

BIOMECHANICS

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Kinesiology of Tai Chi Martial Arts – A Scientific Overview

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Abstract

Background. *Tai Chi Chuan* (TCC) is a stand-up internal martial art, which can handle incoming forces with minimal effort and can overcome hardness with softness. Philosophically, TCC is a martial art based on the principles of changes (Taoism) and the practice of constant equilibrium (Confucianism). Scientifically, the internal power of TCC is attributed to relaxation and mindfulness by means of integrated ground reaction force and rotational torques launched by the body through a kinetic chain, using mechanically efficient mechanisms. TCC’s martial application is a complex process, which is challenging but rewarding. **Problem and Aim.** The claim of relaxation and mindfulness for stability and rooting often causes confusion because most people are unfamiliar with these concepts. The effectiveness of TCC for self-defense is sometimes viewed suspiciously because most people cannot execute the internal power of TCC. This article aims to address these issues by providing a scientific basis for TCC training for martial arts applications.

Method. Evidence-based scientific information, collected through comprehensive literature review processes, were evaluated based on the author’s more than forty years of practicing and teaching experience. Scientific findings were subsequently verified by ancient Classics written by TCC masters to certify the consistency between ancient philosophy and modern science.

Results and Conclusions. Essential information on the biomechanics and kinesiology of Tai Chi martial arts is provided in terms of emotional control, six degrees of freedom in motion, maintaining a central equilibrium, biotensegrity formation, living fulcrum and leverage utilization, ground reaction force enhancement, and body kinetic chain manipulation. Furthermore, the mysterious “*Chi*” and “*Jin*” are scientifically defined to help elucidate the essence of TCC.

Introduction

Tai Chi Chuan (TCC) or *taijiquan* is a martial art based on the principles of changes (Taoism) and the practice of constant equilibrium (Confucianism). After more than 400 years of evolution, the meditative aspect of TCC is recognized for maintaining mental and physical health (in terms of relieving stress and maintaining homeostasis) as well as creating a unique, soft-style martial art. We are fortunate that the ancient TCC

masters left us several precious TCC Classics, which cover the underlying TCC philosophy and methods of practice for martial application. Before the mid-1930s, the TCC Classics were passed down in secret, from generation to generation within individual lineages. Now these TCC Classics are open to the public as the single authoritative guide for developing martial skills. From the historical viewpoint, the prestige and influence of TCC came from its unique martial arts. Thus, the martial art aspects are the most quintessential part of TCC.

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In modern literature, Time Magazine has called TCC "the Perfect Exercise" [Gorman 2002], and the Cable News Network has described TCC as being "Medicine in Motion" [LaMotte 2019]. TCC's health benefits can be further reinforced when the technique's martial abilities are achieved by the practitioners. Practicing TCC for health, as indicated by the U.S. National Institute of Health's National Center for Complementary and Integrative Health [U.S. NIH 2022], is a prelude to practicing TCC for martial application. The next stage of training as illustrated in this paper is to gain internal power for martial application, which must be fully consistent with the TCC Classics. The TCC Classics provide additional physiological and kinesiological aspects of the body's movements and a state of deep relaxation to guide the practitioners to a state of homeostasis. This kind of additional training for martial application can further enhance the physical health and mental strength of TCC practitioners.

To master the essential martial arts, TCC practitioners must abide by all requirements of the TCC Classics. However, the problem is that these texts are written in literary Chinese and they are mainly expressed in metaphors, which makes the translation of the TCC Classics a difficult task for a translator who has not yet acquired a high level of martial skills. As can be imagined, most of the translators are not experts in TCC. It is therefore important to address this problem.

It is also only in the last few decades that biomechanical research into TCC has become possible, but these studies mainly address the health benefits. The purpose of this paper is to explain the most critical martial characteristics of TCC from a kinesiology viewpoint, which will help serve as a scientific basis to support the principles of TCC Classics for self-defense.

Literature search strategy

A broad computerized literature search (in both English and Chinese), over a period without a fixed date of onset up to November 2022, of PubMed, Cochrane Library, Google Search, Web of Science, China National Knowledge Infrastructure, and Chinese Scientific Journal Database. The key words used included a combination of Medical Subject Headings and text-word searching terms, such as "Tai Chi," "Taiji," "martial arts," "biomechanics," "kinetic chain," "internal force," "biotensegrity," and "ground reaction force" were used in the search strategies. A study protocol accompanied by a data extraction form was formulated and critically reviewed to determine their potential relevance to this study. Over 500 English and Chinese language papers were reviewed, but only about 100 papers were considered.

Building a martial arts foundation in TCC training

There are six traditional lineages of TCC; plus several other standardized styles, which were promoted after 1956 for mainly health purposes. Every postural movement of TCC, especially for those six traditional styles, is intended for martial application. So, if the practice methods are inconsistent with the requirements of the TCC Classics, the practitioner will often perform the moves merely as a type of physical, mechanical exercise, without truly comprehending the skills used in self-defense.

In ancient times, TCC was originally called Thirteen Postures (after the Eight Gates and Five Steps). All movements, in all current styles of TCC, are based on these basic thirteen postures, with slight differences in their arrangements and permutations.

The Eight Gates (which are ward-off (棚), roll-back (捋), press (挤), push (按), pull-down (採), split (捌), elbow strike (肘), and shoulder strike (靠) referring to movements of the upper limbs) express the laws of changes in eight directions (four cardinal and four diagonal).

