Meta-Analysis

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Clinical relevance of Tai Chi on pain and physical function in adults with knee osteoarthritis: An ancillary meta-analysis of randomized controlled trials

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Abstract

The clinical relevance of Tai Chi on pain, stiffness, and physical function in adults with knee osteoarthritis (KOA) has not been established. Therefore, the purpose of the current study was to address this gap. Eight randomized controlled trials from a recent meta-analysis representing 407 participants (216 Tai Chi, 191 control) in adults ≥18 years of age with KOA and included the assessment of pain, stiffness, and physical function using the Western Ontario and McMaster Universities Arthritis Index (WOMAC) were assessed. The inverse variance heterogeneity model (IVhet) was first used to pool standardized mean difference effect sizes (ES) for each outcome. Clinical relevance, i.e., number-needed-to treat (NNT) ≤10 and relative risk reduction (RRR) ≥25% was calculated across assumed controlled risks (ACR) ranging from 0.01 to 0.99. Statistically significant improvements were found for pain (ES, −0.75, 95% CI, −0.99, −0.51; $Q = 8.9$, $p = 0.26$; $I^2 = 21\%$), stiffness (ES, −0.70, 95% CI, −0.95, −0.46; $Q = 9.6$, $p = 0.21$; $I^2 = 27\%$), and physical function (ES, −0.91, 95% CI, −1.12, −0.70; $Q = 7.2$, $p = 0.40$; $I^2 = 3\%$). The intersection of results for a NNT ≤10 and RRR ≥25% yielded high evidence and clinically relevant improvements across a wide range of ACR for pain (0.15 to 0.88), stiffness (0.15 to 0.87), and physical function (0.13 to 0.97). These findings suggest that Tai Chi results in statistically significant as well as clinically important improvements in pain, stiffness, and physical function across a wide range of ACR in adults with KOA.

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Tai Chi, osteoarthritis, older adults, aging, meta-analysis

Background

Knee osteoarthritis (KOA), a complex and serious disease marked by a progressive deterioration of cartilage and subsequent inflammation, is a worldwide problem, especially in older men and women.[1] For example, a recent systematic review with meta-analysis estimated that the global prevalence of KOA was 16.0% in those 15 years of age and older, 22.9% in adults 40 years of age and older, 28.7% in those 60 to 69, 34.0% in those 70 to 79, and 49.8% in those 80 years and older.[2] Not surprisingly, the financial costs associated with KOA are high. For example, in the United States (US), the average lifetime cost for persons diagnosed with KOA was estimated at $140,300.[3] Notably, KOA results in increased pain and stiffness, decreased physical function, and increased disability.[4] The association between these outcomes may follow a general pattern of deterioration of cartilage leading to bone-on-bone friction, inflammation, pain, stiffness, reduced physical function, and increased disability.[5]

One potential nonpharmacologic approach for improving pain, stiffness, and physical function in adults with KOA is Tai Chi, a meditative movement therapy defined by Wayne and Kaptchuk as "exercise based on slow intentional movements, often coordinated with breathing and imagery, which aims to strengthen and relax the physical body and mind, enhance the natural flow of what the Chinese call qi (a nontranslatable word that describes the interpenetration and connection of phenomenon, or life energy), and improve health, personal development, and self-defense".[6] In the US, the use of Tai Chi among adults 18 years of age and older was estimated to be 1.1% in 2012.[7] Based on 2012 US Population Census data,[8] this represents more than 3.4 million adults 18 years of age and older who reported practicing Tai Chi in 2012 (unpublished results).

A recent systematic review with meta-analysis of 16 randomized trials representing 986 adults 18 years of age and older with KOA reported statistically significant reductions in pain and stiffness, as well as increases in physical function, as a result of participation in Tai Chi.[9] While these results are encouraging, the clinical relevance of these findings was not quantified.[9] The appropriate quantification of clinical relevance is important because it provides clinicians and others with critical information regarding the potential benefit of an intervention such as Tai Chi on pain, stiffness, and physical function in adults with KOA. Recently, a novel method for determining the clinical relevance of an intervention based on results from an aggregate data meta-analysis has been proposed.[10] The purpose of the current study was to apply this method to determine the clinical relevance of Tai Chi on pain, stiffness, and physical function in adults with KOA.

Methods

Registration

The protocol for this study is registered in Open Science Framework (https://osf.io/ca7sq) but has not been previously published in a peer-reviewed journal.

Data source and eligibility

For the current ancillary study, data from a recent aggregate data systematic review with meta-analysis[9] of 16 randomized trials[11–26] representing 986 men and women ≥18 years of age that reportedly had doctor-diagnosed KOA and that included the assessment of Tai Chi training on pain and physical function were considered for inclusion.[9] A published systematic review with meta-analysis was selected as the primary data source for this new analysis based on (1) its recency (2021),[9] (2) concern by others about redundant systematic reviews with meta-analysis,[27] and (3) a decision using recommendations from the Panel for Updating Systematic Reviews' (PUGs) for when an entirely new systematic review with meta-analysis is needed.[28] Details of this previous aggregate data systematic review with meta-analysis are provided in the original article.[9] Briefly, studies were conducted in three different countries (US,[13,15,18,19,23,24,26] China,[11,12,14,16,17,20] Korea,[21,22,25]) in men and women in which mean between-study group ages ranged from 60 to 79 years.[9] Length of the studies ranged from 8 to 52 weeks with Tai Chi performed 2 to 4 times per week for 20 to 60 min per session.[9] Types of Tai Chi included 24-form,[11,14,16] Tai Chi Quan,[12] Yang style,[13,15,19,20,23,24,26] 8-form,[17] Sun style,[18,22,25] and Tai Chi Qigong.[21] Outcomes in the original meta-analysis included, but were not limited to, pain and physical function measures as assessed by the Western Ontario and McMaster Universities Arthritis Index (WOMAC) for pain, stiffness, and physical function, as well as the 6-min walk test and timed up-and-go test.

