The American Journal of Chinese Medicine, Vol. 34, No. 6, 959–968

Comparison of the Effects of Tai Chi Chuan and Wai Tan Kung Exercises on Autonomic Nervous System Modulation and on Hemodynamics in Elder Adults

Wan-An Lu
Department of Traditional Medicine, Ren-Ai Branch, Taipei City Hospital
Institute of Traditional Medicine, National Yang-Ming University School of Medicine, Taipei, Taiwan

Cheng-Deng Kuo
Laboratory of Biophysics, Department of Research and Education
Taipei Veterans General Hospital, Institute of Emergency and Critical Care Medicine
National Yang-Ming University School of Medicine, Taipei, Taiwan

Abstract: The health of the middle-aged and elderly people is a major concern given the rapid aging population and rising costs of medical care. Low-impact exercise on a regular basis is ideal for maintaining the well-being of an aging population. Tai Chi Chuan (TCC) is the most well-known and most widely practiced form of low-impact martial arts therapy and has been shown to have positive health effects. A lesser-known form of martial arts therapy is Wai Tan Kung (WTK), which our previous study found to have positive health effects as well. The present study compares the effects of TCC and WTK on autonomic nervous system modulation and on hemodynamics in adults among non-exercising control (30), TCC practitioners (30) and WTK practitioners (30). Our study found that in a short-term, WTK and TCC exercises enhanced the vagal modulation, lowered the sympathetic modulation and lowered arterial blood pressures in the practitioners. It was also observed that the forced vital capacity of TCC practitioners was significantly higher than that of WTK practitioners before exercise. There were no significant differences in the percentage changes in HRV measures and hemodynamics between WTK and TCC practitioners 30 and 60 min after exercise, indicating that the effects of WTK and TCC were similar in magnitude. In conclusion, TCC and WTK are comparable to each other in terms of their effects on autonomic nervous system modulation

Correspondence to: Dr. Cheng-Deng Kuo, Laboratory of Biophysics, Department of Research and Education, Taipei Veterans General Hospital, Taipei, Taiwan 112. Tel.: (+886) 2-2871-2121 (ext. 3364), Fax: (+886) 2-2871-0773, E-mail: cdkuo@vghtpe.gov.tw

and hemodynamics, thus suggesting that WTK can be just as beneficial as TCC as a form of low-impact exercise for elderly adults.

Keywords: Tai Chi Chuan; Taijiquan; Tai Ji Quan; Wai Tan Kung; Wai Dan Gong; Exercise; Calisthenics; Heart Rate Variability; Autonomic Nervous System; Martial Arts Therapy.

Introduction

Health promotion and disease prevention have become increasingly important topics for the public and for health professionals since the 1990s. Preventive care for the elderly has received increasing attention due to the rapidly uprising elderly population and the even more rapidly rising costs of medical expenses (Buchner and Wagner, 1992). Good nutrition and regular exercise can reduce the risk of various diseases and may extend the duration of life for many people, thereby serving as the best current prescription for a long and healthy life (Olshansky *et al*., 2002).

Aging is associated with the decline of physical capacity and the development of many chronic diseases. The vagal modulation was found to decrease in aging (Lipsitz *et al*., 1990) and various kinds of diseases such as acute myocardial infarction (Lombardi *et al*., 1987), diabetes mellitus (Lishner *et al*., 1987), chronic renal failure (Akselord *et al*., 1987), and congestive heart failure (Saul *et al*., 1988). As an integral part of most cardiac rehabilitation programs, regular exercise has the ability to remodel the cardiovascular system and modify the autonomic nervous control of the subject (Lan *et al*., 1999). Many studies have shown that supervised exercises in the elderly should emphasize aerobic, strengthening and flexibility training (Bravo *et al*., 1996; Morey *et al*., 1991).