The Five Steps (which are advance (前进), retreat (后退), look left (左顾), look right (右盼), and central equilibrium (中定) referring to movements of the lower limbs) express the principle of footwork.

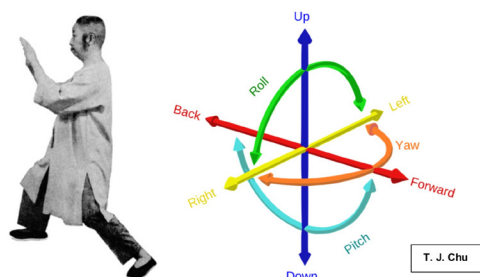
Among the basic thirteen postures, central equilibrium is the most important, and all other twelve postures must have the central equilibrium component within them.

Biomechanically, a simple explanation of the "Five Steps" is that the legs are responsible for attacking, retreating, dodging, advancing, and maintaining central equilibrium; and each footwork controls the motions of six degrees of freedom (three rotational and three translational). These then allow for any necessary self-defense actions.

Thus, for martial arts, leg training is important. As stated in the TCC Classics: "If timing and position are not appropriate, the body will become disordered, and adjustments must be sought in the legs and waist (有不得机势处, 身便散乱, 其病必于腰腿求之)" [Chang 1979: 17].

The nature of TCC training emphasizes relaxation and neuromusculoskeletal control, which is different from the actions of physical resistance training programs. Accordingly, in TCC, the priority of leg training should be placed on muscle tone over muscle growth, to maximize the six degrees of freedom in motion. Muscle tone is simply defined as the resistance to passive stretch, which is physiologically a complex interlaced network encompassing neural circuits in the brain, spinal cord, and muscle spindle. Thus, a tone is maintained by a complex interplay of spinal and supraspinal mechanisms [Ganguly *et al.* 2021].

With proper training, the entire body is free to change its position through forward/backward, up/down, and left/right translation in three perpendicular axes, which are then combined with changes in orientation, through rotation about three perpendicular axes (these being yaw, pitch, and roll (see Figure 1)) [Zelik *et al.* 2015].



Biomechanically, a simple explanation of the Eight Gates concept is that the arms are an extrapolation of the idea of the insubstantial (Yin) and substantial (Yang) changes, along with the eight types of actions added onto the six degrees of freedom in the legs.

The movements of the upper and lower limbs are coordinated through the body kinetic chain, but the lower limbs control the motion of the upper limbs. Thus, in addition to the power of the legs, a TCC practitioner can use various types of actions to cope with any potential threat (for example, to ward off a blow in any of the four cardinal directions involving linear momentum and pressure; or to roll back in any of the other four ordinal directions involving angular momentum and torque).

In TCC, it is critical that the role of the arms is limited to regulating the body's alignment; and to aiming or reaching out to the target. The arms should not be used to apply piecemeal or unintegrated forces, because all the joints in the arm are considered Class-3 levers (e.g., lifting objects using the bicep muscles) and provide negative mechanical advantages. For these reasons, advanced TCC practitioners don't apply piecemeal forces from the arms to interfere with the leverage of the integrated ground reaction force (GRF) from the feet. (More discussion on this is provided in later sessions). This is consistent with Master Cheng Man-Ching's statement that: "TCC is without hands, and hands on is not TCC (太极拳不动手, 动手非太极拳)" [Cheng 1979: 91].

Outsmarting the response to the fear of fighting

In any real situation facing an immediate physical threat, martial artists have all battled against the fears that arise at the beginning of a fight. The result is often a reaction within the amygdala (the part of the brain in the cerebral hemisphere that is involved with experiencing emotions), which is apt to flip individuals into a fight-

flight-or-freeze mode, in response to an immediate threat [Cannon 1932]. This also triggers the release of stress hormones that prepare the body to fight the threat, or to flee from the danger [Barlow 2002].

During the height of the fight-flight-or-freeze response, the routine diaphragmatic breathing of the TCC practice can be a powerful tool to take control away from the amygdala and hand it back to the hippocampus and prefrontal cortex, which can control the fear response in a rational way.

As diaphragmatic breathing slows down the breathing process and sends signals to the brain that the situation is not alarming, the body stops producing the neurotransmitters and hormones responsible for fear and anger emotions [Hopper *et al.* 2019]. When the threat passes, cortisol (a steroid hormone released in response to stress) levels fall. The parasympathetic nervous system – the "brake" – then dampens the stress response. TCC has been demonstrated to activate the parasympathetic nervous system by diaphragmatic breathing [Chin, Kales 2019].

It has also been demonstrated that TCC intervention has a strong effect on neuroplasticity by increasing gray matter volume and the enhancement of functional connectivity [Chi *et al.* 2021]. Compared to other regions of the brain, the hippocampus is more susceptible to neuroplasticity [Weerasinghe-Mudiyanselage *et al.* 2022]. Thus, the neuroplasticity from proper TCC training to acquire a psychological advantage over a bigger and stronger opponent can mitigate the emotional fear response.

Accordingly, Master Cheng Man-Ching indicated that those TCC practitioners who wanted to excel in self-defense must have three characters of fearlessness: (1) fearlessness of enduring the long training required for rooting, (2) fearlessness of suffering losses while investing in yielding, and (3) fearlessness of facing ferocity as softness can overcome hardness [Cheng 1999].

