# TAI CHI AND OLDER ADULTS' HEALTH:
# A NETWORK SCIENCE APPROACH

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**Abstract**

*This study examines the association between older adults' health and Tai Chi based on the past 25 years which between 1996 and 2020. Data was drawn from PubMed, Web-of-Science and Scopus. Patterns, trends, changes and opportunities were estimated by means of scientometric tools built on 2,202 articles, from 6,820 authors, with 26,408 citations from 3,215 institutes in 61 countries. USA, China and UK are the main countries of scientific achievement, while the Harvard Medical School and Chinese University of Hong Kong are at the top of inter-institutional research collaborations. Wolf, Steven L. is the author more cited while Wayne, Peter M. is the most productive author. The hot spots are balance, mindfulness-meditation, osteoarthritis, sleep quality, cardio respiratory function, mental problems, and pain. A network science approach allows to explore the complex structure of Tai Chi networks and to construct arguments about the development of the field. Tai Chi by involving physical movement, controlled breathing and meditation helps to maintain emotional regulation and to be self-aware, necessary for a healthy mind. Being an integral part of Chinese culture, Tai Chi as a weak implementation in the Western countries. The mental and physical benefits of Tai Chi, where time, place and practices are flexible and no special equipment is required, should make it an integral part of both cultures.*

*Keywords: Older adult's health, Tai Chi, Network science analysis, Scientometrics, PubMed, Web-of-Science, Scopus*

## INTRODUCTION

This study focuses the attention in a market segment that is becoming more and more important as a result of the progressive aging of the population and the increase in life expectancy. With the rapid growth of elderly populations worldwide, particularly in developed countries, the prevalence of various age-related diseases has significantly increased (Cheng *et al.*, 2020; Si *et al.*, 2021), namely, various neurodegenerative disorders (Langa, 2018).

According to Megari (2013), during the past decades there was an increasing predominance of chronic disorders, as a result of improved living conditions, better prevention, infectious diseases management, medical technological improvements and overall aging of the population. Atherosclerosis and its effects on diabetes, emphysema, neoplasia, osteoarthritis and cirrhosis are slowly decreasing in prevalence, creating an era where the main health problems are the aging process itself, regardless of specific diseases (Milbank, 2005).

The inevitability of death guides the health sector in postponing both illness and senescence, while improving the vitality of the elderly. Tai chi as a body-mind exercise program has substantial health-promoting benefits (Behere *et al.*, 2019), including physical and mental activity, psychological well-being (Blake and Hawley, 2012) and a better quality of life (Lan *et al.*, 2013). The calm and uncompetitive nature of tai chi makes it recommended in health programs for all ages, where time, place and practice can be very flexible, without the need for special equipment (Yan, 1998). The multifaceted characteristics of Tai Chi can enhance cognition and brain health in older adults (Wayne *et al.*, 2014; Chang *et al.*, 2014; Jiang *et al.*, 2016), can strengthens muscles (Lan *et al.*, 2013), increase balance and confidence of the older adults (Liu and Frank, 2010), and can prevent falls (Gillespie *et al.*, 2012). Fall is seen as the cause of more than half of hospital admissions for older adults (El-Khoury *et al.*, 2013; Wayne, *et al.*, 2011). Cardiovascular conditions (Pan, 2016; Pan *et al.*, 2016; Pan *et al.*, 2015), cardiopulmonary function (Sun *et al.*, 2019), rheumatology (Wang, 2012), chronic pain (Peng, 2012), osteoporosis and cancer (Drake, 2013), are other areas where tai chi can be applied. This mind-body exercise has also been used in people with Parkinson's disease (Lee *et al.*, 2008; Amano *et al.*, 2013; Li *et al.*, 2014), depression (Liu *et al.*, 2019) and problems of sleep (Si *et al.*, 2019). The Alzheimer's Association (2020) shows the importance of factors linked to a greater cognitive decline, such as depression and anxiety which can be combated, among other factors, by the development of physical activity and higher body mass index, which can be obtained through of Tai Chi. Dementia shortens the lives of those affected, as well as their family and caregiver, and is projected to be 74.7 million people in 2030 and 131.5 million people in 2050 (Prince *et al.*, 2015).

The evolution over time of the number and complexity of scientific research makes a networked science approach necessary (Watts and Strogatz, 1998; Watts, 2004). As far as we know, most studies done so far on Tai Chi are mainly descriptive, cross-sectional, cover a limited number of countries, and do not include the centrality and network metrics necessary to overcome subjectivity (van Raan, 2004). As a result, we hope that our findings can add to a deeper understanding of Tai Chi by its contribution to health knowledge. This research identifies the intellectual structure, emerging trends, and future research opportunities, helping to construct arguments about the dynamics of the field in the last quarter of the century.

The main psychiatric currents and western psychological healing traditions have paid little attention to self-control as emotional regulation, necessary to maintain our balance (Bessel van der Kolk, 2020). Tai Chi by involving physical movement, controlled breathing and meditation, helps to maintain emotional regulation and to be aware of ourselves, necessary for a healthy mind. The physical and mental benefits of Tai-chi have made it part

of Chinese culture, yet is rarely used in Western countries. The purpose of this article is to analyze the complex world of Tai Chi. The following research questions are raised:

RQ1: How has Tai Chi evolved over the last twenty-five years?

RQ2: How is knowledge disseminated?

RQ3: How is the intellectual structure of Tai Chi characterized? Is it a small world dominated by a cohesive group of authors? Is there a giant component where the main authors are included?

RQ4: Is scientific production essentially done through collaboration between authors? Are there many isolated and peripheral authors, which can distort the analysis?

RQ5: What are the characteristics of the most productive and cited authors? Is there a correlation between productivity, citations and centrality metrics?

RQ6: Which institutions and countries are most active in publishing articles on the resulting benefits?

RQ7: What journals are the main researches published on?

