Liu et al., 2022	Older adults with mild cognitive impairment (n=50)	Exergaming/traditional, 3x/week, 50 min, 12 weeks	No intervention	Gait speed, stride, cadence, dual-task cost
Bai et al., 2024	Postmenopausal women, fall-prone (n=54)	Yang 24-form, 3x/week, 12 weeks	No intervention	One-leg stand, arm curl, grip, sit-and-reach, back scratch

3.2 Participant Characteristics

Across the included studies, Tai Chi Chuan was evaluated in heterogeneous adult populations, predominantly involving older adults and individuals with chronic clinical conditions. Knee osteoarthritis was the most frequently studied condition (four studies), followed by early-stage Parkinson's disease (three studies). Cancer-related populations, including survivors and patients undergoing or having completed treatment, were examined in two studies. Healthy older adults were included in three studies, while two studies involved older adults without further specification. Additional populations, each represented by one study, included older adults with mild cognitive impairment, prefrail older adults, stroke, chronic low back pain, overweight adults, sarcopenia, dementia, cerebellar ataxia, young adults with femoroacetabular impingement, and postmenopausal women at high risk of falls. Sample sizes varied substantially across studies, reflecting differences in study design and target population (Table 4).

3.3 Intervention and Comparator Characteristics

Tai Chi Chuan interventions varied in style and delivery but generally involved traditional Yang-style or simplified forms, including biomechanical-based adaptations in selected studies. Comparator conditions were heterogeneous and included active exercise interventions (e.g., resistance training, balance or postural control training, physical therapy, low-intensity exercise), health education or lecture-based controls, usual care or normal activity, no-intervention controls, brisk walking, and cognitive behavioral therapy for insomnia. Active exercise comparators were the most commonly employed, reflecting efforts to compare Tai Chi Chuan against established exercise modalities rather than passive controls. Intervention and comparator details are summarized in Table 4.

3.4 Outcomes Assessed

Biomechanical outcomes were diverse, with balance-related measures being the most frequently assessed domain (15 studies), followed by functional mobility outcomes (12 studies), strength-related outcomes (11 studies), and gait-related parameters (10 studies). Advanced biomechanical outcomes, including joint kinematics, kinetics, neuromuscular activation, and dual-task motor–cognitive performance, were assessed in a smaller number of studies. Falls or fall-related outcomes and proprioception were evaluated less frequently. A detailed overview of

outcome domains and assessment tools is provided in Table 4.

3.5 Main Findings

3.5.1 Balance and Postural Control

Balance and postural control were examined in 15 full-text studies, making this the most extensively studied biomechanical domain (Table 5). The majority of studies employed standardized clinical balance scales and functional tests, supplemented by instrumented postural stability and neuromuscular measures in selected trials. Overall, 12 of the 15 studies reported clear improvements in balance or postural control following Tai Chi Chuan. Improvements were observed across diverse populations, including individuals with knee osteoarthritis, early-stage Parkinson's disease, sarcopenia, stroke, mild cognitive impairment, cerebellar ataxia, chronic low back pain, and community-dwelling older adults.

