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REVIEW ARTICLE (META-ANALYSIS)

Effects of Conservative Interventions on Static and Dynamic Balance in Individuals With Chronic Ankle Instability: A Systematic Review and Meta-analysis

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Abstract
Objective: To determine which conservative interventions are effective for static and dynamic balance in patients with chronic ankle instability (CAI).
Data Sources: PubMed, Cochrane Library, Web of Sciences, and CINAHL databases were searched up to March 20, 2022.
Study Selection: Randomized controlled trials investigating the effects of conservative interventions on static and/or dynamic balance in patients with CAI compared with those of different conservative interventions or controls were included.
Data Extraction: Two independent reviewers extracted the data. Certainty of the evidence was assessed using the GRADE approach.
Data Synthesis: Forty-eight studies (1906 participants) were included. Whole-body vibration training (WBVT) was significantly more effective than controls for both static (standardized mean difference, 1.13; 95% confidence interval [CI], 0.58-1.68; moderate-certainty evidence) and dynamic balance (0.56; CI, 0.24-0.88; low-certainty evidence). Balance training (BT) and joint mobilization were significantly more effective than controls for dynamic balance (0.77; CI, 0.41-1.14; and 0.75; CI, 0.35-1.14, respectively), but not for static balance (very low to low-certainty evidence). Adding other interventions to BT had no significant effect on either type of balance compared with that of BT alone (moderate to low-certainty evidence). Strength training (ST) and taping had no significant effect on either type of balance (very low- to low-certainty evidence). Multimodal interventions were significantly effective in improving dynamic balance (0.76; CI, 0.32-1.20; low-certainty evidence). Adding transcranial direct current stimulation to ST was significantly more effective for dynamic balance than ST (0.81; CI, 0.08-1.53; moderate-certainty evidence). The effects on balance were not significantly different among BT, ST, and WBVT (very low- to low-certainty evidence).
Conclusions: The significantly effective interventions reviewed may be treatment options for balance impairments associated with CAI. However, interventions should be chosen carefully, as much of the certainty of evidence is very low to low.
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Lateral ankle sprains (LASs) are 1 of the most common injuries in sports and they occur most commonly in court sports (7 ankle sprains per 1000 exposures).[1,2] Recurrence rates of ankle sprains are high,[1] with 67% of athletes with a previous index LAS suffering recurrence.[3] LASs also cause perceived ankle instability and giving way, as well as reinjury, and these sequelae are defined as chronic ankle instability (CAI).[4] A prospective study found that 40% of patients with acute first-time LAS developed CAI.[5] CAI is associated with diminished health-related quality-of-life[6] and reduced physical activity,[7] and further increases the risk of ankle osteoarthritis.[1,8] Therefore, CAI can be a long-term health issue in sports and in the general population.

CAI involves a variety of impairments (eg, pathomechanical, motor behavioral, and sensory-perceptual impairments).[9] Several studies have investigated the association between sensorimotor function and CAI.[10] A previous scoping review showed that static postural balance was the most commonly assessed factor in

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previous randomized controlled trials (RCTs), followed by dynamic balance.[10] Thus, static and dynamic balance are primary treatment targets for CAI. A recent clinical practice guideline also recommends assessing static and dynamic balance and intervening to improve them for post-LAS and CAI.[11] Additionally, impaired static[12,13] or dynamic balance[12,14] are modifiable risk factors for LASs and they contribute to CAI progression.[5] Moreover, the assessment of static[15] and dynamic[16] balance is necessary to make a decision to return to sports after LAS. Therefore, improving both static and dynamic postural balance impairment is crucial for the treatment of CAI.

Previous meta-analyses have focused on a single intervention, such as balance training (BT),[17,18] joint mobilization,[19,20] muscle strengthening,[21] external supports,[22] and whole-body vibration,[23] to examine their effects on sensorimotor function, including postural balance, in patients with CAI. Therefore, it is unclear whether interventions other than these are effective in balance impairment. A meta-analysis[24] examined conservative therapies to improve dynamic postural balance (excluding taping and bracing) in patients with CAI; however, it did not include static balance as an outcome. This meta-analysis[24] also limited dynamic balance to the Star Excursion Balance Test and did not include other dynamic balance measures (eg, postural stability after jump landing).[25] Previous meta-analyses have also analyzed only dynamic balance, not static balance, with the exception of 1 study that examined the effects of joint mobilization.[20] Interestingly, even if the intervention improves dynamic balance in patients with CAI, it may not improve static balance in a similar manner.[20] To our knowledge, there have been no systematic reviews or meta-analyses on conservative therapies for improving static balance in patients with CAI. To make a clinical decision on which of the various conservative interventions to select for static and dynamic balance impairments in patients with CAI, we need to identify which are effective for each of these impairments and for both. Therefore, this study aimed to determine which conservative interventions are effective for static and dynamic balance in patients with CAI.

Methods

This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[26] The protocol for this systematic review and meta-analysis was prospectively registered with PROSPERO (CRD42020158514).

Search strategy

PubMed, Cochrane Library, Web of Sciences, and CINAHL databases were searched from inception to March 20, 2022. The search strategy for each database is presented in supplementary appendix S1. The search results were exported to Endnote X9 (Thomson Reuters, New York, USA). The reference lists of the relevant systematic reviews were also manually scanned.

Two independent reviewers (Y.K. and T.K.) screened the titles and abstracts of the studies after excluding duplicates. Inconsistencies in screening between reviewers were discussed and resolved. The reviewers independently screened the full text of the remaining studies using specific eligibility criteria. Disagreements during screening were resolved by a consensus between the 2 reviewers.

List of abbreviations:

BT	**balance training**
CAI	**chronic ankle instability**
CI	**confidence interval**
COP	**center of pressure**
LAS	**lateral ankle sprain**
RCT	**randomized controlled trial**
SMD	**standardized mean difference**
ST	**strength training**
TDCS	**transcranial direct current stimulation**
WBVT	**whole-body vibration training**

Eligibility criteria

We included RCTs in English and studies that met the following criteria.

Patients

Patients with CAI who met the following criteria based on the International Ankle Consortium criteria[4]: (1) history of at least 1 ankle sprain (recent sprain within 3 months was excluded); (2) history of giving way, recurrent sprain, or instability; and (3) self-reported ankle instability or function confirmed by a validated questionnaire (Ankle Instability Instrument,[4] Cumberland Ankle Instability Tool,[4] Identification of Functional Ankle Instability,[4] Ankle Joint Functional Assessment Tool,[27] Foot and Ankle Ability Measure,[4] Foot and Ankle Outcome Score,[4] or Foot and Ankle Disability Index[28]).

Intervention and comparator

Conservative treatment was included, and pharmacotherapy and operative treatment were excluded. Control treatment (conservative treatment only), placebo, wait-and-see, and no treatment were included as comparators.

Outcome

Studies measuring static or dynamic balance outcomes were included. Static balance outcome was defined as a measure of postural stability, while the body remains stationary.[29] Dynamic balance was defined as a measure of body stability during the movement of a body part or support base surface.[29]

Data extraction

Two reviewers (Y.K. and T.K.) independently extracted the following data, and any disagreements were resolved by consensus between the 2 reviewers.

Study characteristics

Authors' names and year of publication.

Patients

Total sample size, mean age, and definitions of CAI.

