Tai Chi Exercise Improves Age-associated Decline in Cerebrovascular Function: A Cross-sectional Study

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Abstract

Background: Tai Chi exercise has been reported to enhance physical and mental health in the elderly; however, the mechanism remains elusive.

Trial Design: We recruited 289 elderly people practicing Tai Chi for over 3 years, together with 277 age-matched old people and 102 young adults as controls. 168 Tai Chi players were successfully matched to 168 elderly controls aged 60-69 based on a propensity score for statistics.

Methods: Cerebrovascular function was evaluated by measuring the hemodynamics of the carotid artery. Spearman correlation was performed to validate the age-associated physiological parameters.

Results: Cerebrovascular function in the elderly significantly degenerated compared with young people, and was substantially correlated with age. Compared with the elderly control group, Tai Chi players showed significant improvements in CVHI (cerebral vascular hemodynamics indices) Score ($P = 0.002$), mean blood flow velocity ($P = 0.014$), maximal blood flow velocity ($P = 0.04$) and minimum blood flow velocity ($P < 0.001$), whereas the age-related increases in pulse wave velocity ($P = 0.022$), characteristic impedance ($P = 0.021$) and peripheral resistance ($P = 0.044$) were lowered.

Conclusion: These data demonstrate a rejuvenation role of Tai Chi in improving the age-related decline of the cerebrovascular function.

Trial registration: Chinese Clinical Trial Registry (ChiCTR1900025187).

1. Background

A combination of remarkable increases in life expectancy and declining fertility rates results in a larger elderly population, a problem challenging economic development globally [1]. Although expected lifespan has continued to elongate in past decades, healthspan has barely increased [2]. Moreover, most efforts in research are dedicated to promote longevity, but few studies focus on improving healthy ageing [3, 4].

One major issue impeding the development of this field is the lack of reliable healthspan indicators or biomarkers. Age is an independent risk factor for cerebrovascular diseases, which dominate common health problems in the elderly [2]. Decline in cerebrovascular function is a leading cause for age-related cognitive deterioration, accompanying with high incidence of Parkinson disease, Alzheimer’s disease and stroke [5–8]. Age-related alterations in cerebrovascular function result in increased arterial stiffness, chronic vascular inflammation and endothelial dysfunction, and cause hypertension, arrhythmia, that commonly seen in the elderly [9, 10]. Hence, cerebrovascular functions reflect the health status in the elderly.

Regular sport exercise is associated with improvement in physical health and protection against cerebrovascular diseases [11, 12]. Tai Chi is a famous exercise suitable for the elderly due to its slow and gentle movements [13]. A growing body of carefully conducted research has demonstrated the beneficial
effects of Tai Chi on many conditions commonly associated with age, such as fall prevention, cognitive performance improvement, and muscle strength [14–18]. In addition to disease prevention, Tai Chi has been reported to be an effective treatment for certain neurodegenerative disorders like Parkinson disease and Alzheimer’s disease [15, 17, 19]. However, the mechanism by which Tai Chi exerts beneficial effects on healthy ageing remains elusive.

Here we conducted a cross-sectional study to investigate the impact of Tai Chi practice on age-associated declines of cerebrovascular function by measuring the hemodynamics of the carotid blood flow. Our study provides direct evidence for the anti-ageing effect of Tai Chi through improving blood supply in the brain.

2. Methods

2.1 Trial design

From December 2017 to March 2018, we recruited elderly Tai Chi players, together with age-matched and young adults as controls in Wuhan, China to evaluate the effects of Tai Chi on age-related changes in cerebrovascular functions. This study was approved by both Ethical Committees from Renmin Hospital of Wuhan University and from Wuhan Sports University. This study was registered on Chinese Clinical Trial Registry (http://www.chictr.org.cn; ChiCTR1900025187), and performed in accordance with the principle of the Helsinki Declaration II. Written informed consent was obtained from all participants in advance.

2.2 Basic measurement

All the participants were given a clinical and physiological examination at the Physical Examination Centre, Renmin Hospital of Wuhan University (Wuhan, China). We recorded the gender, age, weight, systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate and calculated body mass index (BMI). Blood pressure in the arms was measured using an automated oscillometric device (OMRON-M6, Omron Healthcare, Vernon Hills, Illinois, USA).