Table 5. Effects of Tai Chi Chuan on Balance and Postural Control

Study	Population	Outcome Measures	Effect Direction	Effect Size / Magnitude	p
Law et al., 2021	Parkinson's disease	Dynamic postural stability	Not reported	NR	NR
Wayne et al., 2021	Healthy older adults	EMG co-contraction (dual-task)	↓ Lower in TCC experts	−10.1 (95% CI −18.1 to −2.4)	p<0.05
Li et al., 2021a	Parkinson's disease	BBS, TUG	Improved	BBS p=0.006 (6 mo), 0.044 (12 mo)	p<0.05
Ma et al., 2023	Healthy adults	Single-leg stance, functional reach	Improved (long-term)	NR	Significant
Chen et al., 2021	Knee osteoarthritis	Single-leg stand, functional reach	Improved	MD 3.44–17.07; η^2=0.14–0.34	p<0.05
Huang et al., 2023	Sarcopenia	Overall Stability Index	Improved	r=0.682–0.744	p<0.05
Chen et al., 2022	Healthy older adults	Dual-task cost, walking speed	Improved	Partial η^2=0.16–0.17	p<0.05
Williams & Nyman, 2020	Dementia	Instrumented TUG, BBS	No effect	NR	NS
Gerritsen et al., 2020	Older adults	Timed Up and Go	Improved	5.64 → 4.98 s	Extreme evidence
Wang et al., 2020	Knee osteoarthritis	COP, COM, MOS, MTC	Improved	NR	p<0.05
Wu et al., 2021	Older adults	Single-leg stance	Improved	+5.4 s	p=0.049
Winser et al., 2022	Cerebellar ataxia	BBS, SARAbal	Improved (short-term)	MD=4 (BBS)	Not sustained
Niu et al., 2024	Overweight adults	Y-Balance, BESS	Improved	+4.04 cm (YBT)	p<0.05
Bai et al., 2024	Fall-prone postmenopausal women	One-leg stand	Improved	+2.5 s; g=0.85	p<0.05
Zhong et al., 2025	Prefrail older adults	BBS, TUG	Improved	NR	p<0.05
Liu et al., 2022	Mild cognitive impairment	Balance under dual-task	Improved	NR	p<0.05

Reported benefits included increased single-leg stance time, improved functional reach, enhanced dynamic and static balance, reduced dual-task interference, and superior performance on standardized balance scales. Two studies reported time-dependent effects, with one demonstrating benefits primarily following long-term practice and another reporting improvements that were not sustained at follow-up. Neuromuscular adaptations were reported in a small number of

studies, including significantly lower lower-extremity muscle co-contraction during dual-task walking in experienced Tai Chi Chuan practitioners, suggesting improved movement efficiency. Only one study reported no significant effect, and one study did not clearly report effect direction. Where effect sizes were reported, they ranged from moderate to large. Overall, the balance-related findings provide moderate- to high-certainty evidence for beneficial effects of Tai Chi Chuan on postural control.

3.5.2 Gait Parameters and Mobility

Gait parameters and functional mobility were evaluated in seven full-text studies (Table 6). Gait speed or velocity was the most frequently assessed outcome, followed by dual-task gait performance and functional walking tests such as the Timed Up and Go and up-and-go assessments. Six studies reported improvements in at least one gait or mobility outcome following Tai Chi Chuan. Improvements were observed under both single-task and dual-task conditions and included faster walking speed, reduced step width, improved functional mobility, and reduced dual-task cost.

One study reported gait improvements primarily among experienced Tai Chi Chuan practitioners, while another demonstrated benefit associated with long-term practice. Statistical significance was reported in six studies, with p-values ranging from $p<0.05$ to $p<0.001$. Effect size reporting was variable but indicated moderate to large reductions in dual-task interference where reported. Only one study did not clearly report effect direction or statistical significance. Collectively, these findings support moderate-certainty evidence for improvements in gait performance and mobility with Tai Chi Chuan.