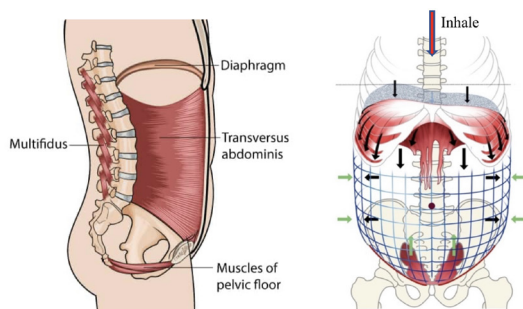
The first two characters are prerequisites to the third character, which is essentially the ability stemming from better relaxation from routine performance of diaphragmatic breathing. The first character of fearlessness entails long-term practice that causes changes to occur in the structure of the brain, which strengthens the neural connections, and improve cognitive skills. Diligent TCC practitioners, with improved neural efficiency, can maintain lower activity levels in the sensory and motor cortex, with less energy expenditure and more effective outcomes [Dunst *et al.* 2014]. The second character of fearlessness requires the TCC practitioners to learn from prior sacrifices and losses to gain the four crucial keys of TCC techniques: touching (沾), sticking (粘), connecting (连), and following (随) for effective self-defense.

Enhancing the neuromusculoskeletal control by diaphragmatic breathing

The traditional TCC training with diaphragmatic breathing affects the whole-body system by not only stimulating the phrenic and vagus nerves for regulating the peripheral nervous system but also strengthening core muscles via an increase of intraabdominal pressure (IAP) for proper load balancing of the pelvis and spine throughout the body kinetic chain [Bordoni *et al.* 2018]. The TCC movements with mindfulness and relaxation help mediate neuromusculoskeletal responses through activating the parasympathetic nervous system and calming down the sympathetic nervous system.

The TCC Classics indicates: "Effortlessly the "Jin" reaches the head-top, while letting the "Chi" (sensation) sink to the Dantien (abdomen) (虚领顶劲,气沉丹田)" [Wang 1979: 29]. This implies that TCC is an effortless action when manifested by diaphragmatic breathing along with correct postural alignment, mindfulness meditation, and rooting in connection with the ground beneath the feet [Chu & Szu 2020]. While the spine and the head naturally held upright as guided by the mind, diaphragmatic breathing can accelerate the circulation of cerebrospinal fluid [Aktas *et al.* 2019]. The cerebrospinal fluid plays an essential role in maintaining the homeostasis of the central nervous system.

Accordingly, the triple function (breathing, peripheral nerve regulation, and core stabilization) of diaphragmatic breathing is a vital part of traditional TCC training [Chu & Szu 2020]. In this case, the core is the muscular cylinder (see Figure 2). While sinking the *Chi* down to the Dantien, the diaphragm serves as the roof of muscular cylinder, whereas the pelvic floor serves as the floor, and the transversus abdominis and multifidus muscles serve as the wall [Chu & Szu 2020].



Contraction of the diaphragm downward increases IAP within the muscular cylinder, thus adding to the spinal stability [Stokes *et al.* 2011]. In addition, diaphragmatic contraction increases the stability of the trunk by minimizing displacement of the abdominal contents into the thorax and maintaining a hoop-like geometry of the abdominal muscles, which increases spinal stability through tension in the thoracolumbar fascia [Kocjan *et al.* 2018]. Moreover, through the diaphragm's fascia and

connective links, the diaphragmatic breathing can activate the thoracic and lumbar erectors, internal and external obliques, quadratus lumborum in the lower back, and the psoas muscle that crosses the rim of the pelvis to connect the legs to the spine [Bordoni, Zanier 2013].

In conjunction, these are all important muscles to stabilize the innermost load-bearing structure – the spinal column. The contraction and strength of these deep muscles are enhanced by the presence of IAP, and the increased pressure provides a stable structure for maximal force production and structural integrity. Therefore, these small and large muscle groups are dependent upon each other for optimum function. From a neuromusculoskeletal perspective, the alignment of the body structure and diaphragmatic breathing have a very direct impact on the function of those core muscles for spinal stabilization.

Exploring the arts of receiving

According to the TCC Classics, progressive martial art ability is developed as follows: "From familiarity with the correct postural processes, one gradually comprehends Jin; from the comprehension of Jin, one can reach wisdom. Without long practice, one cannot suddenly understand it (由著熟而渐悟懂劲,由懂劲而阶及神明,然非用力之久,不能豁然贯通焉)" [Wang 1979: 29]. This means it requires extensive practice of correct postures to become familiar with all the principles of the TCC Classics and to gain the proprioceptive sense and kinesthetic abilities prior to acquiring *Jin*.

Proprioception (an awareness of the position and movement of the body) results from sensory receptors in the nervous system and the body, which are mostly located in the muscles, joints, and tendons; whereas kinesthetic sensations are derived from sensory receptors in the muscle, skin, and joints as well as from central signals related to motor output. This means comprehending *Jin* requires an extensive effort to excel in touching, sticking, connecting, and following an opponent, and then to be able to yield and neutralize their moves with ease, comfort, and least effort. As with many endeavors, there are different levels and stages in comprehension before it is possible to fully understand *Jin*. Advanced *Jin* involves deep interoceptive and proprioceptive awareness, to control both motion and stillness and to maintain homeostatic conditions in fighting.