After reviewing the systematic review with meta-analysis from which data for this study were derived, an a priori decision was made by the first and second authors to exclude eight studies from the current analysis,[11–15,20,22,26] two because they were not randomized controlled trials, but rather, comparative effectiveness studies that compared tai chi to physical therapy,[13,15] three because not all participants had KOA or it could not be confirmed that all participants had KOA,[11,22,26] one[20] because it had been retracted,[29] and two because their data were not included in the outcomes that met our eligibility criteria.[12,14] Thus, for the current study, 8 randomized controlled trials representing 407 participants (216 Tai Chi, 191 control) were eligible for analysis,[16–19,21,23–25] with all limited to assessment using the WOMAC instrument.

Post hoc to our a priori protocol, a decision was made to update the search for potentially eligible studies to include the dates July 1, 2020 through December 2, 2021.[9] Searches for studies published in peer-reviewed journals, with no language restrictions (assuming an English-language abstract was available), were conducted by the first author on December 2, 2021 using the following databases: (1) PubMed, (2) Web of Science, (3) Cochrane Central Register of Controlled Trials (Central), (4) Scopus, a database that has been reported to provide 100% coverage of Embase,[30] (5) CINAHL (EBSCOhost), and (6) Sport Discus (EBSCOhost). The general search phrase was as follows: "(Tai chi OR Taiji) AND osteoarthritis AND (WOMAC OR Western Ontario and McMaster Universities Arthritis Index) AND random*". A list of each database searched is shown in Supplementary file 1. Any foreign-language articles in which the full-text was retrieved were to be translated by the first author using Google translate, while cross-referencing was planned for any articles that underwent full-text review. Search results from each database were imported into EndNote 20[31] as separate files, saved, and then merged into one separate file by the first author. Duplicates were then removed both electronically and manually by the first author and exported to Rayyan[32] for independent and blinded dual screening by the first and second authors. The authors then met to review their screening results. Any discrepancies were resolved by mutual agreement. The final list of studies, including the reason(s) for exclusion, were then exported back to a separate file in EndNote 20. Of the four studies identified,[33–36] all were excluded, two because they were the wrong study design,[34,35] and two because they were the wrong intervention.[33,36] None of the studies required full-text review. A flow diagram of the updated search process is shown in Supplementary file 2.

Data extraction

For the current clinical relevance study, data from eligible studies included in the original meta-analysis[9] were extracted by the first and second authors, independent of each other, using Microsoft® Excel® for Microsoft 365 MSO (16.0.13801.20442). Data extracted included: (1) authors' names, (2) year study was published, and (3) sample sizes, change outcome means, change outcome standard deviations, standard mean difference effect sizes, and 95% CIs for standardized mean difference (SMD) effect sizes for pain and physical function outcomes for Tai Chi and control groups. Any disagreements in data abstraction were resolved by consensus. If consensus could not be reached, the third author provided a recommendation.

Quality of included meta-analysis

The Assessment of Multiple Systematic Reviews (AMSTAR 2) instrument was used to assess the quality of the included meta-analysis from which this clinical relevance analysis was derived.[37] Details regarding this instrument are provided elsewhere.[37] Briefly, this instrument includes 16 questions for evaluating the quality of meta-analyses of randomized controlled trials of healthcare interventions.[37] Conditional on the question, response choices include "Yes", "No", "Partial Yes" or "No-meta-analysis conducted".[37] "Yes" and "Partial Yes" denote that the element was satisfactorily addressed.[37] While not designed to produce an overall score, the following classifications have been proposed with respect to confidence in the findings of the review: "High" ($\leq$1 critical or non-critical weakness), "Moderate" ($\geq$1 one non-critical weakness), "Low" (one critical flaw with or without non-critical weaknesses), or "Critically low" (>1 critical flaw with or without non-critical weaknesses).[37] AMSTAR2 assessments were conducted by the first and second authors, independent of each other. Disagreements were resolved by consensus. If consensus could not be reached, the third author provided a recommendation.

Data synthesis

Effect size metric. Given the different types of data reported in the original studies, the standardized mean difference effect size was the metric used for pain, stiffness and physical function.[9]

Meta-analysis. Prior to addressing the primary purpose of the current study, that is, clinical relevance, a traditional aggregate data meta-analysis was conducted by pooling SMD effect sizes from each study using the inverse variance heterogeneity (IVhet) model, a model that incorporates heterogeneity into the analysis and has been shown to be more robust and theoretically reasonable than the traditional random-effects model used in the original meta-analysis.[38,39] Given the decreased robustness for sample sizes less than five, pain and physical function outcomes were limited to those in which there were at least five effect sizes: WOMAC pain, WOMAC stiffness, WOMAC physical function. Based on the WOMAC scoring system, negative values for all outcomes were indicative of improvements associated with Tai Chi. Two-tailed z-alpha values ≤ 0.05 and non-overlapping 95% CI were considered statistically significant.

