THE KINEMATICAL CHARACTERISTICS OF THE LOWER EXTREMITIES DURING TAI CHI CHUAN EXERCISE

Dewei Mao, Youlian Hong, and Jingxian Li
The Department of Sports Science and Physical Education,
The Chinese University of Hong Kong, Hong Kong, China

There is broad consensus that Tai Chi Chuan exercise can improve the balance control and muscle strength of the lower extremities. However, the mechanism used to promote that balance control and muscle strength is still unclear. The purpose of this study is to provide evidence of the kinematical characteristics of the lower extremities during Tai Chi Chuan exercise and explain the way in which they benefit balance control and muscle strength. A female elite Tai Chi Chuan master was recruited to participate in the study. Five typical movements were selected: Brush Knee and Twist Steps, Step Back to Repulse Monkey, Wave Hand in Cloud, Kick Heel to Right, and Grasping the Bird's Tail. For each typical movement, three trials were recorded and digitized with a video motion analysis system. Kinematical parameters including the step length, the base of gait, angle of gait, mean ankle complex flexion, range of motion, range of motion rotation, and mean knee flexion, range of motion were calculated and analyzed. The results showed that compared to the normal gait, Tai Chi Chuan movements had a longer step length, a wider base of gait, and a larger angle of gait. The small angles and large range of motion existed in both the ankle complex and the knee joint. These kinematical characteristics may help to maintain stable posture and improve the muscle strength of the lower extremities during the performance of Tai Chi Chuan exercise.

KEY WORD: Tai Chi Chuan, ROM of knee, ROM of ankle complex, step length, base of gait, angle of gait.

INTRODUCTION: Studies of the risk factors that are associated with increased falls in community dwelling elderly people show that there is a relationship between the range of motion (ROM) of the knee and ankle complex and balance control and muscle strength. That is, as subjects age, both the force production in the lower extremities and the range of motion of the knee and ankle complex decrease (Mecagni et al. 2000, Whipple et al. 1987). Tai Chi Chuan (TCC) is a Chinese form of exercise that is derived from martial arts folk traditions. It entails extended and natural postures, slow and even motions, light and steady movements, and curved flowing lines of performance. Numerous studies of the impact of TCC exercise on balance control, muscle strength, and flexibility have shown its beneficial effects (Shih 1997, Hong et al. 2000). However, few studies have explored why TCC exercise improves muscle strength and improves balance control. The aim of this study was to 1) describe the characteristics of TCC exercise in terms of the kinematics of the lower extremities, and 2) to provide evidence to explain why and how TCC exercise helps to improve the balance control and muscle strength.

METHODOLOGY: A female TCC elite master (body height 50 kg, body height 157 cm, and aged 28 years) who was the mainland Chinese national champion in 1999 was recruited. A kind of 42-form TCC was selected because it was used for international and national TCC competition, and all basic and typical movements of the various TCC schools were included. Five typical movements, called Brush Knee and Twist Steps, Step Back to Repulse Monkey, Wave Hand in Cloud, Kick Heel to Right, and Grasping the Bird's Tail, were selected for analysis. These five fundamental movements were representative for the following reasons. 1) They come from the Five Stages of Change, Eight Trigrams, and Thirteen Positions that represent the essential or basic positions of TCC, and all of the postures of any given form are variations or manifestations of the thirteen basic, or essential positions (Huang, 1993). 2) They represent the five motion directions of the foot: forward, backward, sideward, upward, and central. The subject was asked to perform each typical movement three times. Two video cameras with 50 Hz frequency were used to film the movement. One camera was set laterally in the approach direction, and the other was set in the forward direction. Before video filming, the subject was asked to warm up and practice the movement to be studied several times. To make sure that the movement was performed continuously and smoothly, the subject was asked to perform three movements, one preceding and one following the movement to be studied. A total of 10 reflective light markers were attached at the bony marks for automatic digitization: the distal end of the mid-toe, the lateral malleolus, the rear of the mid calcaneus, the lateral femoral epicondyle, and the greater trochanter for both sides. The APAS motion analysis system (Ariel Dynamics, USA) was used to digitize the videos and calculate the kinematics parameters including the step length, the base of gait, the angle of gait, the mean ankle complex flexion, ROM, ROM of rotation, and mean knee flexion, ROM. The step length was defined as the distance between a consecutive contact of the mid calcaneus of two feet. The base of gait was defined as the perpendicular distance from the mid calcaneus of the front foot to the longitudinal axis of the rear support foot. The angle of gait was defined as the angle formed by the longitudinal axis of the two feet (Whittle, 2002). The joint coordinate system for the ankle complex and knee referred to the ISB recommendations for standardization on the ankle complex and knee joint respectively (The ISB Standards Subcommittee on the Ankle, Ge, 1995). The angle data were calculated only in the phase in which the foot had contact with the ground. An experienced biomechanics laboratory technician performed the video image digitization throughout the study so that the reliability of the data collection could be assured.