Interoceptive signals arise from many different physiological systems of the body. So, the comprehension of *Jin* relates to mastering and applying various kinds of mechanically efficient GRF and torques while engaged in sensing, yielding, controlling, receiving, and/or launching.

Among all *Jins* that are developed for use in TCC, for martial applications, the most difficult one to master in free fighting is the receiving *Jin* (which relates to

the ability to absorb an incoming force) [Cheng 1993]. This can be considered the essential secret of TCC, but it is rarely discussed in the TCC literature. One of the few references to this mystery was discussed by Master Cheng Man-Ching, who stated that if your achievement reaches this level of “receiving *Jin*”, then you do not have to worry about other kinds of *Jin* [Cheng 1993].

His explanation of receiving *Jin* is analogized as follows. Imagine someone throws a ball to hit another person. If the receiver resists the ball or hits it, it will bounce out. This description is the *Jin* of colliding but is not a receiving *Jin*.

Receiving *Jin* means the receiver can catch the ball and is then able to toss it out, regardless of the speed and weight of the ball. This requires the skills of sticking (moving in contact with the opponent to take control), sensing, lifting, and discharging to enable both catching and discharging to occur almost simultaneously. Since the power can be intensified quickly in a narrow space, it indicates the highest wisdom in free fighting. According to Master Cheng Man-Ching, besides receiving *Jin* as the ultimate supreme capability of TCC, there is nothing else [Cheng 1993].

So, what is “receiving *Jin*?” This is when someone attacks with sudden motion, and no matter whether the attacker contacts your hands or another part of your body, all you think about doing is nothing but “relaxation. Regardless of how the attacker feels about the touch of your body, whether it is hard, or soft movement combined with hard, your effort is not piecemeal. You relax to neutralize the incoming attack by forming a biotensegrity framework, and use the support of GRF that runs from your feet through the legs, waist, and chest to the arms.

If the oncoming attack is a force resulting from a Class-3 lever, regardless of its external or internal nature or its source from the arms or from the waist, an advanced TCC practitioner should be able to easily handle it. But if you employ a Class-3-lever in a disjointed manner, you will create resistance that will provide an attacker an opportunity to detect your intention.

In contrast, the biotensegrity framework and GRF plus torques resulting from relaxation have the exact opposite effect and allow you to unload the incoming force, maintain your body stabilization, and strengthen a counterattack.

Moreover, when counterattacking, the GRF and torques exerted on the attacker can have a “sticking” effect to induce and then follow the resistance from the attacker for you to take advantage of the situation for counteracting.

Establishing a biotensegrity framework for defensive actions

There is no denying that countering the attack may expose the body to a powerful force. Whether or not the oncoming

force can be received depends on many factors such as the timing and angle of the attack, the execution trajectory, the amount of the force, and the neutralizing skills. If the opponent’s oncoming force is powerful and fast, dodging and retreating should be considered by junior practitioners. Defending and controlling the oncoming force by an advanced TCC practitioner depends on a disciplined state of relaxation and the person’s force-sinking abilities, which together form a tactical tensegrity framework of body integration and equilibrium. In this case, integration means that no one muscle is solely performing just one movement, such as stabilizing one body area for freedom of movement in another body area, but all muscles are working as a combined unit all the time, to reach a stable, but dynamic equilibrium.

Accordingly, if there is an impact on one part of the body, a skilled TCC practitioner will start by following the attacker’s strength so that the impacting force is distributed evenly to the relaxed body as a whole without exposing the center of mass.

In other words, the moment of neuromuscular integration and body equilibrium is to find balance and an ease of motion through oppositional strength; with support of the unison of tensioned and compressed parts of the musculoskeletal system forming biotensegrity [Scarr 2014]. Biotensegrity is the application of tensegrity (the tensional behavior of the body) to biological structures such as muscles, bones, fascia, ligaments, and tendons; or rigid and elastic cell membranes; which are made strong by the combined action of tensioned and compressed parts [Levin 2015].

During the moment of *Jin* receiving (receiving a blow), the musculoskeletal system maintains tension through a continuous network of muscles and connective tissues, while the bones provide discontinuous compressive support [Souza *et al.* 2009].

To sustain the required elasticity for biotensegrity, the matrix of interconnected soft tissues including fascia, muscles, tendons, and ligaments must maintain the right amount of tension. This can be compared to tree roots forming a structural network that holds tension within the earth. If the body is just slightly out of alignment, or the required tension and compression becomes disorganized (or unbalanced), the discrepancy will prevent optimal motion and function of biotensegrity.

However, when the body is relaxed and rooted downward, gravity is pressing the body structure down into the ground. Then a rebounding GRF and torque (rotational force) along with the kinetic chain momentum reverberates up the body structure. The integrated internal movement of multiple joints and muscles helps reduce the impacts of oncoming attacks within the biotensegrity framework [Schwartz 2017]. Subsequently, a fully developed body proprioception and capacity to sense body motions are recruited to react to sudden attacks and to self-correct spontaneously and apparently effortlessly.

Proprioception relies on mechanoreceptors located in deep tissues such as muscles, tendons, and fascia sending detailed messages to the brain about body stabilization and movement. It is evident that martial arts training such as TCC can improve the required proprioception and neuromuscular control [Matthews *et al.* 2016].

Cultivating the *Jin* and recognizing the *Chi*

What is TCC's *Jin*? Rather than using the general term “internal force”, it is defined here as “the integrated GRF and rotational torques launched by the body through a kinetic chain, using mechanically efficient mechanisms.”