Heterogeneity was assessed using the Cochran Q statistic,[40] with an alpha value ≤ 0.10 for Q considered to represent statistically significant heterogeneity.[40] Inconsistency in pooled results was estimated using I-squared (I^2), an extension of Q.[41] I-squared values were classified as follows: <25% (very low or nil), 25% to <50% (low), 50% to <75% (moderate), and ≥75% (large).[41] In addition to Q and I^2, tau-squared (τ^2), an absolute measure of between-study heterogeneity, was also computed.

Small-study effects (publication bias, etc.) were estimated using the Doi plot and Luis Furuya-Kanamori (LFK) index.[42] The Doi plot and LFK index have been shown to be more intuitive and robust than the methods used for assessing small-study effects in the original meta-analysis.[42] Based on previous recommendations,[42] LFK values were categorized as follows: <±1 (no asymmetry), between ±1 and ±2 (minor asymmetry), and >±2 (major asymmetry).[42] To examine the effects of each study on the overall pooled results, influence analysis, a type of sensitivity analysis, was conducted by deleting each study from the model once. As an additional form of sensitivity analysis, outlier analysis was conducted by examining results when effect sizes in which their 95% CIs fall completely outside the pooled 95% CI were deleted from the model. Finally, cumulative meta-analysis, ranked by year, was conducted to examine the accumulation of results over time.[43] Meta XL (version 5.3)[44] and the most recent user-written versions of metan and the lfk index for Stata (version 16),[45] were used for all analyses.

Clinical relevance. For the primary purpose of the current study, the clinical relevance for pain and physical function outcomes (WOMAC pain, WOMAC stiffness, WOMAC physical function) were determined using recent, novel methods proposed by Palazon-Bru et al.[10] Details regarding this approach have been described elsewhere.[10] The range of assumed controlled risk (ACR) values in which an intervention would have at least high evidence (NNT ≤10) and be clinically relevant [relative risk reduction (RRR) ≥25%] were calculated.[10,46,47] If the ACR falls within the ACR of the clinician's population, then the intervention might be considered to have large benefit in their population.[10] Based on previous recommendations, these values were chosen given the lack of agreement regarding what values are clinically relevant for WOMAC pain, WOMAC stiffness, and WOMAC physical function. Previously suggested cutpoints for the NNT are <5 (very high), 5 to 10 (high), 10 to 20 (moderate), 20 to 50 (low), >50 (very low).[46] For RRR, values of 25% are typically considered as clinically relevant while values of 50% or greater are almost always considered to be clinically relevant.[10,47]

For the current study, the logit method was first used to convert pooled SMD effect sizes and their 95% CIs for each outcome to odds ratios (OR).[48] The reciprocal of the OR and its 95% CIs (to assess an adverse event) was then calculated so that the NNT could be computed across ACR ranging from 0.01 to 0.99.[10,48] The RRR was calculated by converting the OR to a RR across the same range of ACR as for the NNT.[9,39] All analyses were conducted using recently developed R script[10] in R Studio, version, 1.2.5033.[49]

Modifications to protocol. In addition to an updated search, a post hoc decision was made to include stiffness as an outcome because it is a common patient-reported condition in adults with KOA[50] and is also a component of the WOMAC assessment instrument. No other post hoc modifications were made.

Results

Quality of meta-analysis

AMSTAR results for the quality of the included meta-analysis[9] are shown in Supplementary file 3. Ten of 16 items (62.5%) were rated positively. Collectively, overall confidence in the meta-analysis was judged as "Moderate", with "No" ratings considered to be non-critical weaknesses.

Changes in pain

Treatment effect changes for pain are shown in Figure 1. As can be seen, statistically significant reductions associated with Tai Chi were observed. No statistically significant heterogeneity was observed, and inconsistency was considered to be very low. No asymmetry suggestive of small study effects was found (Supplementary file 4) and no outliers were detected. With each study deleted from the model once, results remained statistically significant (Supplementary file 5). Cumulative meta-analysis, ranked by year, demonstrated that results have remained statistically significant since 2009 (Supplementary file 6).

For clinical importance, the standardized mean difference effect size for pain, when converted to an OR, was 3.89 (95% CI, 2.52, 6.00). The NNT was ≤10 (high evidence) for ACR values between 0.15 and 0.95 (Figure 2(a)) while the intervention was considered clinically relevant (≥25%) when the ACR was 0.88 or less, and ≥50% for ACR values ≤0.66 (Figure 2(b)). The intersection of the NNT and RRR results suggest that ACRs ranging from 0.15 to 0.88 yield high evidence and clinically relevant reductions in pain associated with Tai Chi in adults with KOA. Notably, ACR for a NNT ≤5 ranged from 0.30 to 0.90 while RRR ≥50% ranged from 0.01 to 0.65.

Changes in stiffness

Treatment effect changes for stiffness are shown in Figure 3. As can be seen, statistically significant reductions associated with Tai Chi were observed. No statistically significant

