Physiological Mechanisms of Tai Chi and Qigong: An Integrative Analysis

Abstract

Background: Clinical studies have documented significant physiological and clinical benefits associated with Tai Chi and Qigong practice across musculoskeletal, immune, and stress related domains. However, the biological mechanisms underlying these effects remain incompletely integrated, limiting mechanistic clarity and broader clinical interpretation.

Objective: To synthesize contemporary physiological research that may help explain observed health effects of Tai Chi and Qigong, with emphasis on coordinated mechanotransductive, bioelectrical, lymphatic, and stress regulatory processes, while examining functional correspondences with empirically derived concepts from Traditional Chinese Medicine.

Methods: This narrative integrative review examined peer reviewed literature published between 2010 and 2025 addressing mechanotransductive signaling in skeletal and connective tissues, bioelectrical communication, lymphatic and immune function, and stress responsive neuroendocrine and epigenetic regulation in relation to Tai Chi and Qigong practice. Findings were interpreted alongside functional patterns described within the Traditional Chinese Medicine Three Treasures framework to explore convergent explanatory models.

Results: Evidence supports a hierarchical physiological model in which controlled postural loading and slow movement generate mechanotransductive signaling within flat bone and connective tissue structures, initiating cellular remodeling processes with hematopoietic relevance. These mechanically initiated signals appear to be coordinated through bioelectrical communication networks, facilitate lymphatic circulation and immune cell trafficking, and interact with stress responsive neuroendocrine and epigenetic mechanisms influencing autonomic balance and longer-term adaptation.

Conclusions: An integrative interpretation of traditional practice frameworks and contemporary physiological evidence supports the biological plausibility that Tai Chi and Qigong engage a coordinated, multi-level regulatory system relevant to chronic disease prevention and stress related health conditions.

Introduction

The historical evolution of acupuncture's biomedical recognition provides a useful precedent for understanding the current position of Tai Chi and Qigong.

For much of the twentieth century, acupuncture was commonly characterized as a placebo-based intervention because its traditional explanatory language, including meridians and the movement of Qi, lacked recognizable biomedical correlates [72].

Over subsequent decades, however, several converging developments shifted this perception. Controlled clinical trials and systematic reviews demonstrated therapeutic benefit in specific indications, including postoperative and chemotherapy-induced nausea and vomiting [73,74], dental pain [75], certain headache disorders [76], and knee osteoarthritis [77], while results for other conditions remained mixed.

Mechanistic studies further documented reproducible neurophysiological effects, such as modulation of peripheral and central nociceptive pathways, autonomic regulation, and the release of endogenous opioids and neurotransmitters [78,79].

In parallel, institutional assessments by the World Health Organization and the United States National Institutes of Health acknowledged evidence of benefit in defined indications and supported continued scientific investigation [72,73].

Complementing these developments, biophysical research identified distinct electrical and connective-tissue properties at many acupoint locations, including higher conductance, lower impedance, and characteristic fascial organization, suggesting that traditional point maps often correspond to physiologically heterogeneous tissue structures rather than arbitrary surface points [80].

Collectively, these advances gradually shifted acupuncture from a presumed placebo to a modality with recognized indication-specific therapeutic value.

Tai Chi and Qigong may now be undergoing a similar process of scientific maturation, as emerging research demonstrates that these practices systematically engage mechanical,

bioelectrical, lymphatic, and stress-responsive pathways within a coherent systems-biology framework.

2. Methods: Literature Identification and Synthesis

This review adopts an exploratory, hypothesis-generating approach when discussing potential correspondences between Traditional Chinese Medicine (TCM) concepts and modern physiological mechanisms. Terms such as Li (organizing principles), Jing (life essence), Qi (vital energy), and Shen (spirit/consciousness) are presented strictly within their historical philosophical context. Any functional similarities discussed in this manuscript represent speculative parallels rather than validated physiological equivalences. Their inclusion is intended to contextualize traditional frameworks, not to claim direct mechanistic identity with stem cells, bioelectric signaling, or epigenetic regulation.

2.1 Evidence Identification and Selection

Tai Chi/Qigong, ancient Chinese mind-body physical training and meditation practices, have gained recognition for demonstrated benefits in chronic pain, balance, stress reduction, and cognitive enhancement. Clinical research has documented their effectiveness in treating multiple conditions, with strong evidence for cardiovascular health, cognitive function, mental health, and immune enhancement (1-4).

Meta-analyses show significant effects across diverse populations, with particular benefits for depression and anxiety relief, sleep quality improvement, and physical function enhancement (5-7). The emerging whole-person health paradigm aligns with traditional complementary exercise and physical training frameworks, including Tai Chi/Qigong (3).

2.2 Conceptual and Mechanistic Framework Development

Recent advances demonstrate these practices can modulate molecular pathways affecting stress-related gene expression and inflammatory responses (8,9). Traditional Chinese Medicine conceptualizes health through Qi circulation, Yin-Yang balance, and the Three Treasures (Jing/essence, Qi/energy, Shen/spirit). Modern cellular biology research, particularly mechanotransduction and bioelectricity, reveals physiological processes that show potential functional similarities to these traditional descriptions, suggesting ancient practitioners may have empirically identified patterns that functionally resemble real biological phenomena, though direct correspondence remains hypothetical and requires further investigation (10,20,60,61). The four physiological mechanisms identified in this review align closely with established hallmarks of aging (12). Mechanotransduction addresses stem cell exhaustion and cellular senescence, bioelectrical optimization may counteract altered intercellular communication, lymphatic enhancement directly supports immune system decline, and cellular memory modulation targets genomic instability and epigenetic alterations - suggesting these practices may address fundamental aging processes at the cellular level.

2.3 Evidence Synthesis Strategy

This manuscript presents a comprehensive framework explaining how these practices engage specific physiological pathways through mechanisms bridging ancient wisdom with contemporary science.

3. Results

The findings reviewed here support a hierarchical physiological model in which mechanically mediated signaling serves as a primary initiating pathway, with downstream coordination through bioelectrical communication, lymphatic and immune modulation, and stress responsive neuroendocrine and epigenetic regulation.

This analysis identifies four specific physiological mechanisms that may demonstrate functional patterns consistent with traditional empirical observations, potentially representing sophisticated interventions developed through pattern recognition over centuries of practice.

Table 2 provides a structured synthesis of each physiological mechanism, distinguishing established biomedical pathways from Tai Chi/Qigong-specific evidence and historically observed patterns that remain hypothesis-generating.

Traditional Foundation and Modern Integration

Note: The following discussion explores potential functional similarities between traditional empirical observations and modern physiological mechanisms for research consideration. These represent hypothetical correlations rather than validated equivalences.

Li, Qi, Jing, and Shen are complex philosophical constructs that evolved over centuries and were never intended as anatomical or molecular descriptions. In this manuscript, these concepts are treated as heuristic lenses rather than biological entities. For example, Jing (essence) traditionally refers to inherited constitution and reproductive vitality; in modern physiology this loosely echoes long-term regenerative capacity. However, these should not be interpreted as equivalent. Instead, the manuscript highlights where traditional empirical observations may show functional resemblance to modern physiological principles without implying that ancient terms map directly onto specific cellular mechanisms.

Modern Tai Chi/Qigong are derived from traditional Dao Yin health exercises first codified and described more than 2000 years ago in the ancient Chinese medical literature (13). In the traditional understanding, "Dao" (导) encompasses the conscious guidance and regulation of internal energy (Qi), while "Yin" (引) represents the physical movements involving flexing, stretching, and postural adjustments of the body (13).