RQ8: What are the main research themes versed?

RQ9: What opportunities and hot spots are highlighted?

## MATERIAL AND METHODS

The period of data collection is from January 1996 to December 2020. The data were collected from PubMed, Web-of-Science (WoS) and Scopus. PubMed is a library of biomedical literature from Medline and life science journals, while WoS and Scopus are considered the most widespread and best quality databases for literature research in various scientific fields (Guz and Rushchitsky, 2009). The high quality of the data can explain the good quality of the results obtained.

The study sample focuses on longitudinal data from January 1996 to December 2020. The dimensions chosen for the selection of articles related to the benefit of Tai Chi for the health of older adults were the keywords, the English language and the years of publication. To obtain more scientific and accurate data, only the following keywords included in the title, abstract or keywords were extracted (Fu *et al.*, 2012): "tai chi" OR "tai-chi" OR "t'ai chi" OR "tai ji" OR "tai-ji" OR "tai chi chuan" OR "taijiquan" OR "tai ji quan" OR "shadow boxing." OR "ageing" OR "Older "OR "senior". Among the published documents, the study concerns only the articles, considered responsible for the advances within and between disciplines (Lewis *et al.*, 2007).

The annual distribution of publications in the last twenty-five years shows an increasing growth, where 80.2% of publications occur after 2008, which is equivalent to quadruple the articles published so far. The respective average annual growth rates are 23.1% in publications and 28.3% in citations, showing the growing interest of researchers in this field (Figure 1).
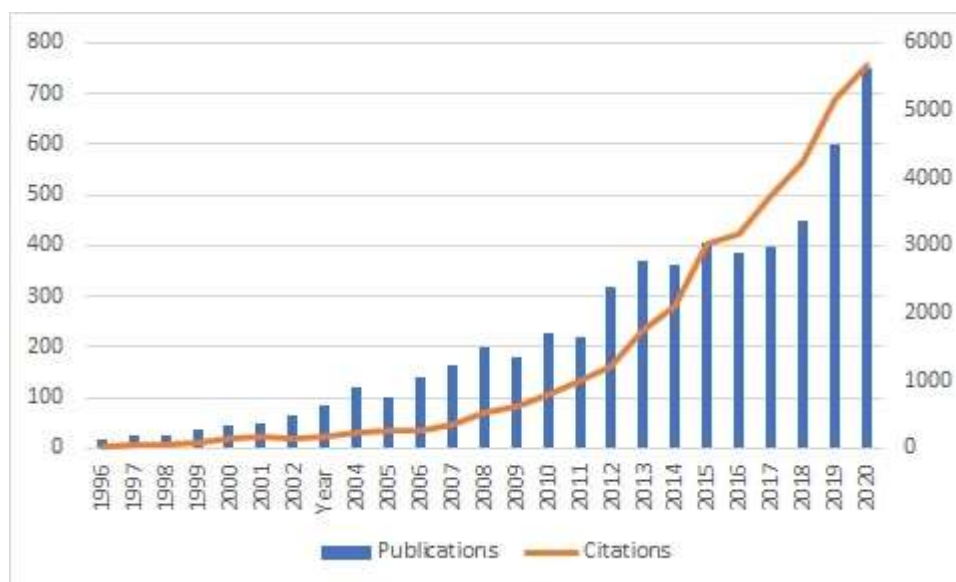
Figure 1. Distribution of publications and citations by year

The growing number and complexity of online publications and their indexing has created the need for scientometric tools for the production of maps, graphs and diagrams that illuminate the patterns, trends and associated processes (Pestana *et al.*, 2019). Visualization facilitates the understanding of a domain in a comprehensive and transparent way (Speel *et al.*, 1999). Various free Java software tools were used to this purpose in our study: CiteSpace (http://cluster.cis.drexel.edu/~cchen/citespace), to convert Scopus data in WoS data, to analyze the structure of networks by slices, and to identify hot spots; Vosviewer (https://www.vosviewer.com/), to create files of nodes and edges as Gephi inputs in order to obtain several centrality measures (https://gephi.org/); and Python (https://www.python.org/downloads/windows/), to clean the data, to aggregate different sources of data, to eliminate duplicates and to identify synonyms. The final sample has 2,202 articles, with 2,955 keywords, reflecting the contribution of 6,820 authors, with 26,408 citations from 3,215 institutes in 61 countries.

In order to represent the complex and dynamic process that identifies tai chi authors and monitors the development of their interactions as they evolve over time, it is necessary to analyze the collaborative network (Scott *et al.*, 2008). This type of network is the most visible and well-documented manifestation of scientific collaboration (Cronin *et al.*, 2003; Glänzel and Schubert, 2005). The collaborative network identifies the structure of knowledge and how information is disseminated (Baggio *et al.*, 2010; Fan *et al.*, 2020). This network is represented by non-targeted and weighted graphics, where the nodes correspond to the actors (authors, countries, institutions, keywords), the edges correspond to their connections (links) and the

weights of the links express the strength of collaboration (Barabási and Albert, 1999). The use of nodes and edges allows an approach from a social network (SNA) perspective (Katz and Martin, 1977). This study analyzes the collaborative network at both the macro and micro levels. At the macro level, information about the structure and quality of the collaborative network is obtained through the metrics: nodes, edges, density, modularity, average degree, average cluster coefficient, average path length and diameter (Scott, 1991; Savié *et al.*, 2014). At the micro level, the performance of the networks of actors is assessed through measures of centrality: degree of centrality, closeness centrality (CC), betweenness centrality (BC), and eigenvector centrality (Pestana *et al.*, 2019).