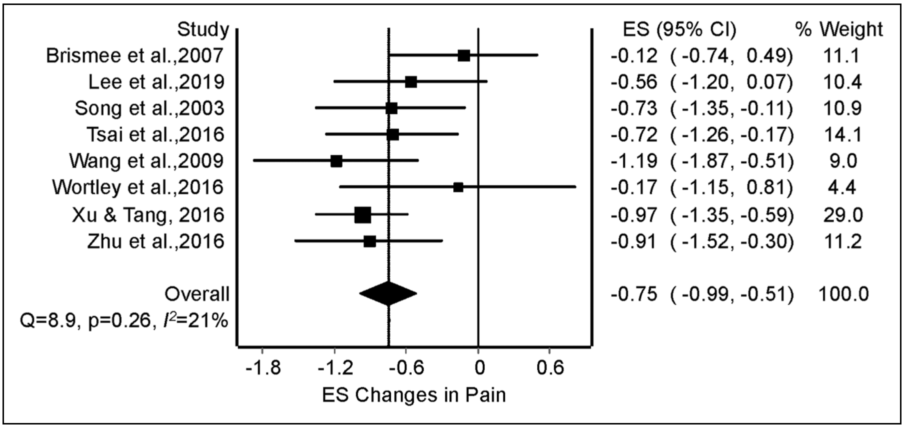

Figure 1. Forest plot for standardized mean difference effect size changes in pain. The black filled squares, sized according to the weight contributing to the overall effect, represent changes in pain from each study while the left and right extremes of the squares represent the lower and upper 95% confidence intervals for changes in pain from each study. The black diamond represents the pooled mean change in pain while the left and right extremes of the diamond represents the pooled lower and upper 95% confidence intervals for changes in pain. The thicker vertical line represents the pooled mean effect while the thinner vertical line represents the zero (0) point.

heterogeneity was observed, and inconsistency was considered to be low. Minor asymmetry suggestive of small study effects was found (Supplementary file 7) and no outliers were detected. With each study deleted from the model once, results remained statistically significant (Supplementary file 8). Cumulative meta-analysis, ranked by year, demonstrated that results have remained statistically significant since the first published study in 2003 (Supplementary file 9).

For clinical importance, the standardized mean difference effect size for stiffness, when converted to an OR, was 3.58 (95% CI, 2.28, 5.62). The NNT was $\leq$10 (high evidence) for ACR values between 0.15 and 0.95 (Figure 4(a)) while the intervention was considered clinically relevant ($\geq$25%) when the ACR was 0.87 or less, and $\geq$50% for ACR values $\leq$0.62 (Figure 4(b)). The intersection of the NNT and RRR results suggest that ACRs ranging from 0.15 to 0.87 yield high evidence and clinically relevant reductions in stiffness associated with Tai Chi in adults with KOA. Notably, ACR for a NNT $\leq$5 ranged from 0.32 to 0.88 while RRR $\geq$50% ranged from 0.01 to 0.61.

Changes in physical function

Treatment effect changes for physical function are shown in Figure 5. As can be seen, statistically significant reductions associated with Tai Chi were observed. No statistically significant heterogeneity was observed, and inconsistency was considered to be very low. Minor asymmetry suggestive of small study effects was found (Supplementary file 10) and no outliers were detected. With each study deleted from the model once, results remained statistically significant (Supplementary file 11). Cumulative meta-analysis,

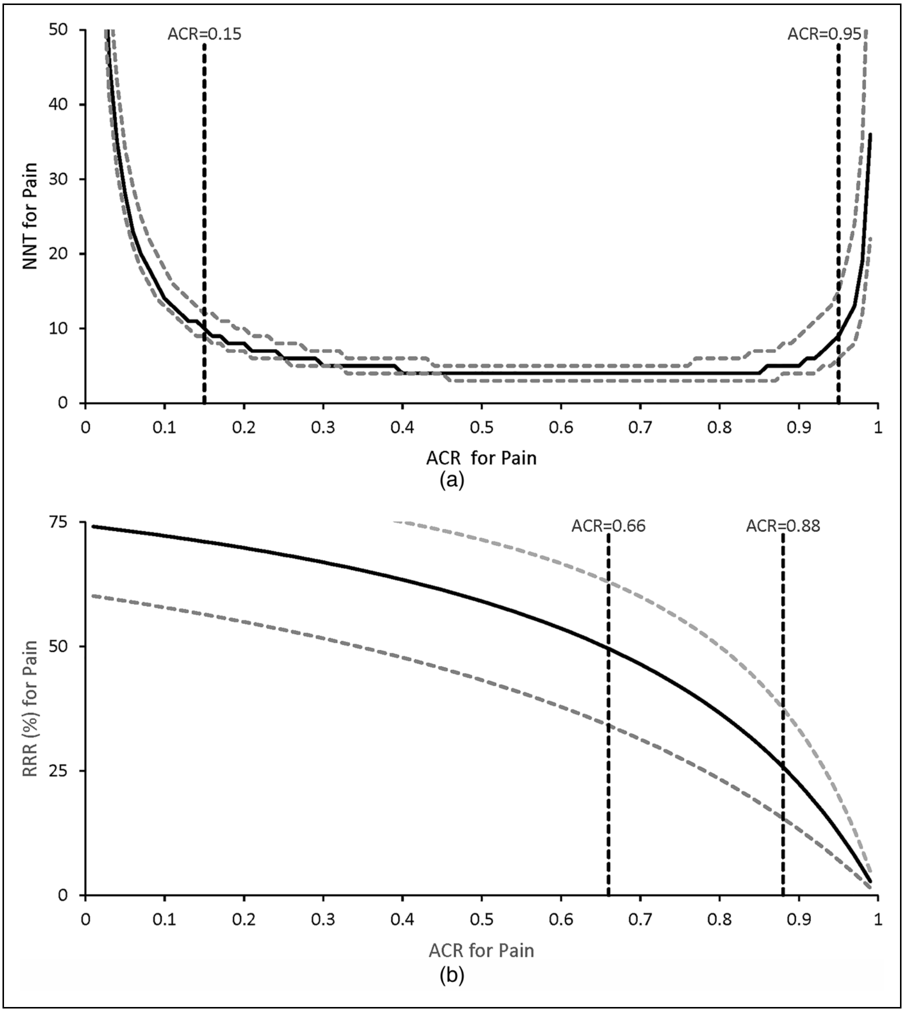

Figure 2. (a) and (b) analysis of the number-needed-to-treat (NNT) for changes in pain depending on the assumed controlled risk (ACR). The two cutpoints represent the ACR for a NNT <10 while the solid and dashed lines represent mean and 95% confidence intervals, respectively, for the NNT (a). Analysis of the relative risk reduction (RRR) for changes in pain depending on the ACR. The two cutpoints represent the ACR when the RRR = 25% and 50%, i.e., clinically relevant intervention, while the solid and dashed lines represent mean and 95% confidence intervals, respectively, for the RRR (b).

ranked by year, demonstrated that results have remained statistically significant since inception of the first study in 2003 (Supplementary file 12).