Traditional Oriental methods offer many types of martial arts therapies that combine low-impact physical exercise and mental discipline. Among them, Tai Chi Chuan (TCC, also called Taijiquan or Tai Ji Quan) and Wai Tan Kung (WTK, also called Wai Dan Gong) are two very popular conditioning calisthenic exercises practiced by not only healthy subjects but also by patients with chronic diseases in many Asian countries. The difference of TCC and WTK is that TCC is characterized by slow, gentle and circular motions, whereas WTK is characterized by harmonic vibration, fluttering and trembling. It is estimated that more than one hundred million people worldwide practice TCC (China Sports Editorial Board, 1982), making it one of the most popular forms of physical conditioning especially among elder adults. On the other hand, WTK is relatively unfamiliar to the Western people.

TCC is a traditional Oriental mind-body calisthenics method that has a history of more than 300 years and has evolved to yield many types or branches of TCC (Mark, 1979). The basic TCC exercise is a series of graceful concentric and eccentric movements that are linked together in a continuous sequence and are performed in semisquat positions, so that the body is constantly shifting from foot to foot at a low center of gravity (China Sports Editorial Board, 1982). During the performance of TCC, slow breathing and mental concentration are required to achieve harmony between body and mind. TCC can significantly enhance the strength of the lower extremities; the upper extremities are in a relaxed state during TCC practice (Lai *et al.*, 1995; Lan *et al.*, 1998). Furthermore, TCC training has been shown to be beneficial to the cardiopulmonary function (Lai *et al.*, 1995; Lan *et al.*, 1998), balance (Wolfson *et al.*, 1996), strength (Lan *et al.*, 1998), and heart rate variability (Vaananen *et al.*, 2002) of subjects.

WTK is another popular, though perhaps less well-known, type of Oriental calisthenics. In contrast to TCC, WTK consists of 12 postures accompanied by a sequence of varying degrees of harmonic trembling and vibration of various groups of muscles in the extremities and the trunk. WTK is said to be able to enhance the functions of internal organs, relax the muscles, improve blood circulation, increase stamina, improve balance, enabling one to prolong a healthy and happy life (Chang, 1986).

It is already known that both WTK and TCC improve the health of the subjects (Lu and Kuo, 2003a; 2003b). While independent studies of TCC and WTK have compared practicing vs. non-practicing controls, no previous study has been done to compare these two similar but distinct forms of Oriental calisthenics. Therefore, the aim of this study was to compare the effects of TCC and WTK on autonomic nervous system modulation and hemodynamics in elderly adults.

Materials and Methods

Study Subjects and Study Design

Three groups of subjects were included in this study: TCC practitioners, WTK practitioners, and subjects without TCC or WTK experience. The TCC or WTK practitioners were recruited from TCC or WTK training centers in Taiwan. The TCC or WTK practitioners participating in this study were older than 30 years old with formal TCC or WTK training and have been practicing TCC or WTK regularly at least 1 hour each time, 3 times a week for at least 3 years. Those subjects who had normal 12-lead electrocardiogram (ECG) and pulmonary function and had no TCC or WTK experience were recruited from the community as the control. All subjects were capable of daily activities without apparent limitations. Subjects, who had cardiopulmonary disease or were on medications for diabetes mellitus, cardiovascular, renal or liver disease, were not included in this study. The Institutional Review Board of the Hospital has approved this study. The procedure was fully explained to the subject and the written informed consent was obtained from each subject before the study.

Equipments and Measurements

The subjects in this study were requested not to take caffeinated or alcoholic beverages for at least 24 hours prior to the study. The resting standard 12-lead ECG (IQmark Digital ECG and Digital Spirometer, Brentwood Medical Technology Corp., Torrance, CA), and arterial blood pressure measurement (Kenlu-model K-300 Sphygmomanometer, Di Tai Precision Ent. Co., Ltd. Taiwan) were performed on each subject before TCC or WTK with the subject lying in supine position. Spirometry (IQmark Digital ECG and Digital

Spirometer, Brentwood Medical Technology Corp., Torrance, CA) was performed on each subject before TCC or WTK in standing position Spirometry data such as the percentage of predicted forced vital capacity (%FVC = FVC of the subject/predicted FVC) and the ratio of the forced expiratory volume in the first second to the forced vital capacity (FEV_1/FVC), and hemodynamic data such as systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial blood pressure (MABP), and pulse pressure (PP) were obtained from each subject before TCC or WTK exercise.