The metrics are now summarized: *density* indicates the degree of concentration of the connections between the nodes in the network, being 1 when it contains all possible connections; *modularity* indicates the strength of dividing a network into clusters and is the most popular method for building an understanding of the dynamics of the network (Chen, 2006; Newman and Girvan, 2004); *average degree* indicates an author's ability to collaborate with another author; *average clustering coefficient* measures the degree to which authors tend to cluster together; the *average path length* indicates how information is disseminated efficiently on the network (Hassanzadeh *et al.*, 2012); *diameter* measures the number of intermediaries along the shortest path connecting the nodes; *closeness centrality* (CC) reflects how quickly information circulates to other authors in the network (Abbasi *et al.*, 2012); *betweenness centrality* (BC) identifies the authors with the greatest influence on the control and dissemination of information anywhere in the network; *eigenvector centrality* informs the importance of a node based on the quality of its contacts.

## RESULTS AND DISCUSSIONS

### Collaborative Network Structure

According to Braun, Glanzel and Scgubert (2001), larger teams are more effective than isolated researchers. The distribution of articles by authors indicates a high degree of collaboration (Table 1). The studies of tai chi are done essentially in co-authorship (86.6%), with only 13.4% single articles, with 3.8% being the isolated authors for working always alone. On average there are 4.4 authors per article, with an emphasis on 32.2% of articles made by three or four authors, and with a majority of 58.3% articles having between two and five authors. Excluding isolated authors, we obtain a small average of articles per author (0.29) and a high average of authors per article (3.58), which reflect the multidisciplinary nature of a domain (Ye *et al.*, 2013). Thus, researchers from different areas in tai-chi, enrich their study by including different perspectives of scientific approach. The small average path length (4.8) indicates that

the information only needs to flow between four to five intermediaries to be transferred from one author to another. The high average clustering coefficient (0.8), shows a high likelihood that neighbors of a node are also connected.

The existence of measurable changes reflects the evolutionary process of a particular research domain (Bettencourt *et al.*, 2009). Therefore, the research in tai chi was divided into four sub-periods in order to obtain a more stable overview of the changes: 1996-2001; 2002-2007, 2008-2013, 2014-2020. The results show an increase in publications, authors and their links, albeit at different rates. Growth has been slower in the number of publications, from 80 in the first subperiod to 1036 in the last period. The number of authors increased 7.6 times, from 392 in the 1996-2001 period to 2,969 in the last period, while the number of links shows the greatest increase, around 17 times more, from 857 in the first period to 15,336 in the last period, supporting an increase over time in collaborations between authors. The average number of links per author increases slightly from 2.19 to 2.34, while in the last two sub-periods they double their values, going from 4.76 to 5.17.

Table 1. Tai Chi Collaborative Network (1996-2020)

| Articles and authors | N | % | Articles and authors | N | % |
|---|---|---|---|---|---|
| Total number of articles | 2,202 | 100 | Total number of authors | 6,820 | 100 |
| Single articles | 296 | 13.4 | Total co-authors | 6,558 | 96.2 |
| Articles with co-authorship: | 1,906 | 86.6 | Isolated authors | 262 | 3.8 |
| Two authors | 336 | 15.3 | Articles and authors | Mean | |
| Three authors | 350 | 15.9 | Mean collaborators per article | 4.4 | |
| Four authors | 359 | 16.3 | Mean authors per article | 3.58 | |
| Five authors | 234 | 10.8 | Mean articles per author | 0.29 | |
| Six authors | 204 | 9.3 | Average path length | 4.8 | |
| Seven authors | 135 | 6.1 | Average clustering coefficient | 0.8 | |
| More than seven authors | 288 | 12.9 | | | |
| Year | Publications | Authors | Links | Avg. links/author | |
| 1996-2001 | 80 | 392 | 857 | 2.19 | |
| 2002-2007 | 357 | 1574 | 3687 | 2.34 | |
| 2008-2013 | 729 | 1885 | 8975 | 4.76 | |
| 2014-2020 | 1036 | 2969 | 15336 | 5.17 | |

An overlay visualization of the pruned network through time is done by eliminating the isolated authors and those with few connections. These peripheral authors can distort the understanding of the network, for being weak and disperse authors. This pruning procedure resulted in a more simplified co-authoring network decreasing from 6,820 authors to 2,206 authors who have the highest link strength (Figure 2). The results show a giant component with

several high connected authors, surrounded by peripheral and isolated authors. Darker colors refer to authors who entered the research in Tai Chi in more distant times, while lighter colors refer to more recent researchers. Most central authors are represented by larger characters.

The pruned network of 2,206 authors is distributed by 205 components, the largest of which has 1,336 authors and represents 60.6% of the network. Of the remaining 204 small components, the largest one contains 18 authors representing only 0.8% of the network. Most components have only two to four authors and represent 17.5% of the network. The small path length and the large clustering coefficient indicate that this social network is a small-world (Barabási and Alber, 1999; Watts and Strogatz, 1998), represented by a giant component, similar to the majority of social networks (Kretschmer, 2004). The dissemination of information among authors is therefore an efficient process that allows researchers to communicate with each other easily and quickly and ensure that information can be easily circulated about the progress of tai chi in the health of older adults.

