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Effects of transcranial direct current stimulation on pain and physical function in patients with knee osteoarthritis: a systematic review and meta-analysis

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Abstract

Background Keen Osteoarthritis (KOA) is a common chronic disabling disease characterized by joint pain and dysfunction, which seriously affects patients' quality of life. Recent studies have shown that transcranial direct current stimulation (tDCS) was a promising treatment for KOA.

Purpose Investigate the effects of tDCS on pain and physical function in patients with KOA.

Methods Randomized controlled trials related to tDCS and KOA were systematically searched in the PubMed, Embase, Medline, Cochrane Library, CINHL, and Web of Science databases from inception to July 23, 2024. The pain intensity was evaluated using the visual analog scale or the numeric rating scale, and the pain sensitivity was assessed using conditioned pain modulation, pressure pain threshold, heat pain threshold, or heat pain tolerance. The physical function outcome was evaluated using the Western Ontario and McMaster Universities Osteoarthritis Index or the Knee injury and Osteoarthritis Outcome Score. Statistical analysis was performed using Review Manager 5.4.

Results Seven studies with a total of 503 participants were included. Compared to sham tDCS, tDCS was effective in reducing the short-term pain intensity (SMD: -0.58; 95% CI: -1.02, -0.14; $p=0.01$) and pain sensitivity (SMD: -0.43; 95% CI: -0.70, -0.16; $p=0.002$) but failed to significantly improve the long-term pain intensity (SMD: -0.26; 95% CI: -0.59, 0.08; $p=0.13$) in KOA patients. In addition, tDCS did not significantly improve the short-term (SMD: -0.13; 95% CI: -0.35, 0.08; $p=0.22$) and long-term (SMD: 0.02; 95% CI: -0.22, 0.25; $p=0.90$) physical function in patients with KOA.

Conclusions The tDCS can reduce short-term pain intensity and sensitivity but fails to significantly relieve long-term pain intensity and improve the physical function in patients with KOA. Thus, tDCS may be a potential therapeutic tool to reduce short-term pain intensity and pain sensitivity in patients with KOA.

Keywords Transcranial direct current stimulation, Knee osteoarthritis, Pain, Physical function

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Introduction

Osteoarthritis is a chronic, disabling disease of multiple etiologies, occurring primarily in joints with high loads and activities; the knee is the most complex and loaded joint in the body and, therefore, most prone to OA [1]. Knee osteoarthritis (KOA) is a common chronic disabling disease in the middle-aged and elderly population and has become the fourth leading cause of disability worldwide [2, 3]. The pathogenesis of KOA is complex and involves multiple factors, such as mechanical stress, inflammation, metabolism, immunity, and genetics, with age, genetics, body weight, gender, and race as risk factors [4, 5]. KOA is characterized by joint pain, stiffness, swelling, and limited joint function due to structural and functional failure of the synovial joint [6]. In particular, the joint pain and dysfunction caused by KOA can significantly impact the quality of life in severe cases [7, 8]. Currently, a variety of treatments have been applied to the treatment of KOA, including oral non-steroidal anti-inflammatory drugs (NSAIDs), weight loss, exercise, modification of daily living abilities, orthotics, physical therapy, and intra-articular injections for the early stage of patients and surgical intervention for the advanced stage of patients [9, 10]. However, the therapeutic effect is limited, and there is a need for more effective treatments for KOA [11–14].

Recent studies have shown that pain-related brain mechanisms are altered in patients with KOA pain and that altered central pain processing is an essential driver of joint pain and dysfunction in patients with KOA [15–18]. Therefore, non-pharmacological interventions targeting central nervous system pain processing are increasingly attractive. Transcranial direct current stimulation (tDCS) is a non-invasive brain stimulation procedure that has demonstrated efficacy in treating chronic pain by altering the cortical excitability of brain tissue [19–25]. However, the therapeutic effect of tDCS for KOA remains unclear. For example, Chang et al. concluded that tDCS was effective in relieving pain and improving physical function in patients with KOA [27]. However, the study by Azizi et al. found that tDCS was not effective in improving pain and physical function in KOA patients compared to the control group [26].

Some clinical studies with small samples have investigated the effect of tDCS in patients with KOA, but their results were inconsistent [26–32]. Thus, this systematic review and meta-analysis aimed to investigate the effect of tDCS on pain and physical function in patients with KOA.

Methods

This study was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [33]. The review protocol was registered on PROSPERO under the registration number CRD42022355451.

Study selection

Two reviewers (JMY and YQW) independently assessed and selected the literature according to the predetermined inclusion criteria. In case of disagreement, a third reviewer (YBZ) would be consulted. The inclusion criteria for the study were based on the PICOS principle: (1) population (P): patients were diagnosed with KOA according to the American College of Rheumatology criteria; (2) intervention (I): the intervention of the experiment group was tDCS; (3) comparison (C): the intervention of the control group was sham tDCS; (4) outcome (O): the outcomes of the study included pain and physical function; (5) study design (S): the study type was restricted to randomized controlled trials (RCTs).

