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SYSTEMATIC REVIEW

Effects of physical exercise on improving erectile function: a systematic review and meta-analysis of randomized controlled trials

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Abstract

Background: The study aims to determine the effects of physical exercise (PE) on improving erectile function in adult men with erectile dysfunction (ED) and to explore appropriate clinical exercise regimens through subgroup analyses of factors such as exercise intensity and cycles. **Methods**: We conducted a systematic review of articles describing randomized controlled trials (RCTs), and conducted subgroup analyses based on demographic and exercise program characteristics. The primary outcome indicator was the International Index of Erectile Function (IIEF) score, which was meta-analyzed to determine the combined effect size. Qualitative analysis was conducted on other relevant indicators. **Results**: A total of 10 studies were included in the meta-analysis and 6 in the qualitative analysis. The results of the meta-analysis indicated a standardized mean difference (SMD) of 0.892 with a 95% confidence interval of [0.395–1.388], a Hedges' g of 0.247, and an I^2 of 88.6% ($p < 0.01$). Subgroup analysis showed that the SMD effect was greater in the <60 years age group, the 0–3 months exercise cycle and the low-intensity group, with $p < 0.05$; no significant differences were observed in the subgroups according to country, object or intervention exercise frequency. **Conclusions**: This study demonstrated that PE significantly reduces IIEF scores in patients with ED compared with other interventions for the treatment of ED, especially in ED patients under 60 years of age with chronic disease state (CDS). Low-intensity with a 0–3 months duration was more effective in improving erectile function. This effect is not related to the country, exercise frequency or intervention group with or without combined drug intervention. These findings have practical value in guiding healthcare professionals in the selection of selecting clinical exercise prescription programs. In addition, physical exercise is also beneficial in improving body mass index, blood pressure and blood sugar. **The PROSPERO Registration**: CRD42023445949, http://www.crd.york.ac.uk/PROSPERO.

Keywords

Erectile dysfunction; Physical exercise; Meta-analysis

1. Introduction

Erectile dysfunction (ED) is defined as the inability to achieve or maintain a penile erection of sufficient quality for satisfactory sexual activity [1–3]. ED is increasingly recognized as a public health challenge; however, it is often overlooked in clinical practice because of its impact on people's privacy [4–6]. ED is a common condition that worsens with age [7] and its incidence is on the rise worldwide [8]. Several studies have shown that ED is a common clinical entity that mainly affects men over the age of 40 [1, 9]. It has been reported that more than 150 million men worldwide suffer from varying degrees of ED [10]. The incidence rate of ED is estimated at 25–30 cases per thousand person years [2]. The incidence of ED rises with the number and severity of chronic conditions [2, 9]. Studies have shown that the occurrence of ED is associated with many comorbidities and risk factors [11]. Several epidemiological studies have reported that erectile dysfunction is a marker of cardiovascular disease (CVD) [1, 2, 12, 13]. Mounting evidence suggests that also gastrointestinal and liver disorders may also be associated to sexual dysfunction, including celiac disease [14, 15]. Penile erection is the result of complex neurovascular processes, and alterations in the vascular endothelium, smooth muscle, psychological, neurological and hormonal systems can lead to ED [16–18]. When younger men present with ED, the risk of future cardiac events is significantly increased, whereas in older men, ED does not appear to be associated with prognosis [13]. Numerous studies have shown that ED shares several modifiable risk factors for cardiovascular disease including atherosclerosis, hypertension, diabetes, smoking, excessive alcohol consumption, recreational drug use, obesity and sedentary lifestyle [8, 9, 19].

PE is defined as the regular, planned, structured and repeated practice of physical activity to improve the subject's physical condition, taking into account parameters such as intensity, volume, frequency and types of sports disciplines [20]. Positive changes in biomarkers of cardiovascular health may occur through physical activity programs, leading to cardiovascular remodeling and the improved recovery of penile hemodynamics and erectile function in patients with metabolic syndrome and/or cardiovascular disease [21, 22]. Physical activity is the most effective way to increase nitric oxide and enhance endothelial function, as well as to increase testosterone and reduce stress and anxiety [17]. The results of the current studies on PE and ED suggest that some of the outcomes have null effect sizes [23–26], but others do not [19, 27–30]. However, the effect sizes of these reports have varied considerably. In addition, sample sizes and study populations vary widely between studies, so a comprehensive and systematic review is needed.

Some studies have shown an improvement in International Index of Erectile Function (IIEF) scores after physical activity. However, the effect size is not statistically significant. These studies suggest that physical activity may play a role in improving ED, but the magnitude of the effect remains unclear. Both physical activity (PA) and PE have the potential to enhance sexual function and cardiovascular health [31]. Studies included in the PA review are largely observational and thus require validation through randomized controlled trials with a high level of evidence. A systematic review by Gerbild demonstrated that PA can be a protective factor against erectile dysfunction and improve erectile function in men affected by vascular ED [4]. Nevertheless, only qualitative studies have been conducted and assessing quantitative effects alone is not sufficient. A review by Silva included seven studies for meta-analysis [22], while another meta-analysis by Lamina included five studies [32], and Khera's review included 11 RCTs that analyzed the extent to which aerobic exercise affects different levels of ED and did not include studies of other exercise types [33]; however, all three reviews lack effective subgroup discussions, which hinders the understanding of the heterogeneity of PE's protective effect on ED in different subgroups. Additionally, emerging research evidence was not included in these analyses. Therefore, more detailed meta-analyses and subgroup analyses are needed to determine the effect of PE on erectile function and to analyze the factors that have an impact.

Consequently, we performed a systematic review and meta-analysis of randomized controlled trials (RCTs) to assess the effect of PE on ED. Furthermore, subgroup analyses have practical value in guiding healthcare professionals in selecting clinical exercise prescription programs, and our study highlights this clinical application. It was necessary to gain insight into the specific programmatic, exercise duration, intensity of exercise and frequency of PE required to improve ED.

2. Materials and methods

2.1 Registration

The protocol was registered in the PROSPERO registry in July 2023 (CRD42023445949; http://www.crd.york.ac.uk/PROSPERO). This systematic review was conducted in accordance with the systematic review checklist (PRISMA 2020) (**Supplementary Table 1**).

2.2 Literature search strategy

As of July 2023, the PubMed, Web of Science, Cochrane Library, China National Knowledge Infrastructure (CNKI) and Chinese Science and Technology Periodical Database (VIP) databases were searched for relevant publications. The search yielded a list of citations for randomized controlled trials investigating the effects of physical exercise and erectile dysfunction management, with the IIEF serving as an indicator of treatment outcomes. This study selected for examinations of the effects of different PE on erectile dysfunction in men. The data on the characteristics of the participants, quality of the studies, objects, exercise programmatic and treatment outcomes were collected and analyzed.

Scope of search: Computer search of Chinese databases (CNKI, VIP) and English databases (Pub Med, Cochrane Library, Web of Science) and other databases, with a time frame from the establishment of each database to July 2023.

