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Preoperative range of motion and applications of continuous passive motion predict outcomes after knee arthroplasty in patients with arthritis

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Abstract

Purpose This study evaluated the clinical efficacy of continuous passive motion (CPM) following knee arthroplasty and determined the predictors of effect sizes of range of motion (ROM) and functional outcomes in patients with knee arthritis.

Methods A comprehensive electronic database search was performed for randomized controlled trials (RCTs), without publication year or language restrictions. The included RCTs were analyzed through meta-analysis and risk of bias assessment. Study methodological quality (MQ) was assessed using the Physiotherapy Evidence Database (PEDro) scale. Inverse-variance weighted univariate and multivariate metaregression analyses were performed to determine the predictors of treatment outcomes.

Results A total of 77 RCTs with PEDro scores ranging from 6/10 to 8/10 were included. Meta-analyses revealed an overall significant favorable effect of CPM on treatment success rates [odds ratio: 3.64, 95% confidence interval (CI) 2.21–6.00]. Significant immediate [postoperative day 14; standard mean difference (SMD): 1.06; 95% CI 0.61–1.51] and short-term (3-month follow-up; SMD: 0.80; 95% CI 0.45–1.15) effects on knee ROM and a long-term effect on function (12-month follow-up; SMD: 1.08; 95% CI 0.28–1.89) were observed. The preoperative ROM, postoperative day of CPM initiation, daily ROM increment, and total application days were significant independent predictors of CPM efficacy.

Conclusion Early CPM initiation with rapid progress over a long duration of CPM application predicts higher treatment effect on knee ROM and function. The results were based on a moderate level of evidence, with good MQ and potential blinding biases in the included RCTs. An aggressive protocol of CPM has clinically relevant beneficial short-term and long-term effects on postoperative outcomes.

Level of evidence II.

Keywords Knee arthroplasty · Arthritis · Range of motion · Continuous passive motion · Functional outcome

Introduction

Continuous passive motion (CPM) immediately after arthroplastic surgery is primarily advocated for its potential benefits on knee ROM and acute stay conditions [23, 24, 35]. The effects of CPM on postoperative outcomes have been investigated through several systemic reviews and meta-analyses [15, 17, 30, 36, 41, 42, 44]. Despite controversies, CPM has been used as an adjunct therapy to the standard postoperative rehabilitation regimen, because it offers short-term benefits during acute stay [6, 17, 30, 36, 44]; however, its long-term effectiveness during postacute follow-up remains uncertain [15, 17, 30].

Most systemic reviews and meta-analyses regarding the effectiveness of CPM have included study selection or inclusion criteria with restrictions on language [15, 30, 36, 41, 42] or publication time [30, 44]. In addition, only a few reviewers have excluded studies with low methodological quality [36, 44]. Furthermore, the majority of the articles included in most systemic reviews were published in American or

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European countries, and few trials with Asian populations have been included [15, 17, 30, 36, 41, 42, 44]; it remains unclear whether countries or patient populations influence the effects of CPM therapy. Thus, the results reported in previous systematic reviews [40] may be biased.

In clinical practice, various prescriptions of CPM are used with multiple application parameters. CPM efficacy may depend on its application protocol, and several studies have compared the effectiveness of various CPM parameters, including the CPM initiation on the postoperative day (POD), the initial ROM (i.e., the flexion arc of motion) in the CPM device, daily increment in ROM, daily usage time, and the total application duration [2, 3, 8, 28, 29]. However, the influence of CPM parameters on treatment outcomes remains unclear [15, 17, 42]; furthermore, it remains unclear whether any parameter predicts the treatment effects on postoperative knee ROM and functional outcomes. Identification of the determinants of CPM treatment outcomes may enhance postoperative rehabilitation, because early maximum ROM regain is a clear prognostic factor for functional activity [33].