RESULTS:

Table 1 The mean ± standard deviation of the gait parameters and knee and ankle complex positions of typical movements (cm for length, degree for angle).

Typical movements	Step length (SD)	Base of gait (SD)	Angle of gait (SD)	Mean ankle angle (SD)	ROM ankle angle (SD)	ROM ankle rotation(SD)	Mean knee angle (SD)	ROM knee angle (SD)
Forward	80.7 (0.58)	69.7 (3.83)	79.5 (11.97)	69.1 (13.5)	65.9 (11.96)	59.26 (3.72)	124.4 (20.2)	75.1 (15.94)
Backward	58.3 (0.58)	44.7 (3.79)	84.1 (18.50)	72.1 (15.2)	62.2 (4.97)	45.8 (4.11)	136.2 (21.2)	72.1 (9.84)
Sideward	71.3 (2.08)	-	18.5 (2.44)	54.7 (8.9)	37.9 (3.29)	47.7 (4.99)	100.1 (15.6)	37.2 (7.84)
Upward	-	-	-	70.3 (13.2)	22.0 (0.92)	0.41 (0.19)	131.0 (13.5)	56.4 (1.09)
Center	83.0 (0.58)	75.5 (0.58)	80.3 (1.14)	70.8 (15.2)	42.7 (1.66)	19.6 (4.28)	138.0 (14.2)	75.3 (25.3)

Table 1 shows the mean ± standard deviation of the gait parameters and knee and ankle complex positions of typical movements. For the gait parameters, the values were larger during center movement than during the other movements, with the exception of the angle of gait of the backward movement. The angle of gait of the sideward movement was 18.5°, which is approaching the value of 12-15° provided by Whittle (2002) for normal gait in adults. The other three angles of gait were around 80°. Among the five typical movements, the mean angles were small but the ROM was larger both in ankle complex and knee joint compared to a young female normal walking (Li, 2003). Besides flexion motion, the ankle complex also has rotation motion, with the exception of upward movement. During the performance of upward movement, one foot (the support foot) was kept on the ground and the other foot was kicked in the air, and the rotation angle of the support foot should have been small. Due to the vibration of the support foot, the data of 0.41° should be reasonable.

DISCUSSION: Two key factors ensure body stability. The first is the support area in which the two feet are enclosed, and the second is the height of the body's center gravity. Figure 1 shows the area enclosed by the two feet. For the purpose of analysis, suppose that the line AB is the right foot, that CD is left foot, and that the lengths are the same and represented as f. CE is the line that extends from DC to AB, and the cross point is E. The length of CA, CE, and AE are a, b, c respectively. Then, the area of the four-sided ABDC is the total area of the triangle DEB and CAE. The equation to calculate is:

$$S = 1/2 \times (f-c) \times (f+b) \times \sin\alpha + 1/2 \times b \times c \times \sin(180-\alpha)$$
$$= 1/2 \times \sin\alpha \times (f^2 + f \times (b-c) - 2 \times b \times c) \qquad (1)$$

Equation (1) shows that the area is related to the length of foot f, the distance from the left heel to the longitudinal axis of right foot b, the distance from the cross point E to the right heel c, and the angle of gait a.