Search strategies

The PubMed, Embase, Medline, Cochrane Library, CINAHL, and Web of Science databases were searched from inception to July 23, 2024. Combined medical terms were searched as follows: ("Transcranial Direct Current Stimulation" OR "tDCS") AND ("Osteoarthritis") AND ("knee") AND ("randomized controlled trial" OR "RCT"). The detailed search strategy is described in Appendix S1. In addition, we manually searched the references of the identified studies to ensure the inclusion of all relevant papers.

Quality assessment

The methodological quality of each included study was assessed by two reviewers (HH and JHZ) using the Cochrane Risk of Bias Tool for risk of bias in the included studies [34]. In case of disagreement, a third reviewer (YBZ) was involved to reach a consensus. The following domains were assessed: (1) random sequence generation; (2) allocation concealment; (3) blinding of participants and personnel; (4) blinding of outcome assessment; (5) incomplete outcome data; (6) selective reporting; (7) other sources of bias. Each item was categorized as low risk, high risk, or unclear risk.

In addition, we assessed the quality of each piece of evidence using the Grading of Recommendations Assessment Development and Evaluation (GRADE) [35]. This system incorporates eight domains of risk of bias, directness of evidence, consistency and precision of results, publication bias, effect size, dose-response, and effect of confounding factors, rated as "high," "moderate," "low," or "very low."

Data extraction and meta-analysis

Data were independently screened and extracted by two reviewers (QZ and YL) using a standardized form. Data

extraction included: (1) the name of the first author and the country and region of the author; (2) the age and sex of the participants; (3) the sample size of the intervention and control groups; (4) the intensity and duration of the intervention and the mode of use in the control group; (5) the time point of outcome assessment; (6) the outcome indicators; (7) Mean and standard deviation (SD) of the differences in visual analog scale (VAS), numeric rating scale (NRS), conditioned pain modulation (CPM), pressure pain threshold (PPT), heat pain threshold (HPTh), heat pain tolerance (HPTo), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and Knee injury and Osteoarthritis Outcome Score (KOOS) between the control and intervention groups. If the mean and SD of the differences were not available, we instead extracted the mean and SD of the pre-intervention and post-intervention values for the control and intervention groups. If consensus could not be reached, a third reviewer (YBZ) acted as an arbiter.

The pain intensity of patients with KOA was assessed by the VAS or the NRS. The VAS score and the NRS score range from 0 to 10 or 100, with higher scores indicating more pain [36]. The pain sensitivity of patients with KOA was assessed by CPM, PPT, HPTh, or HPTo. A multimodal Quantitative Sensory Testing (QST) battery was administered for experimental pain sensitivity [37]. Thermal stimulation was performed using the limit rise method to measure the HPTh and HPTo in the knee. Starting from a baseline of 32 °C, the thermode temperature was increased at a rate of 0.5 °C per second until the participant pressed a button to stop the thermal stimulation. Participants were asked to press a button to assess HPTh when they felt "the first pain" and to press a button to assess HPTo when they "no longer felt able to tolerate the pain." The average of three trials was calculated to determine HPTo and HPTh. Knee PPT was then measured using blunt mechanical pressure delivered by a digital manometer. The pressure was continuously increased (at a rate of 0.3 kgf/cm2/s) while asking participants to notify the experimenter when they felt "the first time they became in pain" to assess PPT. After immersing the contralateral hand in a cold water bath at 12 °C for 1 min, CPM was assessed by determining the change in trapezius PPT. The physical function of patients with KOA was evaluated by the WOMAC or the KOOS. The WOMAC consists of three subscales related to pain during activity (range 0–20), stiffness during the day (range 0–8), and impairment of physical function (range 0–68), with higher scores indicating more pain, stiffness, and impairment of physical function severity. These scales have been widely used in clinical pain studies, and psychometric properties have been demonstrated [38–40]. The KOOS score consists of five sections, with a minimum answer score of 0 and a maximum score of 4 for each question. The scores for each section are calculated individually and then converted to a percentage score using a conversion formula, where a score of 0 means that the part of the joint is functioning very poorly, and a score of 100 means that the part of the joint is functioning perfectly well [41].

We counted data from two assessment time points: the end of the intervention and the end of the follow-up. Review Manager (RevMan) version 5.4 software was used for statistical analysis. The mean and SD of the differences and the sample size were entered into the statistical software. If the difference could not be obtained directly, the mean change was calculated by subtracting the final mean from the baseline mean. According to Cochrane's recommendations, the SD of the baseline change was calculated using a correlation coefficient (r) estimated at 0.7, and the SD of the baseline and final means for each group was calculated using Equation 1[42]. If 95% confidence intervals (95% CI) were provided in the article, SD was calculated according to the Equation 2, where N represents the sample size; if the sample size of each group is small (≤60), then 3.92 needs to be replaced with 2 x t-value, t-value can be obtained by consulting the table of t-boundary values.

$$\mathrm{SD}_{\mathrm{change}} = \sqrt{(\mathrm{SD\ baseline})^2 + (\mathrm{SD\ final})^2 - 2 \times \mathrm{r} \times \mathrm{SD\ baseline} \times \mathrm{SD\ final}} \quad (1)$$

$$\mathrm{SD} = \sqrt{\mathrm{N}} \times (\mathrm{Upper\ bound\ of\ the\ CI} - \mathrm{lower\ bound\ of\ the\ CI}) / 3.92 \quad (2)$$

In this meta-analysis, we used mean differences (MD) and 95% CI to report effect sizes for studies using the same measure and standardized mean differences (SMD) and 95% CI for those continuous outcomes that measured the same outcome using different units. Heterogeneity was tested using the I^2 statistic. As they were heterogeneous in terms of duration of interventions, time points of assessment, and risk of bias between studies, a random-effects model was used for meta-analysis [43].

