brief report

Knee joint biomechanics of simplified 24 Tai Chi forms and association with pain in individuals with knee osteoarthritis: A pilot study

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Abstract

Objectives: Tai Chi (TC) is a multi-beneficial exercise for improving health and function in knee osteoarthritis (OA). Biomechanical insights of 24 TC forms at the knee joint are not well understood. We aimed to examine knee joint biomechanics of TC actions form by form and their interactions with pain in individuals with knee OA.

Methods: Ten knee OA participants were recruited. Their full body motion during performance of 24 TC forms was collected. The knee joint biomechanics were determined by using an inverse dynamic approach based on collected full body kinematics and kinetics. In addition, the knee joint pain level was scored during each TC form. The joint moments were compared between walking trials and each TC form. The relationship between knee joint biomechanics and pain scale was assessed.

Results: The knee adduction moment for five TC forms was different from the walking trial. The knee extension moment for 21 TC forms differed from the walking trial. For TC trials, the knee extension moment, but not the adduction moment, was positively correlated with pain level. Similarly, the knee extension moment was moderately proportional to pain level during the walking trials, but not the adduction moment.

Conclusions: Our pilot results explored the knee joint biomechanics profiles of individual TC forms and examined their associations with knee joint pain. The findings in this study could provide scientific basis to select the best TC forms for the purpose of reducing knee joint pain among individuals with knee OA.

1. Introduction

Knee osteoarthritis (OA) is a leading cause of adult disability, with 27 million affected individuals in the United States [1]. The pathology of knee OA includes intra-articular inflammation, collagen degradation, and frequent abnormal mechanical loading of the knee; these are associated with abnormal mechanical and biological consequences [2]. Disabilities that arise from typical impairments of knee OA include decreased muscle strength, reduced range of motion, and decreased aerobic cardiovascular function [3]. Dysfunction resulting from knee OA affects performance of daily activities, independent functioning, and quality of life. The effects of OA are especially prevalent in older populations [1], in which routine daily activities including walking and sit-to-stand movements can be difficult [4]. It is imperative to develop programs which can alleviate joint pain among people with knee OA.

Tai Chi (TC) is an ancient Chinese tradition and involves a series of sequentially performed component movements which incorporate uninterrupted, slow, and rhythmic weight-bearing activities in loading and unloading fashion. The most common TC practice is simplified Yang style 24 forms [5]. As TC has been proven to improve balance, muscle strength, and joint flexibility and knee OA has been identified as a risk factor of reduced balance and falls in older adults [6], TC could be a particularly well-founded intervention for people with knee OA.

Studies that applied TC to people with knee OA have reported inconsistent results in improving physical functions (such as strength, balance, etc.) [7]. A potential factor leading to such diverse results could be the different forms used in previous studies. The individual TC forms used in prior studies were chosen without specifying a quantitative and objective standard. Therefore, those selected TC forms were not based on knowledge of the biomechanical load acting on the knee during performance of individual TC forms. To maximize the training effect of TC-based intervention targeting people with knee OA, it is critical to select the most beneficial forms. A prerequisite to identify the optimal TC forms is a comprehensive understanding of the biomechanical profile of each TC form.

Similar issues were presented in studies employing TC to reduce the
knee pain level for people with knee OA. The rules of selecting TC forms were not clear, possibly resulting in inconclusive findings among studies [8]. A possible selection system of TC forms for alleviating knee pain is to check if the knee joint biomechanical measurement (like joint moments) is related to the pain level. If such a correlation exists, it will not only provide us an objective way to quantify the pain level, but a system to identify the TC forms which are most beneficial to reduce the knee pain for individuals with knee pain. To our best knowledge, the association between the biomechanical profile and knee joint pain levels of TC forms among individuals with knee OA remain completely unexplored. Such a knowledge gap severely impedes progress towards development of an optimal TC-based program for knee OA. We believe that if TC can be selected based on biomechanical principles for reduction of knee joint pain, the benefits of TC could conceivably be enhanced.

The purpose of this pilot study was twofold: 1) to quantify the biomechanical load of the knee joint during performance of simplified 24 Yang-style TC forms, and 2) to determine whether the load is associated with knee joint pain. By doing so, our findings would fill the knowledge gap regarding mechanistic insights of TC forms in knee OA. The well-understood mechanisms could facilitate the design of effective TC-based interventions for reducing pain in people with knee OA.