Intervention and comparator

Intervention type, frequency, and duration. The interventions in each study were categorized as 1 of the following to pool data in a similar category of interventions: (1) BT; (2) BT plus another intervention; (3) joint mobilization; (4) multimodal intervention; (5) multimodal intervention plus another intervention; (6) strength training (ST); (7) taping; (8) transcranial direct current stimulation (TDCS) plus ST; or (9) whole-body vibration training (WBVT) (supplementary table S1). Interventions other than those mentioned above were not categorized. When multiple comparator groups existed, the placebo or sham group was selected as the control.

Outcome

Means and standard deviations of the primary balance outcome measures at the follow-up time point closest to the end of the intervention period were extracted. One study reported the median and quartiles[30]; therefore, the Box-Cox method was used to estimate means and standard deviations.[31] If multiple outcomes were reported for static and dynamic balance, those with a larger effect size on the difference between the CAI and control groups, as demonstrated previously,[25,32-35] were extracted preferentially (supplementary table S2 and table S3). The balance outcome for the closed-eye condition was extracted preferentially over the open-eye condition.[36] When no previous study was available as a reference for outcome selection, the 2 reviewers discussed and decided on the outcome to be preferentially extracted (supplementary table S2 and table S3). If the outcome data were not provided in the included papers, we emailed the corresponding author to request the data. Studies with data in the graph, but without a response to the data request, were extracted using WebPlotDigitizer (https://automeris.io/WebPlotDigitizer).[37,38] If data were unavailable, the study was excluded from the meta-analysis. The extracted outcomes are shown in supplementary table S2 and table S3, and supplementary table S4.

Risk of bias assessment

Two reviewers (Y.K. and T.K.) independently assessed the included studies using the Cochrane Collaboration Risk of Bias tool.[39] This tool is used to judge whether the selection, performance, detection, attrition, reporting, and other biases are "low risk," "unclear," or "high risk." Disagreements in the risk of bias assessment were resolved by a consensus between the 2 reviewers. If any of the domains were at high risk, the study was considered high-risk, and if all the domains were at low risk, it was considered low-risk. If none of the above criteria were applied, the study was considered unclear.

Data synthesis

Review Manager 5.4.1 (RevMan) (The Cochrane Collaboration, 2020) was used for all the data analyses and syntheses. Data from similar intervention categories were pooled for both static and dynamic balances. Standardized mean differences (SMDs) with 95% confidence intervals (CIs) were calculated from the data at the end of the intervention in each study. The direction of the balance variable was corrected to pool the data and calculate SMD. A positive SMD indicates that the intervention improved balance compared with the comparator. Meta-analyses (random effects) were performed to compare each conservative intervention with a control group (placebo, wait-and-see, or no treatment). Additionally, each conservative intervention was compared with other conservative interventions and with additional interventions, to assess differences in effects between interventions. We interpreted a difference as statistically significant when the 95% CI of the pooled SMD did not contain zero. Data that could not be pooled because of a lack of studies were summarized using forest plots, without calculating the overall effect (supplementary figure S1 and supplementary figure S2). The pooled SMD was interpreted as follows: <0.40, small effect; 0.40-0.70, moderate effect; >0.70, large effect.[40] Statistical heterogeneity was assessed using the I^2 statistic as follows: 0%-40%, might not be important; 30%-60%, moderate heterogeneity; 50%-90%, substantial heterogeneity; and 75%-100%, considerable heterogeneity.[40] Additionally, unplanned sensitivity analyses were conducted to assess the effect of the studies that contributed the most to the high I^2 statistic in each meta-analysis because we found several meta-analyses with more than substantial heterogeneity ($I^2 \geq 50$). Publication bias was assessed using a funnel plot when more than 10 studies were available.[41]

The certainty of the evidence for each meta-analysis was assessed by 2 reviewers using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) methodology.[42] We downgraded the certainty of evidence when the following issues were found[43]: (1) risk of bias (>75% of studies were not rated as low risk of bias); (2) inconsistency (I^2 statistic >50%); (3) imprecision (if the upper or lower limit of the CI crosses 0.5 of the effect size in either direction, the CI is wide and effect estimate is imprecise); (4) indirectness (studies with indirect comparison); and (5) publication bias (asymmetry in the funnel plot).

Results

Study selection and characteristics

The flow and results of the study selection process are shown in figure 1. After screening, 48 RCTs that met the selection criteria

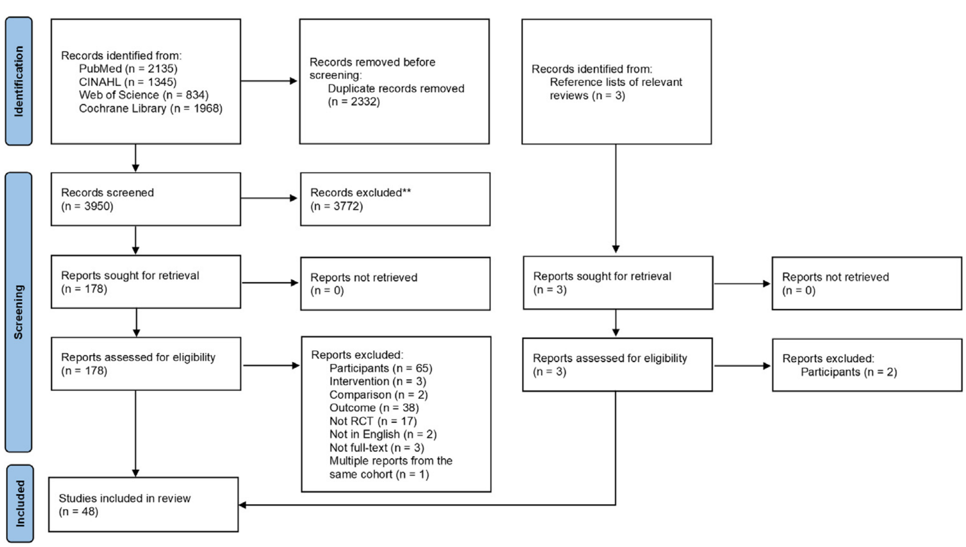

Fig 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.

were included in this systematic review. The characteristics of the patients, interventions, comparators, and outcomes of each study are presented in supplementary table S4. A total of 1906 patients were included in this study. The mean age of the study participants was 16-36.4 years. Thirty RCTs assessed static postural balance. Instrumental assessments included the center of pressure (COP) data (velocity, area, standard deviation, and deviation) during the single-leg stance (n=12),[37,44-54] sensory organization test (n=3),[38,55,56] stability index of the Biodex Balance System (n=1),[57] time-to-boundary (n=2),[58,59] and center of gravity sway (n=1).[55] Non-instrumental assessments included the Balance Error Scoring System (n=6),[60-65] foot lift test (n=3),[66-68] time-in-balance test (n=3),[66-68] number of errors in 30 s of single-leg stance (n=2),[69,70] and Romberg test (n=1).[71] Thirty-seven RCTs assessed dynamic balance, 32 of which used the Star Excursion Balance Test/Y-balance test.[30,38,44-46,48,49,54,58-60,64,66-70,72-86] Others used the dynamic postural stability index after jump landing (n=2),[54,87] the stability index of the Biodex Balance System (n=3),[57,81,88] COP area during kicking in single-leg stance (n=1),[47] and the displacement between COM and COP after the drop landing (n=1).[37]

Risk of bias

The results and summary of the risk of bias assessment are shown in figure 2. Forty-three studies were considered high-risk, 5 were considered unclear, and none were considered low-risk. Most studies lacked blinding of patients or therapists and were judged to be at a high risk of performance bias. For selection bias, many studies were judged as unclear because of a lack of randomization methods. For reporting bias, many studies were judged as unclear because of difficulty in judgment due to a lack of a priori protocol registration. The main reason for the high risk of other biases was the lack of information on prior protocol registration and sample size calculations.