Results

Study selection

After a systematic search of the 6 databases, we found 220 articles, including 49 in PubMed, 49 in Embase, 37 in Web of Science, 33 in Medline, 12 in CINAHL, and 40 in the Cochrane Library database. Seven studies were finally included after a series of screenings. The detailed selection process of these trials is shown in Fig. 1. Detailed reasons for exclusion and references to excluded studies can be found in Appendix S2.

Study characteristics

The characteristics of the 7 included RCTs were shown in Table 1. A total of 503 participants were included,

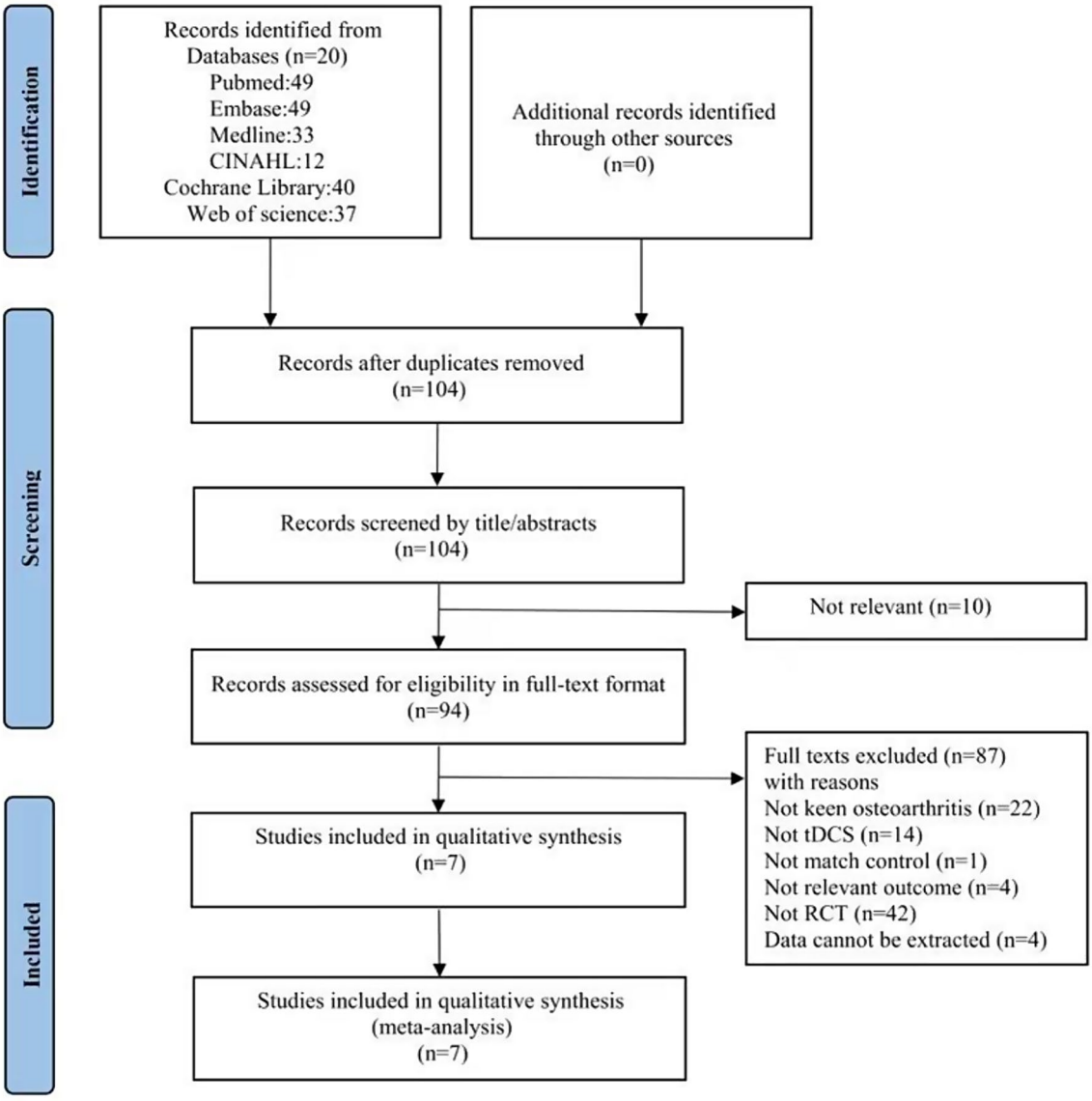

Fig. 1 Flow chart of study selection

with sample sizes ranging from 25 to 120. Most of the included studies included patients older than 50, and only one study included those under 50 [26]. The main intervention parameters of tDCS were shown in Table 2. The active tDCS was performed using a pair of saline-saturated sponge electrodes placed on the skin. The anodal electrode was placed on C3 or C4 (10–20 systems of electroencephalography electrode placement) contralateral to the affected knee, and the cathodal electrode was placed on the supraorbital area (SO) contralateral to the anode. The active tDCS was used for active stimulation using a constant current intensity of 2 mA for 20 min per day. In contrast, for the sham tDCS, the electrode position was the same as for active tDCS, the stimulator provided only 2 mA of current, and the stimulation lasted 30 s in six studies and only 15 s in another study [27]. In all seven studies, the duration of the interventions was not identical, with three studies having a duration of 1 week and several interventions of 5 times a week [26, 30, 32], three studies having a duration of 3 weeks and several interventions of 5 times a week [28, 29, 31], and one study having a duration of 8 weeks and several interventions of 2 times a week [27]. Of all included studies, three studies used the VAS to assess pain intensity [26, 27, 29], and three studies used the NRS to assess pain intensity [28–30]. Two studies used CPM, PPT, HPTh, and HPTo to evaluate pain sensitivity [31, 32], and one study used CPM and PPT to assess pain sensitivity [29]. Four studies used WOMAC to evaluate physical function [27–30], and one study used KOOS to assess physical function [26].

Table 1 Characteristics of the studies included in the review

Study	Country	Age	Sex(M/F)	Intervention	Control group	Outcomes	Time points of assessment
Azizi et al. 2021 [26]	Iran	30–70	18/36	tDCS ($n=27$)	sham tDCS ($n=27$)	KOOS, VAS	Baseline, Week 1, Month 3
Chang et al. 2017 [26]	China	>50	8/17	tDCS + exercise ($n=13$)	sham tDCS + exercise($n=12$)	VAS, WOMAC	Baseline, Week 8
Martorella et al. 2022 [28]	American	50–80	38/82	tDCS ($n=60$)	sham tDCS ($n=60$)	NRS, WOMAC	Baseline, Week 3, Month 3