2. Methods

Ten individuals with mild to moderate knee OA (seven females, mean ± SD age: 65.1 ± 12.0 years; height: 1.67 ± 0.12 m; mass: 83.8 ± 26.3 kg) participated in this study. The inclusion criteria were: 1) individuals aged 40 years and older, 2) meeting American College of Rheumatology criteria for symptomatic Knee OA [9], 3) experiencing the presence of pain/tenderness over the medial region of the knee, and 4) having had no TC experience prior to this study. Persons with the following conditions were excluded from participating: 1) a history of lower extremity joint replacement, 2) any intra-articular knee injection (steroid, hyaluronic acid) within the previous six months, 3) report of a heart condition or replacement, 2) any intra-articular knee injection (steroid, hyaluronic acid) within the previous six months, 3) report of a heart condition or replacement, 2) any intra-articular knee injection (steroid, hyaluronic acid) within the previous six months, 3) report of a heart condition or replacement, 2) any intra-articular knee injection (steroid, hyaluronic acid) within the previous six months, 3) report of a heart condition or replacement, 2) any intra-articular knee injection (steroid, hyaluronic acid) within the previous six months, 3) report of a heart condition or replacement, 2) any intra-articular knee injection (steroid, hyaluronic acid) within the previous six months, 3) report of a heart condition or replacement, 2) any 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may have a protective effect against pain. The lower magnitude of KE moment would reduce the mechanical demand on the knee joint, which may in turn reduce the abnormal mechanical stress on the medial compartment of the knee joint and thus the pain level.

Our results also showed that adduction moment is not proportional to the knee joint pain level during walking and TC actions. TC have higher range of motion of the knee with similar ground reaction support compared to walking [10,13], and TC showed different dynamic stability compared to walking [15], which suggests that TC involves a greater amount of weight-shifting in the frontal plane, with higher mechanical...
demand in the sagittal plane. Our results imply that knee moments in the frontal and sagittal planes may have different mechanisms of modulating knee joint contact stress. More studies are needed to investigate such mechanisms.

Our pilot study has limitations. First, the sample size was relatively small. It is thus possible that our results may have a great variation in the outcome measurements affecting our findings. The small and unbalanced sample size between genders restricted us from considering sex as a factor in our analyses. Second, we did not incorporate healthy control participants in this study, although we used walking as a control to compare with individual TC forms. Third, there could be inconsistency in learning TC forms performance among participants due to the large range of age, body types, or physical capacity in the present study. However, our individualized approach for delivering the TC training could reduce such inconsistencies. All limitations warrant further investigations with a larger sample size.

Our study represents a clinically meaningful and critical step towards the establishment of the biomechanical mechanism of TC in knee OA. Our approach provides a unique opportunity to select the best TC forms for pain reduction and design optimized TC-based rehabilitation programs for knee OA in the future.

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Significance and innovations

- This is the first study to quantify the knee joint biomechanics profiles of individual TC forms during TC practice in knee OA. This would provide insight into our understanding of the movement strategies used in TC.
- Our results provided direct evidence of the musculoskeletal responses of the human body during TC and demonstrated a measurable biomechanical signal of TC at the knee joint (the extension moment), which was associated with pain in knee OA.
- Our pilot study established a scientific foundation for future efforts to refine the most effective TC forms for knee OA rehabilitation.

Credit author statement

Dr. Liu contributes to the conception and design of the study and takes responsibility for the integrity of the work, from inception to finished article. Authors Yang and Liu take responsibility of 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 and Yang. Drafting of the manuscript: Yang and Liu. Critical revision of the manuscript of important intellectual content: Liu and Yang. Statistical analysis: Yang.

Declaration of competing interest

The authors have no conflicts.

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APPENDIX. List of Simplified 24 Tai Chi forms

Form 1: Commencing Form
Form 2: Part the Wild Horse’s Mane on Both Sides
Form 3: White Crane Spreads Its Wings
Form 4: Left and Right Brush Knee and Push Forward
Form 5: Playing the Lute
Form 6: Repulse Monkey Left and Right
Form 7: Grasp Sparrow’s Tail Left
Form 8: Grasp Sparrow’s Tail Right
Form 9: Single Whip
Form 10: Wave Hands Like Clouds
Form 11: Single Whip
Form 12: High Pat on Horse
Form 13: Right Heel Kick
Form 14: Strike to the Ears with Both Fists
Form 15: Turn and Left Heel Kick
Form 16: Left Lower Body and Stand on One Leg
Form 17: Right Lower Body and Stand on One Leg
Form 18: Fair Lady Works with Shuttles
Form 19: Needle at Sea Bottom
Form 20: Fan Through the Back
Form 21: Turn Body, Deflect, Parry, and Punch
Form 22: Apparent Closing a Door
Form 23: Cross Hands
Form 24: Closing Form

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