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Brief Report

Optimal Tai Chi forms in knee osteoarthritis: An exploration from biomechanical rationale to pain reduction

Feng Yang [a], Jonathan Gelfond [b], Donald McGeary [b], Allen Perkins [c], Alison A. Moore [d], Lixin Song [e], Agustín Escalante [b], Wei Liu [f,*]

[a] Department of Kinesiology and Health, Georgia State University, Atlanta, GA, 30303, USA
[b] School of Medicine, University of Texas Health Science Center at San Antonio, San Antonio, TX, 78229, USA
[c] School of Medicine, University of South Alabama, AL, 36688, USA
[d] School of Medicine, University of California, San Diego, CA, 92093, USA
[e] School of Nursing, University of Texas Health Science Center at San Antonio, San Antonio, TX, 78229, USA
[f] School of Health Professions, University of Texas Health Science Center at San Antonio, San Antonio, TX, 78229, USA

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ABSTRACT

Objectives: Tai Chi (TC) shows some beneficial effects in reducing pain in knee osteoarthritis (OA). However, the selection of criteria TC forms in previous studies were unclear and inconsistent, possibly accounting for the varying outcomes and rendering the training effects suboptimal. We have selected four optimal TC (OTC) forms based on the knee joint load and its association with pain. This pilot study sought to examine the effect of the OTC forms on reducing knee pain in individuals with knee OA.
Methods: Fifteen knee OA participants were recruited. Their knee joint pain level was rated by using the Visual Analogue Scale before and after two weeks of OTC training and compared between these two assessments.
Results: The two-week OTC training course was well accepted by our participants. The knee OA pain showed a significant reduction (median pain score: 5 cm before training and 1 cm post-training, Wilcoxon $p < 0.001$) after the two-week training program.
Conclusions: Our pilot results revealed that the 2-week four-form-based OTC program could significantly reduce the knee pain level in people with knee OA. Additionally, our OTC program appears to be about 50% more effective in reducing knee pain than the existing TC-based program, which uses 10 TC forms over 12 weeks (1.59 vs. 1.06 in Hedge's *g*). The findings in this study may inform the development of OTC-based knee pain reduction programs and the design of relevant clinical trials to establish OTC's effectiveness, safety, and dose-response relationship in easing knee OA pain.

Significance and Innovations:

- This is the first study to objectively select optimal TC (OTC) forms using quantitative criteria of knee joint biomechanics in knee OA. This would provide innovative insight into our understanding of how to optimize the TC exercise intervention in knee OA.
- Our results provide potential direct clinical and scientific evidence of OTC on pain reduction and a comparison of effect size between OTC and the most used existing TC forms in knee OA.
- Our study established a firm scientific foundation for future efforts to develop the most effective TC forms for knee OA rehabilitation.

* Corresponding author. School of Health Professions, UT Health San Antonio, 7703 Floyd Curl Drive, San Antonio, TX, USA.
E-mail address: liuw1@uthscsa.edu (W. Liu).

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1. Introduction

Knee osteoarthritis (OA) presents a leading cause of disability in adult Americans [1]. Once the knees become symptomatic, patients with knee OA report pain while weight-bearing, stiffness after prolonged inactivity, crepitus or crunching during passive motion, and an overall decrease in functional ability and quality of life. The effects of OA-related pain are especially prevalent in older populations whose routine daily activities can become highly restricted [2]. It is critical to develop therapeutic programs that can alleviate joint pain among people with knee OA.

TC is a traditional Chinese exercise involving continuous movements (also called forms) between distinct postures and involves dynamic loading-unloading weight-shifting strategies between legs. TC has been broadly used as a nonpharmaceutical modality to treat pain in people with knee OA. Multiple review articles have reported the positive effects of TC training on reducing the pain level in people with knee OA [3–5]. Although the Yang style TC was the most popular TC exercise to treat knee OA pain, the specific TC forms used in previous studies differed substantially. For example, 6 [6], 10 [7,8], and 24 [9] forms of Yang style TC have been adopted previously. These forms were chosen without providing a quantitative and objective standard. Such a knowledge gap could hinder the development of an optimal TC (OTC)-based program for knee OA. Thus, it is interesting and meaningful to ask if there is a way that can maximize the effects of TC training on relieving the pain level for people with knee OA. If the OTC program exists, it would improve knee OA symptoms management and profoundly impact the individuals, their families, and the healthcare system.