Search terms and search formulas: Search terms was in English and Chinese, and Boolean logic was employed in the search formulas, with logical "or" between different exercise modalities and logical "and" between different exercise modalities and diseases; iterative screening, manual searching, and retrospective inclusion of references were used where necessary. The search strategy is shown in **Supplementary Table 2**.

Literature searches were performed through the PubMed, Web of Science, Cochrane Library, VIP and CNKI databases. The search period spanned the inception of the database to 17 July 2023. Scientific databases were searched according to three criteria: study population ("erectile dysfunction (ED)" and "vascular erectile dysfunction"), intervention programs ("exercise", "physical exercise (PE)", "aerobic exercise" and "training") and outcomes ("IIEF", "IIEF-5" and "erectile function"). All search strategies were conducted in relevant databases using both English and Chinese. Two researchers independently completed the initial article screening and a statistical analysis of the basic information in the included literature, as well as the changes in the effect indicators before and after the experiment. A third researcher negotiated the resolution of discrepancies when they existed.

We searched multiple databases from the inception dates to July 2023, using the keywords "exercise" and "erectile function" to identify published systematic reviews or meta-analyses that assessed the impact of PE on ED. A more detailed comparison of the published reviews is presented in **Supplementary Table 3**.

2.3 Inclusion and exclusion criteria

2.3.1 Inclusion criteria

The eligibility criteria were defined according to the PICOS (population, intervention, comparison, outcome, study design) items.

(P) The study included males over the age of 18 years old affected by ED of any grade. There were no restrictions on the race of the study participants.

(I) Physical exercise (PE) is a planned, organized and repetitive physical activity used to improve or maintain physical fitness. An exercise protocol can be classified as low or moderate intensity, with an exercise period of 0–6 months and a frequency of 3–7 times per week. The types of exercise include walking, cycling, rehabilitation training, interval endurance training, resistance training, pelvic floor muscle training and drug combination campaigns.

(C) The comparators included dietary control, health advice, sedentary behavior, usual care and pharmacotherapy.

(O) The outcomes were classified according to the following criteria: the primary outcome measure was erectile function. The primary endpoint was the prevalence of ED assessed by using the IIEF score. ED was quantified using the IIEF score (maximum = 30 points) or the IIEF-5 score (maximum = 25 points) for inclusion in the meta-analysis. Studies that included additional specific indicators, such as body mass index, blood pressure, blood glucose and VO_2 peak, were included in the qualitative analysis.

(S) The study design included experimental intervention studies, mainly consisting of RCTs.

2.3.2 Exclusion criteria

(1) ED secondary to pelvic radical surgery on account of actual or potential nerve injury, spinal trauma or hypogonadism; patient refused to participate in physical exercise.

(2) The full texts not available through various sources, only abstracts, case reports, reviews, lectures, commentaries, *etc.* Additionally, data that were not available for extraction, repeatedly published studies, statistics from a study that could not be converted for application in this study, studies that did not contain relevant outcome indicators, and other research designs, except observational studies, were excluded.

(3) In the experimental group, the intervention was a combination of exercise and a drug or another intervention. In the control group, the intervention was not a separate drug or another intervention.

2.4 Evaluation of bias and quality assessment

The risk of bias and methodological quality of the included studies were evaluated by two independent evaluators using Review Manager 5.3. This evaluation was conducted in accordance with the criteria for selective bias (randomized sampling, grouping), implementation bias (whether the experiment was blinded to subjects and experimenters), measurement bias (whether the experiment operator was blinded to the endpoints), follow-up bias (completeness of results), selective reporting bias and other biases were evaluated. The outcomes were classified as low risk, high risk or unclear. Should a dispute arise between two evaluators during the quality evaluation, a third evaluator will be invited to participate in order to facilitate harmonization.

2.5 Data extraction

After a comprehensive review of the literature, two researchers independently extracted the following data from the eligible literature: external characteristics of the literature (title, authors, year of publication and nationality of the authors); basic information about the subjects (age, gender, country, sample size and whether the patient had a chronic disease); the experimental design and exercise protocol (training period and frequency, duration, exercise program, intensity and intervention group with or without combined pharmacotherapy); and the outcome indicators related to the study (IIEF score of erectile function). The IIEF is a validated questionnaire used to assess the erectile function of men [34, 35]. The higher the IIEF score, the better the man's erectile function is in relative terms. In the event of a discrepancy between the two individual researchers, a third individual was tasked with synthesizing the information and determining a consensus through group deliberation. The requisite outcome indicators were extracted separately for the mean and standard deviation of the pre-test and the mean and standard deviation of the post-test for the intervention and control groups in the study. The mean standard deviation of the difference between the pre-test and post-test were calculated separately.

The subgroups were defined as follows: object (ED, ED with CDS), country (China, foreign), age ($<$60 years; $\geq$60 years), intervention group with or without combined pharmacotherapy (Yes; No), exercise duration (0–3 months; 4–6 months), exercise frequency ($<$5 times/week; $\geq$5 times/week) and training intensity (low intensity; moderate intensity).

2.6 Sensitivity analysis and publication bias

We conducted a sensitivity analysis using a literature-by-exclusion approach. The presence of publication bias was evaluated by means of a visual inspection of a funnel plot. In the event that significant bias was identified, a trim-and-fill analysis was conducted.

The Cochrane Risk of Bias Assessment Tool [36] was employed to evaluate the methodological quality of the included literature in six domains, including selection bias, implementation bias, measurement bias, follow-up bias and reporting bias. Each indicator was evaluated and the quality of the studies was classified into three levels: Grade A: low bias, indicating that each category of bias is low risk and that reasonable bias is unlikely to significantly alter the results; Grade B: moderate bias, indicating that one or more categories of bias are unknown and that there is a moderate likelihood of bias occurring; and Grade C: high bias, indicating that one or more categories of bias have a high likelihood of bias occurring.

2.7 Statistical analysis

The Stata SE 16 software (StataCorp LLC, College Station, TX, USA) was used for the meta-analysis. The data included in the study were continuous and expressed as SMDs and 95% confidence intervals (CIs). The outcome indicators included in the meta-analysis were IIEF, IIEF-5 and IIEF-15, which had different scores and thus required experimental outcome indicator standardization, with effect sizes indicated by SMD. A meta-analysis of the difference in IIEF scores before and after the experiment was performed using a random effects model. The presence of heterogeneity among the studies was tested using the I^2 test. An I^2 of 0% signifies the absence of observed heterogeneity, with a higher value indicating greater heterogeneity. Generally, $I^2 > 56\%$ suggests substantial heterogeneity among the studies; $I^2 < 31\%$ suggests that the studies are homogeneous; and I^2 between 31% and 56% often indicates that heterogeneity cannot be definitively excluded. Subgroup analyses were also conducted to examine the characteristics of the studies and sources of heterogeneity across different classifications.