Collaboration between authors seems to influence the increased regularity of publications and the progress of a discipline (Guillén *et al.*, 2021). The structure of the Tai Chi network demonstrated a high level of collaboration between authors. As a consequence, the most critical authors have the opportunity to play a leading role in strengthening the collaborative network, through the creation of new connections with the peripheral authors, integrating them.
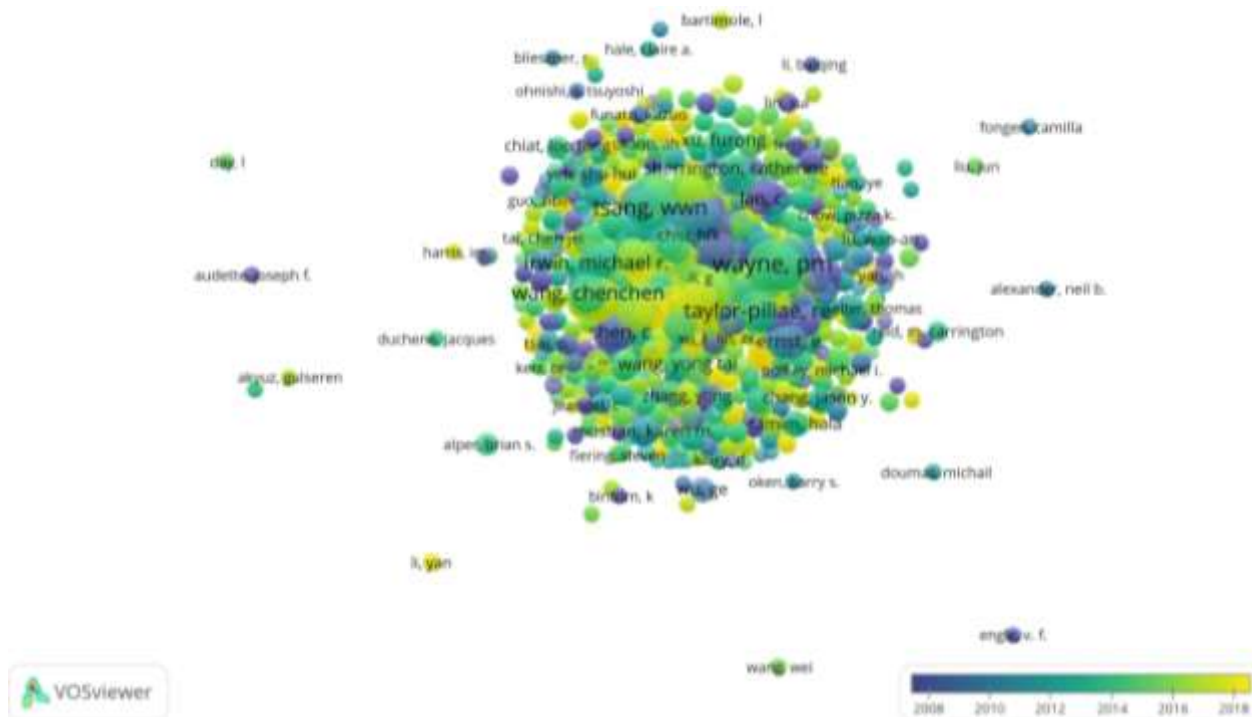


Figure 2. VosViewer: Tai chi pruned collaborative network (1996-2020)

**Productivity and Impact Per Author**

The giant component with dense connections between 2,206 authors increases the likelihood of including the most productive ones (Newman, 2006; Watts and Strogatz, 1998). There is 0.9% (n = 20) of the authors who produced 33.7% (n = 643) of the published articles. The main authors produced more than ten articles, being considered great producers by Crane (1969).

As can be seen in Table 2, the author Wayne, Peter M., from the Division of Preventive Medicine, Osher Center for Integrative Medicine, Harvard Medical School (USA), has the largest number of 72 publications over time, and is the second author with the greatest impact until 2020, with 1,200 citations. The most cited article is co-authored by Wayne and Kaptchuk (2008), and received 155 citations, being 100 citations until 2017, and 55 citations between 2018 and 2020. The authors present a framework for viewing Tai Chi as a complex, multicomponent intervention that integrates various physical, cognitive and ritualistic components. They also discuss how Tai Chi research may benefit from the use of an ecological framework, and outline the benefits and limitations of commonly used clinical research designs to evaluate the efficacy and safety of Tai Chi. Wayne, Peter M., is also related to authors with high scores, as can be seen from his high eingenvector centrality (0.999).

The author Wolf Steven L., from the Department of Rehabilitation Medicine and the Department of Cell Biology at Emory University (USA), ranks 9th in production with 27 documents, being the author with the greatest impact, with 2,797 citations. His most cited article is done in co-authorship with Wolf *et al.* (1996), with 865 citations, being 1815 until 2017 and 47 between 2018 and 2020. The authors conclude that a moderate Tai Chi intervention can impact favorably on defined biomedical and psychosocial indices of frailty and can have favorable effects upon the occurrences of falls. Wolf Steven L., is also the author with greater control of information on the network, as he has the highest betweenness centrality (0.833).

Considering the extent of collaborations between authors, measured by degree centrality, the author Zhang Yan, from the School of Basic Medical Sciences, Peking University of Chinese Medicine, with 37 articles and 328 citations, collaborates with 34 researchers, being the most popular author. His most cited article is co-authored by Yuan, Guo, Liu, Sun, and Zhang (2015), with 99 citations, being 36 until 2017 and 56 between 2018 and 2020. The authors analyze traditional Chinese medicine to treat neck pain and low back pain and the results demonstrated fair effects. The second most popular author is Liu Jian-Ping, from the Center for Evidence-Based Chinese Medicine, Peking University of Chinese Medicine, with 23 articles and 213 citations, who collaborates with 31 authors. His most cited article was done in co-authorship with Yang *et al.* (2015), with 43 citations, being 16 until 2017 and 27 between

2018-2020. The authors analyze 507 studies published between 1958 and 2013 and show the positive health effects mainly on the top 10 diseases: hypertension, diabetes, osteoarthritis, osteoporosis or osteopenia, breast cancer, heart failure, chronic obstructive pulmonary disease, coronary heart disease, schizophrenia, and depression. The majority of 94.1% studies reported positive effects of Tai Chi, either used alone or applied in combination with other therapies including medications, health education and other physical therapies.

