

THE SCIENTIFIC BASIS OF TAI CHI CHUAN ON ENHANCEMENT OF BALANCE CONTROL: CHALLENGE TO BIOMECHANISTS

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The purpose of this article was to review the scientific studies, both published in Chinese and English, on the impact of Tai Chi Chuan (TCC) exercise on balance capacity, and to provide views on future direction of TCC studies. The experimental evidence obtained from both cross-sectional and longitudinal studies suggested that TCC exercise has beneficial effects on balance control capacity and reduction in falling in the elderly. This applied to either healthy people or patients with rheumatoid arthritis, or osteoarthritis. Among the published literature there is a dearth of biomechanical studies for TCC. Only a few of the characteristics of muscular activity, movement kinematics and kinetics during the performance of TCC are understood. Furthermore how TCC exercise helps to improve the human balance control has not yet been explained.

KEY WORDS: Tai Chi Chuan, balance control, muscle strength, flexibility

INTRODUCTION: In most English literature Tai Chi Chuan, abbreviated as TCC, is a traditional Chinese exercise form derived from martial arts folk traditions, handed down from generation to generation for more than 1200 years. In the Chinese Phonetic Alphabet, this exercise form is expressed as Tai Ji Quan, or, by putting them together, Taijiquan. Here the word "Chuan" means boxing and in some literature this word has been omitted.

TCC was gradually and systematically developed to the point of formalization more than 300 years ago in the late Ming (1368 - 1644) and early Qing dynasties (1644 - 1911) of China. To understand TCC, which is a set of systematic calisthenic exercises, one must first understand the origin and meaning of the words Tai Chi. The words Tai Chi first appeared in the book "I Ching", where they refer to the creation of heaven and earth (the sky and the world). The state of the universe before the creation of heaven and earth is called Tai Chi. In simple terms, TCC firstly means, each movement is circular, as represented by the circle in the Tai Chi diagram. Within the circular movement are concealed many variations and changes; there is emptiness and fullness; there is movement and stillness; there is expressed strength and softness; there is forward and backward. All these are the meaning contained in the words Tai Chi. Secondly, TCC is the interplay of Yin and Yang. The theory of Yin and Yang is the theoretical basis of traditional Chinese Medicine. According to the principles of the Yin and Yang theory, in any thing or material are contained two aspects, Yin and Yang. Human beings can be expressed as Yin and Yang, the female as Yin, the male as Yang. Human physiological activity can be described as Yin and Yang, for example with digestion, the intake of nutrients as Yang and the excretion of metabolites as Yin. In traditional Chinese medicine, health is contingent upon the balance between Yin and Yang. Imbalances in these energy forces are thought to produce physical dysfunction that may lead to sickness. TCC is used to seek serenity in action and also to seek action in serenity. The emphasis is in the exercise of mind and consciousness. Lastly, movements of TCC are continuous, from beginning to end, from one posture to the next, the movement is never broken, it is a complete integrated circle.

A lot of TCC schools were devised and developed over the centuries, such as Chen, Yang, Sun and Wu. Among these schools, Chen's TCC is thought to be the earliest devised and has spread most widely. When performing TCC, each movement can be divided into two techniques depending on the height of the center of gravity of the body. They can be performed with a high or a low center of gravity. By 1956, a meeting of TCC masters, convened by the Chinese National Council of Sports and Physical Education, had produced a 'combined style of TCC, namely the Simplified 24-forms TCC. This style of TCC was designed to convey the most representative components of various traditional TCC schools that had evolved over the previous centuries so as to maintain the main characteristics of

TCC but make it easier to learn and to practice. The time required to practice a complete set of exercises has therefore been reduced (Mark, 1979). Today millions of people in China practice TCC, an activity that has become one of the most popular and favored sports and exercise forms in China, especially among the older people.