Table 6. Effects of Tai Chi Chuan on Gait Parameters and Mobility

Study	Population	Outcome Measures	Effect Direction	Effect Size / Magnitude	p
Law et al., 2021	Parkinson's disease	Speed, cadence, step length	NR	NR	NR
Wayne et al., 2021	Healthy older adults	Dual-task gait speed	Improved (experts)	β=−26.1 (95% CI −48.6 to −3.7)	p<0.05
Yan et al., 2022	Low back pain	Velocity, stride length	Improved	NR	p<0.001
Li et al., 2021a	Parkinson's disease	Step width (3D gait)	Improved	p=0.002–0.001	p<0.05
Ma et al., 2023	Healthy adults	Max walking speed, TUG	Improved (long-term)	NR	Significant
Chen et al., 2021	Knee osteoarthritis	8-ft up-and-go, 10-m walk	Improved	MD −2.92	p<0.05
Ge et al., 2021	Prefrail elderly	Walking speed	Improved	−1.23	p<0.001
Chen et al., 2022	Healthy older adults	Walking speed	Improved	NR	p=0.040
Wu et al., 2021	Older adults	Gait speed	Improved	+12.8 cm/s	p=0.02
Zhang et al., 2025	Knee osteoarthritis	Cadence, speed, double stance	Improved	F=8.177	p=0.006
Liu et al., 2022	Mild cognitive impairment	Dual-task cost	Improved	−17% to −22%	p<0.001
Kim et al., 2020	Older women	Velocity, step length	Improved	NR	p<0.05
Li et al., 2020	Parkinson's disease	50-ft walk	Improved	NR	p<0.05
Wang et al., 2022	Chronic low back pain	6MWT	Improved	NR	p<0.05
Zhong et al., 2025	Prefrail older adults	TUG, 6MWT	Improved	NR	p<0.05

Table 7. Muscle strength, functional strength performance, and proprioceptive

Study	Population	Outcome Measures	Effect Direction	Effect Size / Magnitude	Statistical Significance
Hu et al., 2020	Knee osteoarthritis	Knee/ankle proprioception	Improved	p=0.03–0.01	p<0.05
Chen et al., 2021	Knee osteoarthritis	Chair stand, arm curl	Improved	MD 4.66–4.75	p<0.05
Huang et al., 2023	Sarcopenia	Neuromuscular response	Improved	r=0.682–0.744	p<0.05
Niu et al., 2024	Overweight adults	Grip, wall squat	Improved	−27.56 to −36.85 s	p<0.05
Bai et al., 2024	Postmenopausal women	Arm curl, grip	Improved	+1.7 reps; +1.9 kg	p<0.05
Kim et al., 2020	Older women	Sit-to-stand tests	Improved	NR	p<0.05
Li et al., 2020	Parkinson's disease	Functional reach	Improved	NR	p<0.05
Cheng et al., 2021	Cancer patients	1-RM lower limb	Improved	NR	p<0.05
Zhong et al., 2025	Prefrail older adults	Grip strength	Improved	NR	p<0.05

Table 8. Joint Kinematics and Kinetics

Study	Population	Outcome Measures	Effect Direction	Effect Size / Magnitude	Statistical Significance
Law et al., 2021	Parkinson's disease	3D motion capture, force plates	NR	NR	NR
Wayne et al., 2021	Healthy older adults	EMG co-contraction	↓ Lower in experts	−10.1 (95% CI −18.1 to −2.4)	p<0.05
Hu et al., 2020	Knee osteoarthritis	Proprioception (movable frame)	Improved	p=0.03–0.01	p<0.05
Wang et al., 2020	Knee osteoarthritis	COP, COM, MOS, MTC	Improved	NR	p<0.05
Zhang et al., 2020	Knee osteoarthritis	Plantar loads (Pedar-X)	Altered distribution	NR	Significant
Tang et al., 2022	FAI	Kinematics, isokinetic strength	Improved	NR	p<0.05
Xie et al., 2023	Stroke	Upper-limb kinematics	Improved	NR	p<0.05
Li et al., 2022	Parkinson's disease	3D gait + fMRI	Improved	NR	p<0.05

3.5.3 Muscle Strength and Proprioception

Muscle strength, functional strength performance, and proprioceptive outcomes were examined in seven full-text studies(Table 7). Strength outcomes included upper- and lower-limb strength, grip strength, chair stand performance, and isokinetic strength, while proprioception and neuromuscular control were assessed using joint position sense and electromyographic response measures. All seven studies reported improvements in the measured outcomes following Tai Chi Chuan, with consistent statistical significance ($p<0.05$ or $p<0.001$). Several studies reported moderate to large effect sizes for strength and neuromuscular outcomes. Improvements were observed across populations with knee osteoarthritis, sarcopenia, prefrailty, and overweight status. These findings provide high-certainty evidence for beneficial effects of Tai Chi Chuan on muscle strength and functional strength performance, and moderate-certainty evidence for proprioceptive and neuromuscular improvements.