The general basis of TC training reducing pain in people with knee OA is that TC-induced improvements in physical functions, including balance, muscle strength, and endurance, could alleviate pain in knee OA [7]. However, such an understanding may not reveal the underlying TC's mechanisms of altering knee pain in this population. The well-established mechanisms of knee OA include intra-articular inflammation, collagen degradation, and frequent abnormal mechanical loading of the knee. The abnormal mechanical loading is a strong predictor of radiographic OA disease severity and rate of OA progression [10]. One critical mechanism of TC is that TC forms can modulate the knee joint load [11]. If this modulation effect has a direct link with pain in knee OA, then individual TC forms can be optimized or re-configured. We believe that if TC can be selected based on a biomechanical basis for the reduction of knee joint pain, the benefits of TC could conceivably be enhanced.

Our recent study discovered a strong association between the peak knee extensor moment and knee OA pain level (correlation coefficient $= 0.549$, $p < 0.001$) after calculating the knee joint moment for each of the 24 Yang-style TC forms [11]. A prior study also demonstrated the exercise-induced hypoalgesia effect on knee joint pain [12]. Exercise-induced hypoalgesia reduces pain sensitivity and increases the threshold to painful stimuli. Therefore, TC forms, which exhibit higher knee extensor moment inducing stronger painful stimuli, could be selected as optimal forms to reduce knee OA pain. This previous work furnished us with a novel way to objectively and quantitatively identify the OTC forms, which could maximize the TC training effects [11]. According to our past study, TC forms 2 (Part Wild Horse's Mane), 4 (Brush Knees), 8 (Right Grasp Sparrow's Tail), and 10 (Wave Hands like Clouds) are the ones showing the highest knee extension moment during TC practicing among all 24 forms [11]. These four TC forms were selected to assemble an OTC program to treat joint pain in people with knee OA.

This study explored the short-term efficacy of a 2-week training program consisting of the four selected TC forms on reducing knee OA pain. We hypothesized that the OTC forms would lead to a significant reduction in knee joint pain. The findings of the present study could facilitate the design of effective TC-based interventions for reducing pain in people with knee OA.

2. Methods

A convenient sample of 15 individuals with mild to moderate knee OA (10 females, mean ± SD age: 61.3 ± 8.93 years; height: 1.68 ± 0.13 m; mass: 82.7 ± 18.8 kg) were enrolled in this single-group pretest-posttest study. Individuals were included if they 1) aged 40 years or over, 2) were diagnosed with symptomatic knee OA based on the American College of Rheumatology classification criteria with the Kellingren/Lawrence scale of 2–3 on radiographs, 3) were experiencing the presence of pain/tenderness over the medial region of the knee (>2–3 cm on a 10-cm Visual Analogue Scale or VAS), and 4) had no TC experience before this study. Persons with other significant musculoskeletal, cardiovascular, or neurological diseases, a history of lower extremity joint replacement, any intra-articular knee injection within the past six months, or ongoing physical therapy for knee OA were excluded. Participants were recruited from Rheumatology Clinics and Pepper Center at the University of Texas Health Science Center San Antonio using a study flyer and referrals. Before participation, they signed an informed consent document approved by the Institutional Review Board. During the 2-week training period, participants did not take any pain relief medications to avoid the possible confounding effect resulting from the pain drugs. This pilot study was registered at clinicaltrials.gov (ID: NCT03621631).

Through one-on-one instruction from an experienced TC instructor, participants learned how to perform OTC forms correctly and underwent two weeks of thrice-weekly OTC training. Each of the six sessions lasted 30–45 min. Participants self-reported their pain level at the OA knee joint during walking before and after the 2-week OTC training course based on the VAS with a score range of 0 cm ("no pain at all") to 10 cm ("worst pain as it could be") [13].