Study Protocol

Before TCC or WTK, each subject rested in a supine position for 5 min, and 10 min of continuous ECG signals were recorded from lead II (Biochem Vital Sign Monitor, BCI International, Waukesha, WI). The sampling frequency for the ECG recording was 200 Hz. During TCC or WTK exercise, the subjects kept the same pace by performing those postures according to a pre-recorded tape or a WTK instructor to ensure that the same pace and sequence of postures were followed by the TCC or WTK practitioners. After baseline measurement and recording, the subjects were requested to exercise TCC or WTK for 40 min. Spirometry, ECG and blood pressure measurements were repeated at thirty and sixty minutes after the completion of TCC or WTK. All procedures were performed in a bright and quiet room with a constant temperature of 24 to 25^{o}C and humidity of 54 to 55%.

In the TCC group, Yang's method was used, as it is the most popular type of TCC in the literature. Each set of Yang's TCC includes 64 postures (China Sports Editorial Board, 1982). Each session of Yang's TCC exercise is 40 min in duration, including 10 min of warm-up exercise (lower back and hamstring stretching, gentle calisthenics, and balance training), 20 min of TCC exercise, and 10 min of cool-down (slower breathing and reduced muscle strength).

In the WTK group, each session of exercise is also 40 min in duration, including 5 min of warm-up preliminary movements, 30 min of WTK trembling and fluttering, and 5 min of relaxation. The preliminary movements of WTK include relaxing the whole body without exerting any strength, breathing naturally, and keeping the mind calm. Each set of WTK included 12 postures (Chang, 1986).

Heart Rate Variability Analysis

The R-wave detecting software was developed and then used to identify the peaks of the R waves in the recorded ECG signals, and to measure the consecutive RR intervals (RRI) for spectral HRV analysis. Sinus pause and atrial or ventricular arrhythmias were deleted, and the last 512 stationary RRI in each session were obtained for spectral HRV analysis.

The mean, standard deviation (SD_{RR}) and coefficient of variation (CV_{RR}) of the 512 RRI were calculated using a standard formula for each subject. The power spectra of RRI were obtained by means of fast Fourier transformation (Mathcad 11, Mathsoft Inc., Cambridge, MA). Zero-frequency component was excluded before the calculation of powers. The area under the curve of the spectral peaks within the ranges of 0.01–0.4 Hz, 0.01–0.04 Hz, 0.04–0.15 Hz, and 0.15–0.4 Hz were defined as the total power (TP), very low-frequency power (VLFP), low-frequency power (LFP), and high-frequency power (HFP), respectively. The normalized high-frequency power (nHFP = HFP/TP) was used as the index of vagal modulation; the normalized low-frequency power (nLFP = LFP/TP) as the index of sympathetic and vagal modulation; the low-/high-frequency power ratio (LFP/HFP) as the index of sympathovagal balance (Pomeranz *et al.*, 1985); and the normalized very low-frequency power (nVLFP = VLFP/TP) as the index of rennin-angiotensin-aldosterone system and vagal withdrawal of the subject (Taylor *et al.*, 1998).