Effects on static balance

Balance training

Eight RCTs examined the effects of BT on static balance compared withcontrol.[45,47,52,53,59,60,66,67] Pooled data showed no significant effect of the BT compared with that of the controls in improving static balance (SMD, 0.38; 95% CI, −0.02 to 0.77; very low certainty evidence) (fig 3 and table 1). In a sensitivity analysis, excluding 1 study contributing the most to the high I^2-value resulted in a similar result (SMD, 0.23; 95% CI, -0.09 to 0.56; I^2, 22%).[60]

Pooled data from 3 RCTs showed that the effects on static balance were not significantly different between balance and ST (SMD, 0.23; 95% CI, −0.19 to 0.65; low certainty evidence) (fig 3 and table 1).[60,66,68]

Pooled data from 4 RCTs showed that BT plus another intervention had no significant effect on static balance compared with the control (SMD, 0.94; 95% CI, −0.12 to 2.01; very low certainty evidence) (fig 3 and table 1).[37,52,66,71] Excluding 1 study[71] that contributed the most to the high I^2-value did not change the statistical results (SMD, 0.36; 95% CI, −0.13 to 0.85; I^2, 0%).

Four RCTs compared the effects of BT plus another intervention and BT alone on static balance, with no significant differences between the 2 interventions in the pooled data (SMD, 0.36; 95% CI, −0.04 to 0.77; low certainty evidence) (fig 3 and table 1).[52,54,58,66]

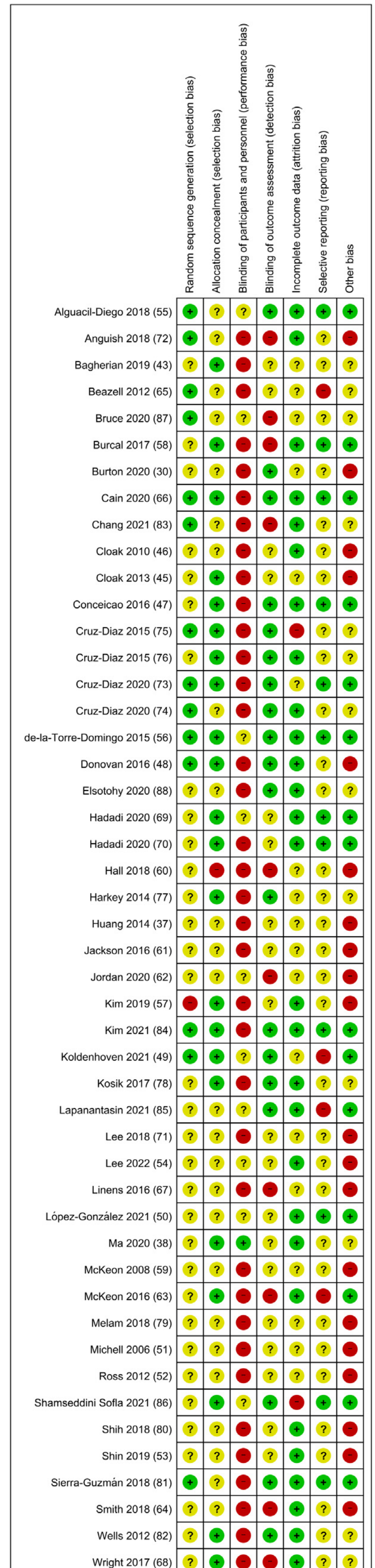

Fig 2 Risk of bias summary for each included study (generated via RevMan 5.4.1, The Cochrane Collaboration, 2020).

Study or Subgroup	Intervention 1 Mean	Intervention 1 SD	Intervention 1 Total	Intervention 2 Mean	Intervention 2 SD	Intervention 2 Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.1.1 Balance training (INT1) vs Control (INT2)								
Cain 2020 (66)	-7.17	4.89	10	-5.64	2.79	11	11.2%	-0.37 [-1.24, 0.49]
Cloak 2013 (45)	-4.4	0.9	11	-5	1.3	11	11.4%	0.52 [-0.34, 1.37]
Conceicao 2016 (47)	-25.99	8.93	22	-24.64	7.33	22	15.7%	-0.16 [-0.75, 0.43]
Hall 2018 (60)	-7.85	3.76	13	-12.69	2.43	13	11.0%	1.48 [0.60, 2.36]
Linens 2016 (67)	-3.82	2.18	17	-4.61	1.72	17	14.1%	0.39 [-0.29, 1.07]
McKeon 2008 (59)	3.91	1.2	16	2.97	0.79	15	13.0%	0.90 [0.15, 1.64]
Ross 2012 (52)	-5.75	2.07	12	-5.81	1.97	12	12.2%	0.03 [-0.77, 0.83]
Shin 2019 (53)	-61.12	16.28	11	-69.51	21.96	11	11.5%	0.42 [-0.43, 1.26]
Subtotal (95% CI)			**112**			**112**	**100.0%**	**0.38 [-0.02, 0.77]**
Heterogeneity: Tau² = 0.17; Chi² = 14.71, df = 7 (P = 0.04); I² = 52%								
Test for overall effect: Z = 1.87 (P = 0.06)								
1.1.2 Balance training (INT1) vs Strength training (INT2)								
Cain 2020 (66)	-7.17	4.89	10	-6.42	4.51	12	25.2%	-0.15 [-0.99, 0.69]
Hall 2018 (60)	-7.85	3.76	13	-10.23	4.49	13	28.8%	0.56 [-0.23, 1.34]
Wright 2017 (68)	-4.35	2.59	20	-5.02	2.96	20	46.0%	0.24 [-0.39, 0.86]
Subtotal (95% CI)			**43**			**45**	**100.0%**	**0.23 [-0.19, 0.65]**
Heterogeneity: Tau² = 0.00; Chi² = 1.46, df = 2 (P = 0.48); I² = 0%								
Test for overall effect: Z = 1.07 (P = 0.29)								
1.1.3 Balance training+another intervention (INT1) vs Control (INT2)								
Cain 2020 (+strength training) (66)	-5.47	2.34	10	-5.64	2.79	11	26.5%	0.06 [-0.79, 0.92]
Huang 2014 (+plyometric training) (37)	-41.72	6.42	10	-46.62	13.14	10	26.2%	0.45 [-0.44, 1.34]
Lee 2018 (+strength training) (71)	18.1	2.42	10	10.9	1.79	10	20.4%	3.24 [1.82, 4.66]
Ross 2012 (+stochastic resonance stimulation) (52)	-4.94	0.9	12	-5.81	1.97	12	26.9%	0.55 [-0.27, 1.37]
Subtotal (95% CI)			**42**			**43**	**100.0%**	**0.94 [-0.12, 2.01]**
Heterogeneity: Tau² = 0.92; Chi² = 14.78, df = 3 (P = 0.002); I² = 80%								
Test for overall effect: Z = 1.74 (P = 0.08)								
1.1.4 Balance training+another intervention (INT1) vs Balance training (INT2)								
Burcal 2017 (+STARS) (58)	1.64	0.88	12	1.78	0.63	12	25.8%	-0.18 [-0.98, 0.63]
Cain 2020 (+strength training) (66)	-5.47	2.34	10	-7.17	4.89	10	21.0%	0.42 [-0.46, 1.31]
Lee 2022 (+stroboscopic glasses) (54)	-1.81	0.31	14	-2.01	0.24	14	28.2%	0.70 [-0.07, 1.47]
Ross 2012 (+stochastic resonance stimulation) (52)	-4.94	0.9	12	-5.75	2.07	12	25.0%	0.49 [-0.32, 1.30]
Subtotal (95% CI)			**48**			**48**	**100.0%**	**0.36 [-0.04, 0.77]**
Heterogeneity: Tau² = 0.00; Chi² = 2.60, df = 3 (P = 0.46); I² = 0%								
Test for overall effect: Z = 1.75 (P = 0.08)								