To reflect the practical value of effect sizes for clinical purposes, the effect size was calculated according to Hedges' *g*. This is also a widely used measure in meta-analysis. Hedge proposed that effect sizes of 0.2, 0.5 and 0.8 correspond to small, medium and large effect sizes, respectively [37].

The studies that were not included in the meta-analysis underwent a qualitative analysis in accordance with the established inclusion and exclusion criteria.

3. Results

3.1 Description of studies

A total of 2699, 6723 and 172 English articles were retrieved from PubMed, Web of Science and the Cochrane Library, respectively. The screening process yielded the inclusion of 14 studies. The CNKI and VIP databases offered 513 and 20 articles in Chinese, respectively, and 2 studies were ultimately included after screening. A total of 16 studies met the inclusion criteria; of these, 10 were included in the meta-analysis and 6 were analyzed qualitatively. Further details on the included studies can be found in **Supplementary Tables 4**,**5** provides an overview of the reasons for exclusion. Fig. 1 illustrates the literature selection process.

The study included 10 randomized controlled trials (RCTs). The subjects were all ED patients, with a total of 725 individuals included in the study. The experimental group received interventions involving PE, which included aerobic training, intermittent exercise, pelvic floor muscle contraction training and other forms of exercise. Meanwhile, the control group was based on usual care and health advice. For this study, two studies were designated as China and eight were designated as foreign. The age of the participants was categorized as <60 years in 6 studies and ≥60 years in two studies. Three studies were conducted in patients with ED and five studies were conducted in patients with ED with CDS, including obese patients and patients with cardiovascular disease. The intervention groups in two studies were a combination of exercise and pharmacotherapy, and the intervention groups in seven studies were exercise alone. The exercise duration was categorized as 0–3 months in six studies and 4–6 months in three studies. The exercise frequency was categorized as <5 times/week in 3 studies and ≥5 times/week in five studies. The exercise intensity was categorized as moderate intensity in four studies and low intensity in four studies. The Primary outcome indicators were addressed in 10 studies. Details on the basic characteristics of the included literature are shown in Table 1.

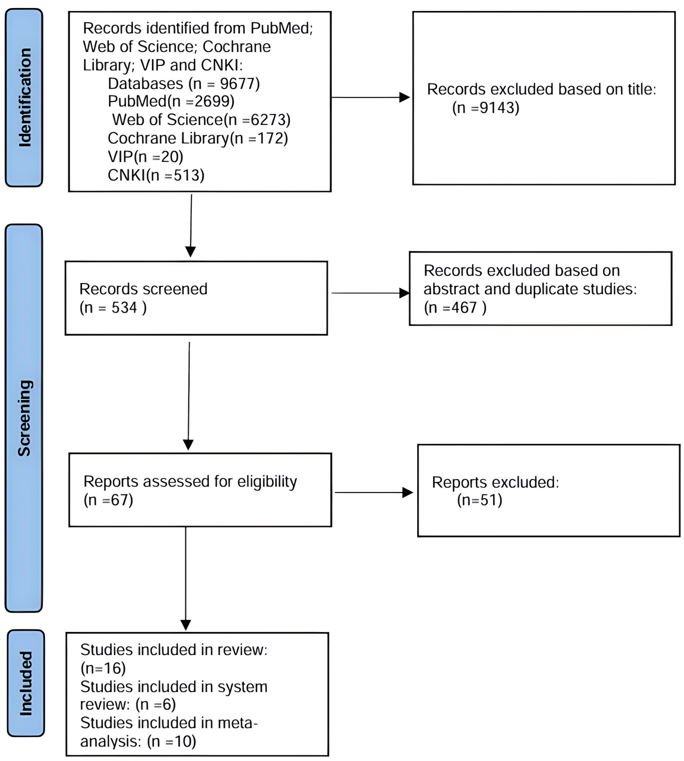

FIGURE 1. Flow chart of literature search and screening process. VIP, Chinese Science and Technology Periodical Database; CNKI, China National Knowledge Infrastructure.

TABLE 1. Characteristics of the included trials and participants.

Study (yr)	Country, Study design	Object	Age (mean ± sd)	Sample	Drop out	Intervention characteristics					Comparator	Outcome
						Movement patterns	Duration (mon)	Intensity	Duration (min/time)	Frequency (times/wk)		
Esposito (2004)	American, RCT	ED with obesity	T: 43.50 ± 4.80 C: 43.00 ± 5.10	T: 55 C: 55	T: 3 C: 3	Walking, AT, DC	24	Low	NR	NR	DC	IIEF
Jones (2014)	American, RCT	ED with RP	NR	T: 25 C: 25	T: 0 C: 0	Walking, AT	6	Low to medium	30–45	5	UC	IIEF
Kałka (2009)	Poland, RCT	ED with IHD	T: 62.35 ± 8.88 C: 61.71 ± 7.35	T: 98 C: 31	T: 0 C: 0	ReT	6	Medium	45	5	UC	IIEF-5
Kalka (2013)	Poland, RCT	ED with IHD	T: 62.07 ± 8.59 C: 61.43 ± 8.81	T: 103 C: 35	T: 0 C: 0	IET, RT	6	Medium to high	45	3	HA	IIEF-5
Lamina (2009)	Africa, RCT	ED	T: 62.10 ± 5.23 C: 64.00 ± 4.77	T: 25 C: 25	T: 3 C: 4	IET, cycling	2	Medium	45–60	3	Sedentary	IIEF
Maio (2010)	Italy, RCT	ED	T: 50.14 ± 6.28 C: 50.32 ± 6.95	T: 30 C: 30	T: 0 C: 0	AT, ED Ph	3	Medium	30–60	3–5	ED Ph	IIEF-15
Vignera (2011)	Italy, RCT	ED	T/C: 57.30 ± 0.50	T: 30 C: 20	T: 0 C: 0	AT, DC	3	Low	30	5	DC	IIEF-5
Sun (2022)	China, RCT	ED with diabetes	T/C: 56.89 ± 5.13	T: 25 C: 25	T: 0 C: 0	PFMT, ED Ph	2	Low	NR	NR	ED Ph	IIEF-5
Zeng (2018)	China, RCT	ED with CVD	T/C: 22.00–60.00	T: 30 C: 30	T: 0 C: 0	AT, CAD Ph	3	Medium	20–40	5	CAD Ph	IIEF-5
Dorey (2004)	England, RCT	ED	T/C: 57.68 ± 12.28	T: 28 C: 27	T: 6 C: 8	PFMT, HA	3	Low	NR	NR	HA	IIEF

Notes: T, test group; C, Control Group; RCT, Randomized Controlled trial; ED, erectile dysfunction; RP, Post-prostatectomy patients; CVD, cardiovascular disease; IHD, Ischemic heart disease; CAD, Coronary Artery Disease; AT, aerobic training; ReT, rehabilitation training; IET, interval endurance training; RT, resistance training; PFMT, pelvic floor muscle training; DC, diet control; UC, usual care; Ph, pharmaceutical; HA, health advice; NR, Not Reported; sd, Standard deviation; IIEF, International Index of Erectile Function.