Due to the normality violation, the Wilcoxon signed-rank test was used to compare the pain level between assessments. The effect size of the Wilcoxon test was calculated as $r = \frac{Z}{\sqrt{n}}$, where Z is the Wilcoxon statistic and n represents the sample size. To compare the effect of reducing pain between the 4-form OTC program and the most used 10-form TC program [7], the effect size of both training paradigms was estimated using Hedge's g. Effect sizes were interpreted as small ($0.2 \leq g < 0.5$), medium ($0.5 \leq g < 0.8$), or large ($g \geq 0.8$), and small ($r < 0.3$), medium ($0.3 \leq r < 0.5$), or large ($r \geq 0.5$). Statistical analyses were conducted using SPSS 29.0 (IBM, NY) with an alpha of 0.05.

3. Results

The 2-week OTC training program showed perfect compliance. All participants completed the 6 training sessions. They did not consider the training difficult and enjoyed the program. The Wilcoxon test showed a statistically significant reduction in knee pain ($Z = -3.335$, $p < 0.001$, -3.20 ± 1.90 cm) with a large effect size ($r = 0.861$) among our participants. The median pain score was 5 cm (25% quartile: 3; 75% quartile: 6) before training and 1 cm (25% quartile: 1; 75% quartile: 1.5) after training (Fig. 1). Among 15 participants, only one exhibited an increased pain level (from 4 to 5 cm). The rest participants exhibited various levels of reductions, ranging between 1 and 6 cm. The group's average pain level dropped from 4.80 ± 1.70 cm before training to 1.60 ± 1.50 cm afterward. The Hedge's g effect size of the pain reduction from the pre-training to post-training assessments was 1.59.

4. Discussion

This preliminary study represents the initial effort to test the innovative concept of selecting TC forms to optimize the training effects on lowering pain in people affected by knee OA. Our results indicated that the OTC program could be well accepted by participants with knee OA and lead to promising effects in reducing knee OA pain, supporting our hypothesis. Specifically, 14 out of 15 participants showed reduced pain in the affected knee during gait after the OTC training (Fig. 1). The

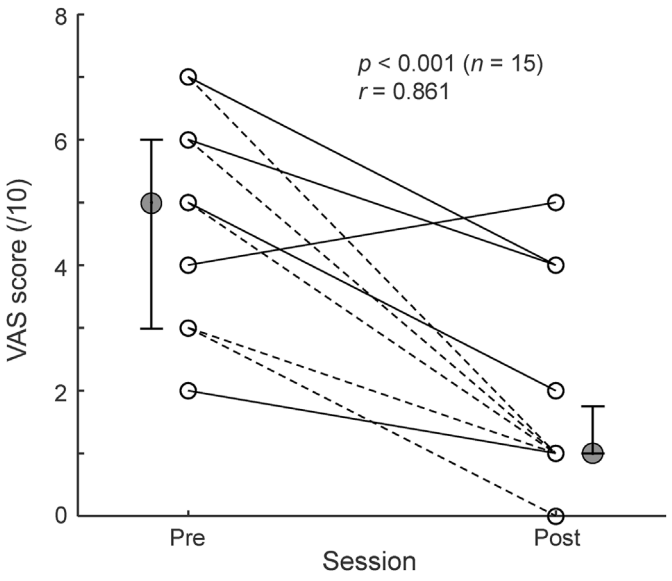

Fig. 1. Spaghetti diagram showing changes in the pain level, quantified by the Visual Analogue Scale score from the pre-training (Pre) to the post-training (Post) assessment for 15 individuals with knee osteoarthritis (the open circles). Also shown are the median and interquartile range of the pain level for both assessments (the shaded circles with vertical bars). The comparison was made using the Wilcoxon signed-rank test. There are five pairs of participants, each (marked as dashed lines) sharing the same Pre and Post pain scores. The post-treatment pain level is significantly lower than the pre-treatment value ($p < 0.001$) with a large effect size ($r = 0.861$).

group's average pain rating dropped about 3.2 cm from the pre-training to post-training assessment.