Regina et al. 2021 [29]	Brazil	>60	16/88	tDCS ($n=51$)	sham tDCS ($n=53$)	VAS, NRS, WOMAC, PPT, CPM	Baseline, Week 3, Month 2
Ahn et al. 2017 [30]	American	50–70	19/21	tDCS ($n=20$)	sham tDCS ($n=20$)	NRS, WOMAC	Baseline, Days 1 ~ 5, Week 1 Week 2, Week 3
Martorella et al. 2022 [31]	American	50–85	38/82	tDCS ($n=60$)	sham tDCS ($n=60$)	HPTh, HPTo, PPT, CPM	Baseline, Week 3
Ahn et al. 2018 [32]	American	50–70	19/21	tDCS ($n=20$)	sham tDCS ($n=20$)	HPTh, HPTo, PPT, CPM	Baseline, Week 1

Notes M: man; F: Female; tDCS: transcranial direct current stimulation; KOOS: Knee injury and Osteoarthritis Outcome Score; VAS: visual analog scale; NRS: numeric rating scale; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; PPT: pressure pain threshold; CPM: conditioned pain modulation; HPTh: heat pain threshold; HPTo: heat pain tolerance

Table 2 Main intervention parameters of tDCS

Study	Stimulation site (anodal electrode)	Stimulation site (cathodal electrode)	Intensity of stimulation (m A)	Duration of stimulation (min)	Duration of intervention	Stimulation of sham tDCS
Azizi et al. 2021 [26]	C3 or C4	SO contralateral to the anode	2	20	5 times per week for 1 week	2 mA of current and the stimulation lasted 30 s
Chang et al. 2017 [27]	C3 or C4	SO contralateral to the anode	2	20	2 times per week for 8 weeks	2 mA of current and the stimulation lasted 15 s
Martorella et al. 2022 [28]	C3 or C4	SO contralateral to the anode	2	20	5 times per week for 3 weeks	2 mA of current and the stimulation lasted 30 s
Regina et al. 2021 [29]	C3 or C4	SO contralateral to the anode	2	20	5 times per week for 3 weeks	2 mA of current and the stimulation lasted 30 s
Ahn et al. 2017 [30]	C3 or C4	SO contralateral to the anode	2	20	5 times per week for 1 week	2 mA of current and the stimulation lasted 30 s
Martorella et al. 2022 [31]	C3 or C4	SO contralateral to the anode	2	20	5 times per week for 3 weeks	2 mA of current and the stimulation lasted 30 s
Ahn et al. 2018 [32]	C3 or C4	SO contralateral to the anode	2	20	5 times per week for 1week	2 mA of current and the stimulation lasted 30 s

Note SO: supraorbital area

Quality of included studies

The risk of bias in the included studies was assessed according to the Cochrane tool for seven studies, as shown in Fig. 2. One study did not use allocation concealment (high risk of bias) [26]. Two studies did not mention allocation concealment (unclear risk of bias) [28, 31]. Five studies did not mention blinding of outcome assessment (unclear risk of bias) [26, 28, 30–32]. One study had incomplete outcome data because the follow-up rate was less than 85% (high risk of bias) [27]. One study used tDCS intervention and exercise therapy, which may have impacted the outcome and led to a risk of bias (high risk of bias) [27]. No studies had selection bias or reporting bias.