Thus, any external and/or internal forces applied by a Class-3 lever are excluded, regardless of their external or internal nature, or their sources, which may be from the arms or from the waist. TCC tactics emphasize simultaneous defense and offense, although neutralization takes priority.

The synchronized transition from a defensive action (receiving the *Jin*) to an offensive action (launching the *Jin*) requires both sensing and neutralizing the incoming force, to control the timing and the opportunity before a counteraction. Concurrently, the feet, legs, and waist must be fully integrated, in preparation for launching the counteracting *Jin*. The feeling of integration, derived from sinking (also known as rooting), originates not only from having good balance but also from connecting all parts of the body down to the ground.

This corresponds to the TCC Classics: “*When launching the Jin, one must sink and relax completely while aiming at the desired direction (发劲须沉着松净, 专注一方); and the power accumulated as drawing a bow and released as an arrow (蓄劲如张弓, 发劲如放箭)*” [Wu 1979: 41].

Thus, the resulting *Jin* (GRF and torques) for offense depends on the sensitive neuromusculoskeletal control cultivated by routine diaphragmatic breathing, the degree of relaxation and mindfulness to sense the GRF and various torques, and the efficacy of transferring the GRF and torques throughout the body's kinetic chain.

For TCC's closed kinetic chain movement, the *Jin* is the GRF plus the consequential three dimensional internal-reaction torques of joints, muscles, and ligaments that synergistically thrust all body segments upward from the feet [Chu, Szu 2020]. Here, the *Jin* is equal to the change in momentum over the change in time.

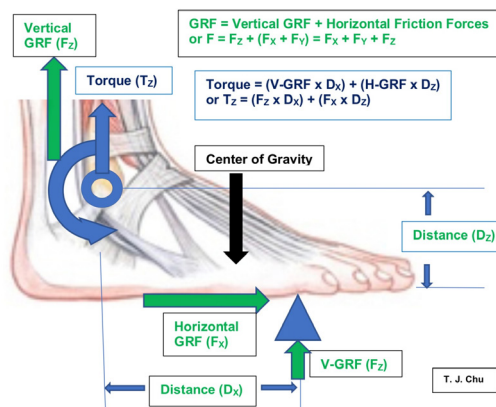
Practicing the traditional TCC through awareness, breathing, and movement explorations can help foster kinesthetic sensory cultivation, body consciousness, and internal strength enrichment. While cultivating the *Chi* routinely through diaphragmatic breathing, the *Jin* will be enhanced over time by integrating body kinetic chain motions, to progressively enhance the neuromusculo-

skeletal sensitivity. This allows deep-layer core muscles to engage more effectively outside of the inhibiting influence of mobilizing muscles, and thus the kinetic chains can be properly utilized for efficient kinetic energy transfer, from the proximal segments to the distal segments, for launching any *Jin* [Chu, Szu 2020].

The magnitude of momentum generated by the GRF and torques, and transferred from segment to segment via the kinetic chain, can be sensed, but the kinetic energy as a scalar quantity cannot be felt. To help cultivate the *Jin* during TCC training for martial arts application, it is necessary to scientifically delineate the *Chi* here as “kinesthetic sensations of position, movement, and force of muscles, tendons, and joints throughout body segments in kinetic chain motions” to help monitor the progressive sensation of the momentum transfer [Chu, Szu 2020].

Augmenting *Jin* from the ground using Class-2 lever

When the lowerbody is correctly balanced and the body parts – particularly the ankles and feet – are sufficiently relaxed, the gravity sensory feedback from the activation of plantar cutaneous mechanoreceptors can help manage the torque produced by the forces of gravity and reaction of the ground [Viseux *et al.* 2019]. The key movements of the ankle joint complex are dorsiflexion/plantarflexion occurring in the sagittal plane, abduction/adduction occurring in the transverse plane, and eversion/inversion occurring in the frontal plane. Rotation in any given plane occurs about an axis perpendicular to that plane. Moreover, the movements of the ankle joint complex are controlled by the torques due to ground reaction. The vertical GRF, horizontal friction forces, and ankle torque at the time of the plantarflexion movement are shown in Figure 3.



The torque can be estimated by multiplying the body weight by the perpendicular distance of the upward effort from the fulcrum (which is also referred to as the pivot point, or center of pressure (CoP)) plus the component resulting

from the horizontal friction forces (see Figure 3). In biomechanics, the center of pressure (CoP) is the term given to the point where the GRF vector is applied; whereas the center of gravity (CoG) is the point where the whole weight of the body acts vertically downward. It is important to note that both the CoP and the downward position of the CoG are not static outcome measures because of the dynamic actions of “Five Steps” during the TCC movements.

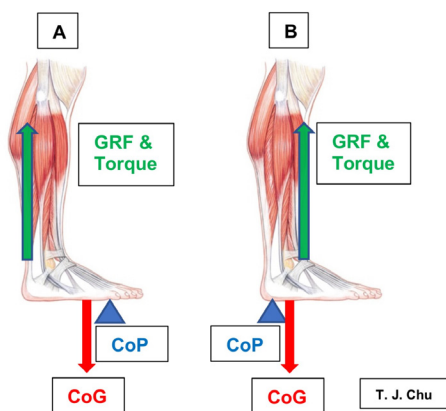
For example, the CoP is at the ball near the toes at the time of a ward-off or push posture, or it moves backwards to near the heel at the time of a roll-back posture.