3.2 Quality evaluation

In terms of the quality assessment, three studies were identified as being at high risk, and the results are presented in Figs. 2,3. In Figs. 2,3, green indicates a "low risk", red indicates a "high risk" and yellow indicates an unclear risk. The results are presented in the following manner: (1) Randomization: one study was identified as having a high risk of bias. (2) Allocation concealment: seven studies did not describe a specific allocation method. (3) Blinding: one study was partially blinded, three were not blinded and the majority did not describe a blinding method. (4) Incomplete data reporting: three studies had case dropouts, but all reported this in their analyses.

The methodological quality of the included studies is evaluated in the following section. The inclusion information was subjected to a comprehensive evaluation in accordance with the seven inclusion criteria of the Cochrane systematic evaluation.

3.3 Erectile function

A total of 10 studies [19, 23–25, 27–30, 38, 39] were included in the meta-analyses, which used either the IIEF score for erectile function or the IIEF-5 score criterion as the primary outcome metric for intervention results. A total of 725 ED patients (excluding the number of lost visits) were included in the meta-analysis. Fig. 4 presents a forest plot of PE versus other interventions, with a 95% confidence interval for the SMD lying to the right of the empty vertical line. The I^2 value was 88.6%, indicating that a random-effects model was chosen for analysis.

Despite the overall effect trending to the right of the null line, five studies did not demonstrate statistical validity. This suggests that some of the studies included in the meta-analysis had an effect size for the experimental group equal to that of the control group and that the experimental factor was not valid. The combined effect size was statistically significant (SMD = 0.892 with a 95% confidence interval of [0.395–1.388]; Hedges' g = 0.247; $p < 0.001$), but there was high heterogeneity (I^2 = 88.6%). This suggests that the combined effect of PE on ED was effective and statistically significant; however, in terms of clinical significance, the findings fall into the low effect size category.

3.4 Subgroup analysis results

Several factors may influence the results, including age, country, disease type, exercise duration, exercise frequency and exercise intensity at the time of patient inclusion. To account for the potential influences, we conducted subgroup analyses to identify any differences in the results between the various subgroups. The results are presented in Table 2.

3.4.1 Country

A total of ten studies were included in this subgroup. The effect size SMD [95% CI] for the Chinese group was 0.946 [0.504–1.388] (I^2 = 18.9%, $p < 0.05$), while the Hedges' g value was 0.787, indicating a medium effect. The foreign group exhibited a mean effect size of 0.895 [0.291–1.500] (I^2 = 90.7%, $p < 0.05$). The observed effect was statistically significant within both subgroups, although not statistically different between subgroups; p = 0.090.

3.4.2 Object

Eight studies were included in this subgroup. Patients with cardiovascular disease and obesity were included in the CDS group. The effect size SMD [95% CI] for the ED with CDS group was 0.623 [0.284–0.961] (I^2 = 63.4%, $p < 0.05$), which was statistically significant. However, the between-group p-value for each subgroup effect size was 0.085, indicating that there was no statistically significant difference between the groups.

3.4.3 Age

Eight studies were included in this subgroup. The effect size SMD [95% CI] for the <60 age group was 1.366 [0.494–2.237] (I^2 = 92.1%, $p < 0.01$), and the Hedges' g value was 0.504, which was statistically significant. A statistically significant difference was observed between the two groups, with PE for ED being more effective in the younger group (aged <60 years) than in the older group (aged ≥60 years).

3.4.4 Intervention group with or without combined pharmacotherapy

Nine studies were included in this subgroup. The effect size SMD [95% CI] for the YES group was 0.813 [0.092–1.533] (I^2 = 69.7%, p = 0.069), and the Hedges' g value was 0.538. The NO group was 0.982 [0.283–1.682] (I^2 = 92.0%, $p < 0.05$). There was no statistically significant difference between the subgroups, with a p-value of 0.616.

3.4.5 Training intensity

Eight studies were included in this subgroup. The moderate intensity group was 0.527 [0.267–0.787] (I^2 = 6.8%, $p < 0.01$); the I^2 value was 6.8%, indicating a low degree of heterogeneity; and Hedges' g value was 0.172, indicating statistical significant. A statistically significance difference was observed between the two groups. Low-intensity PE was more effective than others.

3.4.6 Exercise period

Nine studies were included in this subgroup. The effect size SMD [95% CI] for the 0–3 months group was 1.323 [0.409–2.237] (I^2 = 92.1%, $p < 0.05$), and the Hedges' g value was 0.469, which was statistically significant. A statistically significant difference was observed between the two groups ($p < 0.01$). The results indicated that the PE for ED was more effective in the 0–3 months group.

3.4.7 Exercise frequency

Eight studies were included in this subgroup. The effect size SMD [95% CI] for the <5 times group was 0.460 [0.143–0.776] (I^2 = 20.2%, $p < 0.05$), and the Hedges' g value was 0.060. The effect size SMD [95% CI] for the ≥5 times group was 1.418 [0.356–2.480] (I^2 = 94.0%, $p < 0.01$), and the Hedges' g value was 0.248. This was found to be effective within both subgroups, although not statistically different between subgroups, with a p-value of 0.267.

Upon performing subgroup analyses, we find that the SMD

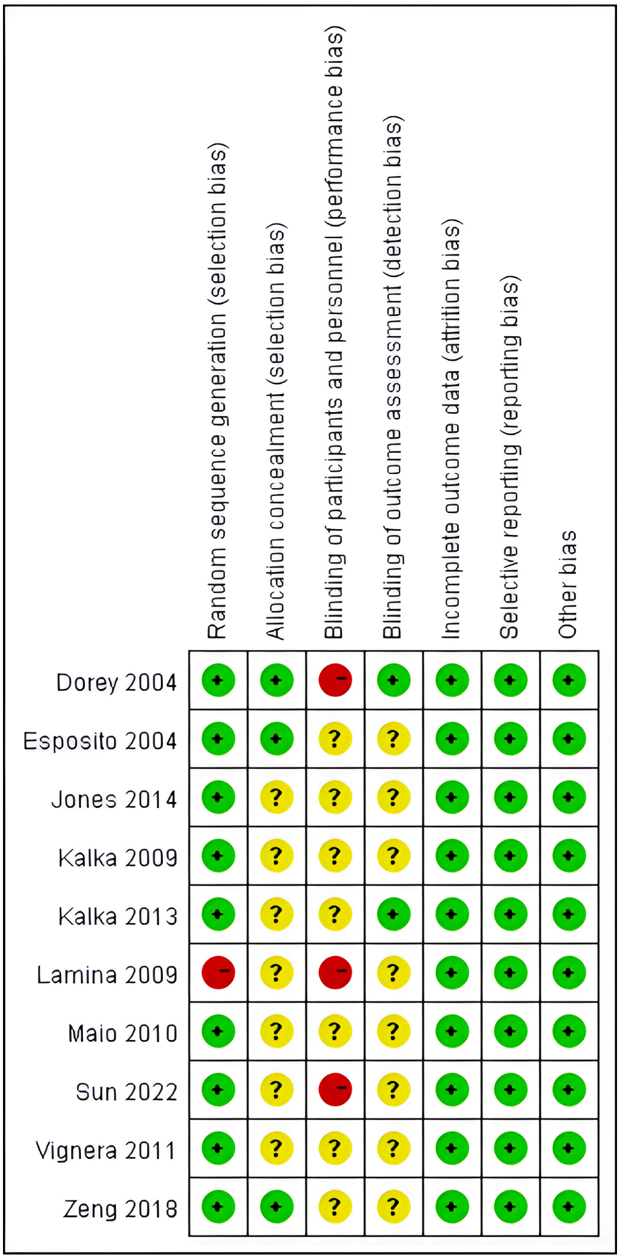

FIGURE 2. Schematic diagram of methodological quality assessment of the literature.