Test for subgroup differences: Chi² = 1.52, df = 3 (P = 0.68), I² = 0%

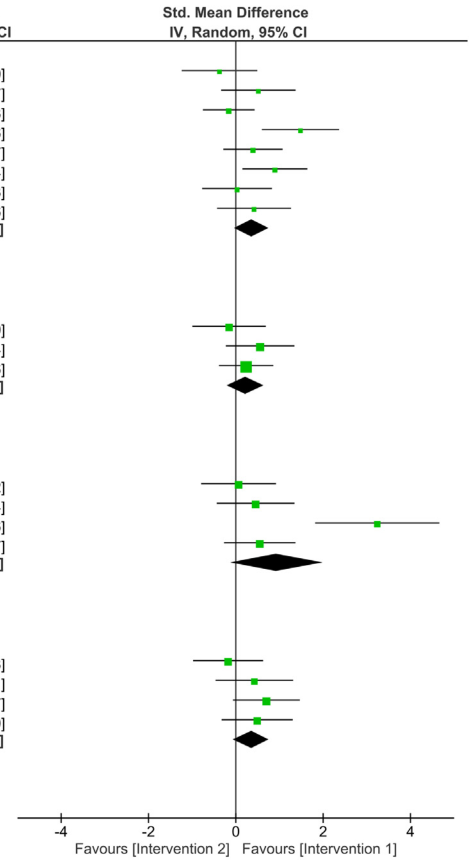

Fig 3 Meta-analyses on the effects of balance training on static balance data (generated via RevMan 5.4.1, The Cochrane Collaboration, 2020). INT1, intervention 1; INT2, intervention 2; STARS, sensory targeted ankle rehabilitation strategies.

Joint mobilization

Pooled data from 2 RCTs showed that joint mobilization was not significantly more effective than control for static balance (SMD, 0.17; 95% CI, −0.95 to 1.29, very low certainty evidence) (fig 4 and table 1).[63,65]

Multimodal

Three RCTs compared the effects of multimodal interventions on static balance with and without special interventions (destabilization devices,[48] visual gait biofeedback,[49] and Exercise Sandal[51]). A meta-analysis showed that the effect on static balance was not significantly different, regardless of the addition of multimodal intervention (SMD, 0.13; 95% CI, −0.30 to 0.56; low certainty evidence) (fig 4 and table 1).

Strength training

A meta-analysis of 3 RCTs showed that the effect of muscle strengthening on static balance was not significantly different from that of the control group (SMD, 0.72; 95% CI, −0.34 to 1.77; very low certainty evidence) (fig 4 and table 1).[60,64,66] Excluding the study by Smith et al. (2018)[64] that contributed the most to the high I^2-value did not change the statistical results (SMD, 0.24; 95% CI, −0.60 to 1.08; I^2, 54%).

Taping

Data from 4 RCTs that compared the effect of taping on static balance with controls were pooled, and it was demonstrated that taping was not significantly effective (SMD, 0.45; 95% CI, −0.12 to 1.02; very low certainty evidence) (fig 4 and table 1).[55,56,61,69] The effect of taping on static balance was significant after excluding 1 study[56] that contributed to a high I^2-value (SMD, 0.68; 95% CI, 0.16 to 1.20; I^2, 27%). Data from an RCT examining the effect of fibular repositioning tape were not available.[70]

Whole-body vibration training

A meta-analysis of 2 RCTs showed that WBVT had a significant effect on static balance compared with controls (SMD, 1.13; 95% CI, 0.58 to 1.68; moderate certainty evidence) (fig 4 and table 1).[45,46]

Results from single studies

Limited evidence from single studies showed that the following interventions had a better effect on static balance than the controls: dry needle,[50] multimodal,[44] semirigid orthosis,[69] soft orthosis,[69] and plantar massage[63] (supplementary figure S1). In comparison with other interventions, virtual reality exercise (the Nintendo Wii Fit Plus program to improve strength and balance) was more effective than BT plus ST in improving static balance (supplementary figure S1).[57] No other interventions were found to have a significant effect.[37,38,62,63,65,66,69]

Effects on dynamic balance

Balance training

We pooled data from 13 RCTs and found that BT was significantly more effective than controls in improving dynamic balance (SMD, 0.77; 95% CI, 0.41 to 1.14; very low certainty evidence) (fig 5 and table 2).[45,47,59,60,66,67,76,80,81,83-85,88] The funnel plot is shown in supplementary figure S3. Sensitivity analysis by excluding the study[47] that contributed the most to the high I^2-value resulted in a similar result (SMD, 0.87; 95% CI, 0.53 to 1.21; I^2, 60%).

Pooled data from 3 RCTs showed that the effects on dynamic balance were not significantly different between BT and ST (SMD, 0.20; 95% CI, −0.22 to 0.62; low certainty evidence) (fig 5 and table 2).[60,66,68]

Pooled data from 3 RCTs showed that the effects on dynamic balance were not significantly different between BT and WBVT (SMD, 0.10; 95% CI, −0.50 to 0.70; very low certainty evidence) (fig 5 and table 2).[45,81,83] Excluding 1 study[83] that contributed the most to the high I^2-value did not change the statistical results (SMD, −0.18; 95% CI, −0.71 to 0.35; I^2, 0%).

Pooled data from 3 RCTs showed that BT plus another intervention was not significantly more effective than the control (SMD, 0.58; 95% CI, −0.46 to 1.62; very low certainty evidence) (fig 5 and table 2).[66,80,84] Excluding 1 study[84] that contributed the most to the high I^2-value did not change the statistical results (SMD, 0.10; 95% CI, −0.46 to 0.65; I^2, 0%). Data from a study in which plyometric training was added to BT were not available.[37]

Five RCTs compared the effects of BT plus another intervention and BT alone on dynamic balance. They found no significant differences between the 2 interventions in the pooled data (SMD, −0.15; 95% CI, −0.49 to 0.19; moderate certainty evidence) (fig 5 and table 2).[54,58,66,80,84]

Joint mobilization

Joint mobilization was significantly more effective than control in improving dynamic balance, as shown by a meta-analysis of 3 RCTs (SMD, 0.75; 95% CI, 0.35 to 1.14; low certainty evidence) (fig 6 and table 2).[75,77,82]

Multimodal

The pooled results of the 2 RCTs showed that multimodal interventions significantly improved dynamic balance over control (SMD, 0.76; 95% CI, 0.32 to 1.20; low certainty evidence) (fig 6 and table 2).[44,73]

A meta-analysis of 4 RCTs showed that the effect on dynamic balance was not significantly different with or without adding another intervention to the multimodal intervention (SMD, 0.40; 95% CI, −0.02 to 0.82; low certainty evidence) (fig 6 and table 2).[48,49,73,79]

Strength training

A meta-analysis of 3 RCTs showed that the effect of muscle strengthening on dynamic balance was not significantly different from that of the control (SMD, 0.46; 95% CI, −0.00 to 0.92; low certainty evidence) (fig 6 and table 2).[60,64,66]