Similarly, for the sake of body stability, the downward position of the CoG should be placed at the “bubbling well” (which is a point on the sole of the foot, just in front of the arch and centered side to side) at the time of a ward-off or push posture, or it shifts to below the ankle at the time of a roll-back posture.

More specifically, the “bubbling well” is located one-third of the way from the base of the toes to the edge of the heel on the sole of the foot between the metatarsals of the second and third toes [Chu, Szu 2020].

In plantarflexion of the foot, the lower leg acts as a Class-2 lever. A Class-2 lever (e.g., a wheelbarrow) is the only lever that can guarantee that the effort (input force) arm will always be greater than the load (output force) arm.

This arrangement results in a higher effort-arm to load-arm ratio, making this Class-2 lever the most mechanically advantageous. In a calf raise, the effort comes from the calf muscles (gastrocnemius, soleus, plantaris); which are attached to the calcaneus bone. In this case, the load comes from the body weight, plus any extra weight from an opponent, which acts on the lever system through the tibia. Here, the fulcrum (the pivot point) is made up of the metatarsophalangeal joint. In this arrangement, the load is then in the middle, and the effort is furthest from the fulcrum. Therefore, the act of plantarflexion can move much more weight than elbow flexion. This is even if the bicep is just as strong as the calf.



Both GRF and torques are influenced by contraction of lower leg muscles. Thus, contracting the calf muscles occurs when the fulcrum (CoP) is placed at the ball of the foot and the body weight (a downward of the CoG)

is shifted to the “bubbling well” (see Figure 4A), at the time of advancing during the “Five Steps” movements.

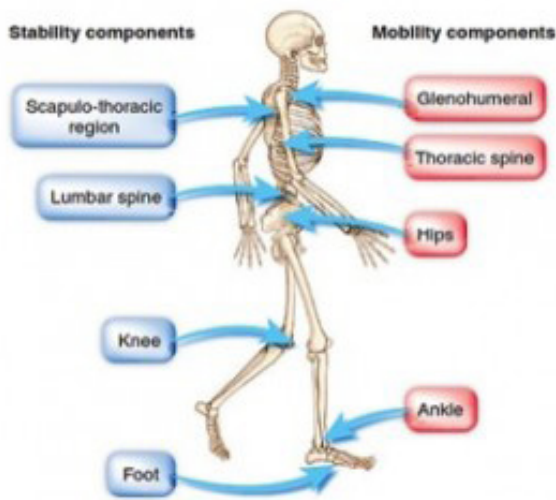
Shifting both CoP and CoG forward (towards the toes) can help maximize the vertical GRF and torques by taking advantage of a Class-2 lever system (where the load (CoG) is located between the fulcrum (CoP) and the upward effort). At the time of retreating during the “Five Steps” movements, contracting the shin muscle (tibialis anterior) can occur when both CoP and CoG are shifted backward where the fulcrum (CoP) is placed at the heel and the body weight (CoG) is under the ankle (see Figure 4B). In this case, the advantage of a Class-2 lever system can also apply. Accordingly, the positions of CoG and CoP can be adjusted to maximize the vertical GRF and torques (greater than the body weight) by using the torque of body weight for self-initiated movements or for responses to an external perturbation force. Moving the body weight to exploit the torque of gravity can be performed with great skill, by advanced TCC practitioners.

Essentially, the explosive GRF with torque generation is the ability to increase *Jin* (GRF, torques) as quickly as possible during a rapid muscle contraction in the lower legs. The rate of force/torque development during rapid muscle contractions is determined by the capacity to produce maximal voluntary activation in the beginning phase of an explosive contraction [Maffiuletti *et al.* 2016]. A change in the contraction of the lower leg muscles often precedes the contraction of the upper body muscles. The GRF and torques can be easily transmitted by body-wide muscle coordination activated by nerve potentials to move the joints and limb segments upward [Bigland, Lippold 1954]. Most skeletal muscles in human body are attached to bones via tendons close to joints, causing these musculo-skeletal systems to be Class-3 levers with mechanical advantages less than one (i.e., the input force is greater than the output force.) Advanced TCC practitioners understand that it’s easier to perform a weighted calf raise than a bicep curl or a tricep extension, because the lever system involved in a bicep curl or a tricep extension is mechanically less efficient than the lever system involved in a calf raise.

The next stage, to boost the *Jin* upwards, is attributed to the angular torque at the ankle while the GRF vector passes upward from the foot and produces movement at each lower extremity joint, starting from the leg segment to the waist segment.

Biomechanically, the interrelated groups of body segments, connecting joints, and muscles work together to perform movements along with the portion of the spine to which they connect. The concept of a joint-by-joint approach implies that the body is made up of “mobile” joints and “stable” joints that alternate as the body segments moving up starting from the ground such that the mobile joints can gain leverage off the

stable joints to effectively transfer the momentum (see Figure 5) [Boyle 2010].