Using meta-analyses and subgroup analyses, this study was aimed to evaluate the clinical efficacy of CPM after knee arthroplasty in patients with arthritis and identified differences between populations. Furthermore, we performed metaregressions to identify the predictors of the effect of CPM therapy on postoperative outcomes during hospital stay and postacute follow-up. For clinical usefulness, determining the predictors of treatment effect of CPM following arthroplasty may help clinical practitioners establish optimal rehabilitation protocols and improve treatment efficiency for arthritis.

Materials and methods

This study was conducted in accordance with Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) guidelines [31] and was registered with the International Prospective Register of Systematic Reviews (PROSPERO, ID number: CRD42018099139). In this study, a comprehensive search for original research articles on the clinical efficacy of postoperative CPM following knee arthroplasty was conducted using the databases of Medline, PubMed, Excerpta Medica dataBASE, Cochrane Library Database, the Physiotherapy Evidence Database (PEDro), and China Academic Journals Full-Text Database and the search engine of Google Scholar. In addition, secondary sources were searched, including papers cited in the systemic review and meta-analysis studies. No restrictions were applied for the publication year and language. If English titles were not provided in non-English articles, they were translated to English using translation software (Ginger Software, Inc.). The search was restricted to published or in-press human studies. Two reviewers (CDL and YSC) independently searched for the articles, screened studies, and extracted data. Any disagreement between the reviewers were resolved through consensus, with other team members (HCC and SWH) acting as arbiters.

Search strategy

We used the following search terms in the Excerpta Medica dataBASE for identifying articles on CPM after knee arthroplasty and associated conditions: ["continuous passive motion" OR "CPM"] AND ["knee arthroplasty" OR "total knee replacement"] AND ["osteoarthritis" OR "gonarthritis" OR "rheumatoid arthritis"]. The detailed search formulas for each database are presented in online Table S1.

Study selection criteria

Articles were included if they fulfilled the following criteria: (1) the trial design was a randomized control trial (RCT) with an experimental group (i.e., CPM) and a comparison control group; (2) CPM was employed as the primary treatment; (3) the control group received regular postoperative nursing care (RNC) or underwent active exercise training (AET); (4) all patients had received a diagnosis of arthritis; (5) primary outcomes included knee joint ROM (active or passive knee flexion or the full range from extension to flexion) and pain measured using a quantifiable scale such as the visual analog scale (VAS); (6) secondary outcomes included patient-reported performance-based physical function; and (7) the following application parameters could be extracted: POD of CPM initiation, initial and final ROM set, daily ROM increment, daily application time, and application duration (i.e., total application days).

Articles meeting any of the following criteria were excluded: (1) the article evaluated an animal model, a case report, or case series; (2) the study in the article was a prospectively designed trial without a comparison group; (3) the full text of the article was unavailable; and (4) the study had fair or poor methodological quality, which was identified as a PEDro score of $<6/10$ [32].

Data extraction and management

For the included studies, a data extraction sheet was developed and refined. An author (CDL) extracted the relevant data from the included studies, and another author (SWH) reviewed the extracted data. Any disagreement between the two authors was resolved through consensus. A third author (THL) was consulted if the disagreement persisted. The data of interest were group design, patient characteristics (population, age, sex, diagnosis, duration of disease onset), surgical

conditions (e.g., prosthesis used and operated leg), CPM application parameters (e.g., POD of CPM initiation, initial setting in ROM, and daily increment in ROM), and follow-up period. The primary outcome of interest in the meta-analysis and metaregression was full knee ROM. If the trial did not report full knee ROM, it was estimated by subtracting knee flexion from knee extension, and knee extension was assumed as 0° when only knee flexion was reported. If the trial reported both active and passive ROM as well as knee flexion and extension, active ROM measures were included in the analyses. Pain severity was evaluated using either the VAS or a patient-reported scale. The functional scores used by the studies were Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Knee Society Score, and Hospital for Special Surgery Knee Scoring.

If any of the CPM application parameters were reported in terms of ranges, the medians of the ranges were used for analyses. If a study did not report any value and stated that the daily ROM increment during CPM therapy was determined according to patient tolerance, the daily ROM increment was assumed to be 15°; this value was chosen, because most of the previous protocols have used daily ROM increments of 5° to 20° [17, 30, 36, 42, 44] and it concurred with our previous results [26].