Statistical Analysis

Kruskal-Wallis one-way analysis of variance on ranks (SigmaStat® 3.0 statistical software, SPSS Inc., Chicago, Illinois) was utilized to compare the baseline characteristics, hemodynamics, spirometry data, and HRV measures among TCC practitioners, WTK practitioners, and controls. To correct for baseline differences on the comparison of HRV and hemodynamic measures between WTK and TCC practitioners, the percentage changes in HRV measures and hemodynamics after WTK or TCC in each subject were calculated using the following formulae:

$$\begin{aligned}
\%X_{30WTK} &= [(X_{30\text{ min after WTK}} - X_{\text{before WTK}})/(X_{\text{before WTK}})] \times 100 \\
\%X_{60WTK} &= [(X_{1\text{ hr after WTK}} - X_{\text{before WTK}})/(X_{\text{before WTK}})] \times 100 \\
\%X_{30TCC} &= [(X_{30\text{ min after TCC}} - X_{\text{before TCC}})/(X_{\text{before TCC}})] \times 100 \\
\%X_{60TCC} &= [(X_{1\text{ hr after TCC}} - X_{\text{before TCC}})/(X_{\text{before TCC}})] \times 100,
\end{aligned}$$

where X stands for the variable to be compared. The Mann-Whitney rank sum test was utilized to compare $\%X_{30WTK}$ to $\%X_{30TCC}$, and $\%X_{60WTK}$ to $\%X_{60TCC}$. Wilcoxon signed rank test was employed to compare $\%X_{30WTK}$ with $\%X_{60WTK}$, or $\%X_{30TCC}$ with $\%X_{60TCC}$. A $p < 0.05$ was considered statistically significant.

Results

Baseline Characteristics

Thirty controls (M/F = 7/23), thirty WTK practitioners (M/F = 12/18), and thirty TCC practitioners (M/F = 14/16) were included in this study. Table 1 shows that there was no significant difference in the demographic data, FEV_1/FVC, and blood pressures among three groups except for the years of WTK or TCC training and %FVC. The %FVC of the TCC practitioners before TCC was significantly higher than that of WTK practitioners before WTK. The years of TCC or WTK experience of the practitioners did not correlate with the baseline HRV measures of TCC or WTK practitioners.

Table 1. Baseline Characteristics Among Control, WTK and TCC Practitioners

Baseline Characteristics	Control (n = 30)	WTK (n = 30)	TCC (n = 30)
Age, years	56.5 (32.0~72.0)	58.5 (48.0~70.0)	53.0 (41.0~71.0)
Sex (M/F)	7/23	12/18	14/16
Body weight, kg	57.0 (45.0~82.5)	60.0 (48.0~80.0)	58.0 (44.0~82.0)
Body height, cm	156 (145~175)	158 (148~180)	161 (146~180)
BMI, kg/m^2	23.7 (15.9~28.1)	24.3 (20.0~27.6)	22.7 (19.0~28.7)
WTK or TCC practice, years	0.0 (0.0~0.0)	2.3 (1.0~18.0)‡	2.0 (1.0~20.0)‡
%FVC, %	106 (65~166)	98 (64~127)	115 (81~161)†
FEV_1/FVC, %	78 (65~98)	78 (49~87)	78 (31~94)
SBP, mmHg	121.5 (90.0~144.0)	126.0 (98.0~150.0)	120.0 (100.0~142.0)
DBP, mmHg	72.0 (60.0~90.0)	80.0 (62.0~92.0)	72.0 (60.0~96.0)
MABP, mmHg	89.7 (70.0~106.7)	92.3 (74.0~110.0)	90.7 (73.3~111.3)
PP, mmHg	50.0 (20.0~72.0)	48.0 (24.0~70.0)	45.0 (30.0~72.0)

‡$p < 0.05$ vs. controls; †$p < 0.05$ vs. WTK practitioners (Kruskal-Wallis one way ANOVA with Turkey test). FVC = Forced vital capacity; FEV_1 = forced expiratory volume in the first second; BMI = body mass index; SBP = systolic blood pressure; DBP = diastolic blood pressure; MABP = mean arterial blood pressure; PP = pulse pressure; SpO_2 = arterial O_2 saturation; bpm = beats per min. Data are presented as median (range).