For clinical importance, the standardized mean difference effect size for physical function, when converted to an OR, was 5.20 (95% CI, 3.55, 7.63). The NNT was ≤10 (high evidence) for ACR values between 0.13 and 0.97 (Figure 6(a)) while the intervention was

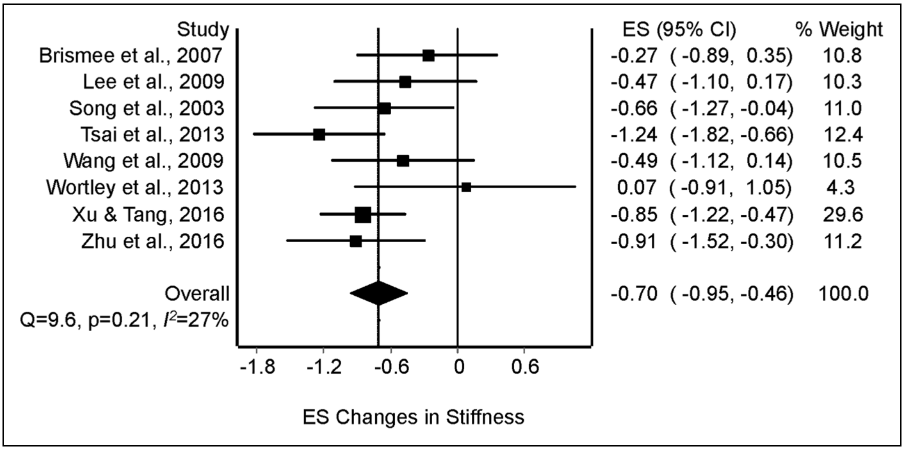

Figure 3. Forest plot for standardized mean difference effect size changes in stiffness. The black filled squares, sized according to the weight contributing to the overall effect, represent changes in stiffness from each study while the left and right extremes of the squares represent the lower and upper 95% confidence intervals for changes in stiffness from each study. The black diamond represents the pooled mean change in stiffness while the left and right extremes of the diamond represents the pooled lower and upper 95% confidence intervals for changes in stiffness. The dashed thicker line represents the pooled mean effect while the thinner vertical line represents the zero (0) point.

considered clinically relevant (≥25%) when the ACR was 0.92 or less, and ≥50% for ACR values ≤0.77 (Figure 6(b)). The intersection of the NNT and RRR results suggest that ACRs ranging from 0.13 to 0.97 yield high evidence and clinically relevant reductions in physical function associated with Tai Chi in adults with KOA. Notably, ACR for a NNT ≤5 ranged from 0.27 to 0.93 while RRR ≥50% ranged from 0.01 to 0.76.

Discussion

Overall findings

The overall findings of the current study suggest that Tai Chi is associated with statistically significant reductions in pain, stiffness, and physical function in adults with KOA. For all outcomes, these results are further supported by (1) the minor asymmetry observed, (2) the lack of statistically significant heterogeneity, (3) very low or low inconsistency, (3) absence of outliers, (4) statistically significant findings when each study was deleted from the model once, and (5) cumulative meta-analysis demonstrating statistically significant findings since at least the year 2009. In addition, and the primary reason for conducting the current study, the clinical importance of Tai Chi on pain, stiffness, and physical function in adults with KOA were supported by NNT values ≤10 across ACR values ranging from as low as 0.13 to 0.97 (high evidence), as well as RRR improvements ≥25% for ACRs as high as 88% for pain, 87% for stiffness, and