Transcranial direct current stimulation plus strength training

Pooled data from 2 RCTs showed that TDCS plus ST was significantly more effective than ST for dynamic balance (SMD, 0.81; 95% CI, 0.08 to 1.53; moderate certainty evidence) (fig 6 and table 2).[38,87]

Whole-body vibration training

A meta-analysis of 5 RCTs showed that WBVT was significantly more effective than control in improving dynamic balance (SMD, 0.56; 95% CI, 0.24 to 0.88; low certainty evidence) (fig 6 and table 2).[45,46,81,83,86]

Results from single studies

Limited evidence from single studies showed that cross-education BT,[88] semirigid orthosis,[69] and Tai Chi[74] had a better effect on dynamic balance than controls (supplementary figure S2). Other interventions had no significant effect compared with

Table 1 Certainty of the evidence and summary of findings in static balance

Meta-analysis	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Certainty
Balance training vs control	Serious	Serious	Not serious	Serious	NA	Very low
Balance training vs strength training	Serious	Not serious	Not serious	Serious	NA	Low
Balance training+another vs control	Serious	Serious	Not serious	Serious	NA	Very low
Balance training+another vs balance training	Serious	Not serious	Not serious	Serious	NA	Low
Joint mobilization vs control	Serious	Serious	Not serious	Serious	NA	Very low
Multimodal+another vs Multimodal	Serious	Not serious	Not serious	Serious	NA	Low
Strength training vs control	Serious	Serious	Not serious	Serious	NA	Very low
Taping vs control	Serious	Serious	Not serious	Serious	NA	Very low
WBV training vs control	Serious	Not serious	Not serious	Not serious	NA	Moderate

Abbreviations: NA, not applicable; WBV, whole-body vibration.

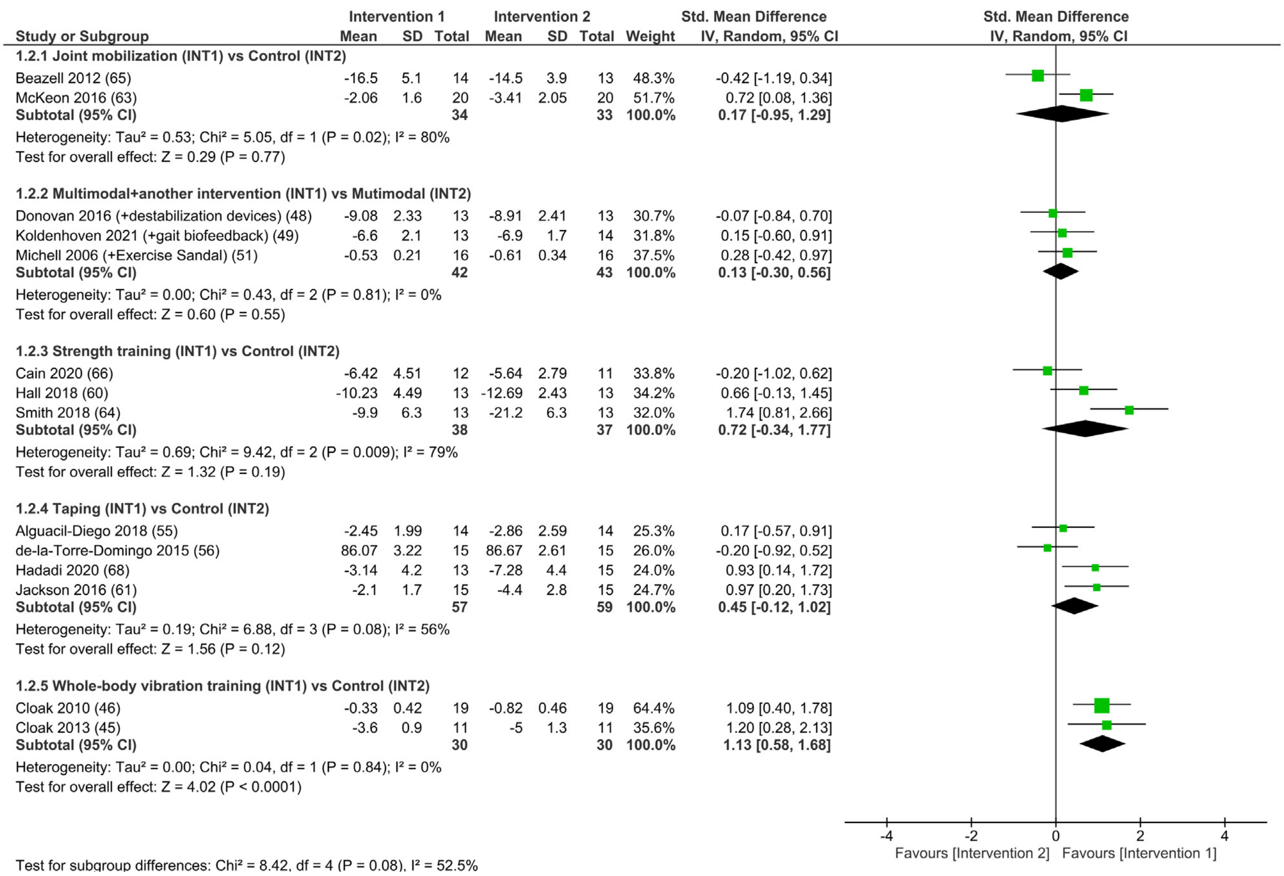

Fig 4 Meta-analyses on the effects of joint mobilization, multimodal intervention, strength training, taping, and whole-body vibration training on static balance data (generated via RevMan 5.4.1, The Cochrane Collaboration, 2020). INT1, intervention 1; INT2, intervention 2.

controls.[69,85,86] In comparison with other interventions, semirigid orthosis was more effective in improving dynamic balance than taping (supplementary figure S2).[69] No other interventions were found to have a significant effect.[30,57,66,69,72,78,85,86]

Discussion

This systematic review and meta-analysis aimed to determine which conservative interventions are effective in improving static and dynamic balance in patients with CAI. BT and joint mobilization were effective in improving dynamic balance but not static balance. The effects of BT on dynamic and static balance were not significantly different compared with those with the addition of other interventions. WBVT was significantly effective for both static and dynamic balance. Multimodal intervention was also significantly effective in improving static (limited evidence) and dynamic balance. When TDCS was added to muscle ST, it had a greater effect on improving dynamic balance than on muscle strengthening. Limited evidence from single RCTs has shown that some conservative therapies are significantly effective in improving static and dynamic balance. However, it is noteworthy that most of the results of this study were based on low or very low certainty of evidence.