Table 2. Top-20 Authors' Productivity and Impact Within 25 Years

| Authors | Productivity | Citations | Degree centrality | Closeness centrality | Betweness centrality | Eigenvector centrality |
|---|---|---|---|---|---|---|
| Wayne, PM | 72 | 1,200 | 25 | 0.212 | 0.503 | 0.999 |
| Wang, Chenchen | 56 | 1,068 | 21 | 0.349 | 0.238 | 0.499 |
| Li, FZ | 51 | 1,632 | 13 | 0.322 | 0.349 | 0.525 |
| Yeh, GY | 45 | 263 | 18 | 0.374 | 0.501 | 0.913 |
| Tsang, WWN | 42 | 727 | 14 | 0.369 | 0.631 | 0.998 |
| Zhang, Y | 37 | 328 | 34 | 0.444 | 0.323 | 0.931 |
| Zou, L | 35 | 257 | 22 | 0.427 | 0.154 | 0.929 |
| Lee, MS | 35 | 666 | 9 | 0.305 | 0.188 | 0.155 |
| Wolf, SL | 27 | 2,797 | 12 | 0.302 | 0.833 | 0.515 |
| Yeung, AS | 26 | 162 | 26 | 0.325 | 0.217 | 0.879 |
| Liu, Y | 26 | 195 | 23 | 0.463 | 0.372 | 0.656 |
| Li, L | 26 | 211 | 16 | 0.395 | 0.151 | 0.611 |
| Taylor-Piliae | 26 | 212 | 7 | 0.392 | 0.129 | 0.306 |
| Wang, Y | 24 | 144 | 9 | 0.308 | 0.169 | 0.378 |
| Liu, J | 23 | 213 | 31 | 0.413 | 0.355 | 0.987 |
| Wang, L | 22 | 119 | 19 | 0.270 | 0.341 | 0.704 |
| Woo, J | 22 | 467 | 5 | 0.403 | 0.122 | 0.219 |
| Song, R | 19 | 429 | 9 | 0.285 | 0.193 | 0.293 |
| Lam, P | 19 | 649 | 7 | 0.346 | 0.186 | 0.122 |
| Sherrington, Catherine | 16 | 1,472 | 10 | 0.309 | 0.356 | 0.245 |

All the most productive authors have low values of closeness centrality, reflecting their independence and efficiency in communicating with other authors. Productivity is positively and significantly associated ($p = 0.05$) with centrality metrics, while negatively associated with the number of citations, according to Spearman's Rho correlation coefficient ($p=0.05$). The most productive authors are characterized by having strong positive associations with the fact of being more independent (Rho = 0.716); and having high score connections (Rho = 0.704). However, productivity has a moderate association with the number of collaborators (Rho = 0.214). There is also a negative association between the year of publication and the number of citations (Rho = -0.309), suggesting that the greater the number of citations received in an

article, the older the article. This result is expected, as these articles will have more time to be cited than the most recent ones.

**Most Active Institutions and Countries**

This study reveals the affiliations and countries of the main authors in the relationship between Tai Chi and the health of older adults. The institutions of the authors' pruned network have low density (0.01) and good modularity (0.515), and are distributed by 268 institutions with 1,237 connections. As shown in Figure 3 and Table 3, the most productive institutions in articles include Chinese University Hong Kong and Hong Kong Polytech University, with 87 and 64 publications respectively (link strength). The United States (USA) with the largest number of institutions (68.4%), shows the strong attraction of researchers in this field. Harvard Medical School (USA) contains the largest inter-institutional research collaborations (59 links) and co-authorship publications (140 link strength). The University of Sidney (Australia) ranks 4th in both inter-institutional research collaborations (34 links) and in co-authorship publications (73 link strength).



Figure 3. CiteSpace: The cluster view of top Institutions (1996-2020)

The participation of universities and medical schools shows the relevance of Tai Chi in the treatment of older adults' health, not only from a theoretical point of view (universities), but also from its practical application (medical schools). Table 3 shows the main institutions according to co-authored collaboration. The number of links and their strength suggest a high level of collaboration between institutions, where the United States plays the most important role.

Table 3. Authors 'Affiliations in Tai Chi for Older Adult's Health (1996-2020)

| Top Co-authorship Institutions | Production | Citation | Link | | Country |
|---|---|---|---|---|---|
| | | | Number | Strength | |
| Chinese Univ Hong Kong | 87 | 2089 | 35 | 87 | Hong Kong |
| Hong Kong Polytech Univ | 64 | 1334 | 25 | 64 | Hong Kong |
| Harvard Univ | 63 | 3026 | 39 | 63 | USA |
| Univ Sydney | 59 | 6028 | 34 | 59 | Australia |
| Harvard Med Sch | 54 | 260 | 59 | 54 | USA |
| Univ Calif Los Angeles | 48 | 2358 | 28 | 48 | USA |
| Shanghai Univ Sport | 47 | 192 | 36 | 47 | China |
| Univ Illinois | 39 | 1150 | 27 | 39 | USA |
| Tufts Univ | 38 | 1276 | 16 | 38 | USA |
| Univ Hong Kong | 35 | 658 | 15 | 35 | Hong Kong |
| Emory Univ | 33 | 2826 | 13 | 33 | USA |
| Massachusetts Gen Hosp | 31 | 795 | 22 | 31 | USA |
| Oregon Res Inst | 31 | 1502 | 9 | 31 | USA |
| Brigham & Women's Hosp | 30 | 507 | 26 | 30 | USA |
| Osher Center for Integrative Medicine | 28 | 239 | 23 | 28 | USA |
| Univ Arizona | 27 | 474 | 10 | 27 | USA |
| Univ New South Wales | 27 | 1705 | 19 | 27 | Australia |
| Beth Israel Deaconess Med Ctr | 25 | 848 | 11 | 25 | USA |
| Texas Tech Univ | 24 | 271 | 7 | 24 | USA |