1) If f, b, c are constant, then there is a maximum value. That is, the larger the a, the more the S. When a is 90°, the area is the maximum value. At this moment, b is just the base of gait. The area is:

$$S = 1/2 \times (f^2 + f\times b - c\times f) \qquad (2)$$

2) If the a is a constant, then there is also a maximum value. That is, the smaller the c, the larger the S when c is zero, which indicates that the extend line of the left foot crosses the point of the heel of the right foot. The area gets a maximum value:

$$S = 1/2 \times \sin\alpha \times f \times (f+b) \qquad (3)$$

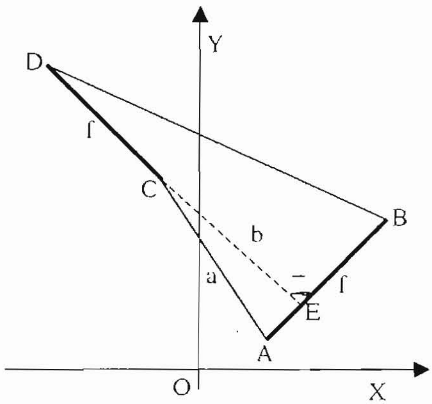

Figure 1 The area of two feet enclosed

From equations (1) to (3), it is clear that to increase the angle of gait a and the base of gait b, and decrease the difference between step length a and the base of gait b can increase the area of the two feet that is enclosed in S. For normal gait, the step length, base of gait, and angle of gait are 60.6cm, 8.9 cm, and 14° respectively (Whittle, 2002). These are much lower than the values obtained from TCC movements (Table 1). This may be one of the reasons why TCC exercise helps to maintain balance.

In comparison, the data reported by Li (2003) showed that the angle complex and the knee joint were around 90° and 175° respectively when females were normally standing on the ground. The mean angle of ankle complex and knee joint show that during TCC exercise, the ankle complex was 50° to 70°, which indicates that the ankle complex is in the dorsiflexion position. The mean angle of the knee joint ranged from 100° to 140°, which indicates that the knee position was kept in a semi squat posture. More dorsiflexion of the ankle complex and the semi squat position of the knee lower the body's center of gravity. Exercise in the semi squat position with continuous alteration of muscle activity from strong contraction to full relaxation and from concentric contraction to eccentric contraction may put a lager loading on muscles of the lower extremities when compared with the standing position (Xu, 2003). Long-term exercise may improve the muscle strength of the lower extremities.

During normal gait, the ROM of the ankle complex and knee joint are about 13° and 20° respectively (Li, 2003). However, the ROMs of the ankle complex and knee joint during TCC were very much larger than normal (Table 1). In addition, with the exception of the motion in dorsi-plantar directions, the ankle complex during TCC exercise also had inversion-eversion direction motions. From this viewpoint, TCC exercise can provide a larger ROM of ankle complex and knee joint exercise. Because there is a relationship between the ROM of the knee and ankle complex and balance control and muscle strength (Mecagni et al. 2000, Whipple et al. 1987), TCC exercise may increase the ROM of the knee and ankle complex, and thus improve muscle strength and balance control.

CONCLUSION: A long distance base of gait and a large angle of gait are beneficial to maintaining a large support area during TCC exercise. Small angles and a large ROM of the ankle complex and knee joint are beneficial to muscle strength and maintaining body posture. These may be the reasons why TCC exercise improves muscle strength and balance control.

REFERENCES:

Ge, W., & Peter, R.C. (1995). ISB recommendations for standardization in the reporting of kinematic data. Journal of Biomechanics, 28(10), 1257-1260.

He, C.F. (1990). A new type of Chinese Taijiquan 48 & Taiji sword 32. Hong Kong Joint Publication Co., 5-20.

Hong, Y.L., Li, J.X., & Robinson, P.D. (2000). Balance control, flexibility, and cardiorespiratory fitness among older Tai Chi practitioners. British Journal Sports Medicine, 34, 29-34.

Li, J.X., Hong, Y.L., & Mao, D.W. (2003). Gait and the metabolic adaptation of walking with negative heel shoes. Research in Sports Medicine, 11(4), 277-295.

Mecagni, C., Smith, J.P., Roberts, K.E., & Susan, B.O. (2000). Balance and ankle range of motion in community-dwelling women aged 64 to 87 years: a correlation study. Physical Therapy, 80(10), 1004-1011.

Shih, J. (1997). Basic Beijing twenty-four form of Tai Chi exercise and average velocity of sway. Perception motor Skills, 84, 287-290.

Xu, D.Q. (2003). The effects of Tai Chi exercise on proprioception and neuromuscular responses in the elderly people. Ph. D Thesis, 27-129.

Whipple, R.H., Wolfson, L.I., & Amerman P.M. (1987). The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. Journal of the American Geriatrics Society, 35, 13-20.

Whittle, M.W. (2002). Gait Analysis. Reed Education and Professional Publishing Ltd. 50-80.