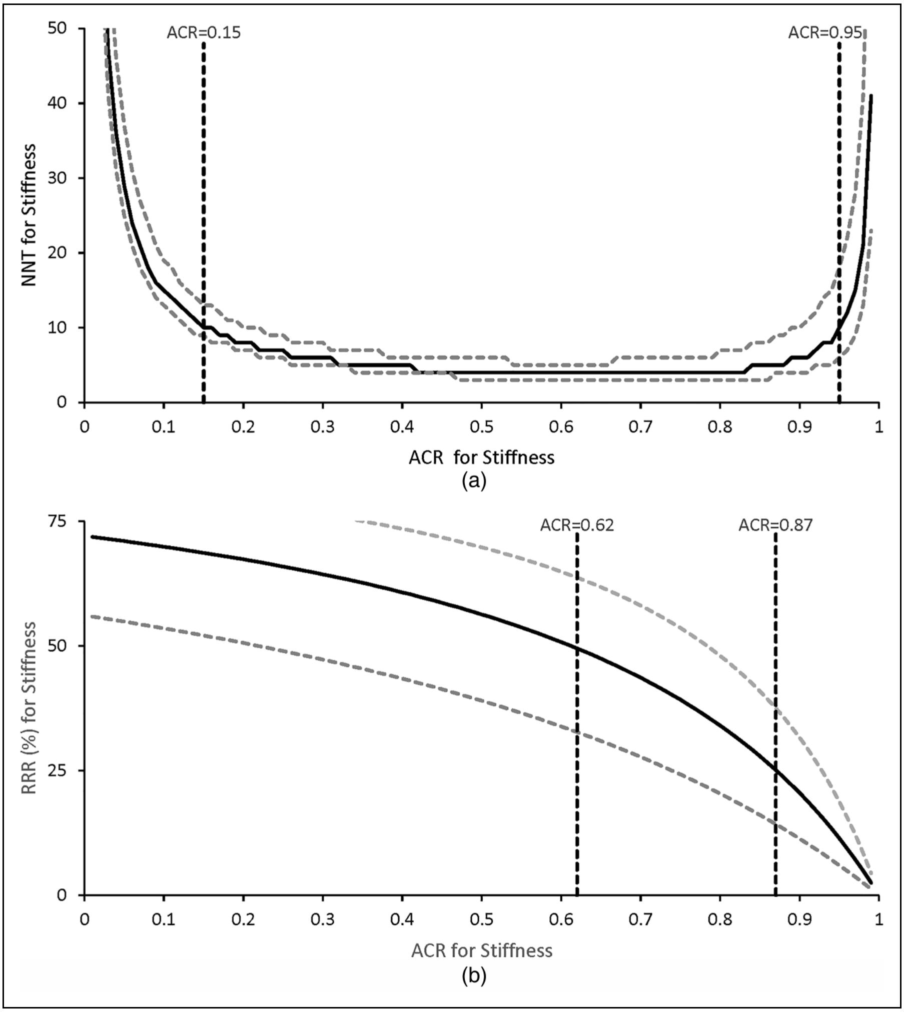

Figure 4. (a) and (b) analysis of the number-needed-to-treat (NNT) for changes in stiffness depending on the assumed controlled risk (ACR). The two cutpoints represent the ACR for a NNT <10 while the solid and dashed lines represent mean and 95% confidence intervals, respectively, for the NNT (a). Analysis of the relative risk reduction (RRR) for changes in stiffness depending on the ACR. The two cutpoints represent the ACR when the RRR = 25% and 50%, i.e., clinically relevant intervention, while the solid and dashed lines represent mean and 95% confidence intervals, respectively, for the RRR (b).

92% for physical function (clinical relevance). From the authors' perspective, the clinical importance of these findings is particularly noteworthy as they cover a wide range of ACRs, and thus, benefit a large number of adults with KOA.

While the clinical importance of Tai Chi on pain, stiffness, and physical function was not addressed in the original meta-analysis,[9] the major reason for this current ancillary

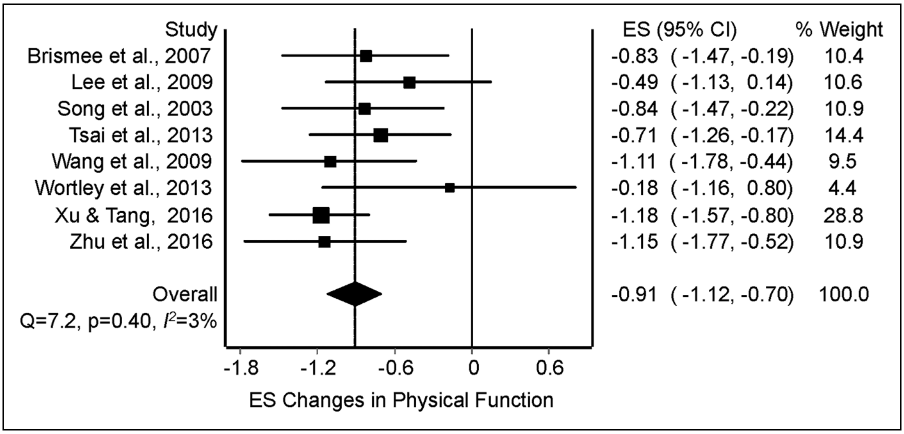

Figure 5. Forest plot for standardized mean difference effect size changes in physical function. The black filled squares, sized according to the weight contributing to the overall effect, represent changes in physical function from each study while the left and right extremes of the squares represent the lower and upper 95% confidence intervals for changes in physical function from each study. The black diamond represents the pooled mean change in physical function while the left and right extremes of the diamond represents the pooled lower and upper 95% confidence intervals for changes in physical function. The thicker vertical line represents the pooled mean effect while the thinner vertical line represents the zero (0) point.

study, a traditional aggregate data meta-analysis was also conducted.[9] For both the current and previous meta-analysis,[9] statistically significant improvements in pain, stiffness, and physical function were found. However, the standardized mean difference effects size improvements in the current meta-analysis were approximately 6% greater for pain, 7% greater for stiffness, and 1% smaller for physical function. There are at least two possible reasons for this. First, and as noted in the methods section of the current paper, an a priori decision was made to exclude eight studies from the current analysis,[11–15,20,22,26] two because they were not randomized controlled trials, but rather, comparative effectiveness studies that compared tai chi to physical therapy,[13,15] three because not all participants had KOA or it could not be confirmed that all participants had KOA,[11,22,26] one[20] because it had been retracted,[29] and two because their data were not included in the outcomes that met our eligibility criteria of at least five effect sizes per outcome.[12,14] Second, the original meta-analysis used a traditional random-effects model while the current meta-analysis employed the IVhet model, a model that has been shown to be more robust and suggested to be more theoretically appropriate to random-effects models.[30,31]