Figure 4 above shows the distributions of the countries of the pruned network, where the majority of connections are located in the center. The size of the characters indicates the countries with the highest degree of collaboration, where the USA, China and the United Kingdom stand out. Connections between various countries show the international nature of Tai Chi research. Collaboration between different countries is likely to result in a greater increase in knowledge, which has a positive impact on the health of older adults.
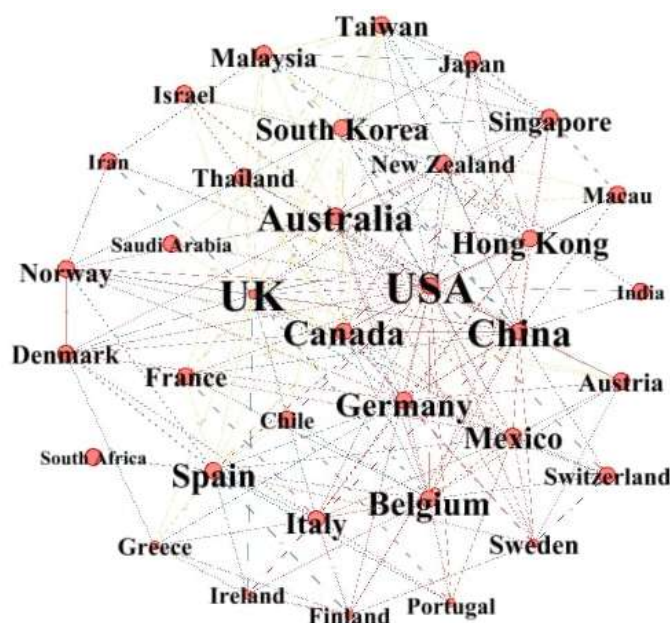
Figure 4. Gephy: Author's country in tai chi for older adult' health (1996-2020)

**Active Diffusors of Knowledge**

Journals are important disseminators of knowledge about Tai Chi. Table 4 shows the main journals identified by the number of articles published (TP) and their impact, measured by citation metrics, as tools for the quality of the article (Garfield, 1972). There is a high concentration of articles published in the 19 main journals, which represents 2.35% of the total and accounts for 31.96% of publications. *Medicine in Science in Sports and Exercise* accounts for the majority of publications with 79 articles, while the *British Journal of Sports Medicine* has 17 publications in the research area and presents the highest values of the quality of journals. *Gerontologist* is the journal with the fewest links to other journals that publish about Tai Chi.

Table 4. Active Diffusors of Knowledge (1996-2020)

| Top Journals | TP | Weight Links | % Articles | Journal metrics | | | |
|---|---|---|---|---|---|---|---|
| | | | | JIF | CS | SJR | SNIP |
| MEDICINE AND SCIENCE IN SPORTS AND EXERCISE | 79 | 99 | 4.45 | 4.48 | 4.34 | 2.071 | 1.669 |
| JOURNAL OF ALTERNATIVE AND COMPLEMENTARY MEDICINE | 56 | 114 | 3.16 | 1.87 | 1.75 | 0.532 | 0.833 |
| EVIDENCE-BASED COMPLEMENTARY AND ALTERNATIVE MEDICINE | 51 | 108 | 2.87 | 1.98 | 2.01 | 0.590 | 0.853 |
| JOURNAL OF THE AMERICAN GERIATRICS SOCIETY | 45 | 125 | 2.54 | 4.11 | 2.83 | 2.132 | 1.790 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| GERONTOLOGIST | 41 | 2 | 2.31 | 3.63 | 3.87 | 1.837 | 2.106 |
| ARCHIVES OF PHYSICAL MEDICINE AND REHABILITATION | 35 | 107 | 1.97 | 2.70 | 3.03 | 1.380 | 1.551 |
| PLoS ONE | 32 | 80 | 1.80 | 2.78 | 3.02 | 1.100 | 1.123 |
| JOURNAL OF AGING AND PHYSICAL ACTIVITY | 32 | 92 | 1.80 | 1.80 | 2.18 | 0.841 | 0.853 |
| JOURNAL OF PHYSICAL THERAPY SCIENCE | 27 | 36 | 1.52 | 0.39 | 1.53 | 0.803 | 0.581 |
| COMPLEMENTARY THERAPIES IN MEDICINE | 21 | 81 | 1.18 | 1.98 | 2.28 | 0.653 | 0.971 |
| AMERICAN JOURNAL OF CHINESE MEDICINE | 21 | 93 | 1.18 | 3.51 | 3.41 | 0.878 | 0.990 |
| BMC COMPLEMENTARY AND ALTERNATIVE MEDICINE | 20 | 72 | 1.13 | 2.48 | 2.69 | 0.754 | 1.165 |
| TRIALS | 18 | 34 | 1.01 | 1.98 | 2.12 | 1.287 | 0.873 |
| BRITISH JOURNAL OF SPORTS MEDICINE | 17 | 103 | 0.96 | 11.65 | 6.02 | 4.141 | 3.401 |
| RESEARCH IN SPORTS MEDICINE | 15 | 41 | 0.85 | 2.55 | 2.64 | 0.908 | 1.029 |
| GERIATRIC NURSING | 15 | 57 | 0.85 | 1.52 | 1.09 | 0.437 | 0.652 |
| EUROPEAN JOURNAL OF INTEGRATIVE MEDICINE | 14 | 50 | 0.79 | 0.95 | 0.94 | 0.276 | 0.471 |
| EXPLORE-THE JOURNAL OF SCIENCE AND HEALING | 14 | 29 | 0.79 | 1.04 | 0.84 | 0.302 | 0.838 |
| BMJ OPEN | 14 | 42 | 0.79 | 2.38 | 2.65 | 1.321 | 1.145 |
| Total publications (%) | 567 | | 31.96 | | | | |

