Brief Report

Dynamic stability based identification of optimal Tai Chi forms for preventing falls among older adults with knee osteoarthritis

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ABSTRACT

Objective: Knee osteoarthritis increases the risk of falls among older adults. Tai Chi (TC) has been increasingly utilized to prevent falls in older adults. However, findings from previous studies are inconclusive, possibly due to a lack of scientifically sound methodologies to identify targeted TC forms, which likely maximize the training effects in preventing falls. It has been recently indicated that individual TC forms challenge body balance to varying degrees, providing us a foundation to select optimal TC forms. The objective of this preliminary study was to examine whether the challenge to body balance quantified by the range of dynamic stability is different between identified optimal TC forms (OTC) and commonly used TC (CTC) forms among older adults with knee osteoarthritis.

Methods: Eight older adults with knee osteoarthritis learned how to perform 24 TC forms correctly. Their full-body kinematics during the performance of 24 TC forms was collected. The range of composite dynamic stability was used as the selection criteria to identify eight OTC forms. The range of composite dynamic stability was then compared between the OTC forms and eight CTC forms.

Results: Overall, OTC forms showed a significantly larger range of composite dynamic stability than CTC forms ($p = 0.021$).

Conclusion: The selected OTC forms could impose a greater challenge on balance control among older adults than CTC forms. The finding in this study is significant as it could furnish a scientific basis for identifying the best TC forms to optimize the effectiveness of TC-based fall prevention interventions.

Significance and Innovations:

- This is the first study to biomechanically identify optimal Tai Chi forms (OTC) using dynamic stability criteria for fall prevention. This would provide mechanistic insight into our understanding of balance control strategies used in TC.
- Our results provide direct evidence that the selected OTC forms are associated with a larger range of composite dynamic gait stability than commonly used TC (CTC) forms. The large range of stability of OTC could impose a great challenge on balance control than CTC forms.
- This study established a scientific foundation for future efforts to select and implement the most effective TC forms for people with knee osteoarthritis in fall rehabilitation.

1. Introduction

Falls are a serious health concern among older adults [1]. Knee osteoarthritis (OA) significantly increases the risk of falls among older adults. Knee OA is associated with about 40% higher odds of future falls than individuals without lower extremity OA [2]. Falls can lead to severe physical, psychological, and economic consequences. It is, therefore, paramount to develop effective and low-impact interventions for people with knee OA to reduce their risk of falls. Tai Chi (TC) training has gained increasing attention for preventing falls [3,4]. However, findings from past TC-based studies have been inconsistent [5]. One possible factor leading to the inconclusive results could be the different TC forms used across studies. Such inconsistency in selecting TC forms could be attributed to the lack of scientifically sound practices to identify effective TC forms, which most likely maximize the training effects in preventing falls.
To address this knowledge gap, we recently conducted a study to examine dynamic stability of the human body when performing each simplified Yang's TC form among older adults with knee OA [6]. Dynamic stability is a comprehensive measurement of the relative kinematics between the human body's center of mass (COM) and base of support (BOS). It has been broadly used to quantify the body's dynamic balance [7,8]. The results indicated that dynamic gait stability in the sagittal and frontal planes varies drastically among TC forms [6]. The range of dynamic stability is also significantly different between TC forms. Our previous studies have reported that excessively high or low dynamic stability value is associated with forward [9] or backward [7] balance loss. Therefore, a large range of dynamic gait stability could cause balance loss and thus pose a significant challenge to the balance control system.

The overload principle, one crucial aspect of the well-established principles of motor learning, has been widely adopted as an essential policy for exercise training in clinical practice [10]. It was also recently proposed to apply the overload principle to balance training [11]. This principle requests that the balance hazards, which trainees experience during training, should be challenging enough to induce an adaptation to the training environment and improve motor functions among trainees. The training-induced motor functions could be executed to react sufficiently and effectively to any challenge to balance in daily living conditions. The larger the range of stability of a TC form, the more challenge the corresponding TC form would impose on the human body to maintain its balance. Thus, the training effect in improving body balance could be greater for the forms with a larger range of stability than those with a smaller range. According to the overload principle, the skills acquired during the TC training process with the more challenging TC forms would be sufficient to handle situations compromising balance in everyday living conditions. The overload principle also offers us a novel perspective to identify effective TC forms that can maximize the effect of TC-based fall prevention programs in the future.

The purpose of this study was to identify eight TC forms that have the most extensive range of dynamic stability among the 24 simplified Yang's style TC. These selected TC forms would form the Optimal TC forms (OTC). The eight forms were chosen to match the number of the commonly used TC forms (CTC). Then, the stability range of the OTC forms was compared with the ones of the CTC forms for preventing falls [12]. We hypothesized that the stability range of the OTC forms would be significantly greater than the CTC forms. The findings from this study would provide meaningful information to conduct a long-term interventional study to examine the effects of OTC in reducing falls for older adults with knee OA relative to CTC forms.