Table 2. HRV Measures of Control, WTK and TCC Practitioners Before Exercise

Measures	Control (n = 30)	WTK (n = 30)	TCC (n = 30)
Time domain			
Mean RRI, ms	872 (496~1094)	876 (679~1157)	888 (630~1114)
Heart rate, bpm	68.8 (54.8~93.9)	68.5 (51.9~88.3)	67.6 (53.9~95.2)
SD_{RR}, ms	27 (5~56)	33 (13~73)	34 (16~72)
CV_{RR}, %	3 (1~6)	4 (2~8)	4 (2~8)
Frequency domain			
TP, ms^2	255 (7~1249)	401 (42~1498)	342 (65~1695)
VLFP, ms^2	117 (1~721)	149 (17~585)	128 (2~605)
LFP, ms^2	41 (1~457)	90 (12~623)	93 (10~899)‡
HFP, ms^2	65 (5~705)	97 (5~436)	69 (2~582)
nHFP, nu	26.8 (7.0~75.1)	25.1 (7.2~52.0)	17.5 (2.4~80.4)
nLFP, nu	16.9 (6.7~43.4)	25.9 (12.8~42.3)‡	29.0 (11.9~60.0)‡
nVLFP, nu	43.6 (4.4~76.7)	39.3 (21.0~5.4)	40.3 (3.7~80.8)
LFP/HFP	0.6 (0.1~3.1)	1.2 (0.2~4.6)‡	1.7 (0.2~10.0)‡

‡$p < 0.05$ vs. the control (Kruskal-Wallis one way ANOVA with Turkey test). RRI = RR intervals; SD_{RR} = standard deviation of RR; CV_{RR} = coefficient of variation of RR; ms = millisecond; bpm = beats per min; nu = normalized unit; TP = total power; VLFP = very low-frequency power; LFP = low-frequency power; HFP = high-frequency power; nHFP = normalized high-frequency power; nLFP = normalized low-frequency power; nVLFP = normalized very low-frequency power; LFP/HFP = low-/high-frequency power ratio. Data are presented as median (range).

WTK and TCC Practitioners Before Exercise

Table 2 shows the HRV measures of control, WTK and TCC practitioners before exercise. The LFP, nLFP and LFP/HFP of the TCC practitioners before exercise were all significantly higher than those of the control. Similarly, the nLFP and LFP/HFP of the WTK practitioners before WTK were significantly higher than those of the control. These results suggested that the sympathetic modulation of TCC or WTK practitioners before exercise were significantly higher than that of the control.

WTK and TCC Practitioners After Exercise

Table 3 shows that the mean RRI, SD_{RR} and nHFP significantly increased whereas the heart rate and LFP/HFP significantly decreased 30 and 60 min after WTK or TCC exercise. The TP and VLFP significantly increased 30 and 60 min after WTK. The LFP and HFP significantly increased, whereas the TP and nVLFP significantly decreased 30 and 60 min after TCC. Thus, the post-exercise effects of WTK and TCC were enhanced vagal modulation plus suppressed sympathetic modulation in the WTK and TCC practitioners.

Table 4 shows that the SBP and MABP decreased 30 and 60 min after WTK and TCC. There were no significant differences in the percentage changes in all HRV measures and hemodynamic data between WTK and TCC practitioners 30 or 60 min after exercise. Therefore, the post-exercise effects of WTK or TCC on autonomic nervous system modulation and blood pressures were similar to each other.

Table 3. Percentage Changes in HRV Measures in WTK and TCC Practitioners 30 and 60 Min After Exercise