Previous meta-analyses have also demonstrated the effectiveness of BT on dynamic balance.[18,24] BT may be an appropriate choice for improving the dynamic balance in clinical practice. However, because the certainty of the evidence was very low, we

Study or Subgroup	Intervention 1 Mean	SD	Total	Intervention 2 Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
2.1.1 Balance training (INT1) vs Control (INT2)								
Cain 2020 (66)	94.37	9.89	10	92.45	11.53	11	7.0%	0.17 [-0.69, 1.03]
Chang 2021 (83)	98.59	11.04	21	84.71	11.86	21	8.3%	1.19 [0.53, 1.85]
Cloak 2013 (45)	82.3	6.1	11	82.2	5.6	11	7.1%	0.02 [-0.82, 0.85]
Conceicao 2016 (47)	-113.8	110.8	22	-96.7	52.6	22	8.7%	-0.19 [-0.79, 0.40]
Cruz-Diaz 2015 (76)	86.68	3.15	35	83.55	1.27	35	9.2%	1.29 [0.77, 1.81]
Elsotohy 2020 (88)	-1.42	0.34	11	-2.38	0.54	10	5.6%	2.07 [0.96, 3.17]
Hall 2018 (60)	79.77	5.88	13	77.02	7.21	13	7.5%	0.40 [-0.37, 1.18]
Kim 2021 (84)	92.228	3.57	25	83.713	6.131	24	8.3%	1.68 [1.02, 2.34]
Lapanantasin 2022 (85)	66.11	8.72	11	60.51	9.25	11	7.0%	0.60 [-0.26, 1.46]
Linens 2016 (67)	0.98	0.11	17	0.86	0.09	17	7.8%	1.17 [0.43, 1.90]
McKeon 2008 (59)	0.91	0.13	16	0.8	0.06	15	7.6%	1.05 [0.29, 1.80]
Shih 2018 (80)	1.16	0.09	15	1.15	0.13	15	7.9%	0.09 [-0.63, 0.80]
Sierra-Guzmán 2018 (81)	98.89	8.57	16	93.27	7.52	17	8.0%	0.68 [-0.02, 1.39]
Subtotal (95% CI)			**223**			**222**	**100.0%**	**0.77 [0.41, 1.14]**
Heterogeneity: Tau² = 0.31; Chi² = 39.36, df = 12 (P < 0.0001); I² = 70%								
Test for overall effect: Z = 4.14 (P < 0.0001)								
2.1.2 Balance training (INT1) vs Strength training (INT2)								
Cain 2020 (66)	94.37	9.89	10	94.04	10.33	12	25.1%	0.03 [-0.81, 0.87]
Hall 2018 (60)	79.77	5.88	13	79.32	5.74	13	29.8%	0.08 [-0.69, 0.84]
Wright 2017 (68)	1.03	0.08	20	1	0.08	20	45.1%	0.37 [-0.26, 0.99]
Subtotal (95% CI)			**43**			**45**	**100.0%**	**0.20 [-0.22, 0.62]**
Heterogeneity: Tau² = 0.00; Chi² = 0.53, df = 2 (P = 0.77); I² = 0%								
Test for overall effect: Z = 0.91 (P = 0.36)								
2.1.3 Balance training (INT1) vs Whole-body vibration training (INT2)								
Chang 2021 (83)	98.59	11.04	21	91.08	13.51	21	37.6%	0.60 [-0.02, 1.22]
Cloak 2013 (45)	82.3	6.1	11	85.4	6.4	11	27.7%	-0.48 [-1.33, 0.37]
Sierra-Guzmán 2018 (81)	98.89	8.57	16	98.77	6.37	17	34.6%	0.02 [-0.67, 0.70]
Subtotal (95% CI)			**48**			**49**	**100.0%**	**0.10 [-0.50, 0.70]**
Heterogeneity: Tau² = 0.15; Chi² = 4.24, df = 2 (P = 0.12); I² = 53%								
Test for overall effect: Z = 0.32 (P = 0.75)								
2.1.4 Balance training+another intervention (INT1) vs Control (INT2)								
Cain 2020 (+strength training) (66)	90.06	10.47	10	92.45	11.53	11	31.6%	-0.21 [-1.07, 0.65]
Kim 2021 (+stroboscopic vision) (84)	92.475	4.965	24	83.713	6.131	24	34.7%	1.54 [0.89, 2.20]
Shih 2018 (+joint mobilization) (80)	1.19	0.12	15	1.15	0.13	15	33.7%	0.31 [-0.41, 1.03]
Subtotal (95% CI)			**49**			**50**	**100.0%**	**0.58 [-0.46, 1.62]**
Heterogeneity: Tau² = 0.70; Chi² = 11.87, df = 2 (P = 0.003); I² = 83%								
Test for overall effect: Z = 1.09 (P = 0.28)								
2.1.5 Balance training+another intervention (INT1) vs Balance training (INT2)								
Burcal 2017 (+STARS) (58)	84.92	8.08	12	86.79	9.12	12	16.5%	-0.21 [-1.01, 0.59]
Cain 2020 (+strength training) (66)	90.06	10.47	10	94.37	9.89	10	13.7%	-0.41 [-1.29, 0.48]
Kim 2021 (+stroboscopic vision) (84)	92.475	4.965	24	92.228	3.57	25	31.6%	0.06 [-0.50, 0.62]
Lee 2022 (+stroboscopic glasses) (54)	1.04	0.08	14	1.13	0.15	14	17.9%	-0.73 [-1.50, 0.04]
Shih 2018 (+joint mobilization) (80)	1.19	0.12	15	1.16	0.09	15	20.2%	0.28 [-0.44, 0.99]
Subtotal (95% CI)			**75**			**76**	**100.0%**	**-0.15 [-0.49, 0.19]**
Heterogeneity: Tau² = 0.01; Chi² = 4.36, df = 4 (P = 0.36); I² = 8%								
Test for overall effect: Z = 0.85 (P = 0.39)								

Test for subgroup differences: Chi² = 13.79, df = 4 (P = 0.008), I² = 71.0%

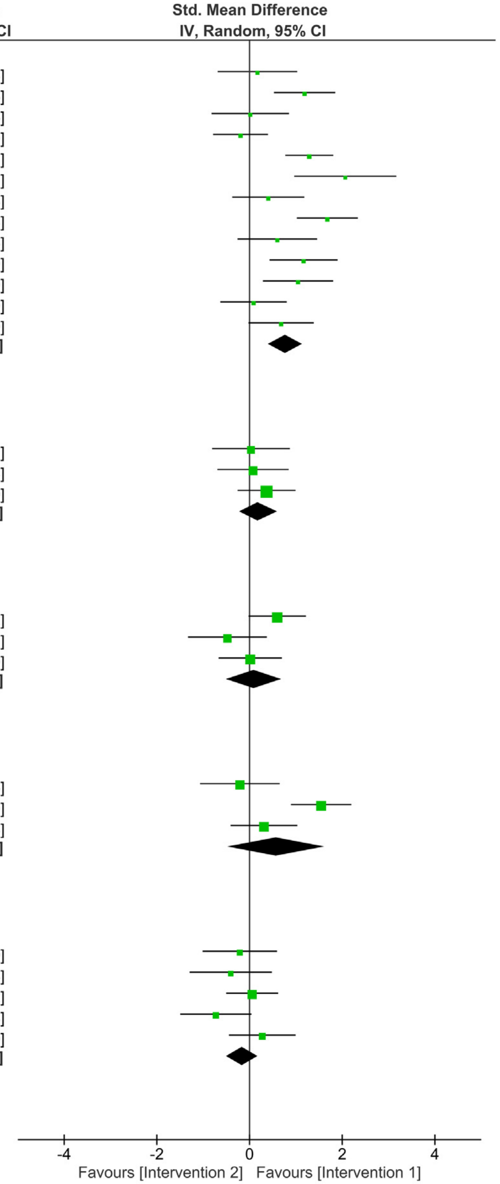

Fig 5 Meta-analyses on the effects of balance training on static balance data (generated via RevMan 5.4.1, The Cochrane Collaboration, 2020). INT1, intervention 1; INT2, intervention 2; STARS, sensory targeted ankle rehabilitation strategies.