During the past twenty years, TCC has spread widely in western countries. The observed beneficial effects of TCC on health, especially for older adults, evoked research interest from western scientists. To our knowledge, the first paper in English that presented an experimental study about TCC was published in China (Gong, et al., 1981). At same year, a paper about TCC was published in an international journal (Koh, 1981). With increasing numbers of older people and increasing expenditure for chronic disease and disability among this older population, TCC has drawn more and more attention from health related government organizations and research interests from scientists. Published results from well-controlled studies about the effects of TCC on health, particularly those focusing on the older population, have enriched the knowledge of TCC and added to the understanding of the characteristics of TCC movement and its impact on health.

Exercise has definite effects on the health of older people, however, the exercise forms that are suitable are relatively few because aging is usually accompanied by a significant decline in organ function. It is well known that joint degeneration, poor eyesight, poor balance and loss of stamina are universal in the older population. Therefore, exercises with low velocity, low impact and high interest level, which also provide a good training effect, are preferred for older persons. Based on the published literature, TCC seemingly has provided all the demands that elderly people require from exercise. Additionally, TCC has the potential to offer more than a form of group exercise to obviate the expenditures associated with poor health since it facilitates a lifestyle that promotes wellness among people of all ages. Before endorsing these views, two relevant questions must be answered. What evidence exists that TCC affords any benefits? What are the underlying mechanisms of the benefits of TCC? The purpose of this article is firstly, to review the scientific studies, both Chinese and English, on the impact of this intriguing form of exercise on balance capacity, and secondly, to provide views on what should be done for the biomechanists in future TCC studies. This review is designed to provide a basis of reference for future biomechanical studies.

BIOMECHANICS STUDY IN TAI CHI CHUAN: There are a limited number of studies of the characteristics of muscular activity, movement kinematics and kinetics of TCC exercise. Zhang et al (1989) reported an electromyography (EMG) study on Chen TCC. One of the later generations of the creator of Chen TCC and another eight Chen TCC masters participated in the study. Using surface electrodes, EMG activities of deltoideus, sacrospinalis (erector spinae), rectus femoris, and gastrocnemius on both sides of the body were recorded while performing the whole set of Chen TCC. The integrative EMG (iEMG) and power frequency EMG were employed for analysis. It was found that the iEMG pattern of the analyzed movements showed alternation of higher amplitude and lower amplitude, and the high amplitude was accompanied by higher frequency while the lower amplitude was accompanied by lower frequency. Analysis of the movement "Ya shou hong chui" (one form in Chen TCC) showed that there was a time difference of 0.014 second in the muscle activity between the upper and lower body extremities. Also, the muscles of the upper extremity on the left side were activated first, then the lower extremity on this side, subsequently the muscles on the right side contracted with the sequence from upper to lower extremities. The EMG activity patterns during TCC practice provided preliminary experimental evidence that TCC exercise demands the involvement and coordination of upper and lower extremities and unilateral and bilateral support. The power frequency EMG, however, did not show any evidence of muscle fatigue during TCC practice, indicating the mild exercise intensity of TCC practice.

Lu et al. (1991) published a biomechanical study on the kicking movement of Chen TCC which was thought to be more powerful than other TCC schools. The kicking movement of Chen TCC differs from the kicking movements of other TCC schools for it is characterized by a jump with high velocity and high power, and is considered as a representative movement of

this school of TCC. One TCC master with twenty-four years of Chen TCC experience served as the subject. He was asked to perform twelve kicking movements on a force platform. EMG signals were collected for a total of nine pairs of muscles (deltoid, biceps brachii, triceps, rectus femoris, biceps femoris, gastrocnemius, rectus abdominis, external oblique abdominis, and sacrospinals at L5). Ground reaction force and 3-D video filming were recorded synchronously with EMG throughout the performance of the kicking. The results showed that there was an appreciable change in both the center of gravity of the body and the momentum of each body segment. The highest amplitude of the iEMG was found in the right rectus femoris, whereas the lowest amplitude of iEMG was recorded in the right biceps femoris among all EMG measurements during kicking. A recent biomechanical study (Lin et al., 1999) examined the pressure distribution pattern and balance control during the kicking movement of TCC. The authors compared the pressure distribution patterns of the stable kick and unstable kick performed by a TCC athlete at national level. The mat pressure measurement system was used to collect the vertical reaction force and the pressure profile of the standing foot during a right kicking movement and a left kicking movement. The partial force and partial pressure were calculated. The pressure-time diagram of the phalanges, metatarsals and tarsals indicated that the pressure profiles or sequences tended to be stable each time the left kick was completed, and the phalanges produced 'fragmented' and large pressure points acting on the ground. The evidence supported a key point of practicing TCC that 'five toes grasping the ground to make us stable as a mountain'.