2.3 Measurement of cerebrovascular function

Left internal carotid artery hemodynamics were measured using a cerebrovascular function tester GT-3000 (Sino Hi-tech, Beijing, China). Cerebral vascular hemodynamics indexes (CVHI) were calculated. The recorded or calculated parameters include CVHI score, mean blood flow rate (Qmean), mean blood flow velocity (Vmean), maximum blood flow velocity (Vmax), minimum blood flow velocity (Vmin), pulse wave velocity (Wv), characteristic impedance (Zcv), dilatability (DI), resistance vascular (Rv), dynamic resistance (DR), critical pressure (CP) level, and diastolic pressure and critical pressure difference (DP).

2.4 Statistical analysis

All data were processed using SPSS 22.0 (IBM Corporation, Armonk, New York, USA) and GraphPad Prism software 8.0 (San Diego, California, USA). To carry out stratified analyses, we performed the propensity
score matching process while simultaneously forcing an exact match of gender, BMI, and age between elderly control group and the Tai Chi group. Then we compared matched groups within clinical parameters. All continuous variables were summarized as mean ± standard deviation (SD), and non-normally distributed continuous variables were summarized as median (25th -75th ). The statistical difference in continuous variables normally distributed data between the two groups was compared using the student’s t test. The Mann-Whitney U test was used for comparisons between groups for non-normally distributed continuous variables. A correlation Spearman test was used to test the coefficients of non-normally distributed continuous variables. P < 0.05 was considered statistically significant. All statistical analyses were two-tailed.

3. Results

3.1 Validation of changes in cerebrovascular function during ageing

We recruited a total of 668 participants, including 289 people aged 49–76 (117 male/ 172 female) who have practiced Tai Chi together with 277 people aged 51–73 (131 male/ 146 female) without Tai Chi training before and 102 young adults aged 22–25 (49 male/ 53 female) (Fig. 1).

To validate which cerebrovascular parameters indeed reflect the health status of the elderly, we first examined the correlation between each parameter and age in elderly control group (Fig. 2). As expected, SBP was significantly correlated with age in the elderly (correlation coefficient 0.182; P < 0.001), and was significantly higher than young controls (P = 0.002; Fig. 2A and 2B). Most of the cerebrovascular function parameters, including CVHI Score, Qmean, Vmean, Vmax, Vmin, Wv, Zcv, DI, Rv and DR, were significantly correlated with age in the elderly (Fig. 2A). Among these parameters, Vmean and Vmin ranked top with high correlation efficient, -0.303 (P < 0.001) and − 0.353 (P < 0.001) respectively, and also significantly decreased in the elderly compared with young controls (Fig. 2A and 2C-E). These data suggest that cerebrovascular function serves as reliable marker to reflect the health status of the elderly.

3.2 Tai Chi exercise improves the age-related decline in cerebrovascular function

To evaluate the effects of Tai Chi exercise, we ran a matching program between Tai Chi group and the elderly control group aged 60–69 years old based on a propensity score to reduce the bias of age, gender and BMI. A total of 168 Tai Chi players were successfully matched to 168 elderly controls, and were used for further analysis. There were no significant differences in basic physiological characteristics between the matched two groups (P > 0.05) (Table 1).
Table 1
Basal characteristics of the young and the matched elderly controls and Tai Chi players.

|                  | Young (n = 102) | Old (n = 168) | Tai Chi (n = 168) | P value# |
|------------------|----------------|--------------|-------------------|---------|
| Age (y)          | 23.25 ± 1.11   | 63.7 ± 2.54  | 63.79 ± 2.51      | 0.762   |
| Weight (kg)      | 62.96 ± 10.09  | 63.18 ± 10.35 | 63.92 ± 9.54      | 0.496   |
| BMI (kg/m²)      | 22.18 ± 2.52   | 24.12 ± 3.09 | 24.17 ± 2.96      | 0.886   |
| SBP (mmHg)       | 115.37 ± 12.74 | 137.55 ± 18.48 | 136.8 ± 16.38     | 0.691   |
| DBP (mmHg)       | 68.98 ± 8.52   | 77.03 ± 10.62 | 78.08 ± 10.09     | 0.352   |
| Heart rate (bmp) | 69.35 ± 11.04  | 75.02 ± 11.65 | 73.51 ± 11.29     | 0.227   |

BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure. #, P values are calculated by comparing elderly group with the Tai Chi group.

