BIOMECHANICS ANALYSIS OF "BRUSH KNEE AND TWIST STEPS" MOVEMENT IN TAI CHI

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The purpose of this study was to analyze the biomechanical characteristics of a typical Tai Chi (TC) movement - "brush knee and twist steps". A 3-Dimensional fixed video filming method was used for data collection. Three elite professional athletes of TC performed this movement three times and the best one was selected for analysis. The kinematics data included the distance of hands and feet, the angle between the feet, the joint angles of wrist, elbow and knee, the 3-dimensional displacement, velocity and acceleration of CG. The analysis showed that TC exercise could enhance the lower extremity muscular strength movement coordination, and the neuromuscular control for posture and balance.

KEY WORDS: tai chi, motion analysis, muscle strength, balance control.

INTRODUCTION: As a means of keeping fit, preventing and curing disease, TC has been widely practiced among the Chinese people since 16th century (Pang, 1987). The observed beneficial effects on health, particularly the maintenance of balance control in older people from TC, have drawn more and more attention from researchers and scientists. TC involves dance-like, graceful movements consisting of specific patterns and sequencing. As described by many literatures, the TC forms depend on either double-stance weight-bearing or single-stance weight-bearing maneuvers, which further requires pivoting the whole body or twisting the trunk. Awareness of movement sequencing originates through body loci at the waist and upper hips, with movement initiated in the semi-squat position and progressing to the distal joints. To our knowledge, however, among the published literatures there is a dearth of biomechanical studies for TC (Li, et al., 2000). The objective of this study was to analyze the kinematics characteristics of one of the typical TC movements - "Brush knee and twist steps", which would be helpful to explain how TC exercises improve the human balance control. This "Brush knee and twist steps" was chosen for analysis because this movement is identified as one of the eight fundamental movements of TC and found in all different TC schools (Pang, 1987). This movement is performed on left and right side symmetrically (Figure 1). The standardized performance of left "brush knee and twist steps" is described as follows (He, 1990): 1) Turn your torso slightly to the left, swinging right palm past torso with a downward curve and swinging left palm past side of the body with an upward curve. 2) As your torso turns to the right, the right palm sweeps right from downward and makes a half circle up to ear level with the palm obliquely upward. Meanwhile, the left palm swings across your torso to the right, until palm faces downward in front of right chest, palm obliquely downward. Draw the left foot back synchronized and in tempo to inner side of the right foot. Look at right palm.

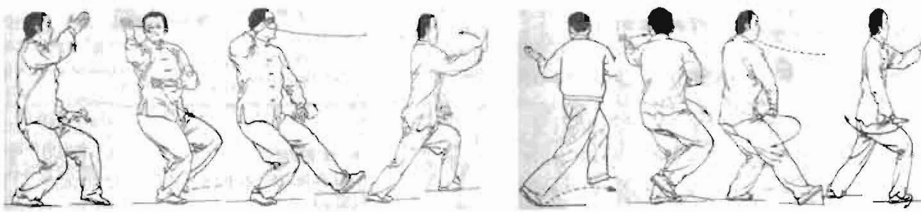

Figure 1. The movement of brush knee and twist steps.

METHODS: Three TC masters (two males and one female) with average 7 years of TC practice experiences were recruited as subjects. The average body weight and body height was 74 kg and 1.79 m in males and 50 kg and 1.57 m respectively. Each subject performed the "Brush knee and twist steps" three times and the best one that was deemed by a national level judger was chosen for analysis. Two video cameras with 50 Hz frequency were used to film the movement. One camera was set laterally of the approaching direction, the other was set in the front of the direction. The distance of both cameras to the starting position of the subjects was 13 m. Before video filming, the subjects were asked to warm up and practice movement to be studied several times. In order to make sure that the movement was performed continuously and smoothly, the subjects were asked to perform three movements, one preceding and one following the movement to be studied. A total of 21 reflective light markers were attached at the bony marks for automatic digitization and the construction of body model which consists of 15 body segments. The APAS motion analysis system (Ariel Dynamics, USA) was used to digitize the films and calculate the kinematics parameters including the displacement, velocity and acceleration of the center of gravity (CG), distance between the two hands, distance between the two feet, angle between the two foot longitudinal axes, wrist joint angle, elbow angle, and knee joint angles. The distance between the two hands was defined as the distance between the second metatarsals joints. The distance between the two feet was defined as the distance between the toes. All data were presented as mean and standard deviation. An experienced biomechanics laboratory technician performed the video image digitization throughout the study so that the reliability of data collection could be assured.

RESULTS: *Kinematics of the Upper Limbs.* The distance between two hands varied from 16% to 68% of the subject's body height with the average of 41% of the body height (BH). The elbow joint angle was found mainly in the range from 100 to 170 degrees and this accounted for 84.3% for the left and 85.7% for the right arm of the total movement time respectively. Similarly, the left and right wrist varied their angles in the range from 100 to 170 degrees for 84.8% and 86.3% of total movement time respectively (Table 1).

Table 1. The kinematics characteristics of upper limb.

Subject	Ratio of Distance between hands to BH (%)	Percentage time where elbow and wrist joint angles vary from 100 to 170 degree (%)			
		Left elbow	Right elbow	Left wrist	Right wrist
1	41	82.6	87.8	87.0	87.4
2	39	82.3	80.3	85.5	87.0
3	42	88.1	89.0	82.0	84.6
Mean	41	84.3	85.7	84.8	86.3

Kinematics of the Lower Limbs. The distance between the feet varied in a considerable range that was 13% to 63% of the subject's body height, averaging 45% of the body height. The angle between two feet varied from 30.9 to 113.0 degrees with the average of 63.8 degrees. The knee angles varied from 72.5 to 165.1 degrees with the average of 121.1 degrees for the left and varied from 60.6 degrees to 162.2 degrees with the average of 114.2 degrees for the right (Table 2).