The *Jin* (GRF, torques) is initiated at the proximal leg segment and proceeds to the more distal segments, with the more distal segment initiating its motion at the time of the maximum speed of the proximal segment. Each succeeding segment generates larger endpoint speeds than the proximal segment [Marshall, Elliot 2000]. Thus, the vertical GRF and torques at the feet as aided by the Class-2 lever of the ankle plantarflexion, or dorsiflexion can be further reinforced by the angular torques firstly at the ankles of the leg segment and subsequently at the hips of the waist segment. In fact, each joint torque can produce linear and angular acceleration of all body segments, due to the dynamic coupling inherent in the interconnected musculoskeletal system. Angular acceleration of the waist and chest segments is principally affected by all the joints of the leg segment with varying degrees of dependence during the gait cycle [Nott *et al.* 2010]. For instance, when the pelvic rotates at the waist segment in the transverse plane, the other joints of the lower limb are involved in rotation as well. In fact, the greater the joint's distance from the trunk, the greater is the rotation (e.g., the tibial rotation is three times the rotation of the pelvis) [Seidenberg, Bowen 2010].

Using only mechanically efficient mechanisms for offensive actions

The human body is composed of a variety of joints; some work biomechanically like levers, others like pulleys, and still others like a wheel-axle mechanism. The synovial joints are moveable and function as lever systems. Most movements in the human body are classified as Class-3 lever systems, which are at a mechanical disadvantage in terms of effort versus load.

As indicated by Master Yang Cheng-Fu regarding ten essentials of TCC, the TCC Classics instructs that “*One should use the mind instead of force. While practicing TCC, one should relax the entire body without allowing any clumsy strength* (此全是用意不用力;练太极拳,全身松开,不使有分毫之拙劲)” [Yang 1979: 83]. Thus, TCC advocates developing skillful forces rather than clumsy Class-3 lever forces. The skillful forces are Class-1 lever (e.g., a scissor) and/or Class-2 lever forces resulting from the integrated GRF and rotational torques launched by the body through a kinetic chain using mechanically efficient mechanisms (or the TCC *Jin* as previously defined). The TCC *Jin* is controlled subconsciously by the mind (brain) via hippocampal neuroplasticity, which is enhanced by the routine TCC practices with relaxation, mindfulness, and diaphragmatic breathing.

In fighting, most of the time, people tend to use unconnected, or unintegrated brute force attack, by using the ends of their limbs. If the physical force is delivered in the arm by moving the hand around the wrist, moving the forearm around the elbow, or moving the whole arm around the shoulder; all these levers are Class-3 type levers with the effort between the resistance (load) and the joint (fulcrum) where the muscle attachments are usually close to the joint. In TCC, the practitioners learn to stabilize those Class-3 levers and integrate them into a tensegrity framework for self-defense under the constant pressure of gravity.

For offense, while letting the tensegrity framework relax, advanced TCC practitioners can develop an excellent way to exert the *Jin*, cleverly using the musculoskeletal system to establish mechanically efficient levers with the GRF and torques rooted in the feet, issued in the legs, dominated by the waist, and delivered to the hands. In other words, using GRF and torques generated from the feet will help convert many inherent Class-3 levers in the human body to either a Class-1 or a Class-2 lever in offense.

The first instance is indicated in the TCC Classics as “*The power comes from the spine* (力由脊发)” [Wu 1979: 41]. In this case, the TCC practitioner can place the fulcrum on the moving axial line (spine) between the GRF with torques (effort) and opponent's body (load) by turning the pelvis around the hip to swing the whole body as a Class-1 lever. It requires very little effort to deliver the *Jin* from the ground toward opponent's center of mass.

The second instance is also indicated in the TCC Classics as “*The force is borrowed from the opponent* (力从人借)” [Li 1979: 71]. In this second case, the TCC practitioner can place the fulcrum on an opponent's forceful arm with the opponent's body (load) between the fulcrum of the opponent and the GRF with torques (effort) of the practitioner by turning the pelvis around the hip to swing the whole body as a Class-2 lever. This

way the TCC practitioner can borrow the incoming force along the direction and momentum of opponent's arm against the opponent's body with little effort because the core power is connected to the torso while applying the GRF with torques toward opponent's center of mass.

Additionally, the TCC Classes indicate that “*Stand like a balance and rotate actively like a wheel* (立如平准,活似车轮)” and “*The Chi is like the wheel, and the waist is like the axle* (气若车轮,腰如车轴)” [Wu 1979: 41; Li 1979: 71]. The rotation of the waist/pelvic region is like turning a wheel on an axle. The hip joints are rotating around the moving axial line (spine) at about the elevation of the sacrum. As is well known, the wheel-and-axle mechanism can mechanically aid the movement of very heavy loads. Besides, the muscles around the pelvis have high muscle-to-tendon ratios (force producers) while the extremities have relatively much more tendon and elastic structures (force amplifiers). In a correctly aligned body, a small movement of the waist along with the *Jin* from the ground can produce very large amounts of force elsewhere in the body.

The TCC Classics indicate that: “*Use a force of four ounces to deflect a thousand pounds* (牵动四两拨千金)” [Wang 1979: 67]. This is the level that all serious TCC practitioners are keen to attain. The prerequisite of using four ounces to deflect a thousand pounds is the ability of receiving the *Jin* while neutralizing the incoming force by following its direction of movement. To induce the opponent's attacking force to emptiness, the point in contact must naturally rotate and the arc of rotation must be aligned in accordance with the direction of the incoming force. Regardless of the magnitude of a force coming to attack, the impact is zero in its tangential direction at the target point. As a result, only a small amount of friction force is required to achieve the effect of “deflecting a thousand pounds with four ounces of effort”. The key lies in sensing the incoming force and inducing the opponent to a tangential direction effortlessly.