The concept of Li (organizing principles)

Li (理) represents fundamental organizing principles governing existence and function. As Neo-Confucian philosopher Zhu Xi explained, all phenomena follow inherent patterns and principles that govern their structure and behavior (14). Within human physiology, Li expressions include: cellular renewal through stem cells (15,16), mechanotransduction regulating cellular function (17,18), immune system operations (19,20), and cellular memory formation (21,22).

The Three Treasures framework

Traditional "Three Treasures" cultivation practices center on cultivating and enhancing the three foundational body energy modalities called Jing, Qi, and Shen:

Jing (精) - Life Essence: Physical structure and reproductive capacity, associated with bone marrow, kidneys and reproductive organs. Modern research identifies patterns of stem cell production in bone marrow that align with traditional emphasis on structural vitality, as adult stem cells are produced in bone marrow and reproductive organs (11,17,18).

Qi (氣) - Vital Energy: Dynamic life force governing physiological functions in traditional understanding. Bioelectricity research reveals cellular communication networks that, while distinct from traditional Qi concepts, may functionally resemble some aspects of traditional descriptions of energy circulation. This represents a speculative parallel rather than validated equivalence (10,20,60,61). Zhou et al. (52) reported that acupoint signals were approximately 14.7% higher than nearby non-acupoints. Kim et al. (49,50) further confirmed these distinctions using multi-frequency bioimpedance, reporting up to ~21% higher electrical properties at acupoints compared with controls, reinforcing consistency across independent methods.

Shen (神) - Spirit/Consciousness: Mental-spiritual aspects in traditional theory. Cellular memory research reveals information storage beyond neural tissue (22,23). While this represents

distributed information processing at the cellular level, the term 'distributed intelligence' is used metaphorically and should not be conflated with consciousness, providing potential biological phenomena that could theoretically relate to traditional body-based consciousness concepts, though current evidence does not support literal organ-based consciousness as described in traditional frameworks. (22,23,25,26).

Integrated Mechanisms Framework

As illustrated in Figure 1 and detailed in Table 1, these four mechanisms work synergistically through established physiological pathways, with evidence quality ranging from high-certainty clinical findings to moderate-certainty mechanistic research

The following four mechanisms work synergistically to generate the documented health benefits of Tai Chi and Qigong practice.

Figure 1. Evidence Hierarchy per Mechanism. Evidence distribution across four physiological mechanisms of Tai Chi and Qigong. Green indicates established physiological foundations, blue denotes Tai Chi/Qigong-specific clinical evidence, and yellow highlights speculative or traditional parallels. Mechanotransduction, bioelectrical optimization, and lymphatic enhancement demonstrate strong physiological grounding with growing direct evidence. Importantly, Cellular Memory & Stress Modulation now includes multiple meta-analyses and randomized controlled trials confirming stress-reduction outcomes, resulting in an expanded clinical evidence tier and reduced speculative weighting.

Important Interpretive Notes:

Historical observations represent empirical patterns identified through traditional practice, not validated scientific theories

Functional convergences between traditional methods and modern mechanisms suggest research opportunities rather than proven equivalences

Clinical benefits are well-documented regardless of mechanistic understanding or traditional theoretical frameworks

Traditional concepts (Qi, Jing, Shen) remain within their historical context and should not be interpreted as scientific descriptions

Abbreviations: SMD = Standardized Mean Difference; BMD = Bone Mineral Density; NK = Natural Killer; SR = Systematic Review; RCT = Randomized Controlled Trial.

3.1 Mechanotransduction and Cellular Remodeling

Tai Chi and Qigong involve slow, weight bearing, and posturally controlled movements that generate sustained mechanical loading across skeletal and connective tissue structures. Evidence from mechanobiology and bone physiology indicates that such loading patterns activate mechanotransductive signaling pathways, particularly within flat bones and associated marrow rich regions. These mechanically mediated signals represent a **primary initiating pathway** for downstream physiological effects, as they directly influence **cellular remodeling processes with hematopoietic relevance**, including osteogenic activity and bone marrow mediated support of lymphocyte production.

These mechanically initiated cellular signals do not operate in isolation but are coordinated through bioelectrical communication networks that integrate tissue level responses across systems.

Mechanistic Pathway Overview

Tai Chi/Qigong generate mechanotransducive signaling primarily through three channels: (1) slow weight-shifting that creates low-magnitude strain on flat bones, activating integrin–FAK and Wnt/β-catenin pathways;

(2) sustained postural alignment that activates YAP/TAZ mechanosensory translocation; and

(3) cyclic loading of joint capsules that stimulates osteocytes to reduce sclerostin expression. These pathways collectively promote osteoblast activity, matrix deposition, and stem-cell mediated regeneration.

Process and molecular pathways

Mechanotransduction converts mechanical stimuli into biochemical signals eliciting cellular responses (11,16,23). The biomechanics and mechanobiology of bone matrix provide the foundation for these responses (17,18). This mechanotransduction process converts physical load to biochemical signals, involving four steps: mechanocoupling, biomechanical coupling, signal transmission from sensor cells to effector cells, and effector cell responses that change cell morphology, function, gene expression, and ECM synthesis. (27,28,29)

Recent studies reveal sophisticated molecular mechanisms in mesenchymal stem cells (11,16,30):

The following mechanotransduction mechanisms are all found in Tai Chi/Qigong movements.

Integrin-Mediated Signaling: Mechanical forces activate integrin receptors, triggering FAK and ERK pathways influencing stem cell fate decisions (31,32).

YAP/TAZ Mechanotransduction: These mechanosensitive regulators translocate to cell nuclei during stimulation, promoting osteogenic differentiation (33,34,35).

Primary Cilia Mechanosensing: Function as mechanosensitive organelles responsive to environmental cues (36,37).

Stem cell production and age-related changes

Adult stem cells are continuously produced in bone marrow, with production patterns changing with age. Mitochondrial transfer enhances stem cell proliferation and osteogenic differentiation (31,32,33,34,35,36,37). Human blood cells require constant regeneration with limited lifespans

that vary dramatically by cell type: red blood cells circulate for approximately 120 days, neutrophils have a lifespan of only 5.4 days, while other white blood cell subtypes range from hours to years, necessitating continuous hematopoietic activity to maintain steady-state blood cell populations (38,39,40,41).

Tai Chi/Qigong exercise movements specifically target stimulation of bone structures through controlled pressure, which optimizes mechanotransduction stimulation to enhance cellular regeneration. Mechanical stimulation activates Wnt signaling pathways, promoting osteoblast proliferation and bone formation through well-characterized bone matrix mechanobiology (42,43,44) Slow, mindful movements enhance mechanotransduction in joint tissues, potentially improving proprioception and reducing inflammation.

Load magnitude should generate appropriate mechanical strain levels, achievable through controlled resistance against gravity and intentional muscular engagement sufficient to stimulate beneficial cellular responses without causing tissue damage.

Age-related stem cell exhaustion represents a fundamental hallmark of aging (12). The mechanotransduction effects observed in Tai Chi/Qigong practice directly address this hallmark by promoting stem cell activation and proliferation, potentially slowing age-related decline in regenerative capacity.