Quality of outcome indicators

We used the GRADE level of evidence to assess the critical outcome indicators of the included studies. We found a high risk of bias for the outcome indicator used to assess pain intensity and physical function, allowing a risk of bias rating of severe. The outcome indicator used to assess KOA physical function involved a small sample size ($n<400$), enabling imprecise risk ratings of severe. No serious risk was identified for the remaining items, so the final rating for the indicator used to assess pain intensity was moderate, the final rating for the indicator used to evaluate pain sensitivity was high, and the final rating for the indicator used to assess physical function was low, as detailed in Table 3.

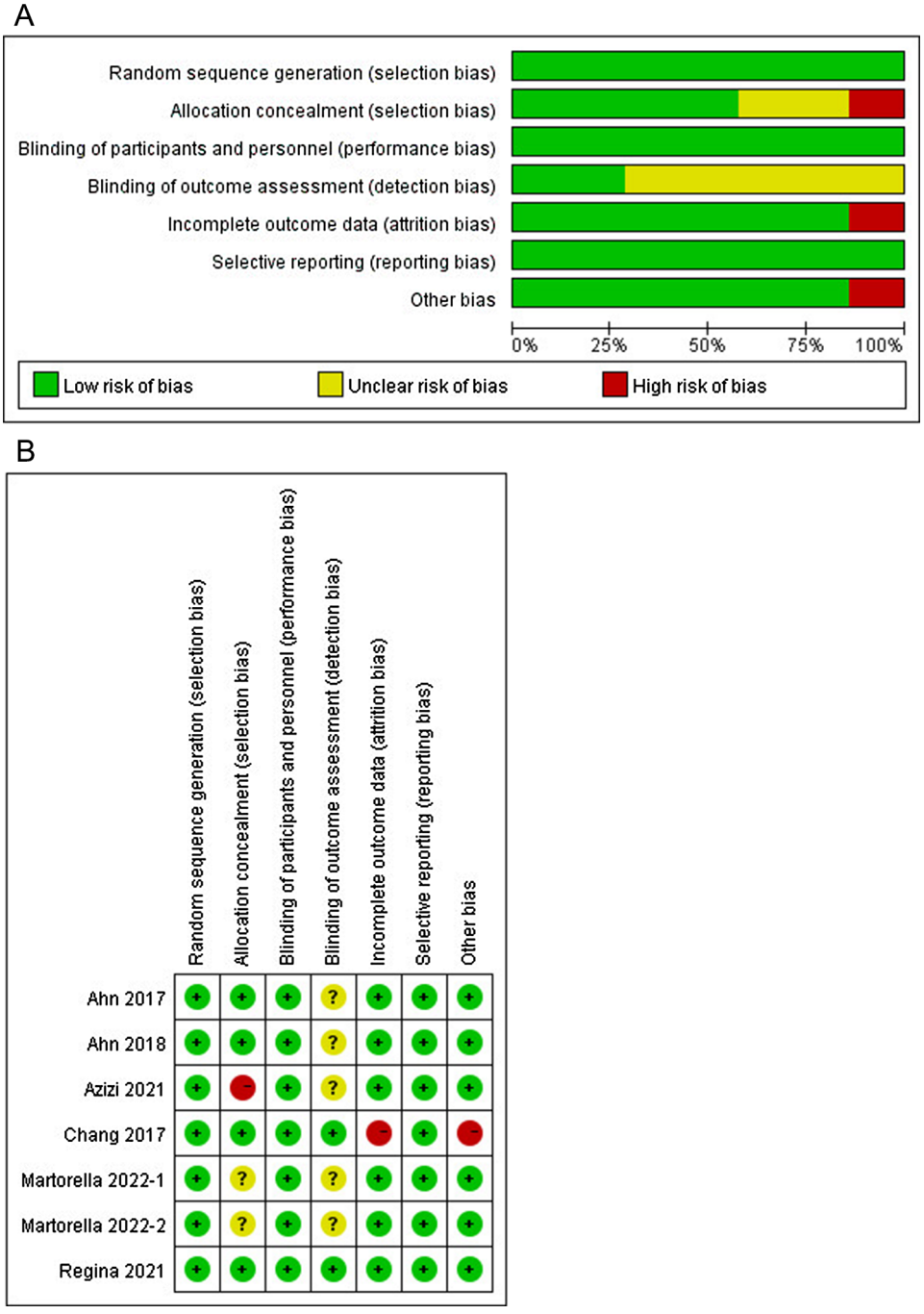

Fig. 2 Risk of bias graph and summary of included studies. **(A)** The risk of bias graph shows the overall risk of bias in each domain. **(B)** The risk of bias summary indicates the risk of bias in each domain for each study

Effect of tDCS on pain intensity

Five studies assessed the effect of tDCS on short-term pain intensity in patients with KOA using the VAS score or the NRS score [26–30]. Meta-analysis (Fig. 3A) showed that tDCS was effective in reducing short-term pain intensity in patients with KOA (SMD: -0.58; 95% CI: -1.02, -0.14; $p=0.01$). Four studies assessed the effect of tDCS on long-term pain intensity in patients with KOA using the VAS scores or the NRS scores. Meta-analysis (Fig. 3B) showed that tDCS did not significantly improve long-term pain intensity in patients with KOA (SMD: -0.26; 95% CI: -0.59, 0.08; $p=0.13$).