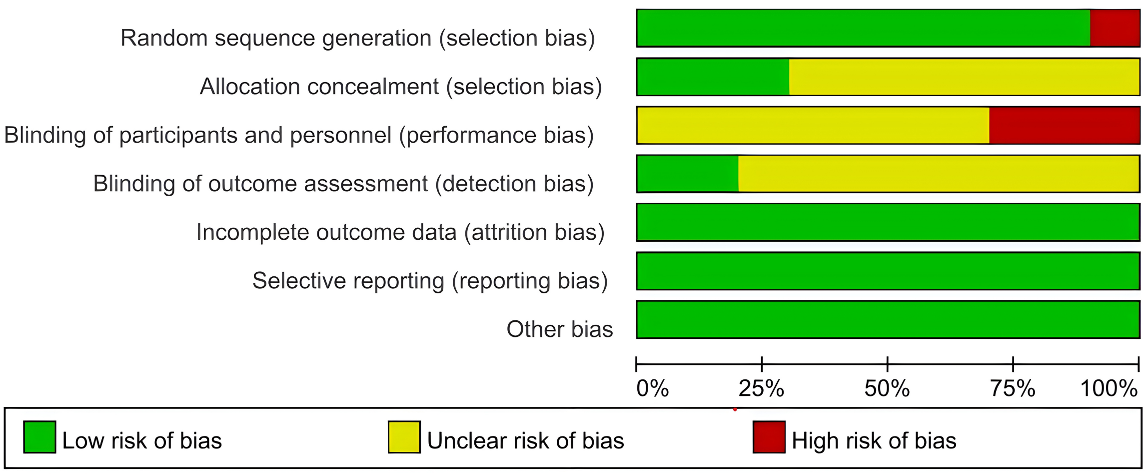

FIGURE 3. Statistics of each risk factor as a percentage of all included literature.

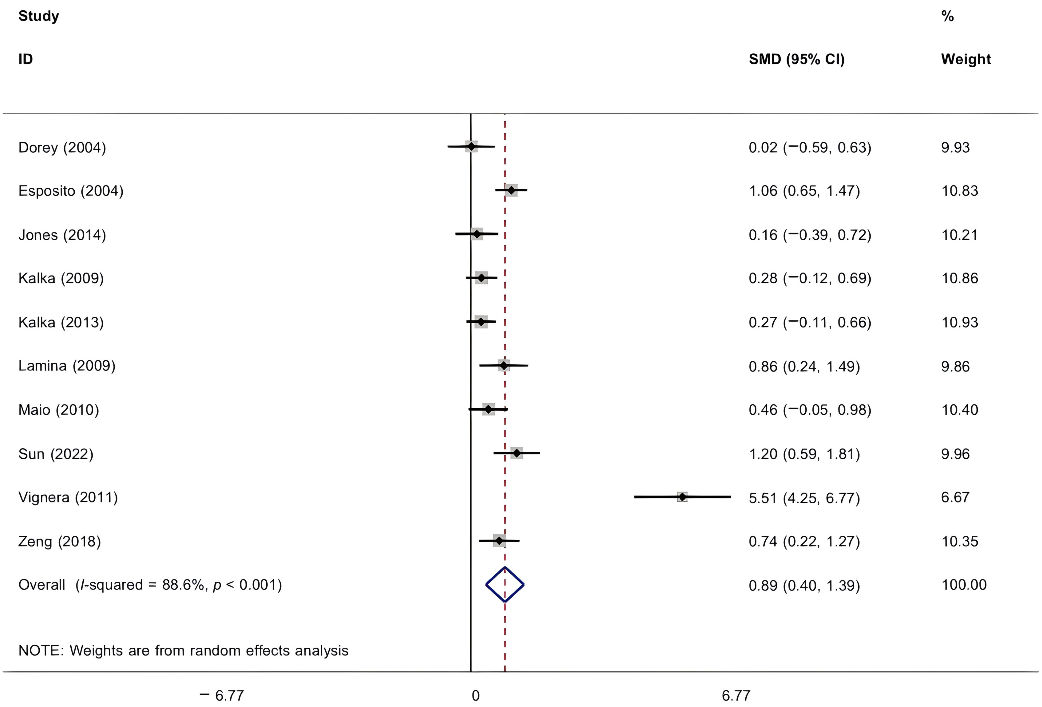

FIGURE 4. Meta-analysis results of erectile function. SMD, standardized mean difference; CI, confidence interval.

TABLE 2. Subgroup analysis of erectile function.

Group standard	Study quantity	SMD Mean difference (95% CI)	Hedges' *g*	*p* within group	Heterogeneity		
					p heterogeneity	I^2 (%)	*p* between sub-groups
All	10	0.892 (0.395–1.388)	0.247	<0.001	<0.001	88.6	
Country							
China	2	0.946 (0.504–1.388)	0.787	<0.001	0.267	18.9	0.090
Foreign	8	0.895 (0.291–1.500)	0.213	<0.001	<0.001	90.7	
Whether suffering from chronic illnesses							
Normal	3	1.906 (−0.375–4.187)	0.094	0.102	<0.001	96.7	0.085
ED with CDS	5	0.623 (0.284–0.961)	0.385	<0.001	0.027	63.4	
Age							
<60	6	1.366 (0.494–2.237)	0.504	<0.001	<0.001	92.1	<0.001
≥60	2	0.277 (−0.002–0.556)	0.279	0.052	0.964	0	
Intervention group with or without combined pharmacotherapy							
Yes	2	0.813 (0.092–1.533)	0.538	0.027	0.069	69.7	0.616
No	7	0.982 (0.283–1.682)	0.286	<0.001	<0.001	92.0	
Training intensity							
Low	4	1.815 (0.416–3.215)	0.730	0.011	<0.001	94.9	<0.001
Medium	4	0.527 (0.267–0.787)	0.172	<0.001	0.359	6.8	
Intervention period, mon							
0–3	6	1.323 (0.409–2.237)	0.469	<0.001	<0.001	92.1	<0.001
4–6	3	0.254 (0.004–0.503)	0.105	0.046	0.937	0	
Exercise frequency, times/wk							
<5	3	0.460 (0.143–0.776)	0.060	<0.001	0.258	20.2	0.267
≥5	5	1.418 (0.356–2.480)	0.248	<0.001	<0.001	94.0	

Notes: CDS, chronic disease state; ED, erectile dysfunction; SMD, standardized mean difference; CI, confidence interval.

effect was greater in the <60 years age group, the 0–3 months exercise cycle, and the low-intensity group, with $p < 0.05$; no significant differences were observed in the subgroups according to country, object or intervention exercise frequency. We observed that one subgroup exhibited an elevated I^2 value, while another exhibited a decreased I^2 value. Furthermore, meta-regression analyses were lacking, indicating that the potential sources of heterogeneity affecting ED effects remain unknown. The subgroup analyses determined that age, exercise intensity and intervention period may have been sources of heterogeneity in this study.