Table 2 Certainty of the evidence and summary of findings in dynamic balance

Meta-analysis	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Certainty
Balance training vs control	Serious	Serious	Not serious	Serious	Serious	Very low
Balance training vs strength training	Serious	Not serious	Not serious	Serious	NA	Low
Balance training vs WBV training	Serious	Serious	Not serious	Serious	NA	Very low
Balance training+another vs control	Serious	Serious	Not serious	Serious	NA	Very low
Balance training+another vs balance training	Serious	Not serious	Not serious	Not serious	NA	Moderate
Joint mobilization vs control	Serious	Not serious	Not serious	Serious	NA	Low
Multimodal vs control	Serious	Not serious	Not serious	Serious	NA	Low
Multimodal+another vs Multimodal	Serious	Not serious	Not serious	Serious	NA	Low
Strength training vs control	Serious	Not serious	Not serious	Serious	NA	Low
TDCS+strength training vs strength training	Not serious	Not serious	Not serious	Serious	NA	Moderate
WBV training vs control	Serious	Not serious	Not serious	Serious	NA	Low

Abbreviations: NA, not applicable; TDCS, transcranial direct current stimulation; WBV, whole-body vibration.

cannot conclude that the present results show a true effect. BT may not be the first option to improve dynamic balance, as there were no significant differences from other interventions. The different types and volumes of BT (between 1 and 18 sessions) may have contributed to the high heterogeneity. More high-quality RCTs are needed to determine the type of training most effective in improving dynamic balance.

Regarding the effects of BT, there are several possible reasons for the lack of significant improvement in static balance. First, the type and volume of BT varied (between 1 and 18 sessions). It is necessary to determine the type and extent of each type that is effective for static balance. Next, most of the extracted outcomes were measured in a closed-eye condition.[47,52,53,59,60,66,67] Although some training programs included exercises with eyes closed, the content mostly consisted of exercises in the open-eye condition. Therefore, static balance assessment without visual information might not have provided sufficient improvement; therefore, it might be worthwhile in the future to examine the amount of BT with closed eyes.[89] However, because dynamic balance is assessed in the open-eye condition, BT would have resulted in significant dynamic balance improvement. The certainty of the evidence for the result that BT is not effective for static balance is very low, and the lower limit of the 95% CI is close to zero (−0.02) in comparison with the control. Therefore, it is possible that new studies may change the conclusion in the future.

In clinical practice, it may be common to add other interventions to a single one. We found that adding other interventions to the BT did not have any further effect on balance. The certainty of evidence for the effect on dynamic balance was moderate; therefore, this result may be close to the true effect. However, the additional types of intervention pooled in this meta-analysis were broad (sensory-targeted ankle rehabilitation strategies,[58] ST,[66,71] plyometric training,[37] joint mobilization,[80] stochastic resonance stimulation,[52] and stroboscopic glasses[54,84]). Some of these individual studies found additional interventions to be more effective than BT alone in improving balance outcomes, which we did not extract.[52,54,66,84] Additional effects may be partially present but were not detected in this meta-analysis. Further RCTs are needed to determine the additional types of interventions that would be beneficial.

WBVT is an appropriate intervention option for improving both static and dynamic balance. However, this may not be the first option because it was not significantly different from BT in these effects. Physiological changes induced by vibration stimulation may lead to more proprioceptive feedback.[86] Furthermore, most WBVT programs include a single-leg standing balance task.[45,46,81,83] The integrated effects of vibration stimulation and BT may be beneficial for both types of balance. The 2 studies that examined the effects of this intervention on static balance assessed it with open eyes.[45,46] As in studies examining the effects of BT, assessments under closed-eye conditions may be necessary. The certainty of the evidence for this effect on static balance is moderate; however, owing to the small sample size, this result should be interpreted with caution.

Joint mobilization was more effective than the control in improving dynamic balance, but not static balance, similar to a previous meta-analysis.[20] The increased dorsiflexion range of motion and increased afferent input from the joint and surrounding tissues by joint mobilization could be the mechanisms of dynamic balance improvement, but it failed to significantly improve the static balance. The low to very low certainty of this evidence makes it difficult to determine whether this intervention should be chosen to improve balance in clinical practice. However, this intervention may be implemented for dorsiflexion range of motion limitations,[20] and it would be important to assess whether dynamic balance improved as a result. Because the target sites (talocrural[63,75,77,82] or tibiofibular joint[65]) and volumes (from 1 to 6 sessions) of joint mobilization differed between the studies, further RCTs are needed to identify suitable methods for improving balance.

ST and taping did not significantly improve the static and dynamic balance compared with the control group. These results partially differed from those of previous meta-analyses on ST and kinesio taping.[21,90] This discrepancy with our meta-analysis could be attributed to differences in the language and design of the included studies and extracted data.[21,90] Interestingly, the effect size of hip ST reported by Smith et al was large.[64] Therefore, it may be worthwhile to investigate the effects of hip ST. The certainty of the evidence on the effects of muscle strengthening and taping was also very low to low; therefore, it would still be difficult to conclude that there was no effect on balance.

Our results on multimodal intervention support those of a previous meta-analysis of dynamic balance.[24] Limited evidence has shown that multimodal treatment improves static balance. Multimodal interventions used corrective exercises[44] and CrossFit training[73] that included a variety of exercises. Although the certainty of evidence regarding the effect on balance outcomes was low in this meta-analysis, multimodal interventions also improved self-reported functional outcomes in patients with CAI.[91] Therefore,