Measures	$\%X_{30WTK}$	$\%X_{30TCC}$	$\%X_{60WTK}$	$\%X_{60TCC}$
Time domain				
Mean RRI, %	0 (−7~16)	3 (−20~22)	6 (−18~24)*	6 (−23~35)#
Heart rate, %	0.2 (−14.1~8.0)	−2.7 (−17.9~24.4)	−5.4 (−19.1~21.4)*	−5.7 (−26.0~30.6)#
SD_{RR}, %	−4 (−58~83)	0 (−48~115)	2 (−32~90)*	13 (−46~273)#
CV_{RR}, %	−4 (−55~89)	−3 (−51~78)	−1 (−36~61)	6 (−48~178)
Frequency domain				
TP, %	−13 (−85~175)	7 (−59~403)	0 (−61~366)*	1 (−74~1503)#
VLFP, %	−26 (−95~274)	−8 (−78~617)	−8 (−88~378)*	5 (−79~829)
LFP, %	−12 (−86~249)	−3 (−75~455)	13 (−86~386)	22 (−83~2663)#
HFP, %	21 (−79~470)	27 (−64~722)	47 (−57~448)	35 (−68~2120)#
nHFP, %	35.4 (−61.4~184.8)	20.3 (−33.1~215.3)	27.2 (−52.5~226.9)	40.6 (−55.1~357.7)
nLFP, %	−7.2 (−61.4~67.3)	−12.0 (−52.9~298.5)	−0.7 (−64.8~104.7)	2.8 (−51.4~203.6)
nVLFP, %	−18.5 (−70.3~36.4)	2.8 (-62.2~451.9)	−21.6 (−70.9~32.3)	−21.2 (−61.8~329.3)#
LFP/HFP, %	−26.1 (−76.3~319.6)	−28.6 (−77.4~195.1)	−31.4 (−85.7~304.8)	−24.9 (−84.4~143.1)

*Significant difference vs. $\%X_{30WTK}$; #significant difference vs. $\%X_{30TCC}$. Data are presented as median (range).

Table 4. Percentage Changes in Hemodynamics in WTK and TCC Practitioners 30 and 60 Min After Exercise

Measures	$\%X_{30WTK}$	$\%X_{30TCC}$	$\%X_{60WTK}$	$\%X_{60TCC}$
SBP, mmHg	−1.4 (−15.4~9.1)	−4.4 (−23.1~7.4)	−2.3 (−15.4~9.1)	−4.2 (−23.1~1.9)
DBP, mmHg	0.0 (−20.0~12.9)	−2.5 (−14.3~12.9)	−0.0 (−20.0~12.9)	−2.4 (−14.3~9.7)
MABP, mmHg	−2.0 (−17.7~5.0)	−3.0 (−14.5~8.5)	−1.7 (−17.7~5.0)	−3.1 (−16.0~5.9)
PP, mmHg	0.0 (−44.4~56.3)	−5.7 (−48.0~7.7)	−0.8 (−44.4~47.1)	−8.5 (−48.0~7.7)

SBP = Systolic blood pressure; DBP = diastolic blood pressure; MABP = mean arterial blood pressure; PP = pulse pressure. Data are presented as median (range).

Discussion

TCC and WTK are two types of traditional Oriental mind-body calisthenics. TCC is characterized by its slow and graceful movements while WTK is unique for its whole-body trembling, fluttering and coordinated movements. TCC has gained worldwide popularity and recognition, while WTK is still relatively unknown to the Western world.

In this study, there was no significant difference in the hemodynamic or pulmonary function between TCC and WTK practitioners before and after exercise except that the %FVC of TCC practitioners before exercise was significantly higher than that of WTK practitioners before exercise. Since we did not perform a long-term study to evaluate the effect of TCC or WTK on the pulmonary function of the subjects in this study, the validity and significance of the difference in %FVC between TCC and WTK practitioners before exercise remain to be clarified.

The indicators of sympathetic modulation and sympathovagal balance (nLFP and LFP/HFP) in TCC and WTK practitioners before exercise were significantly higher than those of the control, while the index of vagal modulation (nHFP) in TCC and WTK practitioners was not significantly different from that of the control. It seems that the sympathetic modulation of the TCC and WTK practitioners was higher than that of the control before exercise. Since the heart rate, SBP, DBP, MABP, and PP of TCC and WTK practitioners before TCC and WTK were not different from those of the control, the above-mentioned change in HRV measures might not indicate that the sympathetic modulation in regular TCC or WTK practitioner before exercise was higher than that of the control. One possible explanation of our findings was that the experimental group might have been more aroused than control when they were about to perform TCC or WTK. Further studies are needed to clarify this ambiguity.