Table 2. The Kinematics characteristics of lower limp.

Subject	Ratio of distance of feet to BH (%)	Angles between two feet (degree)	Knees angles (degree)	
			Left	Right
1	45	64.24	126.60	112.92
2	43	61.57	117.95	111.86
3	48	65.63	118.75	117.73
Mean	45	63.81	121.10	114.17

Kinematics of the CG. The position of CG during the movement was found at 34% to 45% of subject's body height, with the average of 40% of the body height (Fig 2). The CG moved in three dimensions and the average velocities of CG in the anterior-posterior (X), superior-inferior (Y) and media-lateral (Z) directions were 0.17, 0.07 and 0.22 m/s respectively. The acceleration of CG was very low with the average value of 0.47, 0.23 and 0.62 m/s/s in the X, Y and Z directions respectively (Table 3).

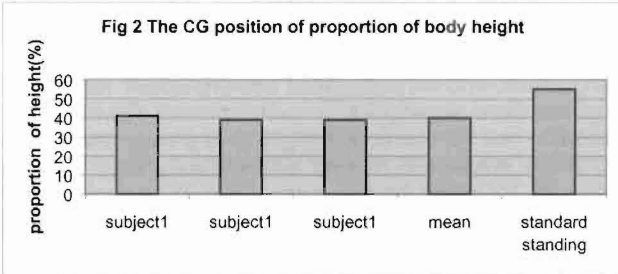

Figure 2. The CG position of the proportion of body height.

Table 3. The velocity and acceleration of CG.

	Velocity (m/s)			Acceleration (m/s^2)		
Subject	**X**	**Y**	**Z**	**X**	**Y**	**Z**
1	0.23	0.08	0.16	0.56	0.29	0.35
2	0.16	0.06	0.27	0.51	0.17	0.87
3	0.11	0.08	0.23	0.34	0.24	0.65
Mean	0.17	0.07	0.22	0.47	0.23	0.62

DISCUSSION: *Upper Limb Movement.* From the data for the distance between two hands and the angles of elbow and wrist joints, two movement characteristics can be found for the upper limb. First, the ratio of the distance between two hands to the body height was quite large. The relative large distance between the hands would increase the moment of inertia, relucting against the change of angular motion of the body (Peter, 1999) and enhancing the stability of balance. Second, the arms maintained circle form that was indicated by the relatively large angles of elbow and wrist for the most of movement time. This circle form of the arm demonstrated the characteristics of TC movement in which circle movement is addressed for the body segments. As stated by XU (1995), "TC not only can practice the movements with harmonious and unbroken but can move with the whole body segments and exercise the muscles, bones, ligaments with stabile and well distributed." From the scientific view, the circle movement characteristics in TC might increase the challenge in movement coordination between upper and lower limbs, and subsequently play the training effect on the movement coordination.

Lower Limb Movement. The lower extremity movements in "Brush knee and twist steps" have been characterized by the relatively large distance and angle between the feet, and the average knee angle that is found in the semi-squat posture. According to the rule of body balance control, supporting area is one of the factors that affect the stability of balance (Peter, 1999). Thus large distance between the feet might increase the body stability during the TC movement. Regarding the angle between the feet, the large range of change allowed the body to easily move in the three directions. The average value of the knee angles provided evidence that the semi-squat posture was assumed throughout the whole movement. The data also indicated that the deep squatting was also included in the movement, suggesting that strong muscle strength is needed. *The Movement of CG.* The data of the CG obtained from practicing the "brush knee and wrist step" revealed that CG was kept at low position, moved smoothly, slowly and continuously in the three directions (X, Y, Z), with very small acceleration. The lower position of CG (around 40% of subject's body height) suggested that body was kept in the semi-squatting posture. It is known that the CG position is at the level of 55% body height when standing erectly (Peter, 1999). The CG level during the TC movement was 15% lower than that in the standing, which increase the body stability on one hand and increase the demand to muscle strength on the other hand. The movement velocity of CG during the TC practice was found very slow, 0.17, 0.07 and 0.22 m/s in X, Y, and Z directions respectively. Moreover, the acceleration of CG was found considerably small, 0.47, 0.23 and 0.62 m/s^2 in X, Y, and Z directions respectively. The lower CG position, and the slow and smooth movement of TC require considerable amounts of muscle strength, endurance, and the capacity of neuromuscular control. Moreover, the body movement found in the three dimensions is more complex than that of walking which is mainly in two directions. Thus TC movement might have greater challenge to posture control and the muscles that are involved in moving different body segments coordinately. These movement characters of TC might be the reason why TC exercises have been found to improve and maintain the movement capacity, such as muscle strength and balance control.

CONCLUSION: During performing the "brush knee and twist steps" movement, the TC master showed coordinated upper and lower extremity movement. To enhance the stability of balance, the TC master maintained a large distance between hands and feet, and lowering the CG by maintaining a certain amount of knee angle. This knee angle, on the other hand, created the semi-squatting posture that would demand considerable exertion of eccentric contraction of the knee extensors. The very small three-dimensional velocity and acceleration of CG showed that neuromuscular control and movement coordination are required and therefore trained in practicing TC. The findings would help explain why long term TC exercise could improve strength, flexibility and balance, and prevention of falls.

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