These biomechanical studies mentioned above emphasized the profiling of some specific TCC movements. Only a few biomechanical studies have concentrated on explaining the mechanism of TCC exercise for improving functional capacity, particularly in posture control and balance. Forrest (1997) tried to explain the mechanism behind the positive effect of TCC exercise on balance control after examining the effects of a sixteen weeks TCC training program on anticipatory postural adjustments. Eight subjects (average age 36.5 years) in good health, with no prior training in TCC were tested. The battery of tests included the dropping of a 2.2 kg load onto an unstable board, on which the subject stood, which was also on a force platform. The level and direction of instability were varied. The results found counterintuitive reductions in the anticipatory postural adjustments of several muscle groups while the standing stability improved. The author stated that the findings from his study could be used as an indication that practicing TCC leads to a greater use of the elasticity of the peripheral structures involving muscles, ligaments, and tendons while the participation of the central neural structures of postural equilibrium is decreased. In order to explore the mechanism of TCC exercise to improving posture control, more experimental evidence is needed.

BENEFICIAL EFFECTS OF TAI CHI CHUAN ON BALANCE CONTROL: TCC exercise demands precise joint movements, stability and balance. Performing TCC depends on either double-stance weight-bearing or single-stance weight-bearing maneuvers, which further requires pivoting the whole body or twisting the trunk. In performing TCC, the roles of the muscles continually change between stabilizers and movers, between weight-bearing and non-weight-bearing and between contraction and relaxation. It has been suggested that the practice of TCC may enhance the repertoire of motor programs stored in the brain (Tse & Bailey, 1992) and therefore may serve to train the various balance systems to promote greater steadiness. Numerous studies about the impact of TCC exercise on balance, muscle strength and flexibility have been reported and have demonstrated the beneficial effects of TCC exercise.

Cross-sectional comparison. Cross-sectional studies provided positive evidence that TCC has beneficial effects on balance and flexibility. Tse and Bailey (1992) reported that TCC practitioners performed significantly better on right and left single leg stance with eyes open, and heel-to-toe walking than the non-practitioners. But this was not the case with single leg stance with eyes closed. Lan et al. (1996) found that long-term TCC practitioners showed better scores in the stand-and-reach test. Hong et al. (2000) supported the findings by Lan et al. by reporting that long-term (13.2 years) elderly TCC practitioners performed better in

the tests of single leg stance with eyes closed (right and left), total body rotation (right and left), knee extension and ankle plantar flexion than the control group. These findings suggested that elderly people who exercise using TCC regularly and long-term, would improve their balance capacity with and without the help of vision.

TCC intervention. Besides the cross-sectional studies, a number of TCC intervention studies on balance capacity and muscle strength in elderly people have been conducted. Schaller (1996) found that a 10-week exercise of an easy-to-learn westernized form of TCC resulted in a significant improvement in the scores of single leg stance with eyes open, but not in the single leg stance with eyes closed. Moreover, the scores of the sit-and-reach test for TCC practitioners were not improved. Wolf et al. (1996) demonstrated with a large sample size, that a moderate TCC intervention could impact favorably on some biomedical and psychosocial indices of frailty. The results indicated that TCC participants had a substantial reduction in risk of multiple falls by as much as 47.5%, in addition to other positive influences such as an increase in hand grip strength, and increased ambulating speed. Fear of falling was also reduced in the TCC group when compared with the non-exercise group. Jacobson et al. (1997) reported significantly better balance control (tilting board test), strength of knee extension (maximal voluntary extension test) and kinesthetic sense (gleno-humeral medial rotation at 90 degree) in adult TCC participants than the sedentary control group after 12-week TCC intervention. Shih (1997) reported on the average velocity of sway in his study of a 16-week TCC intervention and stated that TCC exercise was associated with substantial reductions in antero-posterior sway velocities between pre and post tests.