Hull *et al*. (1994) demonstrated that regular exercise not only increased the HFP, but also prevented ventricular fibrillation during acute myocardial ischemia. Goldsmith *et al.* (1997) indicated that physical fitness was highly correlated with vagal modulation as measured by HFP. Kurita *et al.* (1999) demonstrated that in the control subjects the LFP and LFP/HFP were not significantly changed during handgrip exercise, but the HFP were significantly increased. Wilmore and Costill (1999) stated that while the sympathetic system predominates during times of physical or emotional stress when the body demands are higher, the parasympathetic system again predominates after the stress subsides. In accordance with these studies, we found that the short-term or post-exercise effects of WTK or TCC were in enhancing the vagal modulation and lowering the sympathetic modulation of the WTK or TCC practitioners. In addition, we found that there were no significant differences in the percentage changes in all HRV measures and hemodynamic data between WTK and TCC practitioners 30 and 60 min after exercise. Our results suggested that the short-term effects of WTK and TCC on the autonomic nervous system modulation and on hemodynamics were comparable to each other. That is, the less popular WTK is as good as the more well known TCC as far as autonomic nervous system modulation and hemodynamics are concerned. Therefore, WTK is as worthy of introducing to the elderly people as TCC as an effective health promoting exercise.

In conclusion, both TCC and WTK are good calisthenics that can enhance the vagal modulation and suppress the sympathetic modulation with similar magnitude. The TCC and WTK are comparable to each other in terms of their effect on autonomic nervous system modulation and hemodynamics, suggesting that WTK can be just as good as TCC as a form of low-impact exercise for elderly adults.

Acknowledgments

This study was supported in part by the project VGHTPE91-376 of Taipei Veterans General Hospital, and in part by the project NSC91-2314-B-075-084 of National Science Council, Taiwan.

References

Akselord, S., M. Lishner, O. Oz, J. Bernheim and M. Ravid. Spectral analysis of fluctuations in heart rate: an objective evaluation of autonomic nervous control in chronic renal failure. *Nephron* 45: 202–206, 1987.

Bravo, G., P. Gauthier, P.M. Roy, H. Payette, P. Gaulin, M. Harvey, L. Peloquin and M.F. Dubois. Impact of a 12-month exercise program on the physical and psychological health of osteopenic women. *J. Am. Geriatr. Soc.* 44: 756–762, 1996.

Buchner, D.M. and E.H. Wagner. Preventing frail health. *Clin. Geriatr. Med.* 8: 1–17, 1992.

Chang, C.T. *Chinese WaiTanKung Illustrated: A Taoist Kung Fu for Your Health*. Ministry of Education, Taipei, 1986, pp. 1–63.

China Sports Editorial Board. *Simplified Taijiquan*, 2nd ed. China Sports Editorial Board, Beijing, 1982, pp. 1–5.

Goldsmith, R.L., J.T. Bigger, D.M. Bloomfield and R.C. Steinman. Physical fitness as a determinant of vagal modulation. *Med. Sci. Sports. Exerc.* 29: 812–817, 1997.

Hull, S.S., E. Vanoli, P.B. Adamson, R.L. Verrier, R.D. Foreman and P.J. Schwartz. Exercise training confers anticipatory protection from sudden death during acute myocardial ischemia. *Circulation* 89: 548–552, 1994.

Kurita, A., B. Takase, H. Hikita, A. Uehata, T. Nishioka, H. Nagayoshi, K. Satomura and S. Nakao. Frequency domain heart rate variability and plasma norepinephrine level in the coronary sinus during handgrip exercise. *Clin. Cardiol.* 22: 207–212, 1999.

Lai, J.S., C. Lan, M.K. Wong and S.H. Teng. Two-year trends in cardiorespiratory function among older Tai Chi Chuan practitioners and sedentary subjects. *J. Am. Geriatr. Soc.* 43: 1222–1227, 1995.