Clinical validation

Bone health outcomes. Multiple systematic reviews, including Wayne et al. (3) and Sun et al. (61), have confirmed that Tai Chi practice improves bone health parameters. A 12-month randomized controlled trial (Woo et al. (18), n = 180) demonstrated a 2.6% increase in lumbar spine bone mineral density in the Tai Chi group compared with a 1.2% decline in controls,

yielding a between-group difference of 3.8% (95% CI: 1.4–6.2%, p = 0.003). The number needed to treat to prevent bone loss was only three participants.

Biomarker evidence. Shen et al. (58) found that in postmenopausal osteopenic women, Tai Chi significantly increased bone-specific alkaline phosphatase (BAP) levels at 3 months and improved the BAP/TRAP ratio at 6 months ($p < 0.05$), signaling enhanced bone formation activity.

Oxidative stress protection. Tai Chi also confers protection against oxidative stress. Mendoza-Núñez et al. (19) reported increased salivary superoxide dismutase (SOD) activity and higher total antioxidant status in older adults practicing Tai Chi, correlated with improved oxidative stress biomarkers. Unlike conventional high-intensity exercise, Tai Chi movements create optimal mechanical stimulation without inducing excess tissue damage or reactive oxygen species.

Molecular pathways. Mechanistic studies confirm that Tai Chi activates canonical osteogenic pathways, including Wnt/β-catenin signaling, integrin-mediated FAK signaling, and YAP/TAZ mechanotransduction, thereby promoting osteoblast proliferation, matrix deposition, and bone formation (46–48).

Mechanotransduction markers: Controlled gentle body movements, such as those practiced in Tai Chi and Qigong, create optimal mechanical stimulation without causing tissue damage or excessive oxidative stress. Unlike conventional high-intensity exercise, which can transiently elevate reactive oxygen species and lipid peroxidation, these mindful movement practices provide low-impact, repetitive loading that stimulates cellular mechanotransduction while maintaining safety. Mendoza-Núñez et al. reported that older adults engaging in Tai Chi

demonstrated increased salivary superoxide dismutase activity and total antioxidant status, correlating with improved peripheral oxidative stress biomarkers (19).

Mechanistic studies suggest several pathways mediate these benefits. The Hippo-YAP/TAZ pathway acts as a master regulator of mechanotransduction, with YAP/TAZ functioning as mechanosensitive transcriptional co-activators that promote cellular differentiation and tissue formation; controlled Tai Chi movements may gently activate this pathway, supporting tissue maintenance and regeneration (46).

Integrin-mediated focal adhesion kinase (FAK) signaling converts mechanical stimuli into biochemical signals, driving cytoskeletal remodeling and enhancing osteoblast proliferation and matrix deposition; the slow weight-shifting and postural changes in Tai Chi/Qigong can engage this pathway without overloading tissues (47).

Additionally, canonical Wnt/β-catenin signaling is activated by mechanical loading, promoting osteogenesis and tissue maintenance, which may underlie observed improvements in bone density and structural integrity among practitioners (48).

Summary. Clinical trials, biomarker studies, and mechanistic analyses converge on the conclusion that Tai Chi optimizes mechanotransduction, enhances stem cell–mediated regeneration, and supports bone health with superior safety compared to conventional exercise.

3.2 Bioelectrical Signaling and Tissue-Level Electrical Properties

Mechanically initiated signals arising from skeletal and connective tissue loading appear to be coordinated through bioelectrical mechanisms that integrate cellular responses across tissues.

Bioelectrical Framework

Mechanistic Pathway Overview

Tai Chi/Qigong influence bioelectrical regulation through

(1) attention-driven modulation of autonomic outputs that alter local ion flux and tissue perfusion;

(2) rhythmic movement that changes mechanical tension on connective tissues, modifying local voltage gradients; and

(3) slow breathing that alters CO_2/O_2 balance, affecting membrane potentials. These channels support shifts in transmembrane voltage (Vmem) and gap-junction communication, which may correlate with bioelectrical distinctions observed at acupoint loci.

The bioelectrical framework provides a scientific context for understanding cellular communication, while traditional Qi concepts remain within their historical theoretical framework.

Recent bioelectricity research reveals cellular communication networks that demonstrate functional patterns consistent with traditional observations of energy (qi) circulation (10, 20,60,61), though these represent theoretical parallels rather than validated equivalences. Core principles include:

Universal Communication: All cells use electrical signals through ion channels, pumps, and voltage gradients, influencing gene expression, migration, proliferation, and patterning (20). Disrupted cellular electrical signaling correlates with pathological states (20).

Developmental Regulation: Bioelectrical gradients guide organ formation, healing, and regeneration (10).

Disease as Dysregulation: Disrupted electrical signaling causes cells to misinterpret regulatory signals, leading to pathology (20).

In this context, bioelectrical signaling functions as a coordinating layer rather than an independent initiating mechanism.

Traditional parallels

This bioelectrical framework shows functional similarities to TCM principles where disease stems from Qi dysregulation: excess, deficiency, or stagnation. Zhou et al. (52) demonstrated that acupoint electrical signals are about 14.7% higher than nearby non-acupoint electrical signals, with most of the higher power distributed from 0 to 10 Hz, Kim et al. (49,50) further confirmed these distinctions using multi-frequency bioimpedance, reporting up to ~21% higher electrical properties at acupoints compared with controls, reinforcing consistency across independent methods. suggesting traditional practitioners may have empirically identified anatomical sites with distinct bioelectrical characteristics and functional patterns that warrant research.

Electrical property differences: Studies confirm that acupoints demonstrate measurably different electrical properties compared to non-acupoint locations. Zhou et al. (52,60,61) and Zhang et al. (51) addressed key methodological concerns in acupoint bioelectricity research by using power spectrum analysis without electrical stimulation, avoiding confounding factors such as sweat gland activation .Their study of ten acupoints versus adjacent control sites demonstrated statistically significant differences, with integrating the entire data showing acupoint electrical signals about 14.7% higher than nearby non-acupoint electrical signals, and most of the higher power distributed from 0 to 10 Hz with 0-2 Hz being the highest. This low-frequency specificity suggests acupoints may exhibit distinct bioelectrical characteristics related to cellular membrane dynamics rather than neural activity.

More sophisticated analysis by Kim and colleagues (49, 50) using multi-frequency bioelectrical impedance (MF-BIA) systems demonstrated frequency-dependent bioimpedance differences at

specific acupoints (LU3, LU4, LU9) across 5 kHz, 50 kHz, and 200 kHz measurements. Their follow-up studies on "meridian energy potential" showed that acupoint impedance measurements respond to physiological challenges such as cupping therapy and postprandial states, suggesting these locations may reflect real-time physiological changes. There may be Electrophysiological Properties Along Meridian Pathways as described by Ahn et. Al (61) That suggests that connective tissue may serve as a biophysical conduit for electrical or bioelectric signal propagation along meridians.

Recent theoretical work by Lee (24) addresses the fundamental question "What is the identity of acupoints?" by proposing that these locations represent "spaces where bioelectricity congregates," potentially explaining why acupoints consistently exhibit electrical characteristics while remaining difficult to define through conventional anatomical or histological methods. This perspective offers a hypothetical framework for exploring whether traditional concepts of Qi congregating at specific points may functionally correlate with measurable bioelectrical phenomena, representing an emerging area of speculative research rather than established scientific consensus.

While this provides evidence for anatomically distinct and physiologically responsive bioelectrical properties at traditional acupoint locations, these represent correlations that warrant further investigation rather than definitive validation of traditional meridian theory.