The beneficial effects of low intensity TCC exercise on the maintenance of gains in balance and strength in the health of older adults has also been demonstrated by Wolfson et al. (1996). TCC intervention has helped alleviate joint pain and has increased strength, flexibility, and balance in older patients with osteoarthritis (Lumsden et al., 1998) and rheumatoid arthritis (Van Deusen & Harlowe, 1987; Kirsteins et al., 1991). TCC exercise has had therapeutic effects on improving the range of motion of the upper extremities and in preventing further deterioration. Table 1 summarizes the experimental evidence of TCC studies on balance, muscle strength and flexibility.

PREVENTION OF FALLS: Falls, a real problem in public health, are the main cause of accidental death in the elderly according to data from the American National Safety Council, (1988). Falls and subsequent fractures which occur in the elderly are a big medical and social problem throughout the world, increasing expenditure for chronic disease and disability. A poor balance capacity, decreased muscle strength and flexibility, and the changes of gait with aging are some of the risk factors related to falls in the elderly (Nickens, 1985; Perry, 1982). TCC exercise emphasizes continuous, slow movement with small to large expressions of motion, the shift of body weight from unilateral to bilateral, the progressive flexion of the knees, and rotation of the trunk, head and extremities. These movement components seemingly offer potential benefits in reducing the risk factors of falls. A study conducted by Wolfson et al. (1996), with a relatively large sample size, provided important scientific evidence that TCC exercise could impact favorably on reducing falls in elderly individuals. Wolf et al. (1996) examined the effects of intervention with TCC exercise or computerized balance training on improving frailty or reducing falls in older people through physical, functional, behavioral, and environmental measures with an education group serving as the control for the study. They compared the specific biomedical changes among the three groups. Yang's 108-form TCC was simplified to 10 forms for the TCC training. Each intervention lasted 15 weeks with hourly sessions for the education and balance training groups while the TCC group met for two hourly sessions but with a total instructional time equivalent to the other groups. All subjects were followed for 4 months after the 15 weeks of intervention. The results showed that TCC training reduced the number of falls by 47.5%, significantly attenuated the fear of falling, and improved physiological and psychosocial measures. These findings demonstrated the beneficial effects of TCC exercise on prevention of falling in elderly individuals. The changes of gait with aging are thought to be a factor related to falling in older persons. A preliminary study about the impacts of TCC exercise on gait in the elderly has been reported by Wolf and Gregor, (1999). They examined the gait of fifteen individuals from each of 20 independent living facilities. Each group experienced either 60 - 90 minutes of Tai Chi exercise classes twice a week for 48 weeks or received information on wellness behaviors for one hour per week over the same period. Three of the 15 volunteers from each facility were evaluated for strength and their gait analyzed every 4 months for a period of 2 years. All subjects were tested for baseline measures at the start of the project and then three times during the 1st year (during the TCC or wellness classes) and three times during the 2nd or follow-up year for a total of seven sessions. They calculated total body kinematics, lower extremity kinetics and center of pressure during gait initiation. They studied normal walking at a preferred speed and situations during normal walking where the individual had to move unexpectedly to the right in the step cycle and had to make unexpected turns beginning with either the right or left foot. The exemplar data indicated that individual strategies were apparent during each of these movements and that each subject displayed a unique movement signature during both walking and turning. This study provided an indication that examined the changes in kinematics and kinetics in TCC practitioners and made a comparison with those sedentary older person which might be helpful in exploring the scientific bases of the beneficial effects of TCC exercise in the prevention of falls in the elderly.