Implications for research

There are several implications for the conduct of future research. First, given that the WOMAC is a self-report instrument that includes the potential biases associated with almost any self-report instrument, as well as the difficulty in blinding participants to

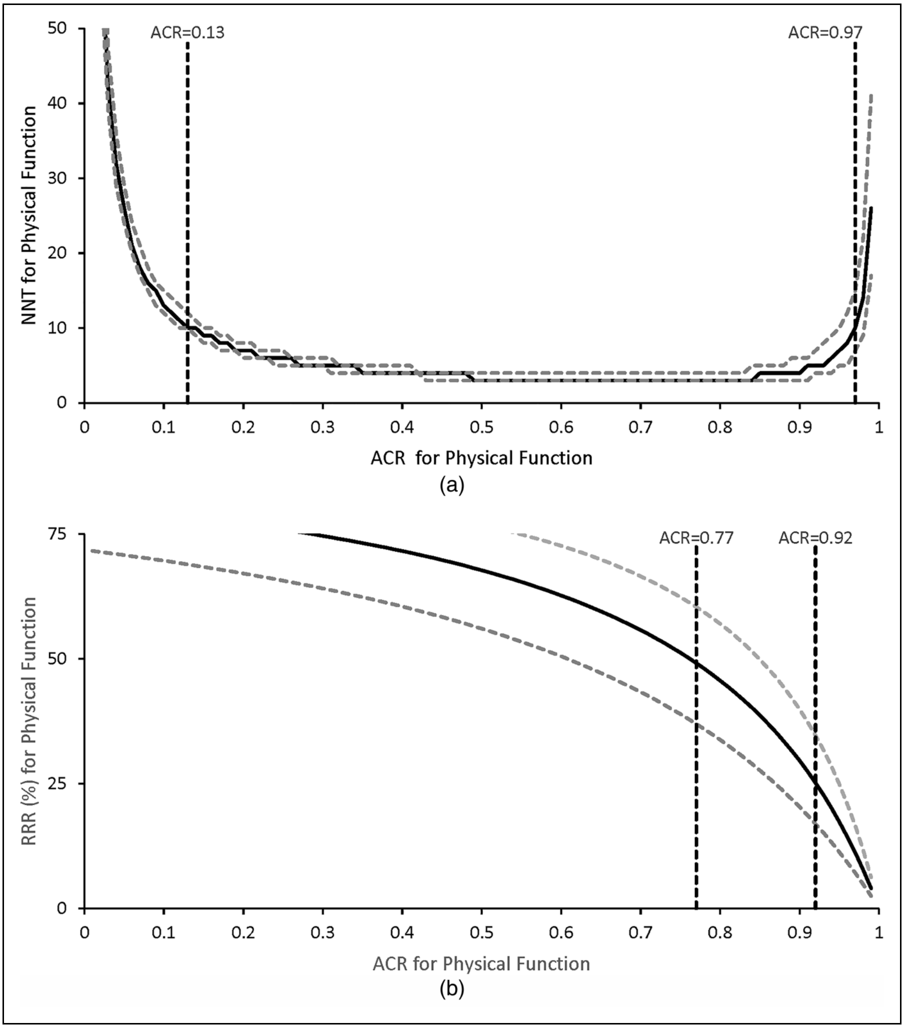

Figure 6. (a) and (b) analysis of the number-needed-to-treat (NNT) for changes in physical function depending on the assumed controlled risk (ACR). The two cutpoints represent the ACR for a NNT <10 while the solid and dashed lines represent mean and 95% confidence intervals, respectively, for the NNT (a). Analysis of the relative risk reduction (RRR) for changes in physical function depending on the ACR. The two cutpoints represent the ACR when the RRR = 25% and 50%, i.e., clinically relevant intervention, while the solid and dashed lines represent mean and 95% confidence intervals, respectively, for the RRR (b).

meditative movement interventions such as Tai Chi, it would appear plausible to suggest that a need exists for future randomized controlled trials that use performance-based measures to assess the effects of Tai Chi on those outcomes in which it is possible to assess such, e.g., physical function, in adults with KOA. For example, while the previous meta-analysis reported statistically significant improvements in performance-based tests (6-min walk, timed up-and-go, balance score),[9] there were several limitations to these findings that support further randomized controlled trials. For the 6-min walk test, this consisted of the inclusion of a retracted study[20,29] that yielded a large standardized mean difference effect size of 1.61, another study in which KOA could not be confirmed,[11] and two studies that were not randomized controlled trials.[12,14] Exclusion of these studies would have resulted in only two studies for potential pooling in the current meta-analysis, however, the criteria was at least five.[19,23] For the timed up and go test, one study in which KOA could not be confirmed was included,[11] leaving only four studies for analysis.[12,14,18,19] Finally, balance score results were available for only four studies.[12,14,23,25]

Another area of future research is a potential examination of the dose-response effects of Tai Chi on selected outcomes such as pain and physical function in adults with KOA. The establishment of such could lead to more optimal treatment in adults with KOA.

To enhance practical application, a third suggested area for future research is the conduct of a large network meta-analysis that compares the effects, including clinical importance, of different meditative (tai chi, yoga, qigong) and non-meditative (aerobic exercise, strength training, combined aerobic and strength training) movement therapies on those outcomes considered to be important in adults with KOA (pain, stiffness, physical function, quality of life, etc.). The inclusion of different pharmacological interventions in a network meta-analysis may also be considered, although a comparison of the separate effects of meditative and non-meditative movement therapies against different pharmacological therapies on selected outcomes such as pain and physical function may be challenging given that most adults with KOA use pharmacological therapies.[51] However, one could compare the potential advantages of those using different pharmacological therapies alone versus those using pharmacological therapies combined with different meditative and non-meditative movement therapies on selected outcomes in adults with KOA. Given that most studies do not compare the effects of different interventions head-to-head, the network meta-analysis approach may be particularly appealing since it allows for the inclusion and pooling of both direct and indirect evidence.