3.5 Sensitivity analysis

A sensitivity analysis of the findings for the erectile function indicator revealed that one of the studies was highly biased and that the results were not sufficiently stable. Excluding Vignera' s study reduced the effect size from 0.892 [0.395–1.388] ($p < 0.01$) to 0.556 [0.290–0.823] ($p < 0.01$). Nevertheless, the study remained statistically significant (Fig. 5).

3.6 Publication bias

The publication bias of each indicator was examined using a funnel plot (Fig. 6). The distribution of study sites was essentially symmetrical near the x = 0 vertical line, but a few study sites were still to be scattered. This indicates the potential for publication bias.

3.7 Qualitative analysis

The systematic review included six more studies following the inclusion of ten analyzed in the meta-analysis [26, 40–44]. In the study by Maresca [44], a two-month intervention combining drug therapy and exercise training was administered to 20 male patients with erectile dysfunction and metabolic syndrome. The results demonstrated that VO_2 peak

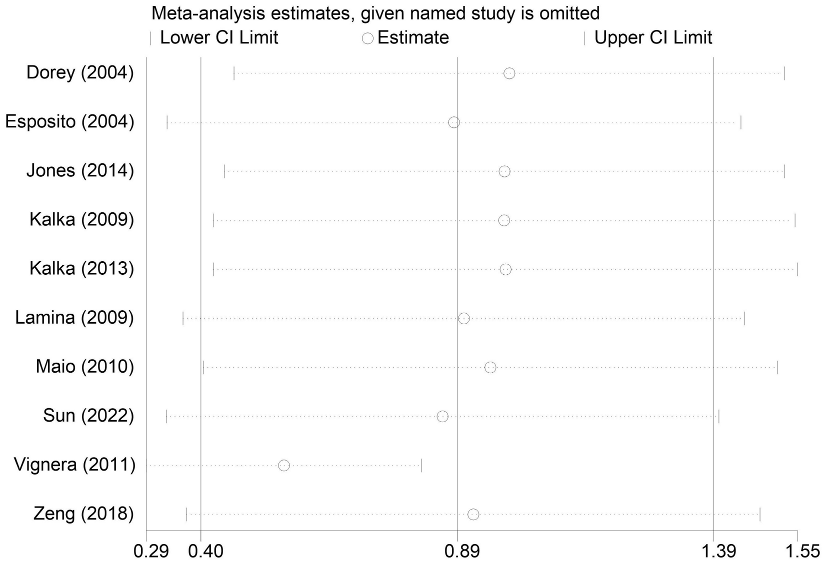

FIGURE 5. Sensitivity analysis for meta-analysis. CI, confidence interval.

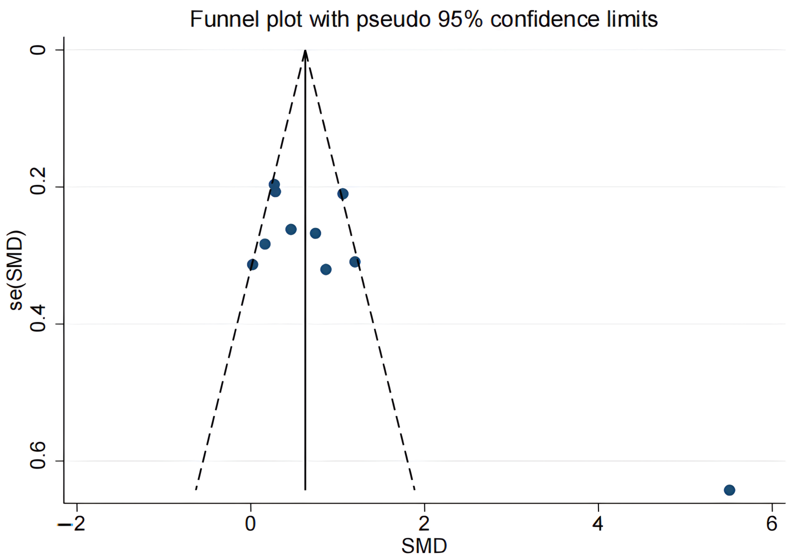

FIGURE 6. Funnel plots. se, standard error; SMD, standardized mean difference.

and IIEF scores were significantly higher following the intervention, while other indicators did not differ significantly after the experiment. In a 2015 study, Kalka [40] demonstrated that cardiac rehabilitation is associated with improvements in ED status, while PA was linked to enhanced endothelial and atherosclerotic function. In a study by Esposito [43], the results for body mass index, waist circumference, blood glucose, high density lipoprotein (HDL), cholesterol, triglycerides and blood pressure (systolic; diastolic) in the experimental group differed significantly from those the control group after two years of receiving detailed advice to reduce weight and increase physical activity. The study by Kirilmaz [26] employed an additional pharmacotherapy, which resulted in a more pronounced intervention. Combining pharmacotherapy and exercise was more effective than exercise alone. Esposito's study [27] indicated that vascular endothelial function improved, and body mass index decreased in the experimental group following the exercise. The study [19] by Lamina revealed that systolic blood pressure (SBP) (t = 4.914, $p < 0.001$), diastolic blood pressure (DBP) (t = 3.645, p = 0.001), and VO_2 max (t = 6.053, $p < 0.001$) were significantly lower in the exercise group than in the control group ($p < 0.05$). Brief periods of exercise can enhance the efficacy of adjunctive treatment for ED in older hypertensive men, thereby reducing blood pressure. The study by Lin YH [42] demonstrated that patients who underwent pelvic floor muscle training interventions exhibited significant improvements in erectile function at both 6 and 12 months. Our meta-analysis indicates that the effects of PE are already evident at the 0–3 months mark. Table 3 provides detailed information on the six studies included in the qualitative analysis.