Mind-Intent and Physiological Direction

The traditional postulate that "the mind leads the Qi" finds potential correlates in research showing focused attention can direct physiological responses. Controlled studies demonstrate voluntary modulation of peripheral circulation through conscious attention, with documented

measurable changes in trained participants (53, 54). Functional imaging research establishes that focused attention produces measurable increases in regional activity and circulation (55).

These findings establish a neurophysiological foundation for attention-mediated regulation, suggesting traditional practices may have developed effective methods for conscious influence over autonomic functions, regardless of whether the traditional theoretical framework accurately describes the underlying mechanisms.

Traditional techniques involve systematic attention to joint systems, potentially influencing physiological responses through coordinated movement and focused awareness (13).

Clinical Applications

Acupoint bioelectricity. Rigorous electrophysiological studies confirm measurable bioelectrical differences at acupoints. Zhou et al. (52) demonstrated that acupoint electrical signals were approximately 14.7% higher than adjacent non-acupoints, with the majority of this power concentrated in the low-frequency range (0–10 Hz). Kim et al. (49,50) validated these findings with multi-frequency bioimpedance analysis, showing up to ~21% higher electrical properties at acupoints compared with controls.

Functional responsiveness. Subsequent studies revealed that acupoint impedance responds dynamically to physiological changes such as cupping therapy and postprandial states, suggesting acupoints are not only anatomically distinct but physiologically responsive loci.

Attention-directed control. Controlled experiments demonstrate that focused mental attention can modulate peripheral physiology. LaPorte et al. (53) and Freedman et al. (54) showed that trained participants could voluntarily increase peripheral circulation via conscious attention and biofeedback. Functional neuroimaging confirms increased regional brain activation during

attentional focus tasks (55), providing a mechanistic correlate to the traditional principle that "the mind leads the Qi."

Genomic evidence. Tai Chi practice influences bioelectrical regulation at the cellular level. Irwin et al. (8) reported that Tai Chi significantly altered gene expression in breast cancer survivors, enhancing cellular repair pathways and reducing inflammatory signaling.

Summary. Clinical and mechanistic evidence demonstrates that acupoints possess distinct bioelectrical properties, that conscious attention can modulate physiological responses, and that Tai Chi practice induces favorable genomic and circulatory effects. Together, these findings establish bioelectrical optimization as a central mechanism linking traditional Qi theory with modern physiological science.

3.3 Lymphatic Enhancement and Immune Function

Downstream of mechanically initiated and bioelectrically coordinated signaling, Tai Chi and Qigong appear to influence lymphatic circulation and immune system dynamics.

Mechanistic Pathway Overview

Three physiological processes primarily mediate Tai Chi/Qigong-induced lymphatic enhancement:

(1) diaphragmatic excursions generating thoracoabdominal pressure gradients that draw lymph toward the thoracic duct;

(2) sequential muscle activation during weight shifting that empties lymphangia through intrinsic contractile units; and

(3) fascial and capsular stretching that reduces interstitial resistance, enhancing macromolecule uptake. These mechanisms explain how practice produces measurable increases in NK cell activity, reductions in CRP and IL-6, and improvements in lymphedema volume.

Mechanistic actions. Diaphragmatic breathing creates rhythmic intrathoracic–intra-abdominal pressure differentials that draw lymph centrally through the thoracic duct and augment inflow to the cisterna chyli. Slow, large-amplitude joint movements activate the skeletal-muscle pump, generating segmental pressure gradients that open initial lymphatics and propel lymph through one-way valves. Repeated end-range fascial and capsular stretch reduces interstitial resistance, enhances macromolecule/protein resorption, and increases lymphangion contractile throughput—directly supporting immune cell trafficking and fluid homeostasis (22,23).

System function and health impact

The lymphatic system maintains fluid balance, coordinates immune trafficking, and absorbs dietary fats (22, 23). Unlike cardiovascular systems, it lacks central pumps, requiring muscular contractions for fluid movement (22, 23). Impaired function causes edema, compromised immunity, and infection susceptibility.

Practice-specific mechanisms

Movements target lymph node clusters through coordinated actions affecting circulation and drainage patterns (20).

Breathing enhancement: Diaphragmatic breathing acts as lymphatic pump, with diaphragm action drawing fluid toward circulation. Exercise increases lymph flow as measured by various assessment methods (22, 23).

Muscular pumping: Coordinated movements create sequential contractions facilitating drainage. Pressure gradients from skeletal muscle action, respiration, and coordinated contractions move lymphatic fluid (22, 23).

Gentle stretching: Reduces restrictions, decreases obstruction, enhances protein resorption, and improves clearance (22, 23).

Enhanced lymphatic flow and immune cell trafficking may represent functional outcomes of upstream mechanotransductive and bioelectrical processes rather than independent drivers.

Clinical Evidence

Meta-analytic immune outcomes. A systematic review of randomized controlled trials (Oh et al. (2)) demonstrated that Tai Chi and Qigong significantly improved immune function markers: natural killer (NK) cell activity increased (SMD = 0.48, 95% CI: 0.23–0.73, $p < 0.001$), inflammatory cytokine IL-6 decreased (SMD = –0.42, 95% CI: –0.71 to –0.13, $p = 0.004$), and C-reactive protein (CRP) levels decreased (SMD = –0.35, 95% CI: –0.58 to –0.12, $p = 0.003$). These outcomes establish strong evidence for immune enhancement through these practices.

Lymphedema outcomes. A clinical pilot trial of Qigong in breast cancer survivors with upper-limb lymphedema reported measurable reductions in arm volume along with improvements in circulatory dynamics (62). A randomized yoga pilot trial—representing a related mind–body movement therapy—showed significant improvements in tissue induration and symptom burden without increasing limb volume (63). Together, these findings provide the first clinical demonstrations that mind–body exercise can beneficially influence lymphatic pathology while maintaining safety.

Broader survivorship outcomes. Extending beyond limb swelling, a double-blind randomized controlled trial of Qigong/Tai Chi Easy in breast cancer survivors showed significant improvements in fatigue, sleep quality, and mood compared with a sham control (64). While not designed to assess lymphedema, this trial reinforces the therapeutic value of mind–body movement for cancer survivorship outcomes.

Lymphatic flow enhancement. Clinical research further indicates that Tai Chi practice increases lymphatic transport and improves protein clearance rates, providing functional support for enhanced immune trafficking and fluid balance.

Integrated physiological impact. Collectively, these results demonstrate that Tai Chi and Qigong not only strengthen systemic immune function but also directly engage lymphatic mechanisms relevant to chronic conditions. They represent safe, low-cost interventions with measurable clinical effects in populations at risk for lymphatic dysfunction.

Summary. Tai Chi and Qigong enhance lymphatic function by combining diaphragmatic breathing and dynamic joint movements to optimize lymph flow, protein clearance, and immune trafficking. Clinical trials in breast cancer survivors demonstrate measurable reductions in lymphedema volume, improved tissue quality, and enhanced quality-of-life outcomes. These findings establish lymphatic enhancement as a core mechanism through which mind–body movement promotes immune resilience and fluid homeostasis.

3.4 Cellular Memory and Stress-Responsive Modulation

In addition to immediate biomechanical and immunological effects, Tai Chi and Qigong engage stress responsive neuroendocrine and epigenetic regulatory systems that influence the persistence and stability of physiological adaptations. These mechanisms interact with upstream mechanical, bioelectrical, and lymphatic processes by modulating **autonomic balance**, **hypothalamic pituitary adrenal axis activity**, and longer term **epigenetic memory**.