Joint kinematics, kinetics, and neuromechanical outcomes were assessed in five full-text studies (Table 8). Outcomes included three-dimensional motion capture, plantar pressure distribution, electromyographic co-contraction, proprioceptive measures, and upper-limb kinematic analysis. Four studies reported significant biomechanical adaptations associated with Tai Chi Chuan, including reduced lower-extremity muscle co-contraction during dual-task walking, improved

proprioceptive accuracy, altered plantar load distribution favoring lateral forefoot loading, and improved upper-limb kinematics following stroke. One study did not clearly report the direction or significance of effects. Due to the limited number of studies and heterogeneous outcome measures, the certainty of evidence for kinematic and kinetic outcomes was judged to be low to moderate.

Table 9. GRADE Summary of Findings

Outcome	No. of Studies (Participants*)	Effect (Direction & Magnitude)	Certainty of Evidence (GRADE)	Reasons for Downgrading
Gait speed / velocity	11 studies (n ≈ NR)	Consistent improvement; statistically significant in most studies ($p<0.05$ to $p<0.001$); reductions in dual-task cost up to 22%	MODERATE ⊕⊕⊕◯	Downgraded for inconsistency (heterogeneous protocols, populations)
Step / stride length	4 studies (n ≈ NR)	Improvement reported in all studies; statistically significant where reported	MODERATE ⊕⊕⊕◯	Downgraded for imprecision (limited number of studies, incomplete effect sizes)
Cadence / double stance time	3 studies (n ≈ NR)	Significant improvements reported (e.g., reduced double stance time)	LOW ⊕⊕◯◯	Downgraded for small number of studies and incomplete reporting
Dual-task gait performance	2 studies (n ≈ NR)	Significant reductions in dual-task cost (17–22%)	MODERATE ⊕⊕⊕◯	Downgraded for indirectness (specific populations, task paradigms)
Functional mobility (TUG, up-and-go)	3 studies (n ≈ NR)	Significant improvement in completion time	MODERATE ⊕⊕⊕◯	Downgraded for imprecision
Muscle strength (lower & upper limb)	6 studies (n ≈ NR)	Significant improvements in chair stand, grip strength, 1RM ($p<0.05$ to $p<0.001$)	HIGH ⊕⊕⊕⊕	No serious limitations
Functional performance (chair rise, reach)	5 studies (n ≈ NR)	Consistent and statistically significant improvement	HIGH ⊕⊕⊕⊕	No serious limitations
Proprioception / neuromuscular response	2 studies (n ≈ NR)	Significant improvement in joint position sense and neuromuscular response	MODERATE ⊕⊕⊕◯	Downgraded for small number of studies
Joint kinematics / kinetics	4 studies with results (5 protocols)	Reduced EMG co-contraction; altered plantar load distribution; significant where reported	LOW ⊕⊕◯◯	Downgraded for imprecision and reporting bias (many protocols without results)
Adverse events / safety	10+ studies	No serious adverse events reported; high adherence	MODERATE ⊕⊕⊕◯	Downgraded for indirectness (inconsistent reporting)

3.6 Comparative Effectiveness and Generalizability

Comparisons with no-intervention or usual-care controls demonstrated that Tai Chi Chuan was associated with clinically meaningful and statistically significant improvements in balance, gait, and strength outcomes across multiple populations, with effect sizes ranging from moderate to large. When compared with active exercise interventions, Tai Chi Chuan generally showed comparable or superior effects on balance and functional mobility, although targeted exercise programs occasionally produced greater improvements in specific outcomes such as muscle mass or selected gait parameters. Tai Chi

Chuan was consistently reported as safe and feasible, with high adherence and minimal adverse effects. Overall, the comparative findings support moderate- to high-certainty evidence for the effectiveness and generalizability of Tai Chi Chuan as a biomechanically relevant intervention in adult populations.

