BIOMECHANICAL ANALYSIS OF FOOT MOVEMENT DURING A SET OF TAI CHI CHUAN EXERCISE

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A set of the 42-form Tai Chi Chuan movements performed by a TCC master were studied using 3-D video filming and Pedar insole pressure measurement. The results showed that TCC exercise is full with the transform of foot positions among the single leg support, single leg support with the opposite leg semi support and double leg support in three dimensions and is full with the transform of different weight bearing patterns associated with the open and closed kinetic chain movement. There was the highest pressure in the hallux area during the single leg support phases, suggesting the training effects of TCC on hallus' muscle.

KEY WORDS: Tai Chi, kinematics, kinetic chain, foot pressure, hallux.

INTRODUCTION: Tai Chi Chuan (TTC) is a Chinese traditional exercise form that has been popularly practiced for several centuries by Chinese people and also has been understood and practiced as an exercise form by Western people since last century. The practice of TCC was originally related to concerns about the physical fitness and capacity for self-defence. However, over the centuries TCC has become far more focused on the enhancement of physical and mental health. The interaction between mind and body has long been seen as more important than the development of any martial arts skills. The TCC exercise is described as body movement at a slow and smooth velocity, semi-squatting body posture, circle movement path in limbs, well-coordinated sequencing movement in the segments of the body, and interaction between body movement, brain awareness and deep breath. A large body of scientific evidences has demonstrated the beneficial effects of TCC practice on human movement capacity in wide range of age, particularly in elderly people (Li, Hong, & Chan, 2001). The most considerable impacts of TCC practice are found on the improvement of muscle strength, flexibility and balance capacity (Li, et al., 2001). However, the mechanism of TCC on enhancement of movement capacity is still unclear. It has been suggested that studying the kinematics and kinetics characteristics of TCC exercise would provide scientific basis of TCC exercise on improving the movement capacity, particularly the balance capacity. Unfortunately, to our knowledge, little biomechanics study that describes the kinematics and kinetics characteristics of a whole set of TCC has been published. Only a few studies that profiled the kinematics characteristics in some TCC movements were reported in international conferences. With the increasing interest in TCC exercise and the understanding on the beneficial effects of TCC exercise on health, there is a need to quest the scientific basis of TCC practice on improving movement capacity, particularly muscle strength and balance capacity. In addition, the biomedical researchers have been particularly encouraged to fill the gap in TCC study so as to provide scientific evidences on how TCC exercise improves human movement capacity (Wolf, 1999). Therefore, the objectives of this study were 1) to analyse the kinematics and kinetic characteristics of foot movement in a whole set of TCC, and 2) to find any link between the kinematics and kinetics characteristics of TCC exercise and its training components on muscle strength and balance capacity. It was also hoped that this study could provide a strategy for data analysis in the future biomechanics analysis on TCC - a complex exercise and full with changes in movement.

METHODS: One 23-year old male TCC master, body height 1.82m and body weight 73 kg, was invited to participate in the study. 42-form Tai Chi was chosen for analysis because this set of TCC has been selected for international and national TCC competition, and all basic and typical movements of different TCC schools are included in this set. The movements were filmed by two video cameras (Sony, Japan), one located in front of and one laterally to the subject with 13 m distance, for three-dimensional analysis purpose. A total of 21 reflective light markers were fixed on the landmark positions of the subject for digitisation. The Pedar Insole Mobile system (Novel GmbH, Munich) was used to measure the foot pressure information during the subject's movement. The sample rate was 50 Hz for both video camera and Pedar system. The synchronization of video filming with Pedar insole measurement was realized by filming the LED trigged by Pedar system. APAS motion analysis system was used to digitise the video and calculate the kinematics parameters. In order to clearly describe the kinematics changes in TCC, the movement of foot was divided into four phases in accordance with the basic steps in TCC. They are 1) double leg support that was determined by the fully touch of two feet (DLS) on the ground, 2) single leg support that was determined as only one foot touching the ground while the other swinging (SLS), 3) one leg support with the other semi-support by the touch of toe that was determined as one foot fully touches while the other only touches on toe (SLSTT), and 4) one leg support with the other semi-support by the touch of heel that was determined as one foot fully touches while the other only touches on heel (SLSHT). The following kinematics parameters were calculated: 1) The total time of practicing the set of 42-form TCC, 2) The time proportion of DLS in the set, 3) The time proportion of SLS, left and right, in the set, 4) The time proportion of SLSTT, left and right, in the set, and 5) The time proportion of SLSHT, left and right, in the set. The Kinetics dada of Pedar system were processed using Novel Win software. Plantar pressure distribution and relative loads were extracted for seven areas: hallux and lateral toes (01, 02), medial, central, and lateral forefoot (03, 04, 05), midfoot (06), and heel (07). According to the kinematics data analysis, kinetics data were accordingly divided into four phases for analysis. The peak pressure and relative loads were calculated in all single support phases in both left and right sides. Paired t-test was used to compare any difference in the relative loads among different areas in foot mask. The level of $\alpha = 0.05$ was used for all tests as the criterion value in determining the presence or absence of significance. Data analysis was performed on SPSS (Windows).