CVHI Score is an overall evaluation score for cerebrovascular hemodynamic analysis. Compared with the elderly controls, Tai Chi players showed a significant increase in CVHI Score [86.63 (72.25-95.00) in Tai Chi group and 91 (81.25–98.31) in elderly control group; P < 0.01], which almost approached the level in young control group [92.25 (86.63-97)] (Table 2). In detail, Tai Chi significantly increased the carotid blood flow velocity including Vmean (P = 0.014), Vmax (P = 0.04) and Vmin (P < 0.001), whereas reduced arterial resistance indices including Wv (P = 0.022), Zcv (P = 0.021) and Rv (P = 0.044) (Table 2). These data suggest a rejuvenation of the carotid hemodynamics by Tai Chi exercise in the elderly.
Table 2
Impact of Tai Chi practice on cerebrovascular hemodynamics.

|                  | Young (n = 102) | Older (n = 168) | Tai Chi (n = 168) | P value# |
|------------------|-----------------|-----------------|-------------------|---------|
| CVHI Score       | 92.25 (86.63-97)| 86.63 (72.25-95)| 91 (81.25–98.31)  | 0.002   |
| Qmean (cm/s)     | 9.55 (8.42–11.2)| 9.18 (8.48–10.31)| 9.6 (8.73–10.39)  | 0.151   |
| Vmean (cm/s)     | 22.72 (21.15–24.5)| 17.58 (15.87–19.56)| 18.35 (16.86–20.62) | 0.014   |
| Vmax (cm/s)      | 49.61 (45.91–53.51)| 36.59 (33.23–39.91)| 38.23 (33.92–41.43) | 0.04    |
| Vmin (cm/s)      | 11.52 (10.33–12.4)| 8.27 (7.38–9.15) | 8.56 (7.97–10.04) | < 0.001 |
| Wv (m/s)         | 9.97 (7.99–12.44)| 19.87 (15.5-23.96)| 18.04 (14.19–22.24) | 0.022   |
| Zcv (kPa·s/m)    | 10.46 (8.4-13.06)| 20.87 (16.28–25.16)| 18.94 (14.9-23.36) | 0.021   |
| DI               | 0.96 (0.77–1.2) | 0.53 (0.43–0.66) | 0.54 (0.44–0.66) | 0.606   |
| Rv (kPa·s/m)     | 49.52 (44.18–56.78)| 75.12 (64.4–90.8) | 71.56 (63.69–81.15) | 0.044   |
| DR (kPa·s/m)     | 27.03 (23.71–31.71)| 45.83 (34.88–54.69)| 42.57 (34.34–52.45)| 0.144   |
| CP (kPa·s/m)     | 5.35 (4.14–6.27)| 5.92 (4.51–7.05)| 5.85 (4.46–6.91) | 0.876   |
| DP (kPa)         | 3.19 (2.72–3.82)| 3.68 (2.94–4.49)| 3.73 (3.05–4.48) | 0.515   |

Data are median (25th -75th ). Variables are analyzed with Mann-Whitney U test for comparisons. P < 0.05 is considered statistically significant for two-tailed tests. #, P values are calculated by comparing elderly control group with the Tai Chi group. CVHI, cerebral vascular hemodynamics indices; Qmean, mean blood flow rate; Vmean, mean blood flow velocity; Vmax, maximum blood flow velocity; Vmin, minimum blood flow velocity; Wv, pulse wave velocity; Zcv, characteristic impedance; DI, dilatability; Rv, resistance vascular; DR, dynamic resistance; CP, critical pressure; DP, diastolic pressure and critical pressure difference.

4. Discussion

Ageing and age-related diseases have become the major threat to human health [20]. Maintaining normal functional ability while getting old is the major goal to achieve healthy ageing. However, lack of clinical makers to indicate the health status in the elderly substantially prevents the development of this research field. Here we demonstrate that the cerebrovascular function represents a reliable indicator for healthy ageing, and Tai Chi exercise is effective to improve the age-related decline in cerebrovascular function.