Effect of tDCS on pain sensitivity

Three studies assessed the effect of tDCS on short-term pain sensitivity in patients with KOA by CPM,

Table 3 GRADE evidence profile for outcomes among trials included in the systematic review

Outcomes	Number of studies	Design	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Absolute effect	GRADE quality	Symbolic expression
Short-term pain intensity: (VAS or NRS)	5	RCT	-1[#]	0	0	0	0	SMD 0.58 lower (1.02 to 0.14 lower)	Moderate	⨁⨁⨁⊖
Long-term pain intensity: (VAS or NRS)	4	RCT	-1[#]	0	0	0	0	SMD 0.26 lower (0.59 lower to 0.08 higher)	Moderate	⨁⨁⨁⊖
Pain sensitivity: (CPM, PPT, HPTh, or HPTo)	3	RCT	0	0	0	0	0	SMD 0.43 lower (0.7 to 0.16 lower)	High	⨁⨁⨁⨁
Short-term physical function: (WOMAC or KOOS)	5	RCT	-1[#]	0	0	-1*	0	SMD 0.13 lower (0.35 lower to 0.08 higher)	Low	⨁⨁⊖⊖
Long-term physical function: (WOMAC or KOOS)	3	RCT	-1[#]	0	0	-1*	0	SMD 0.02 higher (0.22 lower to 0.25 higher)	Low	⨁⨁⊖⊖

Notes VAS: visual analog scale; NRS: numeric rating scale; CPM: conditioned pain modulation; PPT: pressure pain threshold; HPTh: heat pain threshold; HPTo: heat pain tolerance; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; KOOS: Knee injury and Osteoarthritis Outcome Score; RCT: randomized controlled trial; SMD: standardized mean differences; [#]Downgraded by levels due to a high risk of bias; *Downgraded by levels due to small sample size (n<400)

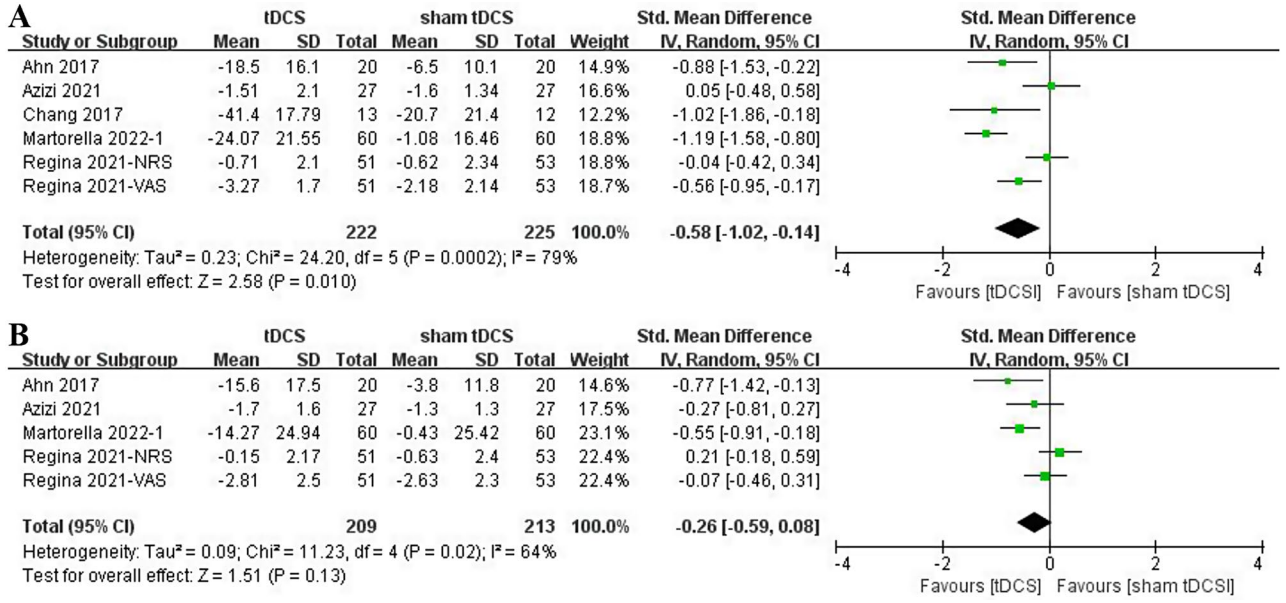

Fig. 3 Forest plot of the effect of tDCS on pain intensity in patients with KOA. **(A)** The effect of tDCS on short-term pain intensity. **(B)** The effect of tDCS on long-term pain intensity. NRS: numeric rating scale; VAS: visual analog scale

PPT, HPTh, or HPTo [29, 31, 32]. Meta-analysis (Fig. 4) showed that tDCS was effective in reducing short-term pain sensitivity in patients with KOA compared with the control group (SMD: -0.43; 95% CI: -0.70, -0.16; p=0.002). Only one study evaluated the effect of tDCS on long-term pain sensitivity in patients with KOA, and the results of this study showed that tDCS failed to improve long-term pain sensitivity in patients with KOA [29].