Study or Subgroup	Intervention 1 Mean	SD	Total	Intervention 2 Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
2.2.1 Joint mobilization (INT1) vs Control (INT2)								
Cruz-Diaz 2015 (75)	89.44	5.46	30	85.32	2.8	30	54.4%	0.94 [0.40, 1.47]
Harkey 2014 (77)	83	11	15	78	9.7	15	29.4%	0.47 [-0.26, 1.20]
Wells 2012 (82)	85.04	7.55	9	79.12	11	8	16.2%	0.60 [-0.38, 1.58]
Subtotal (95% CI)			**54**			**53**	**100.0%**	**0.75 [0.35, 1.14]**
Heterogeneity: Tau² = 0.00; Chi² = 1.13, df = 2 (P = 0.57); I² = 0%								
Test for overall effect: Z = 3.70 (P = 0.0002)								
2.2.2 Multimodal (INT1) vs Control (INT2)								
Bagherian 2019 (44)	93.7	7.1	20	85.3	9.4	20	45.1%	0.99 [0.33, 1.65]
Cruz-Diaz 2020 (73)	92.63	3.3	24	90.56	3.8	21	54.9%	0.57 [-0.02, 1.17]
Subtotal (95% CI)			**44**			**41**	**100.0%**	**0.76 [0.32, 1.20]**
Heterogeneity: Tau² = 0.00; Chi² = 0.83, df = 1 (P = 0.36); I² = 0%								
Test for overall effect: Z = 3.36 (P = 0.0008)								
2.2.3 Multimodal+another intervention (INT1) vs Mutimodal (INT2)								
Cruz-Diaz 2020 (+self-mobilization) (73)	94.57	2.56	25	92.63	3.3	24	32.5%	0.65 [0.07, 1.22]
Donovan 2016 (+destabilization devices) (48)	81.6	4.88	13	76.61	7.42	13	20.8%	0.77 [-0.03, 1.57]
Koldenhoven 2021 (+gait biofeedback) (49)	77.8	5.5	13	79.2	5.6	14	22.5%	-0.24 [-1.00, 0.51]
Melam 2018 (+tube exercises) (79)	93.8	4	15	92.2	4.8	15	24.2%	0.35 [-0.37, 1.07]
Subtotal (95% CI)			**66**			**66**	**100.0%**	**0.40 [-0.02, 0.82]**
Heterogeneity: Tau² = 0.06; Chi² = 4.32, df = 3 (P = 0.23); I² = 30%								
Test for overall effect: Z = 1.86 (P = 0.06)								
2.2.4 Strength training (INT1) vs Control (INT2)								
Cain 2020 (66)	94.04	10.33	12	92.45	11.53	11	32.0%	0.14 [-0.68, 0.96]
Hall 2018 (60)	79.32	5.74	13	77.02	7.21	13	35.7%	0.34 [-0.43, 1.12]
Smith 2018 (64)	96.3	8.9	13	88	8.8	13	32.4%	0.91 [0.09, 1.72]
Subtotal (95% CI)			**38**			**37**	**100.0%**	**0.46 [-0.00, 0.92]**
Heterogeneity: Tau² = 0.00; Chi² = 1.84, df = 2 (P = 0.40); I² = 0%								
Test for overall effect: Z = 1.95 (P = 0.05)								
2.2.5 TDCS+strength training (INT1) vs Strength training (INT2)								
Bruce 2020 (87)	-0.49	0.04	11	-0.51	0.05	11	48.6%	0.42 [-0.42, 1.27]
Ma 2020 (38)	100.16	4.38	14	96.07	2.02	14	51.4%	1.16 [0.35, 1.97]
Subtotal (95% CI)			**25**			**25**	**100.0%**	**0.81 [0.08, 1.53]**
Heterogeneity: Tau² = 0.09; Chi² = 1.53, df = 1 (P = 0.22); I² = 35%								
Test for overall effect: Z = 2.18 (P = 0.03)								
2.2.6 Whole-body vibration training (INT1) vs Control (INT2)								
Chang 2021 (83)	91.08	13.51	21	84.71	11.86	21	27.1%	0.49 [-0.12, 1.11]
Cloak 2010 (46)	97	13.5	19	87.5	10.3	19	23.4%	0.77 [0.11, 1.44]
Cloak 2013 (45)	85.4	6.4	11	82.2	5.6	11	14.1%	0.51 [-0.34, 1.36]
Shamseddini Sofla 2021 (86)	97.9	18.21	12	96.04	14.74	10	14.5%	0.11 [-0.73, 0.95]
Sierra-Guzmán 2018 (81)	98.77	6.37	17	93.27	7.52	17	20.9%	0.77 [0.07, 1.47]
Subtotal (95% CI)			**80**			**78**	**100.0%**	**0.56 [0.24, 0.88]**
Heterogeneity: Tau² = 0.00; Chi² = 1.93, df = 4 (P = 0.75); I² = 0%								
Test for overall effect: Z = 3.45 (P = 0.0006)								
Test for subgroup differences: Chi² = 2.59, df = 5 (P = 0.76), I² = 0%								

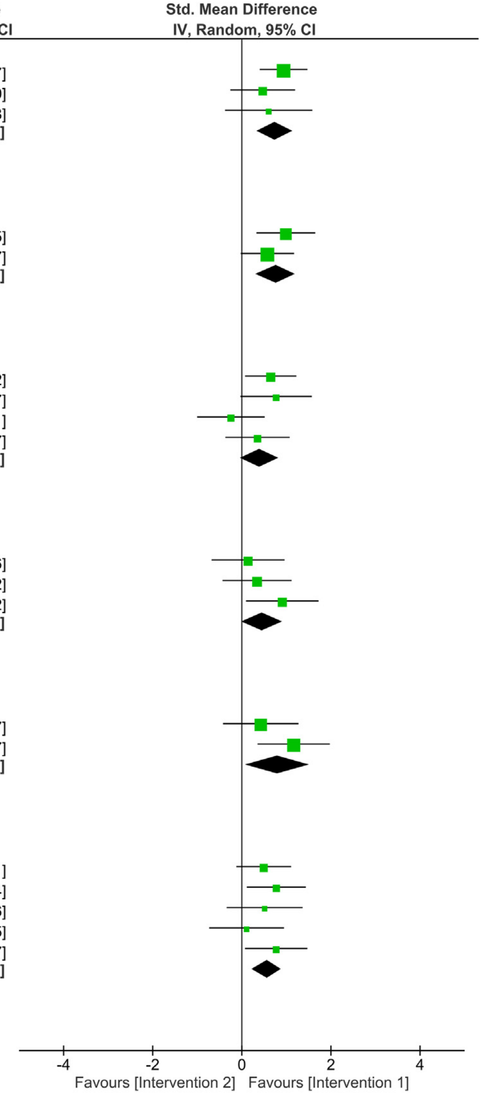

Fig 6 Meta-analyses on the effects of joint mobilization, multimodal intervention, strength training, transcranial direct current stimulation (TDCS), and whole-body vibration training on static balance data (generated via RevMan 5.4.1, The Cochrane Collaboration, 2020). INT1, intervention 1; INT2, intervention 2.

this intervention may be an appropriate treatment option for patients with CAI. The addition of other interventions (joint self-mobilization,[73] destabilization devices,[48] visual gait biofeedback,[49] or elastic tubing exercises[79]) to multimodal interventions would have no further effect (low-certainty evidence). Owing to the variety of additional interventions, further research is needed to pursue further potential effects.

TDCS for muscle ST to promote sensorimotor cortex excitation improved dynamic balance beyond muscle strengthening alone. This may involve a decrease in corticomotor excitability in patients with CAI.[92] Interventions for neuroplasticity-related changes in CAI may be effective adjunct therapies to exercise. Despite the moderate certainty of evidence, the 2 RCTs that examined TDCS had relatively small sample sizes[38,87]; therefore, larger RCTs are needed.

Regarding other interventions, a semi-rigid orthosis was effective for both static and dynamic balance. Additionally, virtual reality exercises were more effective than balance plus ST for static balance, and semi-rigid orthotics were more effective than taping for dynamic balance. The results of a single RCT may be worth further investigation.

Regarding clinical implications, static balance may be improved by the clinical use of WBVT in patients with CAI; however, the certainty of this may not be high. For dynamic balance, BT, joint mobilization, multimodal intervention, and WBVT may be used. However, the evidence for all these is very low to low; therefore, the effects may not be true and should be interpreted with caution. The addition of TDCS to exercise therapy may also have beneficial effects and requires further research.

Study limitations

Several limitations should be considered in this review. First, none of the studies included in this review had a low risk of bias. This was mainly due to the lack of blinding of participants and therapists in most studies. Blinding was impractical in many studies because of the nature of interventions, such as exercise and manual therapy. Thus, the results of this study should be interpreted with caution. Second, we found diversity in the type and duration of interventions across studies. This may have contributed to the moderate to high heterogeneity (I^2 >50%) observed in some meta-analyses. Third, the outcome extraction rules are not described in the a priori protocol. Therefore, to minimize the effect of bias, we extracted outcomes based on the effect size of the difference between the CAI and control groups, as identified in previous studies.[25,32-35] Finally, only articles published in English were included in the present review. This might have increased the risk of publication bias.

Conclusions

Low to moderate certainty evidence showed that WBVT was effective for both static and dynamic balance compared with controls. BT, joint mobilization, multimodal intervention, and WBVT were only effective for dynamic balance, whereas ST and taping had no effect. However, the certainty of this evidence varied from very low to low. Additionally, BT was neither superior to the other interventions, nor did the addition of other interventions produce superior effects. Moderate-certainty evidence showed that TDCS for muscle ST had a greater effect on improving dynamic balance than did muscle strengthening. These interventions may be an option for static and dynamic balance impairments in patients with CAI, but should be selected with caution because of the very low to low certainty of most evidence.

Keywords

Ankle; Ankle joint; Exercise therapy; Postural balance; Rehabilitation; Sprains and strains

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