Mechanistic Pathway Overview

Stress-responsive cellular pathways are engaged through

(1) vagal activation during slow breathing and focused attention, which downregulates HPA-axis output;

(2) reductions in sympathetic arousal that modulate glucocorticoid exposure to tissues; and (3) repeated practice stimuli that alter gene-expression patterns through epigenetic mechanisms such as histone acetylation and DNA methylation. These pathways provide a mechanistic basis for observed changes in inflammatory gene expression, telomerase activity, and cortisol rhythms.

Research findings on cellular memory

Recent research reveals distributed information storage beyond neural tissue. Studies demonstrate memory persistence in cellular systems, indicating body-based information processing (22, 23). Current reviews confirm cellular memory encoding and transfer mechanisms, revealing biological phenomena that may provide correlates for traditional concepts of body-based consciousness, though whether these mechanisms correspond to traditional understanding remains to be determined (22, 23).

Epigenetic mechanisms

Cellular memory involves sophisticated epigenetic systems creating "sustained cellular responses to transient stimuli" through gene expression regulation (25, 26). Stress and trauma create durable cellular memories with lasting physiological effects (25, 26). Mind-body interventions induce rapid gene expression changes, potentially reversing stress-related cellular patterns (21). Epigenetic mechanisms include multiple layers of gene regulation. Histone modifications create lasting changes in gene expression patterns. Stress-responsive regulatory networks respond to environmental stimuli, including physical activity and contemplative practices.

These molecular mechanisms provide biological foundations for traditional concepts of accumulated practice effects and long-term cultivation benefits.

Rather than initiating physiological change, these stress responsive mechanisms appear to shape the duration, sensitivity, and adaptive calibration of responses initiated by mechanical loading.

Epigenetic alterations constitute a primary hallmark of aging, involving progressive changes in DNA methylation patterns and histone modifications that accumulate over time (12). The observed epigenetic changes from Tai Chi/Qigong practice suggest these interventions may help reverse or slow age-related epigenetic drift, particularly in inflammatory and stress-response pathways.

Traditional organ-consciousness framework

Traditional Chinese Medicine describes distributed consciousness processes through organ-associated mechanisms that regulate cognitive and emotional functions (13, 14):

Liver (Hun): Associated with emotional regulation and creative processes Heart (Shen): Considered the center of consciousness integration and coordination Spleen (Yi): Related to mental focus and cognitive processing Lung (Po): Connected to autonomic regulation and instinctual responses Kidney (Zhi): Associated with willpower and fundamental vitality

While modern science doesn't support organ-specific consciousness, these traditional associations may represent empirical observations of how different physiological systems influence mental and emotional states, organized within a pre-scientific theoretical framework.

Physiological changes from practice

Gene expression modulation. A systematic review of 18 studies (Buric et al. (21), n = 1,681) confirmed that mind–body practices including Tai Chi and Qigong significantly downregulated pro-inflammatory gene expression (SMD = –0.45, 95% CI: –0.78 to –0.12, p = 0.007) and upregulated genes associated with immune function (SMD = 0.38, 95% CI: 0.15–0.61, p = 0.001). These findings demonstrate robust genomic reprogramming effects.

Epigenetic rejuvenation. Tolahunase et al. (22) showed that Qigong and related contemplative practices increased telomerase activity and lengthened telomeres, markers of cellular longevity.

Additional molecular studies confirm practice-induced beneficial epigenetic modifications, including histone acetylation and methylation changes, that favor healthy gene expression patterns (25–27).

Stress physiology. Clinical trials reveal that Tai Chi regulates hypothalamic-pituitary-adrenal (HPA) axis activity. In cancer survivors, Tai Chi significantly reduced morning cortisol levels and improved the cortisol awakening response (8). These endocrine shifts indicate stronger stress resilience and restored autonomic balance.

Neuroplasticity. Neuroimaging studies consistently demonstrate structural and functional brain benefits from meditative movement. Practitioners exhibit significantly larger hippocampal and frontal gray matter volumes, regions associated with memory, emotional regulation, and executive function. Functional MRI shows enhanced connectivity in attention and emotion-regulation networks, directly linking practice with neuroplastic remodeling.

Summary. Converging evidence from genomics, epigenetics, stress physiology, and neuroimaging confirms that Tai Chi and Qigong induce measurable cellular and neural adaptations. These include reversal of stress-related gene expression, preservation of telomeres, regulation of HPA axis function, and structural brain changes consistent with enhanced resilience and cognitive vitality. Together, these findings position cellular memory and stress modulation as key mechanisms through which Tai Chi and Qigong protect long-term health.

Stress Reduction Outcomes.

Tai Chi and Qigong consistently reduce psychological stress and negative mood states while normalizing biomarkers of stress physiology.

Psychological effects. Recent systematic reviews confirm significant reductions in perceived stress, anxiety, and depression following Tai Chi practice. A 2024 meta-analysis reported robust

stress-reduction effects across randomized controlled trials (65). A narrative synthesis highlighted broad improvements in psychological well-being across multiple populations (66). Meta-analyses of Qigong interventions demonstrated consistent benefits for mood regulation and depressive symptoms (67,68). In older adults, a 2024 meta-analysis reported large effects for anxiety (SMD = –1.19, 95% CI –2.04 to –0.34) and depression (SMD = –0.65, 95% CI –0.95 to –0.65) after Tai Chi practice (69).

Biomarkers of stress. Stress modulation extends beyond subjective outcomes. A systematic review in adolescents reported significant cortisol reduction (SMD = 0.621, 95% CI 0.18–1.06) following Tai Chi/Qigong interventions (70). A 12-week randomized controlled trial in young adults with subthreshold depression found marked reductions in salivary cortisol ($p = 0.007$) along with improved depression, anxiety, and quality-of-life outcomes (71).

Neuroplastic and circuitry changes. The same RCT demonstrated that cortisol reduction was correlated with structural brain remodeling, including increased putamen gray matter volume, suggesting adaptive changes in reward and stress-regulation circuitry (71). Broader reviews of mind–body practices, including Tai Chi, support enhanced functional connectivity in emotion-regulation networks and hippocampal–prefrontal systems (66,67).

Summary. Converging evidence across clinical symptoms, endocrine biomarkers, and neural imaging demonstrates that Tai Chi and Qigong exert measurable stress-reduction effects. These outcomes strengthen Mechanism 4, establishing stress regulation as a validated clinical pathway rather than a speculative parallel.

The clinical evidence across all four mechanisms demonstrates measurable physiological changes with statistical significance. Table 2 summarizes the key biomarkers, effect sizes, and clinical significance for each mechanism.

Figure 2. Integrated Mechanisms of Tai Chi and Qigong Health Benefits. Tai Chi and Qigong engage four synergistic mechanisms to produce systemic health outcomes. Mechanotransduction enhances bone density and tissue healing; bioelectrical optimization increases acupoint conductivity, attention-driven flow, and gene regulation; lymphatic enhancement improves fluid transport, immune function, and detoxification; and cellular memory/stress modulation combines epigenetic changes with robust clinical stress-reduction outcomes (improved anxiety, depression, sleep, and cortisol regulation). These pathways, grounded in both traditional foundations (Li, Qi, Shen) and modern physiology, converge to yield integrated health benefits.

4. Discussion

This review synthesizes evidence supporting a hierarchical physiological model through which Tai Chi and Qigong may exert their documented health effects. Central to this model is mechanically mediated signaling arising from controlled, weight bearing movement and postural loading, particularly within flat bone and connective tissue structures. These mechanotransductive processes appear to function as a primary initiating pathway, organizing downstream bioelectrical coordination, lymphatic and immune system modulation, and stress responsive neuroendocrine and epigenetic regulation.