RESULTS AND DISCUSSION: *Kinematics characteristics of foot movement*. In Practicing whole set of 42-form TCC took 6 minutes and 16 seconds. Throughout the practice of the set, there were total of 216 foot movement changes, in terms of touch down, fully touch, take off and swing in three directions, namely anterior-posterior, media-lateral, and superior-inferior. There was a transformation of foot position every 1.7 seconds. Figure 1 illustrates the results of kinematics analysis of foot movement. The average time of DLS accounted for 43 % of the total time. The average time of SLS accounted for 11% and 10% of the total time for left leg and right side respectively. The average time of SLSTT and SLSHT with the left leg full support was 11% and 6% respectively. On the other hand, for the right leg fully support the average time of SLSTT and SLSHT account for 12% and 6% respectively. The kinematics data analysis revealed that TCC movement is full with the change in foot position. This change is characterised by the shift of supporting space, from double leg support to full single leg support, and full single leg support with the opposite leg semi-support on toe or heel. Furthermore, the change of foot movement showed a symmetric trend between left and right. Performing TCC relies on double-stance weight-bearing and single-stance weight-bearing manoeuvres, which further require the pivoting of the whole body or twisting of the trunk. The kinematics data in foot movement demonstrated that in performing TCC, the roles of the foot continually change between the body supporter and movers, and weight-bearers and non-weight-bearers. Both the cross-sectional and longitudinal studies of TCC have demonstrated the effects of TCC on improving balance capacity (Tse, & Bailey 1992; Hong, Li, & Robinson, 2000). The change of foot among the four movement phases suggested that movement of TCC is characterised as the transform of open and closed kinetic chain movements. The two types of foot movement, SLSTT and SLSHT, allow the practitioners to control their body's centre of gravity and remain stable. Thus, the TCC exercise demands highly on the balance control capacity. Balance control of CG and accurate adjustment in foot position during the practice of TCC forces the muscles involved in to work hard, which would lead to the increased muscle strength. Unfortunately, the quantitative assessment of muscular activity involved in balance control and foot movement adjustment during TCC practice is still lacking and needs further investigation.

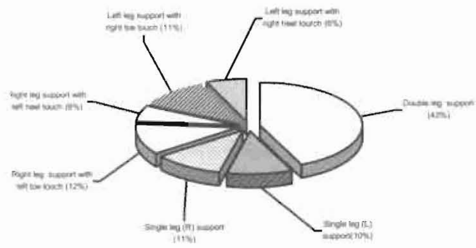

Figure 1. Time distribution of four types of foot movement phase in 42-form TCC practice.

Plantar pressure distribution Statistical analysis showed that there was a significant higher pressure ($p<0.000$) in the hallux area compared with other areas of the foot mask for the same foot in the single support phases during TCC practice. Except the hallux area, the pressures in other six areas of the foot mask showed relative similar pressure distribution. Figure 2 illustrate the average load in each area of foot mask in right and left foot. The evidence of high pressure in hallux area suggests that the hallux plays an important role in single leg support phases of TCC exercise.

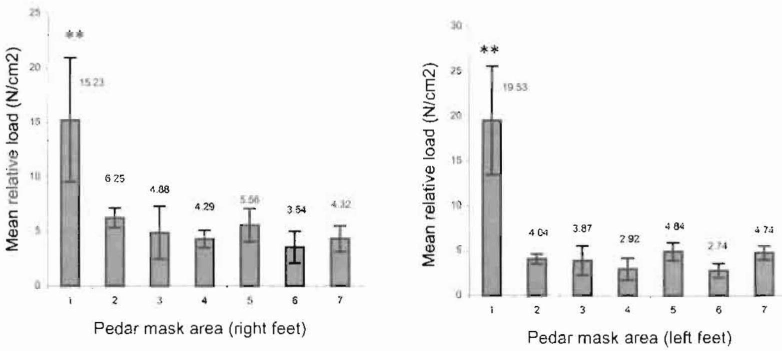

Figure 2. Average relative loads in each area of foot mask in right or left leg during single support phases in TCC exercise. Foot mask area: 1, hallux; 2, lateral toes; 3, medial forefoot; 4 central forefoot; 5, lateral forefoot; 6, midfoot; 7, heel. **, $P<0.000$, mask 1 vs mask 2, 3, 4, 5, 6, & 7 respectively.

Another remarkable finding of the kinetics was the greatest relative pressure in hallux area on the foot during the single support phases. Studies have found that the toe pressure weakness, particularly the hallux pressure weakness, is importance factor associated with posture instability (Tanaka, Nariyasu, & Ifukube, et al. 1996). Moreover, the distribution of body weight on soles of feet is changed as age (Yanagida, & Asami, 1997). The body weight distribution tended to shift from heels to outer toes across age (Yanagida, & Asami, 1997). The Elderly people had significantly greater hallux pressure than young people (Tanaka, et al., 1996). These evidences might indicate that the training on the toe exertion should be able to help improve the stability. The results from this study suggested that TCC exercise has high challenge to toe's exertion, and subsequently provide a training effect to the toe's muscle.

CONCLUSION: kinematics analysis of foot movement in performing a set of 42-form TCC demonstrated that TCC exercise is full with the transform of foot positions among the single leg support, single leg support with the opposite leg semi support and double leg support in three dimensions and full with the transform of full, semi-, and non-weight bearing associated with the open and closed kinetic chain movement. The kinetic data revealed that there was the highest pressure in the hallux area during the single leg support phases, suggesting the training effects of TCC on hallus' muscle.

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