Effect of tDCS on physical function

Five studies assessed the effects of tDCS on short-term physical function in patients with KOA through WOMAC or KOOS [26–30]. Meta-analysis (Fig. 5A) showed that tDCS did not significantly improve short-term physical function in patients with KOA (SMD: -0.13; 95% CI: -0.35, 0.08; p=0.22). Three studies evaluated the effects of tDCS on long-term physical function

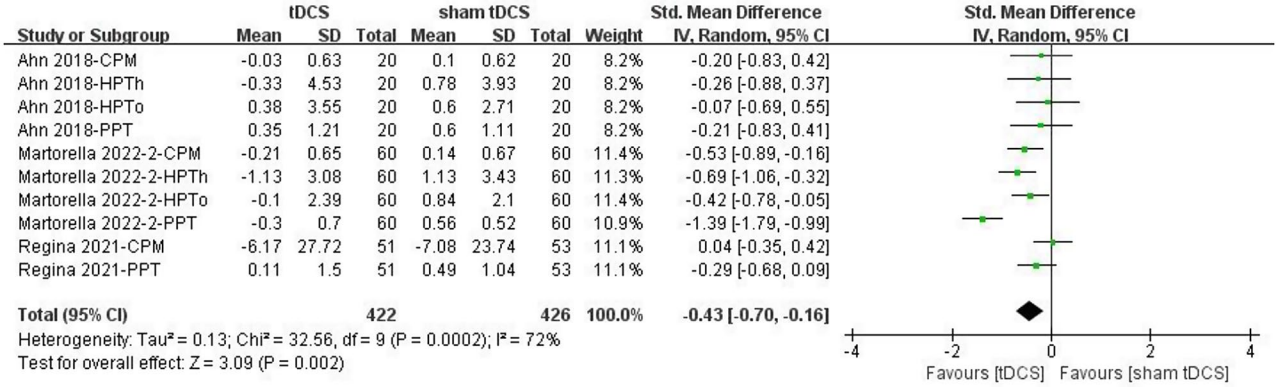

Fig. 4 Forest plot of the effect of tDCS on short-term pain sensitivity in patients with KOA. CPM: conditioned pain modulation; HPTh: heat pain threshold; HPTo: heat pain tolerance; PPT: pressure pain threshold

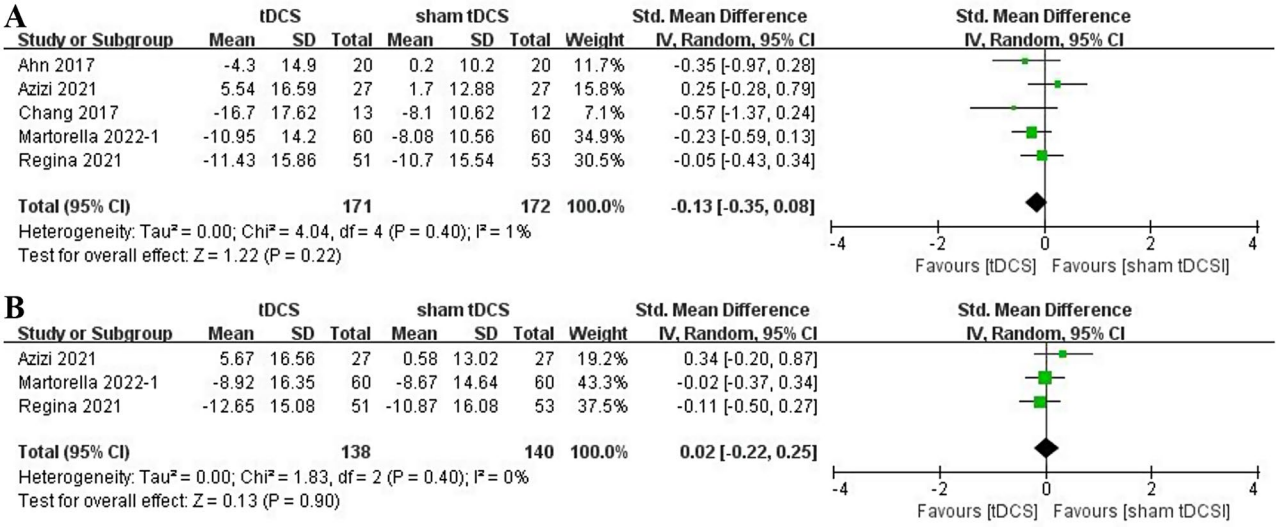

Fig. 5 Forest plot of the effect of tDCS on physical function in patients with KOA. **(A)** The effect of tDCS on short-term physical function. **(B)** The effect of tDCS on long-term physical function

in patients with KOA via WOMAC or KOOS [26. 28–29]. Meta-analysis (Fig. 5B) showed that tDCS did not significantly improve long-term physical function in patients with KOA (SMD: 0.02; 95% CI: -0.22, 0.25; $p=0.90$).