Table 4…

## Keyword Analysis

To identify trends and research topics, network analysis of keywords is carried out. The keywords used as a sample selection criterion were eliminated, as they would naturally be the most frequent ones. A network with 2,955 keywords was obtained, divided into four sub-periods to compare emerging, increasing and decreasing themes. The most frequent keywords lead us to identify the scientific production with the greatest scientific impact, representing the mainstream of research in each sub-period and its evolution. The co-occurrence of keywords allows the identification of convergent and correlated themes (Pestana and Sobral, 2019; Sohn and Min, 2017). Both metrics (frequency, co-occurrence) allow to map the intellectual structure of the discipline and the changes in structure over time (Ding *et al.*, 2001). The network shows the co-occurrence of the most relevant keywords by subperiod, where you can see many links distributed by a few nodes: 1996-2001 has 11 keywords with 49 links; 2202-2007 has 34 keywords with 427 links; 2008-2013 has 58 keywords with 1,351 links; 2014-2020 has 59 keywords with 1,492 links. The number of keywords increased 5.4 times from the first to the last period, while the number of links increased 30.4 times more, suggesting an increase in the lines

of research. The high stability in the structure of the keywords in each subperiod is given by the high average clustering coefficients (0.92; 0.85; 0.89; 0.91). There is an expansion of the central keywords, as the average degree increases over time (9.91; 25.12; 46.59; 50.58). There is a dominant group of keywords, because the density is high in all sub-periods (0.89; 0.76; 0.82; 0.87). The study converges into a small area of research, as only 24.2% (n = 713 keywords) have 3 or more co-occurrences. To identify the main concerns of research, we focus on those that have 10 or more co-occurrences, which corresponds to 103 keywords.

Between 1996 and 2001 the lines of research are linked to women, body exercises and balance, but there is also a complementary use of Tai Chi for exercise, muscle strength, men, martial arts, psychological aspects and meditation. Exercise, fall, body balance and internal validation through randomized clinical trials appear in all subperiods. The randomized clinical trial is necessary to guarantee the scientific rigor of the intervention studies (Steckler and McLeroy, 2008). In the second subperiod, new topics emerge, such as quality of life, well-being, yoga, movement therapy, depression, treatment outcome and relaxation. After 2008 there is the greatest amount of research and, therefore, new themes arise. From 2008 to 2013 the lines of research focus on quality of life, mindfulness-meditation, cognitive therapy, depression, cardiovascular risk, body balance, yoga. The new topics mainly include cardiovascular risk, meta-analysis, cognitive therapy, osteoarthritis, kinesiotherapy, bone density, rheumatoid arthritis, Parkinson's disease, mental health and music therapy. From 2014 to 2020 the lines of research focus on cancer therapy, cognitive therapy, yoga, body balance, mental health, mindfulness-meditation, quality of sleep, pain. The central new topics that emerge are mainly: pathophysiology, fatigue, anxiety, cost-benefit analysis, breathing, attention and Alzheimer's disease.

The lines of research are mainly grouped into four major areas of investigation: physical function (balance, flexibility, body awareness; postural control, gait, falls, motor activity, mobility); bones and muscles (bone mineral density, strength); emotional and cognitive function (mood, stress, depression, memory, cognition, anxiety, psychological well-being) and internal validity (meta-analysis, randomized clinical trials). Essentially from 2008 onwards, the application of Tai Chi includes broader fields of medicine, such as medical emergencies (stroke, accidental falls), medical rehabilitation (cardiac rehabilitation, pulmonary rehabilitation), diseases of the nervous system and several different organic diseases, such as cancer, obstructive pulmonary disease and cardiovascular disease.

Figure 4 is a word cloud image that describes trends in Tai Chi for the health of older adults over the four subperiods of time. The main lines of research have the highest links and

are identified by keywords with the largest character sizes. Other frequent keywords that appear 10 or more times are represented in smaller characters.
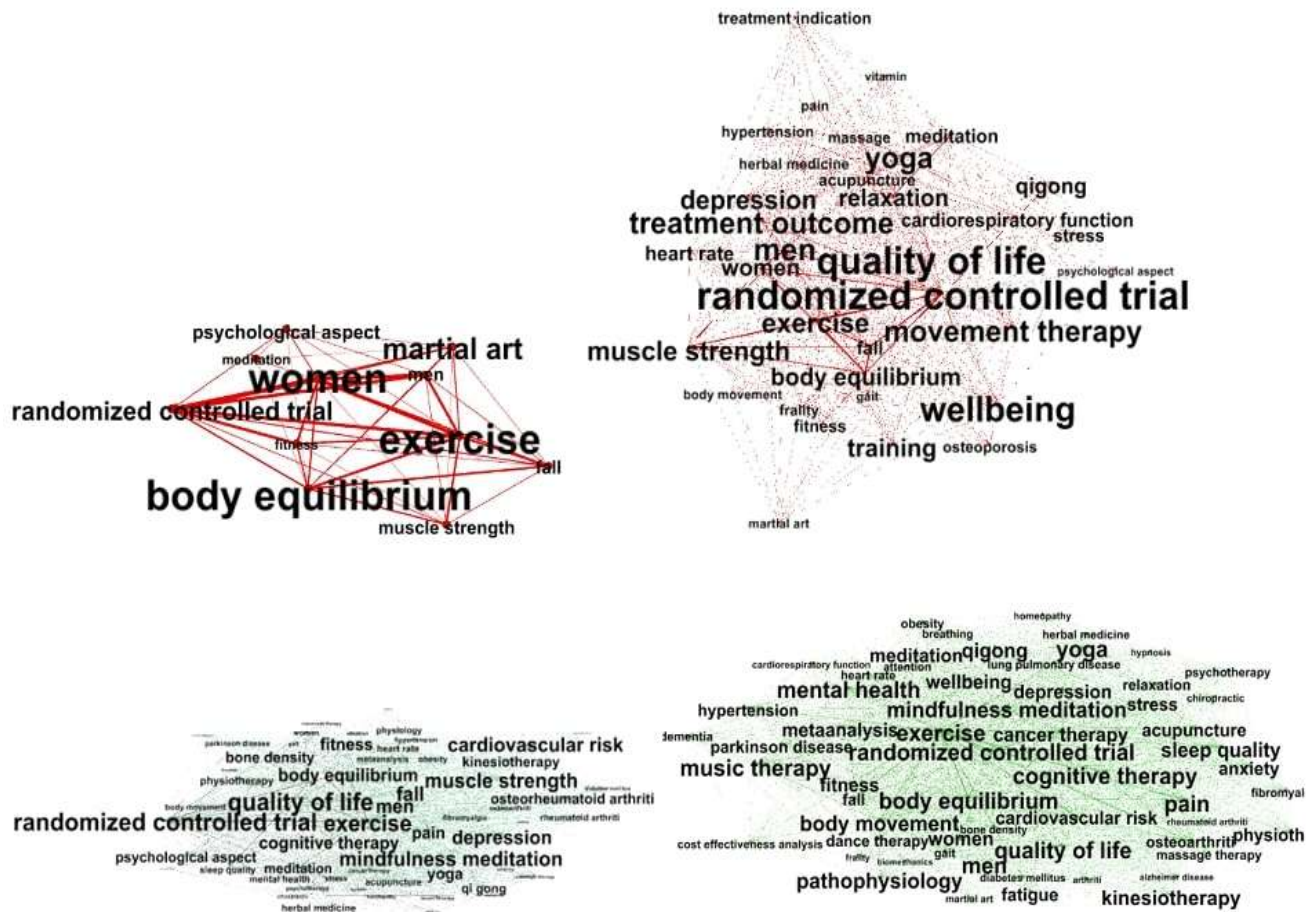