Extant TC intervention studies in knee OA are mainly focused on conceptual principles of muscle strength, balance, and flexibility during human locomotion tasks such as walking [14]. However, such a concept does not directly address the core mechanisms of TC training decreasing knee pain. The lack of understanding of mechanisms leads to unclear rationales for selecting TC forms in previous studies concerning TC training in knee OA. Previous TC-based clinical trials selected TC forms possibly by considering manageability and feasibility [6–9]. Therefore, the training effects of the existing TC programs may not reach the maximum level in lowering pain. This could also explain the inconsistent results produced by previous studies on the efficacy of TC training in people with knee OA [3–5]. Our recent findings that the knee extensor moment is strongly proportional to the knee joint pain level and that different TC forms have distinct knee extensor moments made it possible for us to select OTC forms to reduce knee pain from an innovative perspective [11]. The results indicated that the OTC forms could cause significant improvements in knee pain for people with knee OA.

The Hedge's *g* for the 10-form TC program in the previous study for reducing knee OA pain over 12 weeks was estimated as 1.06 [7], which was much smaller than the effect size (1.59) of our OCT program. The OTC program was about 50% more effective than the existing TC program [7]. Considering the shorter duration (2 vs. 12 weeks) and less number of TC forms (4 vs. 10 forms) of the OTC than the existing TC program, the OTC program could be more acceptable, easier to learn, and more conveniently manageable for people with knee OA, presenting an appealing TC-based training modality to alleviate knee pain for them.

Grounded upon our previous rigorous work [11], this present study took an important step to clinically examine the effect of the OTC program on knee OA pain reduction and compared the training effect size to the most used TC forms. Our results suggest that the TC training program can be re-configured by using musculoskeletal mechanistic information to maximize the effect with fewer TC forms and shorter training duration. Given the limited physical capacity and impaired cognitive functions in people with knee OA [15], a shortened training duration and reduced number of TC forms could facilitate the implementation of TC training in managing OA symptoms.

Our pilot study has limitations. First, as the first of its kind, this study enrolled a small sample size of 15 participants. It is thus possible that the results may have a large variation in the outcome measurements and may not be generalizable to the knee OA community. Second, the single-group design may not eliminate the effects on our findings from other uncontrolled third-party factors. For example, the pain reduction could be due to factors, such as the use of pain medication prior to the study, other physical activities during the study, and the natural history of knee OA with pain fluctuation. However, the large effect size of our OTC program and the comparison of the training effects between OTC and the existing TC program as a reference group could address this concern, at least, in part. Third, there could be inconsistency in learning OTC forms performance among participants due to the large range of age, body types, or physical capacity in the present study. Nevertheless, our one-on-one approach to delivering the TC training could mitigate such inconsistencies. Last, the training duration in this study was two weeks. It remains unknown if a longer training program would generate an even larger effect on reducing the pain level and whether the training effects can be retained for a certain duration. All limitations require further investigations with a large and diverse sample size and a rigorous study design.

In conclusion, this pilot study represents a clinically meaningful and scientifically sound step towards the effort of optimizing the effects of TC-based programs on managing OA symptoms. The OTC concept furnishes a unique viewpoint to select the best TC forms for pain reduction and restore lost function following treatment for knee OA. The results also provide critical connecting information for us to design large-scale OTC-based clinical trials to further study its effectiveness, safety, and dose-response relationship in relieving pain in people with knee OA.

Author contributions

Dr. Liu contributes to the conception and design of the study and takes responsibility for the integrity of the work, from inception to finish of the article. Drs. Yang, Gelfond, McGeary, Perkins, Moore, Song, and Escalante contribute to the conception of the study. Authors Yang, and Liu take responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design*: Liu. *Acquisition of data*: Liu. *Analysis and interpretation of data*: Liu, Yang, Gelfond, McGeary, Perkins, Moore, Song, and Escalante. *Drafting of the manuscript*: Liu and Yang. *Critical revision of the manuscript of important intellectual content*: Liu, Yang, Gelfond, McGeary, Perkins, Moore, Song, and Escalante. *Statistical analysis*: Yang.

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Declaration of competing interest

The authors have no conflicts.

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