CONCLUSION: Tai Chi Chuan is a time-honored and life-time exercise that has gained recognition as an exercise form for people of a wide age range, for the younger and the older, for male and for female individuals. Studies have demonstrated that TCC may be classified as a moderate exercise, and its intensity does not exceed 55% of an individual's maximal oxygen intake (Zhuo, Shephard, Plyley, & Davis, 1984). The experimental evidence obtained from both cross-sectional and longitudinal studies suggested that TCC exercise has beneficial effects on musculoskeletal function, posture control capacity and reduction in falling in the elderly. This applied to either healthy people or patients with rheumatoid arthritis, or osteoarthritis. In consideration of the characteristics of TCC exercise and its valuable effect on improving the physical condition of human beings, at least in older people, TCC exercise has great potential value to health promotion and rehabilitation, particularly for

the maintenance of balance control in the elderly.

Among the published literature biomechanical studies on TCC are limited. A few of the characteristics of muscular activity, movement kinematics and kinetics during the performance of TCC are understood but how TCC exercise helps to improve the human balance control has not yet been explained. This question provides a big challenge to the scientists of medicine and biomechanics.

Table 1 Summary of the Studies of the Effect of TCC Exercise on Balance Control

Reference	Subject	Test item	Measuring methods	Results
Tse & Bailey (1992) (CS)	N = 9 (TCC) N = 9 (Con) Age = 65 to 86 yrs	Questionnaire & balance	- Single leg stance with eyes open and closed, - Heel-to-toe walking with eyes open	TCC group had significantly better posture control capacity with vision.
Schaller (1996) (10-wk IN)	N = 24 (TCC) N = 22 (Con) Age = 70 ± 5.9 yrs	Balance & flexibility	- Single limb stance with eyes open and eyes closed forms - Sit and reach test	Significantly improved the balance capacity with vision, did not change the flexibility.
Wolf et al (1996) (15-wk IN & 4-m follow up)	N = 72 (TCC) N = 64 (BT) N = 64 (Education) Age = 76.2 yrs	Muscle strength & flexibility	- Isometric contractions about the hip, knee, or ankle - Grip strength - Fear of falling questionnaire	Fear of falling was reduced after the TCC intervention compared with Education group.
Wolfson et al. (1996) (6-m TCC IN after 3-m BT & strength training)	N = 110 Age = 80 yrs (mean)	Balance & muscle strength	Losses of balance during sensory organization testing, single stance time, voluntary limits of stability, isokinetic torque of eight lower extremity movements, gait velocity	TCC training has the effects of maintenance for the significant gains of balance and strength.
Shih (1997) (16-wk TCC IN)	N = 110 Age = 30.8 ± 7.8 yrs	Balance	Velocity of sway in anterior and posterior at static and dynamic conditions	Significantly decreased the average velocity of sway on dynamic conditions, but not on static condition.
Jacobson et al. (1997) (12-wk TCC IN)	N = 12 (TCC) N = 12 (Con) Age = 30.4 ± 4.3 yrs	Stability, muscle strength & kinesthetic sense	Isometric muscle strength at 90°, Lateral body stability, kinesthetic sense in the glenohumeral joint at 30°, 45° and 60°	Lateral stability, kinesthetic sense at 60°, and strength of the knee extensor were significantly improved
Forrest (1997) (12-wk TCC IN)	N = 8 Age = 36.5 yrs	Anticipatory postural adjustments	Level and direction of instability on unstable board	Improved standing stability
Hong et al. (2000) (Case controlled study)		Balance capacity, trunk rotation, & flexibility	- Single limb stance with eyes open and eyes closed forms - Sit and reach test	

Note: CS: cross sectional study. IN: intervention. m: month. wk: week. Con, control. BT, balance training

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