Discussion

Pain is the predominant symptom of patients with KOA, and severe joint pain can affect the quality of life [44, 45]. Previous studies thought that the pain of KOA patients is caused by regional peripheral afferents injury [46]. However, recent studies have found that central nociceptive sensitization plays a crucial role in KOA, leading to local and widespread nociceptive hyperalgesia in these patients [47–49]. tDCS is a non-invasive neuromodulator acting on the central nervous system and can alter neuronal excitability [50–52]. Therefore, tDCS may improve endogenous central pain inhibition in elderly KOA patients by attenuating the effects of central sensitization and modulating brain activity that processes pain, resulting in pain relief [53]. Also, it interacts with various neurotransmitters associated with pain processing, such as dopamine, 5-hydroxytryptamine, acetylcholine, and g-aminobutyric acid [54–58]. In addition, several studies have suggested that inhibition of thalamic sensory neurons and de-inhibition of periaqueductal grey matter neurons may be responsible for pain relief [59]. The results of our meta-analysis showed that tDCS was effective in relieving short-term pain intensity and pain sensitivity in patients with KOA but failed to significantly improve long-term pain intensity in patients. This may be due to the following reasons: Firstly, it may be that tDCS was used alone rather than in combination with another treatment; most of the included studies used tDCS only as an intervention; only the study by Chang et al. combined exercise therapy, but it did not evaluate the long-term effects of tDCS [27]. Secondly, the number of tDCS interventions in most studies may be too low, resulting in tDCS being able to modulate pain control in

the short term, but its therapeutic effects are not maintained. Therefore, future studies on tDCS in combination with other therapies are needed, as well as more studies to determine the optimal duration and number of tDCS treatments to achieve maintenance of the treatment effect.

KOA patients often suffer from recurrent disease, so their physical functions are usually affected [60, 61]. Our findings suggest that tDCS did not significantly improve physical function in patients with KOA. The lack of statistical significance for physical function may be due to three reasons: Firstly, most of the included studies had a low number of interventions, Chang and colleagues conducted a 16-session tDCS intervention and found that tDCS improved overall physical function (as assessed by WOMAC) in patients with KOA [27]. Secondly, tDCS intervention alone may not improve physical function in patients with KOA, but one study that combined tDCS intervention with exercise therapy showed that tDCS improved physical function in patients with KOA [27]. Finally, the WOMAC includes pain, stiffness, and joint function. However, we only analyzed the total scores of the WOMAC because only one study examined all three aspects [30]. Therefore, tDCS with an increased number of interventions or in combination with other interventions (e.g., exercise therapy) may be able to improve patients' physical function.

In addition, there are some limitations to this study. Firstly, the number and sample sizes of studies included in this analysis were minimal, which may impact the accuracy of the results. Secondly, the high degree of heterogeneity between studies reduces the quality of that evidence, making comparability of studies difficult. Thirdly, because only one study evaluated the long-term effects of tDCS on pain sensitivity in patients with KOA [29], we could not assess the long-term effects of tDCS on pain sensitivity in patients with KOA. Finally, because the intervention sites, intervention parameters, and duration of tDCS were essentially the same in the included studies, we were unable to explore the effects of tDCS on patients with KOA with different intervention sites, intervention parameters, and duration of intervention.

Conclusions

Our findings indicate that tDCS can reduce short-term pain intensity and sensitivity but fails to significantly relieve long-term pain intensity and improve the physical function in patients with KOA. Thus, tDCS may be a potential therapeutic tool to reduce short-term pain intensity and pain sensitivity in patients with KOA. In addition, we found that combining tDCS with other therapies (e.g., exercise therapy) or increasing the number of interventions may improve physical function in patients with KOA. Future studies will require larger sample sizes, longer follow-up times, longer durations of tDCS treatment, and studies of different stimulation sites to determine the optimal tDCS dose and parameters for patients with KOA.

Abbreviations

KOA	Knee osteoarthritis
tDCS	Transcranial direct current stimulation
RCT	Randomized controlled trial
GARDE	Grading of Recommendations Assessment Development and Evaluation
SD	Standard deviation
VAS	Visual analog scale
NRS	Numeric rating scale
CPM	Conditioned pain modulation
PPT	Pressure pain threshold
HPTh	Heat pain threshold
HPTo	Heat pain tolerance
QST	Quantitative Sensory Testing
WOMAC	Western Ontario and McMaster Universities Osteoarthritis Index
KOOS	Knee injury and Osteoarthritis Outcome Score
95% CI	95% confidence intervals
MD	Mean differences
SMD	Standardized mean differences
SO	Supraorbital area

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12891-024-07805-3.

Appendix S1

Appendix S2

Acknowledgements

Not applicable.

Author contributions

Yanlin Wu collected the data and wrote the manuscript. Yun Luo supervised this study and revised the manuscript. Jiaming Yang and Yongqiang Wu selected the literature. Qiang Zhu and Yi Li extracted the data. Hao Hu and Jiahong Zhang assessed the quality of each included study. Yanbiao Zhong solved the difference. Maoyuan Wang provided the idea and designed this study.

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Data availability

Data are available on reasonable request to the corresponding author at: wmy.gmu.kf@gmail.com.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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