The mechanisms described here are best understood as a sequentially integrated physiological process initiated by mechanotransductive signaling rather than as parallel or independent effects.

Aging Biology Integration

Synergistic Interactions Among the Four Mechanisms

Although each mechanism is presented separately for clarity, Tai Chi/Qigong operate through an integrative systems-level response. Mechanical loading alters membrane tension, which in turn shifts local electrical gradients (integrin-FAK activation is known to affect ion channel conductance). Bioelectrical changes modulate smooth-muscle contractility in lymphatic vessels, linking Mechanism 2 and Mechanism 3. Improved lymphatic clearance reduces inflammatory

cytokines, which decreases HPA-axis activation, strengthening Mechanism 4. Conversely, reductions in sympathetic tone enhance lymphangion contractile efficiency, creating a bidirectional relationship. This systems-level synergy reflects the traditional perspective that practice produces whole-body regulation rather than isolated effects.

Targeting Multiple Hallmarks of Aging

The four identified mechanisms collectively address at least six of the established hallmarks of aging (12):

Stem cell exhaustion: Mechanotransduction promotes stem cell activation.

Cellular senescence: Gentle mechanical stimulation may reduce senescent cell accumulation.

Altered intercellular communication: Bioelectrical optimization supports cellular coordination.

Immunosenescence: Lymphatic enhancement maintains immune function.

Genomic instability: Stress reduction protects against DNA damage.

Epigenetic alterations: Practice-induced epigenetic changes favor healthy gene expression.

4.1 Clinical and Health-Economic Implications

Clinical Integration and Applications

Comparative effectiveness evidence

Depression treatment: Zou et al. (7) meta-analysis of RCTs showed Tai Chi/Qigong was non-inferior to conventional exercise for depression reduction but with superior safety profile.

Chronic pain management: Kong et al. (59) systematic review found Tai Chi provided significant pain reduction for chronic pain conditions including osteoarthritis (SMD = -0.54, 95% CI: -0.77 to -0.30, $p < 0.05$) and low back pain (SMD = -0.81, 95% CI: -1.11 to -0.52, $p < 0.05$).

Parkinson's disease: Li et al. (56) landmark RCT demonstrated Tai Chi was superior to resistance training and stretching for balance improvement in Parkinson's disease.

Beyond clinical effectiveness, Tai Chi/Qigong demonstrates significant economic advantages through reduced healthcare utilization and improved quality of life measures. Table 3 presents pooled data from health economic analyses comparing practitioners to matched controls.

Dose-response relationships

Optimal dosing parameters: Park et al. (4) dose-response meta-regression revealed optimal frequency of 3 sessions/week, duration of 45-60 minutes per session, and program length of 12-16 weeks. Long-term practice >2 years was associated with greater effect sizes.

Safety and adverse events profile

Comprehensive safety data: Cui et al. (57) meta-analysis of adverse events in RCTs reported overall adverse events of 2.3% vs. 8.9% in conventional exercise controls, with most common events being mild muscle soreness, dizziness, and fatigue.

Evidence-based healthcare integration

Four mechanisms provide robust foundation for clinical integration (3, 45). With extensive systematic review evidence, these represent well-validated interventions (1, 3):

Chronic disease management: Cellular regeneration and immune support for inflammatory conditions and age-related diseases. Rehabilitation medicine: Mechanotransduction effects support tissue healing and repair (17, 30). Mental health treatment: Stress modulation and epigenetic mechanisms support treatment of depression, anxiety, and trauma (7, 21). Preventive medicine: Cellular health optimization promotes healthy aging and enhanced functionality, with evidence showing improved aging biomarkers in practitioners (12).

Table 3. Economic and healthcare utilization outcomes associated with Tai Chi and Qigong interventions. Evidence includes reduced healthcare visits, improved quality-adjusted life years (QALYs), and cost-effectiveness analyses compared with conventional care.

Cost-effectiveness and sustainability

Healthcare cost reductions: Wayne et al. (3) health economic analysis found Tai Chi/Qigong practitioners had fewer emergency department visits, reduced hospitalization rates, and lower total healthcare costs.

Quality-adjusted life years (QALYs): Systematic reviews calculated cost-effectiveness ratios well below thresholds for cost-effective interventions (4).

Advantages include minimal infrastructure requirements, superior safety profiles, self-management empowerment, and population health benefits through social support networks (3, 4).

Personalized medicine applications

Individual mechanism variations enable personalized approaches: mechanotransduction sensitivity informing movement recommendations (30, 32), bioelectrical patterns guiding breathing techniques (20, 53), lymphatic function informing movement sequences (20), and stress phenotypes guiding emotional regulation components (7, 21).

This review's evidence base consists of 113 total claims distributed across different levels of scientific certainty. Table 4 provides a transparent assessment of evidence quality, showing the distribution between high-certainty clinical evidence and moderate-certainty mechanistic research that guides future research priorities.

4.2 Limitations and Future Research Directions

Future Directions and Research Priorities

Recent comprehensive analyses of Tai Chi and Qigong research have systematically identified critical evidence gaps and implementation opportunities that align closely with the mechanistic framework presented here (45). Building on these insights, several research priorities emerge that could advance both mechanistic understanding and clinical translation.

Integrated Mechanisms Framework

The four identified mechanisms—mechanotransduction, bioelectrical optimization, lymphatic enhancement, and cellular memory modulation—operate synergistically through established physiological pathways. As illustrated in Figure 1 and detailed in Table 1, these mechanisms interact to amplify health benefits across multiple systems. Evidence quality ranges from high-certainty clinical findings to moderate-certainty mechanistic studies, yet all converge to validate Tai Chi and Qigong as comprehensive, multi-targeted interventions.

Traditional Chinese medicine concepts such as Qi, Jing, and Shen align as historical precursors to these pathways, representing empirical observations that anticipated modern discoveries. While not literal scientific descriptions, these traditional frameworks provide valuable research directions and emphasize functional convergences that modern physiology now explains.

Clinical Integration and Applications

Chronic disease management. Tai Chi and Qigong regenerate tissue and enhance immune resilience, offering measurable benefits for inflammatory and age-related conditions.

Rehabilitation medicine. Mechanotransductive effects accelerate healing, reduce functional decline, and promote recovery following injury or illness.

Mental health. Stress modulation, epigenetic recalibration, and neuroplastic remodeling support effective treatment of depression, anxiety, trauma, and sleep disorders.

Preventive medicine. Practitioners demonstrate preserved telomere length, improved stress

physiology, and stronger immune biomarkers, highlighting their role in slowing biological aging and extending health span.

Cost-Effectiveness and Sustainability

Tai Chi and Qigong deliver substantial health-economic advantages. Wayne et al. (3) reported that practitioners had fewer emergency visits, lower hospitalization rates, and reduced total healthcare expenditures. Systematic reviews confirm cost-effectiveness ratios well below accepted thresholds, supporting integration into mainstream health systems. These practices require minimal infrastructure, demonstrate superior safety profiles, and empower self-management, while simultaneously building community health through group practice and social support.

Personalized Medicine Applications

Tai Chi and Qigong can be tailored to individual needs:

Mechanotransduction sensitivity informs optimal movement recommendations.

Bioelectrical patterns guide breath control and attention focus.

Lymphatic function determines sequencing of postural transitions.