4. Discussion

Our results indicate that PE may enhance IIEF scores and improve erectile function levels in patients. A growing body of literature indicates that exercise has a positive effect on improving ED [19, 23, 25, 27, 29, 30, 38, 39], and in our study, the effect size of PE on enhancing IIEF score in ED patients was found to be relatively modest. Given the high degree of heterogeneity, a subgroup analysis was conducted based on country, object, age and test protocol (including whether the experimental group was combined with drug therapy, training intensity, exercise period or exercise frequency). As noted above, subgroup analyses have practical value in guiding healthcare professionals in selecting clinical exercise prescription programs, and our study highlights this clinical application. Several studies have indicated that exercise may be beneficial in improving ED in men.

The Hedges' g value of the China group with a high effect size (Hedges' g = 0.787) was higher than that of the foreign group, and the effect of PE on ED was higher than that of the foreign group. Both studies in the Chinese group employed a combination of pharmacotherapy and exercise, and the effect of medication may have a greater impact on the IIEF scores of patients with ED. In Maresca's study [44], exercise training in ED patients treated with PDE 5 inhibitors demonstrated additional benefits, with further improvements in ED.

The subgroup included both subjects with CVD and obesity in the ED with CDS group, whereas the normal ED group consisted of subjects with ED only. Subgroup analyses revealed that Hedges' g values were higher in the ED with CDS group than in the normal ED group, and the effect size was larger in the ED with CDS group. This suggests that PE programs are more effective for ED patients with CDS Penile erection is a hemodynamic process involving increased arterial inflow and restricted venous outflow; the main cause of ED is arterial dysfunction, the etiology of which is usually multifactorial, with cardiovascular disease being the most common comorbidity [32, 45]. Several mechanisms of action can explain how exercise improves sexual function, and these proposed benefits always seem to revolve around heart health parameters [46, 47]. Studies have shown a high correlation between cardiovascular disease, ED and obesity [48]. Aerobic exercise, such as jogging, swimming or cycling, is highly beneficial to improving cardiovascular health, which, in turn, helps to improve erectile function [49]. Hypertensive ED patients can also improve the quality of their ED with interval exercise training [19]. Obesity is also a related factor [50], and there is an association between overweight or obesity and ED. Some authors have suggested that the arterially protective effect of physical activity is not limited to the coronary vasculature but also extends to the entire arterial system [40, 51]. In addition, in apparently healthy men with cardiovascular risk factors, a reduced risk of ED is associated with stable interpersonal relationships and a higher level of education [51] and maintaining a healthy weight and fat distribution through exercise may help improve erectile function. PE is also associated with the primary prevention of cardiovascular disease, hypertension, obesity, depression and even diabetes. A multitude of studies on men have demonstrated a correlation between optimal cardiometabolic health and superior erectile function. Furthermore, men with diabetes [52], hypertension, and obesity are at a heightened risk for ED. Exercise can reduce the effects of these complications and thus improve ED in men. Since ED is considered a risk factor for impending ischemic heart disease, exercise can treat both conditions [53]. Consequently, PE may be more efficacious in improving erectile function in the ED and CDS groups.

There were significant differences between the two age subgroups ($p < 0.01$). The 95% CI of the $\geq$60 age group was [−0.002–0.556], showing no statistical significance. The Hedges' g value for the <60 age group was 0.504 with a medium effect size. The subgroup analyses showed that PE is more effective in improving erectile function in patients younger than 60 years old with ED. There is a paucity of domestic research on exercise for the treatment of ED. A cross-sectional study conducted in Hong Kong, China, showed that the majority of older adults aged 65 years and older suffer from ED [54]. Among men over 40, low and high levels of physical activity were associated with a more than 20% reduction in the risk of erectile dysfunction [55]. In all countries studied, a substantial proportion of men over the age of 35 exhibited some degree of ED (57–81%). The factors associated with ED were largely consistent across countries, yet their distribution varied considerably [56]. A population-based study [57] conducted in Turkey demonstrated that ED affects a significant proportion of Turkish men aged 40 years or older;

TABLE 3. Summary of results from studies of PE effects on ED not included in meta-analyses.

Study	Study design	Object	Age (mean ± sd)	Sample size	Test group	Comparator	Outcome
Kalka (2015)	RCT	ED with IHD	T: 62.12 ± 8.71 C: 61.43 ± 8.68	T: 115 C: 35	Cardiac Rehabilitation Program	Usual care	PE was beneficial for ED, with a statistically significant increase in mean erectile dysfunction in the study group from 12.46 ± 6.01 (95% CI = 11.35–13.57) initially to 14.35 ± 6.88 (95% CI = 13.08–15.62) after the cardiac rehab program, compared to initial ED.
Kirilmaz (2015)	RCT	ED with T2MD	T/C: 54.9 ± 9.1	T: 41 C: 42	Exercise control of blood sugar and ED pharmacotherapy	Exercise and control of blood sugar	Lifestyle changes and glycaemic control may improve erectile function in ED patients with type 2 diabetes. As it is not possible to ensure that patients fully comply with recommended dietary and lifestyle changes, it is recommended that PDE 5 be added to the recommendations for improving sexual function.
Begot (2015)	RCT	ED with MI	T: 59 ± 10 C: 57 ± 9	T: 41 C: 45	Home-walking	Usual care	Both groups improved their ability to walk after discharge, with a significant increase in 6-minute walking distance of 76 meters in the comparison group for those who took part in the walking program, compared with an increase of 30 meters relative to baseline in the control group. The impact of increased sexual activity in heart failure patients who receive PE is associated with the degree of improvement in functional capacity and quality of life.
Lin YH (2012)	RCT	ED with RP	T/C: 65.75 ± 6.12	T: 35 C: 27	PFMT	Receive exercise after 2 months	All participants experienced severe sexual dysfunction (100%) within the first month after surgery. At 3, 6, 9 and 12 months, the incidence of sexual dysfunction in the experimental group was 94.3 per cent, 88.6 per cent, 82.9 per cent and 65.7 per cent, respectively, compared with 100 per cent, 100 per cent, 96.3 per cent and 92.6 per cent in the control group.
Esposito (2009)	RCT	ED	T: 45.3 ± 6.9 C: 45.7 ± 6.9	T: 104 C: 105	Detailed advice on diet and exercise	Health advice	Erectile function scores improved in the intervention group. At baseline, 35 subjects in the intervention group and 38 in the control group had normal erectile function (34% and 36%, respectively). After 2 years, there were 58 and 40 in the intervention and control groups, respectively (56% and 38%, p = 0.015). After the exercise intervention, body mass index, waist circumference, blood glucose and blood pressure decreased in both experimental and control groups and were statistically significant.
Maresca (2013)	RCT	ED with MetS	T: 69.0 ± 2.8 C: 68.0 ± 3.6	T: 10 C: 10	Pharmacotherapy and exercise	ED pharmacotherapy	There were no significant differences in the basic anthropometric characteristics of the study subjects. Although both groups improved their IIEF scores after two months, the improvement was more pronounced in the experimental group (C: 11.2 *vs.* 14.2, p = 0.02; T: 10.8 *vs.* 20.1, $p < 0.001$). Peak exercise oxygen consumption (VO_2 peak) improved only in the experimental group of patients, and there was a significant correlation between changes in VO_2 peak and changes in IIEF scores.