Since cerebrovascular ageing is associated with cognitive decline, dementia and brain pathology, it is crucial to unveil the predictors of cerebrovascular function status for early detection and prevention [21].
Previous clinical evidence has shown that the cerebrovascular indices were highly sensitive to ageing [22, 23]. In the present study, we identified 11 cerebrovascular parameters that were significantly correlated with age in the elderly. CVHI score is a hemodynamic indicator reflecting the cerebrovascular structure and function, and is closely related to the occurrence of cerebrovascular diseases. Lower Vmax and Vmin in the aged people suggest that the blood supply is frequently insufficient, a possible reason for the high incidence of neuronal diseases in the elderly.

Arterial hemodynamics indices Vmean, Vmax, and Vmin are main parameters reflecting diastolic blood flow velocity. Cerebral dynamic Wv and Zcv are related to the elasticity of the arterial wall. Lowered Wv and Zcv indicate the better overall elasticity of the arteries. Rv is a quantitative indicator of the degree of the flow of small blood vessels and capillaries. Compared with the elderly controls, those who have practiced Tai Chi for 3 years showed alterations in most of the cerebrovascular parameters towards the young controls (Table 2). Firstly, these findings prove the effectiveness of Tai Chi to improve the cerebral health status in the elderly. Secondly, these findings support that the cerebrovascular parameters might serve as reliable indicators for healthy ageing. Thirdly, our study implicates that the age-related decline in cerebrovascular function is a reversible process. These ideas would prompt novel strategies to develop anti-ageing products.

Tai Chi has many positive effects on the health of the elderly, including improved motor ability, exercise efficiency and emotional state [24, 25]. In this study, we found that Tai Chi-style physical activity could prevent the ageing-induced cerebrovascular function decline of the elderly, which may effectively reduce the related cerebral diseases [16, 26–28]. In addition to the treatment of specific diseases, Tai Chi players provide a cohort of healthy ageing population, which would be an irreplaceable opportunity to investigate the molecular mechanisms of ageing in human.

This study also has some limitations. Firstly, this is a cross-sectional study involving a cohort of Tai Chi players with variable durations of Tai Chi practicing. The impact of duration or intensity of Tai Chi practicing on cerebrovascular function need to be further investigated. Secondly, we did not select another style of exercise as a strict control for Tai Chi. Thus, the observed changes would also reflect a general impact of regular physical activity. Thirdly, the conclusions need to be further validated by a longitudinal cohort with well-controlled Tai Chi training.

Taken together, in this cross-sectional study, we found that the age-related decline in cerebrovascular hemodynamics in the elderly is significantly improved by Tai Chi practice. Our findings provide novel insights into healthy ageing and anti-ageing strategies.

**Abbreviations**

SBP systolic blood pressure

DBP diastolic blood pressure
BMI body mass index
CVHI Cerebral vascular hemodynamics indexes
Qmean mean blood flow rate
Vmean mean blood flow velocity
Vmax maximum blood flow velocity
Vmin minimum blood flow velocity
Wv pulse wave velocity
Zcv characteristic impedance
DI dilatability
Rv resistance vascular
DR dynamic resistance
CP critical pressure
DP diastolic pressure

**Declarations**

- **Ethics approval and consent to participate**

This study was approved by both Ethical Committees from Renmin Hospital of Wuhan University and from Wuhan Sports University. This study was registered on Chinese Clinical Trial Registry (http://www.chictr.org.cn; ChiCTR1900025187), and performed in accordance with the principle of the Helsinki Declaration II. Written informed consent was obtained from all participants in advance.

- **Consent to publish**

Not applicable.

- **Availability of data and materials**

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

- **Competing interests**

There is no confliction of interests.
- Funding

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- Authors' Contributions

Z.W., T.L. and X.C. conceived and designed the project. L.L., J.W., G.S., X.Y., K.X., C.Y., H.Y., Z.D., J.W. and Y.J. collected the data. L.L. and J.W. performed analyses. L.L. and Z.W. drafted the manuscript. All authors have read and approved the manuscript.

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