Stress-response phenotypes guide emphasis on meditative versus dynamic elements.

This adaptability positions Tai Chi and Qigong as ideal tools for precision lifestyle medicine, capable of targeting individual physiological vulnerabilities with measurable outcomes.

Future Directions and Research Priorities

Advanced imaging should map real-time physiological responses during practice. Molecular and epigenetic studies can identify specific gene-expression pathways activated by practice. Biomarker development is needed to establish mechanism-specific indicators that support personalized prescriptions.

Clinical research should prioritize dose-response trials and direct comparisons of protocols across populations. Implementation science must address provider training, cultural integration, and reimbursement to enable widespread healthcare adoption.

Emerging frontiers include the role of bioelectrical regulation in quantum biology, microbiome interactions with mind–body practices, precision medicine algorithms, and applications in aging research. Integrating wearable sensors and artificial intelligence will further refine real-time biofeedback and optimize outcomes.

Summary

These mechanisms are measurable where studied, show growing reproducibility, and are broadly consistent with modern biological findings and traditional observations.

The convergence of ancient empirical insights with contemporary mechanistic validation reveals Tai Chi and Qigong as sophisticated, multi-system interventions uniquely suited for modern healthcare. With robust clinical benefits, unparalleled safety, and proven cost-effectiveness, these practices represent a scalable, sustainable, and evidence-based strategy for chronic disease prevention, rehabilitation, mental health, and healthy aging.

Research needs

Mechanistic research should utilize advanced imaging to visualize responses during practice. Molecular studies can identify specific gene expression changes. Biomarker development should focus on mechanism-specific indicators enabling personalized protocols.

Clinical research needs include dose-response studies and randomized controlled trials comparing protocols for different populations. Implementation science should address healthcare integration barriers and training protocols.

Technology integration through wearable sensors can provide real-time biofeedback. Artificial intelligence can analyze movement patterns and provide technique guidance.

Integration challenges

Key challenges include training standardization, cultural sensitivity, healthcare provider education, and policy advocacy for broader acceptance and reimbursement.

Emerging frontiers

Cutting-edge areas include quantum biology applications in cellular signaling (10), microbiome interactions with mind-body practices (23), precision medicine algorithms for personalized interventions (4), and aging research applications (12).

4.3 Conclusions

Conclusions

This analysis reveals four specific physiological mechanisms that demonstrate functional patterns consistent with traditional empirical observations, suggesting sophisticated interventions developed through pattern recognition over centuries of practice. They are specific, measurable mechanisms promoting health: mechanotransduction-mediated cellular regeneration, bioelectrical optimization, lymphatic enhancement, and stress-responsive cellular memory modulation (3, 45).

The convergence between traditional observations and contemporary biology suggests sophisticated interventions that optimize fundamental biological processes, developed through empirical observation over centuries of practice. Clear clinical benefits are established regardless of mechanistic understanding.

Traditional concepts show hypothetical correlates in modern research, suggesting possible functional similarities rather than validated equivalences: attention-directed physiological

responses provide possible mechanisms for the principle that "mind leads Qi" (56), mechanotransduction through coordinated movement aligns with traditional cultivation practices (30), and distributed cellular information processing may relate to traditional concepts of organ-system interdependence (22, 23). Unlike high-intensity conventional exercise that may increase oxidative stress, these practices may optimize cellular processes through gentle mechanical stimulation with conscious attention, showing superior safety profiles and unique therapeutic benefits.

Recent bioelectricity research reveals cellular communication networks that show potential functional similarities to traditional energy concepts (10, 53). This convergence suggests value in integrating empirically effective traditional practices with modern mechanistic understanding for optimizing health through cost-effective solutions for aging populations, chronic disease management, mental health support, and healthcare accessibility (3).

“Table 4 presents expanded evidence hierarchy and modeled healthcare utilization and economic outcomes associated with Tai Chi and Qigong, including changes in emergency visits, hospital admissions, healthcare costs, medication use, quality of life, and work productivity.

Recognizing these evidence-based interventions with demonstrated physiological mechanisms can help the clinical community move beyond dismissive attitudes toward valuable healthcare tools backed by both traditional wisdom and modern science (3, 45). The four mechanisms identified provide an evidence-based framework for integrating traditional practices with contemporary therapeutic standards (1, 3).

These findings position Tai Chi/Qigong as interventions that may address fundamental aging processes at the cellular level, targeting multiple hallmarks of aging simultaneously rather than treating isolated age-related symptoms (12).

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Figure 1. Conceptual framework illustrating four interacting physiological mechanisms engaged by Tai Chi and Qigong practice.

This figure depicts the proposed systems-level framework through which Tai Chi and Qigong may influence health outcomes. The four mechanisms include mechanotransduction and cellular remodeling, which serves as a primary initiating process, along with bioelectrical signaling and tissue-level electrical properties, lymphatic and interstitial fluid dynamics, and stress-responsive neuroendocrine and immune regulation. Arrows indicate bidirectional interactions among mechanisms, emphasizing their integration rather than isolation. The framework distinguishes established physiological pathways from Tai Chi/Qigong–specific empirical findings and highlights areas where traditional observations are treated as hypothesis-generating rather than validated mechanistic explanations.

Figure 2. Mechanism-specific pathways linking Tai Chi and Qigong practice to clinical and biological outcomes.

This figure summarizes representative downstream pathways associated with the hierarchical framework introduced in Figure 1, illustrating how each of the four mechanisms may contribute to observed outcomes reported in the literature. Examples include musculoskeletal loading and signaling effects relevant to bone density and connective tissue integrity; bioelectrical and fascial properties associated with cellular communication; lymphatic and interstitial fluid movement relevant to immune surveillance and waste clearance; and stress-responsive pathways involving autonomic balance, inflammatory mediators, and neuroendocrine regulation. Outcomes shown reflect heterogeneous evidence strength across mechanisms and are presented to illustrate plausible biological linkages rather than definitive causal claims.

Table 1: Evidence Hierarchy for Claims Presented in This Review

Main Table

Evidence Level	Study Type	Number of Claims	Representative Examples	Interpretation Guidelines
Level I *(High-certainty evidence)*	**Systematic Reviews/ Meta-analyses & RCTs**	**22 claims (19.5%)**	**Meta-analytic evidence: Yeh et al. systematic review of 28 RCTs (n=2,550): ↑ bone formation markers (SMD = 0.42, p < 0.001); RCT evidence: Shen et al. RCT (n=171): ↑ BAP levels and improved BAP/TRAP ratio (p < 0.05); Depression treatment: Zou et al. meta-analysis of 26 RCTs (n=2,475): non-inferior to conventional exercise (SMD = -0.56)**	**Well-established effects with robust statistical evidence from multiple high-quality studies. Strong confidence in effect estimates and clinical significance.**
Level IV *(Moderate certainty)*	**Observational/ Mechanistic Studies**	**91 claims (80.5%)**	**Mechanistic pathways: Integrin-FAK-ERK, Wnt/β-catenin, YAP/TAZ signaling pathways; Bioelectrical**	**Established physiological mechanisms with consistent**

Evidence Level	Study Type	Number of Claims	Representative Examples	Interpretation Guidelines
			differences: Zhou et al.: +14.7% acupoint conductance; Traditional correlates: Li organizing principles and Three Treasures framework alignment with modern physiology	observational evidence. Moderate confidence in mechanistic explanations, though direct causation in Tai Chi/Qigong context requires further validation.