Figure 5. Keyword's analysis by degree: top left (1996-2001), top right (2002-2007), bottom left (2008-2013), bottom right (2014-2020).

Table 5 shows a burst of citation of keywords over time through CiteSpace. Burst of citation identifies keywords associated with a high wave of citation, which means that these keywords have attracted extraordinary attention from other researchers, and are indicators of emerging trends (Chen *et al.*, 2014). We present the keywords with high citation burst from 1996 until 2020 to obtain an understanding of changes across time, previously commented, and speculate future trends. It appears that emerging trends link Tai Chi to the reduction and prevention of some risk factors such as: pain, cardiorespiratory function, cancer therapy, osteoarthritis. Other emerging trends focus on sleep quality, mindfulness-meditation exercises, body movements, quality of life, mental health and depression.

Table 5. Hot Spots in Tai Chi for Older Adult's Health

| Keywords | Strength | Begin | End | 1996 - 2020 |
|---|---|---|---|---|
| body equilibrium | 55.9 | 1997 | 2013 | |
| fall | 45.2 | 1996 | 2011 | |
| muscle strength | 44.7 | 1997 | 2013 | |
| meditation | 33.6 | 1997 | 2013 | |
| blood pressure | 22.6 | 1998 | 2013 | |
| exercise program | 10.0 | 2000 | 2013 | |
| body equilibrium | 18.4 | 2004 | 2012 | |
| randomized controleed trials | 13.2 | 2006 | 2013 | |
| wellbeing | 13.2 | 2003 | 2013 | |
| quality of life | 5.0 | 2002 | 2006 | |
| cognitive therapy | 15.8 | 2008 | 2013 | |
| cognitive therapy | 14.6 | 2008 | 2013 | |
| depression | 12.2 | 2008 | 2012 | |
| pain | 10.5 | 2008 | 2013 | |
| quality of life | 26.0 | 2014 | 2020 | |
| depression | 79.2 | 2014 | 2020 | |
| mental health | 19.6 | 2017 | 2020 | |
| cancer therpay | 10.0 | 2014 | 2020 | |
| mindfulness | 8.9 | 2017 | 2020 | |
| body movement | 78.2 | 2014 | 2020 | |
| pain | 31.1 | 2014 | 2020 | |
| cardio respiratory function | 26.6 | 2015 | 2020 | |
| cancer therapy | 66.3 | 2016 | 2020 | |
| mindfulness-meditation | 19.6 | 2017 | 2020 | |
| osteoarthriti | 17.7 | 2017 | 2020 | |
| sleep quality | 88.8 | 2017 | 2020 | |

## CONCLUSION

The networked science approach over 25 years of research demonstrates that Tai Chi for the health of older adults evolves with growth rates in publications and citations, due to the interest of new researchers with new ideas. The link between theoretical knowledge and practical applications shows that research is done between universities and medical schools. Scientific achievements show that Tai Chi is multidisciplinary and covers several countries. The structure of the networks determined based on metrics, makes the results reliable. there is a maturation of the network structure with a close relationship between researchers (Bibi et al., 2018). The most influential and productive authors are identified in the giant component (Barabási and Albert, 1999; Kretschmer, 2004; Newman, 2001), and play a leading role in strengthening the collaborative network, necessary for the regularity of publications and for the

progress of this field. The authors who produce the most have greater collaborations (Braun *et al.*, 2001; Ye *et al.*, 2013). Influential authors have a high number of citations that show the power to create links between people, ideas, publications and institutions (Blázquez-Ruiz *et al.*, 2016).

Hotspots and search trends are identified in the keyword network analysis. Tai Chi converges into four identified areas: physical function; bones and muscles; emotional and cognitive function and internal validity. Trends include broader fields of medicine, such as medical emergencies, medical rehabilitation, diseases of the nervous system and several different organic diseases. The complexity of the research created the need to include the analysis of social networks and their visualization, surpassing previous bibliometric studies.

However, this study suffers from some limitations. In fact, the analysis is based on articles extracted from PubMed, WoS and Scopus, and includes only those written in English. Therefore, we can have excluded some relevant authors who have published in other languages and in other databases. The present results are intended to provide new theoretical bases for future research in this field, providing a unique understanding of the structure and patterns of the domain. Tai Chi for older adults' health is a knowledge domain that can be easily accesses and updated. Researchers interested in improving health or preventing diseases in older adults have here a useful tool. In a constantly evolving world, network science analysis must be done regularly to keep up researchers with new changes.

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