3.7. Certainty of Evidence Across Outcome Domains (GRADE Assessment)

The GRADE Summary of Findings indicates moderate-certainty evidence that Tai Chi Chuan improves balance and postural control, gait and mobility, and muscle strength and proprioception in adult populations (Table 9). Across these outcome domains, the certainty was downgraded primarily due to risk of bias, related to lack of blinding and incomplete reporting in several trials, and imprecision, reflecting modest sample sizes and variability in intervention duration. However, downgrading for inconsistency or indirectness was not applied, as effect directions were largely concordant across studies and outcomes were directly relevant to adult biomechanical function. The certainty of evidence for joint kinematics and kinetics was rated as low, owing to a limited number of completed trials, smaller sample sizes, and reliance on protocol-based studies without reported results. No serious concerns regarding publication bias were identified. Overall, the GRADE assessment supports Tai Chi Chuan as an effective intervention for improving clinically relevant biomechanical outcomes in adults, while highlighting the need for further high-quality trials to strengthen evidence for advanced biomechanical measures.

4. Discussion

This systematic review synthesizes evidence on the effects of Tai Chi Chuan (TCC) on human biomechanics in adults and demonstrates that, despite clinical and methodological heterogeneity, TCC is consistently associated with improvements in balance, postural control, gait performance, muscle strength, and proprioception across diverse populations. These benefits were observed in healthy older adults as well as individuals with chronic neurological and musculoskeletal conditions, including Parkinson's disease, knee osteoarthritis, sarcopenia, stroke, chronic low back pain, and mild cognitive impairment (Kim et al., 2020; Huang et al., 2023; Liu et al., 2022; Bai et al., 2024). Collectively, the findings support TCC as a multicomponent intervention capable of addressing key biomechanical impairments linked to functional decline and fall risk.

Interpretation of Main Findings

The most robust and consistent evidence was identified for balance and postural control, which constituted the most frequently assessed outcome domain. Improvements were reported across clinical scales (e.g., Berg Balance Scale, Timed Up and Go) and instrumented measures (e.g., limits of stability, electromyography-based co-contraction), with predominantly moderate-certainty evidence (Wayne et al., 2021; Chen et al., 2021; Winser et al., 2022). These findings are biomechanically plausible given the slow, continuous weight-shifting, single-leg stance, and multidirectional movements inherent to TCC practice, which may enhance sensorimotor integration and postural reflexes (Yan Chen et al., 2022; Ma et al., 2023).

Gait and mobility outcomes, including gait speed, stride length, cadence, and dual-task performance, also improved in most studies, supported by moderate-certainty evidence (Liu et al., 2022; Yan et al., 2022; Zhang et al., 2025). Reductions in dual-task cost and improvements in complex locomotor tasks suggest that TCC may enhance motor–cognitive integration, a clinically relevant adaptation for older adults and neurological populations (Chen et al., 2022; Li et al., 2021a). However, more advanced gait metrics, such as minimum toe clearance or margin of stability, were examined in fewer trials, limiting confidence in these specific outcomes.

Evidence for muscle strength and proprioception was uniformly positive, with all included studies reporting statistically significant improvements in lower limb strength, grip strength, functional

performance, or joint position sense (Hu et al., 2020; Cheng et al., 2021; Niu et al., 2024). While several trials reported moderate-to-large effect sizes, the overall certainty of evidence remained moderate due to small sample sizes and short intervention durations in some studies.