Implications for practice

The establishment of the clinical importance of Tai Chi on pain, stiffness, and physical function in adults with KOA suggests that this is a viable treatment option that might be used as a sole intervention or combined with pharmacological therapy. As previously noted, the innovative approach used in the current study suggests that the clinical benefits of Tai Chi on pain, stiffness, and physical function extend across a wide range of ACR, therefore establishing the therapeutic benefits across a wide range of participants with KOA, something that had not previously been addressed. To support this contention, it has been estimated that worldwide, 654.1 million adults 40 years of age and older had KOA in the year 2020.[2] Based on a conservative NNT of 10, this means that 65.41 million adults could improve their pain, stiffness, and physical function across a wide range of ACR by participating in tai chi.

Given that osteoarthritis, including KOA, is considered an age-related disease,[52] as well as the increased number of co-morbidities that occur with advancing age,[53] the use of Tai Chi when compared to more traditional forms of exercise may be especially appropriate given the more gentle and flowing movements involved in Tai Chi. However, to the best of the authors' knowledge, and as previously mentioned, there is currently no consensus on the type or dose of Tai Chi needed to improve outcomes such as pain, stiffness, and physical function in adults with KOA. Therefore, until such consensus is reached, it would appear plausible to suggest broad recommendations based on the studies included in the current meta-analysis. This includes any type of Tai Chi performed 2 to 4 times per week for 20 to 60 min per session.[9] Finally, and more broadly, adherence to the recent American College of Rheumatology/Arthritis Foundation Guidelines for the Management of Osteoarthritis, including KOA, is recommended.[54]

Implications for policy

While the current findings should be helpful to researchers and practitioners, they should also be helpful for decision makers (funding agencies, policymakers, etc.), as it provides them with evidence-based information for prioritizing resources aimed at programs like Tai Chi that may yield the greatest potential return on investment.

From a policy perspective, third-party payment for Tai Chi programing in countries such as the US appears warranted. This recommendation coincides with recent and broader recommendations from the Osteoarthritis Action Alliance, Centers for Disease for Disease Control and Prevention, and Arthritis Foundation aimed at the development of mechanisms to reimburse those responsible for the delivery of evidence-based, self-management and physical activity programs.[55] Policies aimed at including Tai Chi as part of the Exercise is Medicine (EIM) Initiative, a program aimed at making physical activity assessment and promotion a standard in clinical care, would also seem appropriate for those with KOA.[56]

Strengths and limitations

The major strength of the current study, from the authors' perspective, is the use of a recently developed and novel approach[10] to examine the clinical importance of Tai Chi on pain, stiffness, and physical function in adults with KOA, something that to the best of the authors' knowledge, has never been examined in this population. This provides important information to researchers, practitioners, and policymakers regarding the benefits of Tai Chi across a wide range of ACRs, the results of which suggest enhanced reach. Additional strengths include the use of more focused and robust analyses than previously used[9] to pool results and examine for small-study effects,[38,39,42] all of which should lend itself to increased confidence in the findings. The former notwithstanding, several potential limitations exist. First, estimates such as NNT derived from aggregate data, including aggregate data meta-analyses, have been criticized for being potentially misleading at the level of the individual.[57] Second, one may not be able to generalize beyond the characteristics of the participants and interventions represented in the included studies.[15–18,20,22–24] Third, because of the small number of studies, no attempt was made to conduct subgroup or meta-regression analysis to examine for potental assoications between changes in pain, stiffness, and physical function with covariates such as age, sex, dose of Tai Chi, etc. However, it's important to realize that meta-regression and subgroup analyses do not support causal inferences in aggregate data meta-analysis because the included studies are not randomly assigned to covariates.[58,59] In addition, an examination of the dose-response effects of Tai Chi on changes in pain, stiffness, and physical function in adults with KOA should only take place after properly testing to ensure that true inter-individual response differences are the result of Tai Chi itself versus other factors such as random variation (biological day-to-day variation, measurement error) and/or physiological responses associated with behavioral changes that are not the result of Tai Chi (sleep, diet, etc.).[60–62] Fourth, since the WOMAC is a self-report instrument, it suffers from the potential biases inherent in most self-report instruments, for example, social desirability bias. Finally, like any aggregate data meta-analysis, the potential for ecological fallacy, specifically Simpson's paradox, exists.[63]

Conclusions

The findings of the current study suggest that Tai Chi results in statistically significant as well as clinically important improvements in pain, stiffness, and physical function across a wide range of ACRs in adults with KOA.

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None.

Authors' contributions

GAK was responsible for the conception and design, acquisition of data, analysis, and interpretation of data, drafting the initial manuscript and revising it critically for important intellectual content. KSK was responsible for the conception and design, acquisition of data, and reviewing all drafts of the manuscript. LFC was responsible for the conception and design, interpretation of data and reviewing all drafts of the manuscript. All authors read and approved the final manuscript.

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Informed consent/institutional review board approval

The proposed study is an aggregate data meta-analysis of previously reported summary data. Therefore, neither Informed Consent nor Institutional Review Board Approval is required.

Availability of data

All data for this study are available from the corresponding author upon reasonable request.

Supplemental material

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