Notes: T, test group; C, Control Group; RCT, Randomized Controlled trial; RP, Post-prostatectomy patients; IHD, Ischemic heart disease; MI, Myocardial infarction; T2MD, Type 2 diabetes mellitus; MetS, metabolic syndrome; PFMT, pelvic floor muscle training; sd, standard deviation; ED, erectile dysfunction; PE, physical exercise; CI, confidence interval; PDE, Phosphodiesterase; IIEF, International Index of Erectile Function.

is associated with several serious medical conditions; and that severity [56] and prevalence increase with age [57–59]. Other factors that are closely associated with the condition include the presence of four or more health problems, depression, higher International Prostate Symptom Score questionnaire (IPSS) scores, and a lack of physical activity.

As noted, combining exercise and pharmacotherapy has been demonstrated to be more effective than exercise alone. The Hedges' *g* value in the exercise combined with pharmacotherapy group was 0.540 with a medium effect size. It has been proposed that PE can alleviate ED by reducing endothelial cell apoptosis without resorting to other pharmacological methods [16]. This is contrary to the results of the present study. In a pilot study, Kirilmaz [26] found that medication combined with exercise was more effective than exercise alone. PE can also be used as an adjunctive treatment to improve the level of erectile function in ED patients. Drugs act by inhibiting the activity of 5-phosphodiesterase, preventing it from hydrolyzing cyclic guanosine phosphate. This prolongs the action time of cyclic guanosine phosphate, thus relaxing the penile smooth muscle and increasing penile blood flow, such that the penile cavernous sinus can be rapidly congested and dilated to achieve a good-quality erection [60]. Numerous studies [28, 38, 44] have demonstrated that physical exercise is more effective in improving erectile dysfunction when combined with specific pharmacological therapies.

The subgroup analysis showed that low-intensity exercise of more than five sessions per week at 0–3 months was more effective than moderate intensity at 4–6 months and less than five sessions per week. Low-intensity exercises are more effective, and this seems to be due to the overlooked effect of pelvic floor muscle exercises, which target the deeper muscles accurately and are thus more effective. Pelvic floor muscle training through the contraction of the pelvic floor muscles can enhance the strength, tension and coordination of these muscle groups, increase fatigue-resistant muscle fibers, improve local venous blood circulation and promote better penile erection [14]. However, a cross-sectional study [56] showed that the prevalence of moderate-to-vigorous activity at work (heavy physical labor) and during leisure time (strenuous exercise) in countries such as Pakistan, Egypt and Nigeria were half that of moderate to severe ED. Contrary to our findings, one study [61] showed that building muscle for more than 10 minutes per month reduced the risk of ED by 25 percent. However, Khoo [62] showed that 200 to 300 minutes of moderate-intensity exercise per week improved IIEF scores in obese men more than 90 to 150 minutes of exercise per week. Studies have yielded divergent results from those of subgroup analyses. Salama [63] posits that moderate and vigorous-intensity physical activities are associated with healthy erectile function and a reduced risk of ED. However, the evidence remains inconclusive owing to the study design, which was not an experimental intervention. The rationale behind the greater specificity of short-cycle PE is that it is more targeted than long-cycle interventions. The longer duration of PE may present challenges in ensuring subject compliance, potentially leading to less favorable outcomes than those observed in shorter-term studies. Following the general recommendations regarding PE may reduce in IIEF scores and alleviate ED.

However, it is essential to acknowledge that a multitude of factors can contribute to ED, encompassing both physical and psychological elements. A cross-sectional study [64] by Korean scholars showed that a range of disorders, including anxiety, depression and age, were associated with ED. An experimental study by Li Ling [65] showed that positive stress reduction therapy can improve ED in men, with improved IIEF scores after the intervention. Additionally, this therapy can effectively enhance the self-regulation abilities of ED patients. Moreover, exercise has a positive effect on reducing anxiety, depression and stress. These improvements in mental health may have a positive impact on erectile function.

This meta-analysis and systematic review of research studies provides evidence that PE, in addition to its use as a preventive treatment in the healthcare system, also has a positive effect on people with ED. In this study, ED in men was measured using the IIEF or IIEF-5 score. PE was found to increase IIEF scores in men with ED, although the effect was small. Owing to the high degree of heterogeneity, we conducted subgroup analyses, with subgroups including country, age, disease type, exercise intensity, exercise period and exercise frequency. Our findings support the previous hypothesis [19, 30] that exercise improves IIEF scores in ED patients.

This study sought to investigate the effectiveness of a PE exercise program in improving ED in patients. However, owing to the limited number of studies included in this study, there is a need to include more of the literature and conduct more studies to demonstrate the effect of PE on ED. The strengths of this meta-analysis are as follows: The first strength is the more systematic and complete data extraction. A comprehensive search was conducted to identify eligible studies from multiple countries in two languages (English/Chinese). This approach further reduced potential regional and language bias. Furthermore, the subjects' personal information and the intervention programs were extracted in greater detail. Secondly, two methods (Hedges' *g* and SMD) were employed to analyze the effect of exercise training. For instance, Hedges' *g* reflects the actual clinical effect, whereas the standardized mean difference reflects the statistical effect, thereby demonstrating the influence of various factors on the intervention. Finally, a relatively more comprehensive subgroup analysis of personalized exercise prescriptions for ED patients was conducted. However, the present study also has some limitations; first, although subgroup analyses were performed, it was not possible to determine the source of heterogeneity because of underlying factors, complicating our interpretation of the study data. Second, some of the original studies included did not differentiate the severity of ED, so no further analysis was conducted on the impact of PE on patients with different baseline levels of ED. Finally, there were fewer quantifiable outcome metrics, and although the IIEF score better reflects the state of erectile function in men, more outcome metrics are needed to support the feasibility of the study results.

5. Conclusions

This study demonstrated that PE significantly reduces IIEF scores in patients with ED compared with other interventions for the treatment of ED, especially in ED patients under

60 years of age with CDS. Low-intensity PE with 0–3 months duration was more effective in improving erectile function. This effect is not related to the country, frequency of intervention, or intervention group with or without combined drug intervention. These findings have practical value in guiding healthcare professionals in selecting clinical exercise prescription programs. In addition, physical exercise is beneficial in improving body mass index, blood pressure and blood sugar.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the corresponding author.

AUTHOR CONTRIBUTIONS

JXC, QHZ and HMH—Study concept and design. JXC, QHZ, XL and WJW—Data extraction and analysis. CJT and HMH—review editing. JXC and QHZ—contributed equally to this work and share first authorship. All authors have read and agreed to the published version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

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CONFLICT OF INTEREST

The authors declared no conflicts of interest with respect to the authorship or publication.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jomh.org/files/article/1895344095676514304/attachment/Supplementary%20material.docx.

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