In contrast, evidence for joint kinematics and kinetics remains limited and was graded as low certainty. Although available studies indicate favorable changes in muscle co-contraction patterns, plantar loading distribution, and movement efficiency (Wayne et al., 2021; Zhang et al., 2020), more than half of the identified studies in this domain were protocols without reported results (Law et al., 2021; Tang et al., 2022; Xie et al., 2023), necessitating cautious interpretation.

Comparative Effectiveness and Clinical Relevance

When compared with no intervention or usual care, TCC consistently demonstrated superior improvements in balance, gait, and muscle strength, with moderate to large effect sizes across pre-frail, fall-prone, and clinical populations (Ge et al., 2021; Cruz-Díaz et al., 2020; Bai et al., 2024). Comparisons with active exercise interventions—including resistance training, balance training, stretching, walking, or Taekkyon—suggest that TCC is generally as effective as or superior to these comparators for balance and functional mobility outcomes (Kim et al., 2020; Chen et al., 2021; Sadeghian et al., 2023). However, resistance or task-specific training occasionally produced greater improvements in isolated outcomes such as muscle mass or specific gait parameters, indicating that TCC may be best positioned as a comprehensive, integrative intervention rather than a replacement for all exercise modalities (Winters-Stone et al., 2023).

From a clinical perspective, the low-impact nature, high adherence rates, and absence of serious adverse events reported across studies underscore the safety and feasibility of TCC, particularly for older adults and individuals with chronic disease (Winser et al., 2022; Tao et al., 2024; 2023 Science of Tai Chi & Qigong Abstract Supplement).

Methodological Considerations and Limitations

Several limitations should be considered when interpreting these findings. Lack of participant and instructor blinding was universal and contributed to some concerns in RoB2 assessments. Small sample sizes, short intervention durations, and heterogeneity in Tai Chi styles, dosage, and outcome measures limited precision and precluded robust meta-analysis for several outcomes. Incomplete reporting of intervention fidelity and adherence further constrained reproducibility. Additionally, outcomes such as falls and advanced biomechanical metrics demonstrated greater variability, contributing to lower certainty ratings under GRADE (Williams & Nyman, 2020; Winters-Stone et al., 2023).

Despite these limitations, the predominance of randomized controlled designs, consistent direction of effects, and convergence of findings across populations strengthen confidence in the overall conclusions. Importantly, null or non-sustained effects—particularly in dementia populations—were transparently reported, underscoring the need for population-specific tailoring and realistic expectations of benefit (Williams & Nyman, 2020).

Implications for Practice and Future Research

The findings support TCC as a safe, feasible, and effective intervention for improving biomechanical health in adults, with moderate-certainty evidence for balance, gait, and muscle strength outcomes, and emerging evidence for more advanced biomechanical measures. Clinicians and policymakers may consider incorporating TCC into fall prevention, rehabilitation, and healthy aging programs, particularly where accessibility and long-term adherence are priorities.

Future research should prioritize adequately powered randomized trials with standardized reporting of Tai Chi protocols, objective biomechanical assessments, and longer follow-up periods. Further investigation into dose–response relationships, mechanistic pathways, and

comparative effectiveness against targeted exercise interventions will be essential to strengthen the evidence base and refine clinical recommendations.

Conclusion

This systematic review provides moderate-certainty evidence that Tai Chi Chuan improves balance and postural control, gait and mobility, and muscle strength and proprioception in adults, including older individuals and those with chronic neurological and musculoskeletal conditions. Across diverse populations and comparator conditions, Tai Chi Chuan demonstrated consistent, clinically meaningful biomechanical benefits with a favorable safety and feasibility profile. In contrast, evidence for joint kinematics and kinetics remains limited and of low certainty, reflecting the small number of completed trials and methodological constraints. Overall, Tai Chi Chuan represents an effective, low-risk intervention for enhancing biomechanical health in adults, while further well-designed trials using standardized biomechanical measures are required to strengthen evidence for advanced movement and neuromuscular outcomes.

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