TCC is an interesting and effective martial art like playing American football with specific defensive and offensive strategies. In defense, the TCC practitioner is relaxed, forming a stable biotensegrity framework. In offense, the TCC practitioner is efficient and can powerfully use mechanically efficient levers (within a living fulcrum) along with the efficient wheel-and-axle mechanism.

Conclusion

Practicing TCC can be enjoyable, challenging and fulfilling for health benefits; and it should improve the practitioner's skill as a martial artist as well.

However, many people may still wonder how a “soft” TCC can be an effective martial art. Here, the secret may lie in the fact that many TCC's martial

aspects have been misunderstood and many physical and psychologic skills may take years to develop if the method employed is inadequate. Moreover, some may be misinformed and do not fully understand the mysterious nature *Chi* and they may not understand how body mechanics can make their moves more powerful.

This study provides an extensive review of the structure, function, and motion of the biomechanics of TCC and offers a scientific clarification that may help martial art achievement. The mysterious *Chi* and *Jin* are scientifically defined, to help understand the essence of TCC.

As the fundamental step to develop the martial ability, the lower limbs should have six degrees of freedom to help control the eight types of actions of the upper limbs. To overcome the initial fear of fighting, the routine diaphragmatic breathing can be a powerful tool to take control away from the amygdala hijack. Diaphragmatic breathing can further enhance neuromusculoskeletal control to help maintain the central equilibrium of the body.

In defense during free fighting, the most difficult action is to receive and neutralize the oncoming force. This requires training on relaxation, proprioceptive and interoceptive awareness, as well as the basic skills of touching, sticking, connecting, and following. Additionally, establishing a biotensegrity framework in the body from relaxation and alignment are necessary to help disperse incoming forces for defensive actions.

Synchronizing a quick switch from defense to offense requires a sensitive neuromusculoskeletal control as cultivated by routine diaphragmatic breathing to allow effective transfer of GRF and torques upward throughout the body kinetic chain. The sensational feeling of *Chi* can help monitor the momentum transfer. The powerful *Jin* (GRF and torques) of TCC is augmented at the feet using a Class-2 lever. The way to apply the augmented *Jin* from the ground naturally and with agility is by reducing the dependence on local muscle strength (avoiding Class-3 levers) and using whole-body power efficiently (enabling Class-1 and Class-2 levers and wheel-and-axle mechanisms).

More research in the topic areas is recommended, and it is clear that new advances in science can empower us with new ways to further comprehend the TCC Classics and help reveal TCC's martial capabilities. It is highly recommended that future research on both the health and martial aspects of TCC should recruit those who have acquired certain *Jin* from the ground and can demonstrate TCC's soft-style martial arts. Further scientific research studies on TCC's *Jin* (GRF and torques) are certainly needed, including direct measurement via kinematic data analysis and indirect estimation via computer modeling.

Conflicts of interest and other issues

The author declares that this article was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Kinezyjologia sztuk walki Tai Chi – przegląd naukowy

Słowa kluczowe: *Tai Chi*, sztuki walki, biomechanika, łańcuch kinetyczny, siła wewnętrzna, siła reakcji podłoża

Streszczenie

Tło. *Tai Chi Chuan* (TCC) jest wewnętrzną sztuką walki wykonywaną w pozycji stojącej, która może radzić sobie z napływającymi siłami przy minimalnym wysiłku i może pokonać twardość miękkością. Z perspektywy filozoficznej, TCC jest sztuką walki opartą na zasadach zmian (taoizm) i praktyce stałej równowagi (konfucjanizm). Z naukowego punktu widzenia, wewnętrzna moc TCC jest przypisywana relaksacji i uważności za pomocą zintegrowanej siły reakcji podłoża i momentów obrotowych uruchamianych przez ciało poprzez łańcuch kinetyczny, przy użyciu mechanicznie wydajnych mechanizmów. Zastosowanie TCC w walce jest złożonym procesem, który jest trudny, ale satysfakcjonujący. Problem i cel. Twierdzenie o relaksacji i uważności dla stabilności i zakorzenienia często powoduje zamieszanie, ponieważ większość ludzi nie jest zaznajomiona z tymi koncepcjami. Skuteczność TCC w samoobronie jest czasami postrzegana podejrzliwie, ponieważ większość ludzi nie potrafi wykorzystać wewnętrznej mocy TCC. Niniejszy artykuł ma na celu zajęcie się tymi kwestiami poprzez dostarczenie naukowych podstaw treningu TCC do zastosowań w walce. Metoda. Oparte na dowodach naukowych informacje, zebrane w wyniku kompleksowego przeglądu literatury, zostały ocenione na podstawie ponad czterdziestoletniego doświadczenia autora w praktyce i nauczaniu. Odkrycia naukowe zostały następnie zweryfikowane przez starożytne klasyczne utwory napisane przez mistrzów TCC, aby potwierdzić spójność między starożytną filozofią a współczesną nauką.

Wyniki i wnioski. Zasadnicze informacje na temat biomechaniki i kinezyjologii sztuk walki Tai Chi są dostarczane w zakresie kontroli emocjonalnej, sześciu stopni swobody w ruchu, utrzymywania centralnej równowagi, tworzenia biotensegrity, żywego punktu podparcia i wykorzystania dźwigni, zwiększania siły reakcji podłoża i manipulacji łańcuchem kinetycznym ciała. Co więcej, tajemnicze "Chi" i "Jim" są naukowo zdefiniowane, aby pomóc wyjaśnić istotę TCC.