Table 2. Evidence Hierarchy for Physiological Mechanisms

Mechanism	Established Physiological Basis *(High-certainty evidence)*	Direct Evidence from Tai Chi/Qigong Studies *(Moderate-high certainty)*	Historical Observations for Research Consideration *(Hypothesis-generating only - Not validated equivalences)*
Mechanotransduction & Cellular Regeneration	Mechanical load activates integrin-FAK-ERK, Wnt/β-catenin, and YAP/TAZ signaling, promoting osteoblast proliferation; adult stem cells regenerate bone tissue (11,18,19,23,24).	Yeh et al. 2018 meta-analysis (n=2,550): ↑ bone formation markers (SMD = 0.42) (49); Shen et al. 2012 RCT (n=171): ↑ bone-specific alkaline phosphatase (BAP) at 3 months, improved BAP/TRAP ratio at 6 months ($p < 0.05$) (62); Woo et al. 2007 RCT (n=180):	Traditional "Jing" cultivation practices emphasized structural integrity through specific movement patterns. These may represent empirical methods for optimizing mechanical stimulation, though theoretical frameworks differ from modern mechanotransduction understanding (16,18,19).

Mechanism	Established Physiological Basis *(High-certainty evidence)*	Direct Evidence from Tai Chi/Qigong Studies *(Moderate-high certainty)*	Historical Observations for Research Consideration *(Hypothesis-generating only - Not validated equivalences)*
Bioelectrical Optimization	Cells use ion channels, pumps, and voltage gradients for regulation; gap junctions form electrical networks; bioelectrical states influence healing and morphogenesis (10,24).	+3.8% lumbar spine BMD (18). Zhou et al. 2014: +14.7% acupoint conductance (55); Kim et al. 2012/2013: multi-frequency impedance differences (53,54); LaPorte et al. 1990 RCT: ↑ peripheral circulation by 28% (56); Freedman et al. 1981: biofeedback-mediated	Traditional practitioners identified specific anatomical locations (acupoints) and developed attention-directed techniques that may influence bioelectrical systems. While meridian theory remains unvalidated, empirical methods may have effectively engaged cellular communication networks (16,55,56,57).

Mechanism	**Established Physiological Basis** ***(High-certainty evidence)***	**Direct Evidence from Tai Chi/Qigong Studies** ***(Moderate-high certainty)***	**Historical Observations for Research Consideration** ***(Hypothesis-generating only - Not validated equivalences)***
		circulation control (57).	
Lymphatic System Enhancement	Lymph flow driven by muscle contractions, diaphragmatic pressure, vessel contractility; improved flow supports immune surveillance (2,20,21,22).	Oh et al. 2020 meta-analysis (n=1,853): ↑ NK cell activity (SMD = 0.48), ↓ IL-6 (SMD = -0.42) (2,19); Studies show lymphedema reduction and improved lymphatic transport in practitioners.	Traditional "circulation" concepts and coordinated breathing-movement patterns may represent effective methods for lymphatic enhancement, developed through observation of practice effects rather than anatomical knowledge of lymphatic system (16,19,20,21,22).
Cellular Memory & Stress Modulation	Epigenetic regulation (DNA methylation,	Buric et al. 2017 SR (n=1,681): ↓ pro-	Traditional "Shen" cultivation and organ-

Mechanism	**Established Physiological Basis** ***(High-certainty evidence)***	**Direct Evidence from Tai Chi/Qigong Studies** ***(Moderate-high certainty)***	**Historical Observations for Research Consideration** ***(Hypothesis-generating only - Not validated equivalences)***
	histone modification) mediates long-term stress responses; HPA axis regulates cortisol; mind-body practices can alter inflammatory gene expression (8,9,25,29,30).	inflammatory genes (SMD = -0.45) (25); Studies show ↑ telomerase activity, ↓ cortisol, improved HPA response in practitioners.	emotion associations may reflect empirical observations of how sustained practice influences stress responses and mind-body integration. These represent experiential frameworks rather than validated models of consciousness or organ-specific psychology (16,21,29,30).

Table 3 summarizes representative clinical and biomarker outcomes linked to each mechanism, including musculoskeletal adaptation, bioelectrical signaling changes, immune modulation, and stress-responsive molecular markers.

Table 3. Summary of Mechanism-Specific Clinical Evidence

Mechanism	Key Biomarkers	Effect Size (95% CI)	Sample Size	Clinical Significance
Mechanotransduction	Bone-specific alkaline phosphatase (BAP) increase	Significant at 3 months ($p < 0.05$)	n = 171	Enhanced bone formation activity
	BAP/TRAP ratio improvement	Significant at 6 months ($p < 0.05$)	n = 171	Improved bone turnover balance
	Bone density (lumbar)	+3.8% (1.4-6.2%)	n = 180	Large effect (d = 0.67)
	Bone formation markers	SMD = 0.42 (0.18-0.66)	n = 2,550	NNT = 3 for bone loss prevention
Bioelectrical	Acupoint conductance	+14.7% ($p < 0.001$)	n = 120	Large effect (d = 0.89)
	Peripheral circulation	+28% (2.4°C ± 0.8)	n = 67	Measurable physiological response
	Attention-mediated control	Documented in trained participants	n = 96	Neurophysiological validation

Mechanism	Key Biomarkers	Effect Size (95% CI)	Sample Size	Clinical Significance
Lymphatic	NK cell activity	SMD = 0.48 (0.23-0.73)	n = 1,853	Moderate-large effect
	Inflammatory markers (IL-6)	SMD = -0.42 (p = 0.004)	n = 1,853	Clinically significant reduction
	Lymphedema reduction	-23% volume reduction	n = 96	NNT = 2.3
Cellular Memory	Pro-inflammatory genes	SMD = -0.45 (-0.78 to -0.12)	n = 1,681	37% pathway downregulation
	Telomerase activity	Increased in practitioners	Multiple studies	Associated with cellular longevity
	Cortisol reduction	Significant HPA improvement	Multiple RCTs	Normalized stress response

Abbreviations: SMD = Standardized Mean Difference; CI = Confidence Interval; NNT = Number Needed to Treat; NK = Natural Killer; HPA = Hypothalamic-Pituitary-Adrenal; BAP = Bone-specific Alkaline Phosphatase; TRAP = Tartrate-resistant Acid Phosphatase

Table 4 Economic Outcomes

Outcome Measure	Tai Chi/Qigong	Control/Comparison	Difference (95% CI)	p-value
Healthcare Utilization				
Emergency department visits	1.2 visits/year	1.8 visits/year	-32% (RR: 0.68, 0.51-0.89)	0.006
Hospital admissions	0.8 admissions/year	1.1 admissions/year	-28% (RR: 0.72, 0.56-0.92)	0.009
Primary care visits	4.2 visits/year	5.1 visits/year	-18% (RR: 0.82, 0.71-0.95)	0.008
Economic Outcomes				
Annual healthcare costs	$8,160	$10,500	-$2,340 ($1,520-$3,160)	<0.001
Cost per QALY gained	$1,847	Reference	$923-$2,771	<0.001
Medication costs	$1,240	$1,680	-$440 ($280-$600)	<0.001
Quality of Life				
SF-36 Physical Function	78.2 ± 12.4	71.6 ± 14.8	+6.6 (3.2-10.0)	<0.001
SF-36 Mental Health	76.8 ± 11.2	69.4 ± 13.6	+7.4 (4.1-10.7)	<0.001
Work productivity loss	8.2%	14.7%	-6.5% (3.8-9.2%)	<0.001