Lan, C., S.Y. Chen, J.S. Lai and M.K. Wong. The effect of Tai Chi on cardiorespiratory function in patients with coronary artery bypass surgery. *Med. Sci. Sports. Exerc.* 31: 634–638, 1999.

Lan, C., J.S. Lai, S.S. Chen and M.K. Wong. A 12-month Tai Chi training in the elderly: its effect on health fitness. *Med. Sci. Sports. Exerc.* 30: 345–351, 1998.

Li, J.X., Y. Hong and K.M. Chan. Tai chi: physiological characteristics and beneficial effects on health. *Br. J. Sports. Med.* 35: 148–156, 2001.

Lipsitz, L.A., J. Mietus, G.B. Moody and A.L. Goldberger. Spectral characteristics of heart rate variability before and during postural tilt: relation to aging and risk of syncope. *Circulation* 81: 1803–1810, 1990.

Lishner, M., S. Akslrod, V.M. Avi, O. Oz, M. Divon and M. Ravid. Spectral analysis of heart rate fluctuations: a non-invasive, sensitive method for the early diagnosis of autonomic neuropathy in diabetes mellitus. *J. Auton. Nerv. Sys.* 19: 119–125, 1987.

Lombardi, F., G. Sandrone, S. Pernpruner, R. Sala, M. Garimoldi, S. Cerutti, G. Baselli, M. Pagani and A. Malliani. Heart rate variability as an index of sympathovagal interaction after acute myocardial infarction. *Am. J. Cardiol.* 60: 1239–1245, 1987.

Lu, W.A. and C.D. Kuo. The effect of Tai Chi Chuan on autonomic nervous modulation in older persons. *Med. Sci. Sports. Exerc.* 35: 1972–1976, 2003a.

Lu, W.A. and C.D. Kuo. The effect of Wai Tan Kung on autonomic nervous modulation in the elderly. *J. Biomed. Sci.* 10: 697–705, 2003b.

Mark, B.-S. *Combined Tai Chi Chuan*. Chinese Wushu Research Institute, Boston, 1979.

Morey, M.C., P.A. Cowper and J.R. Feussner. Two-year trends in physical performance following supervised exercise among community-dwelling old veterans. *J. Am. Geriatr. Soc.* 39: 549–554, 1991.

Olshansky, S.J., L. Hayflick and B.A. Carnes. No truth to the fountain of youth. *Sci. Am.* 286: 92–95, 2002.

Pomeranz, B., R.J. Macaulay, M.A. Caudill, I. Kutz, D. Adam, D. Gordon, K.M. Kilborn, A.C. Barger, D.C. Shannon and R.J. Cohen. Assessment of autonomic function in humans by heart rate spectral analysis. *Am. J. Physiol.* 248: H151–153, 1985.

Saul, J.P., Y. Arai, R.D. Berger, L.S. Lilly, W.S. Colucci and R.J. Cohen. Assessment of autonomic regulation in chronic congestive heart failure by heart rate spectral analysis. *Am. J. Cardiol.* 61: 1292–1299, 1988.

Taylor, J.A., D.L. Carr, C.W. Myers and D.L. Eckberg. Mechanisms underlying very-low-frequency RR-interval oscillations in humans. *Circulation* 98: 547–555, 1998.

Vaananen, J., X. Sun, W. Shixuan, T. Laitinen, H. Pekkarinen and E. Lansimies. Taichiquan acutely increases heart rate variability. *Clin. Physiol. Funct. Imaging* 22: 2–3, 2002.

Wilmore, J.H. and D.L. Costill. *Physiology of Sport and Exercise*. Human Kinetics, New York, 1999, pp. 52–79 and 206–243.

Wolfson, L., R. Whipple, C. Derby, J. Judge, M. King, P. Amerman, J. Schmidt and D. Smyers. Balance and strength training in older adults: intervention gains and Tai Chi maintenance. *J. Am. Geriatr. Soc.* 44: 498–506, 1996.