2. Methods

The collection and processing of the data used here can be found elsewhere [6]. Briefly, eight older adults with knee OA (mean ± standard deviation age: 62.8 ± 12.2 years; body height: 1.62 ± 0.17 m; and body mass: 81.3 ± 28.5 kg) learned how to correctly perform 24-form simplified Yang's TC under the instructions of an experienced TC instructor on an individual basis. All participants were diagnosed based on the American College of Rheumatology classification criteria for symptomatic knee OA with Kellgren/Lawrence scale of 2–3 on radiographs. Four randomly selected TC forms were taught within a one-day session, and three sessions were conducted weekly. At the end of each session, participants performed the respective TC forms. Their full-body kinematics during the TC performance portion was collected using a motion capture system (Vicon, UK) [13].

The TC forms during the performance portion of all sessions were selected as the representative trials to be analyzed. The body's COM kinematics were computed based on the filtered marker trajectories. The two components of the COM motion state (i.e., its position and velocity) were calculated relative to the BOS. Dynamic stability was calculated in both the sagittal and frontal planes over the entire duration of each TC form. The minimum and maximum values of dynamic stability in either plane were then determined for each TC form. Next, the range of dynamic stability was calculated as the difference between the maximum and minimum stability values on both planes for all TC forms. The composite range of stability was then defined as the addition of the ranges of anteroposterior and mediolateral dynamic stability. As stated, a larger composite stability range could indicate that the respective TC form represents a more significant challenge to maintain balance [7,9].

Then, the first eight TC forms with the highest composite stability range were determined, forming the OTC forms. The composite stability range was compared between the OTC and CTC forms by independent t-test. The statistical analyses were performed within SPSS 26 (IBM, NY), and a significance level of 0.05 was applied.

3. Results

Dynamic stability range exhibited significant variances in both the sagittal (anteroposterior direction) and frontal (mediolateral direction) planes (Fig. 1). The anteroposterior stability ranged between 0.047
(Form 1) and 0.797 (Form 8, Fig. 1a), and the mediolateral stability spanned from 0.180 (Form 1) to 3.936 (Form 10, Fig. 1b). Similarly, the composite stability range varied significantly: 0.227 (Form 1) – 4.149 (Form 10) (Fig. 1c). The first eight TC forms with the largest composite stability range were: 10, 2, 14, 4, 18, 8, 15, and 11. They were selected to constitute the OTC program. Compared with the eight CTC forms (Forms: 1, 2, 4, 6, 7, 9, 10, 18) [12], the OTC program showed a significantly larger composite stability range (2.81 ± 0.68 vs. 2.25 ± 1.20, p = 0.021, Fig. 2).

4. Discussion

The principal objective of this pilot study was to investigate whether the OTC forms, which were biomechanically identified based on their composite dynamic stability range, challenge the body’s balance more than the CTC forms among older adults with knee OA. The results supported our hypothesis that the range of the composite dynamic stability is significantly higher for the selected OTC forms than CTC forms. Since the range of dynamic stability represents the degree of challenge that TC forms impose on the body, the selected OTC forms may be more effective in improving balance, thereby reducing the risk of falls among older adults with knee OA than CTC forms.

Previous studies on TC fall prevention programs were based on a rationale of the common belief that TC training can improve balance, muscle strength, and range of motion [14]. These TC-induced changes support the general conceptual synopsis that TC would be a well-founded intervention for fall prevention. The caveat is that specific objective mechanisms of TC movements related to fall risk, such as dynamic stability, are missing. TC forms commonly used in prior studies were chosen without specifying a measurable and objective criterion [12,15], which may lead to inconsistent or sub-optimal effects in reducing the risk of falls. Our previous results showed that individual TC forms are associated with different levels of the range of stability, implying various challenges in maintaining body balance [8]. Such information provides us a valuable and objective framework to choose the best TC forms from the perspective of improving balance. The eight OTC forms selected based on this framework could be more beneficial to improve balance than the TC forms used in previous studies. Although the findings from the present study theoretically endorse the positive effect of OTC forms in reducing falls, longitudinal, randomized controlled trials with large sample sizes are needed to further determine the practical and clinical effectiveness of the OTC forms in reducing falls relative to the CTC forms. The present study provided important connecting information to design such trials.

The present study had limitations. First, the sample size was small. This may weaken the generalizability of our findings in the present study. As an initial step of selecting the optimal TC forms for preventing falls, our results can still shed light on maximizing the effects of TC-based fall prevention training. Second, the TC learning duration may not be sufficient for the participants to grasp the performance of TC. However, the participants’ movements should have captured the key biomechanical characteristics of TC forms as the experienced TC instructor kept monitoring and correcting the participants on an individual basis during the learning. Long-term interventional studies with larger sample sizes are needed to address these limitations.

In spite of the limitations, the results of this pilot study suggested that quantitative biomechanical criteria allow us to identify the possibly optimal TC forms for improving balance using the composite range of dynamic stability. The OTC forms identified in this study reflect the overload principle and could be more effective in improving balance in older adults with osteoarthritis than CTC forms. It is anticipated that the benefits of TC could be conceivably enhanced if TC can be tailored based on a biomechanical basis for challenging balance during TC practice.

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 the finished article. Authors Liu and Yang 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 and Yang. Drafting of the manuscript: Liu and Yang. Critical revision of the manuscript for important intellectual content: Liu and Yang. Statistical analysis: Yang.

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Declaration of competing interest

The authors have no conflicts.

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