Assessment of methodological quality

The PEDro classification scale was employed to assess the methodological quality in the included trials [10]. Any disagreement between the two researchers (CDL and HCC) was resolved through consensus, and a third researcher (THL) was consulted if the disagreement could not be resolved. On the basis of the PEDro score, the methodological quality of the included RCTs was rated as high ($\geq 7/10$) or medium ($< 7/10$) [5].

Assessment of risk of bias

Two authors (CDL and HCC) independently assessed the risk of bias of the included studies using the Cochrane risk of bias tool [18, 20]. Any difference of opinion was resolved through consensus, and if necessary, any disagreement was resolved by a third reviewer (THL).

Statistical analysis

The effect sizes of CPM on the primary and secondary outcome measures were estimated by calculating the standard mean differences (SMDs) of the mean outcome between the treatment and control groups weighted by the inverse of the variation for every included study. SMD was used for meta-analysis when different scales were used to measure the same concept (e.g., pain and function score). In accordance with Cohen's criteria [9], we categorized the magnitude of the SMD as trivial ($d < 0.20$), small ($0.20 \leq d < 0.60$), moderate ($0.60 \leq d < 1.20$), and large ($d \geq 1.20$), which represent the categories modified by Hopkins [21]. If data were reported as a standard error or confidence interval (CI), they were recalculated algebraically from the trial data for imputing the sample mean and SD following the Cochrane Handbook for Systematic Reviews of Interventions [20]. The odds ratio (OR) with a 95% CI was estimated to indicate treatment success. Statistical heterogeneity of the included studies was assessed using the Q test (χ^2) and I^2 statistics, with high values indicating high heterogeneity [4]. If the study had more than one CPM or control intervention, each comparison was considered as an independent one for the meta-analyses [19]. Random-effects models were used for the meta-analyses. The effects of CPM on primary and secondary outcomes during hospital acute stay (≤ 2 weeks) and postacute follow-up (> 1 month) were separately analyzed. All meta-analyses were conducted using RevMan 5.3 (The Nordic Cochrane Centre, Copenhagen, Denmark).

Subgroup analysis was performed on the basis of the population area, follow-up duration, methodological design, and quality level. The significance of all subgroup differences was assessed, and I^2 statistics were computed to estimate the degree of subgroup variability. Potential publication bias was investigated through the visual inspection of a funnel plot [39] and through Egger's regression asymmetry test [13].

Following a previously described method [5], we graded levels of evidence (LoE) for each outcome of interest in accordance with an evidence synthesis guideline [12] derived from van Tulder's criteria [43] (Table 1).

To determinate the significant predictors of CPM efficacy for primary and secondary outcomes, inverse-variance weighted univariate and multivariate metaregression was performed using SPSS (version 17; IBM, Armonk, New York, USA). The mean age, body mass index, preoperative ROM as well as function, CPM application parameters, intervention design, control-group type, and follow-up duration were entered as covariates. First, univariate linear regression analyses were separately performed for each covariate at acute stay and postacute follow-up. To determine significant parameters, all CPM application parameters were then included in a stepwise multivariate regression analysis as covariates; the analysis was controlled for age, methodological design, preoperative ROM, and follow-up duration.

Results

Trial flow

The search yielded 916 articles (Fig. 1). After duplicate article removal and abstract screening, 160 eligible RCTs

Table 1 Guidelines of evidence synthesis

Level of evidence	Criterion of judgment
Strong	Provided by consistent[a] statistically significant (or nonsignificant) pooled results in SMD or OR derived from multiple RCTs, including at least two high-quality RCTs[b]
Moderate	Provided by statistically significant results in one high-quality RCT[b] ***or***
	Provided by inconsistent[a] statistically significant pooled results in SMD or OR derived from multiple RCTs, including at least one high-quality RCT[b] ***or***
	Provided by consistent[a] statistically significant pooled results in SMD or OR derived from multiple medium-quality RCTs[b]
Limited	Provided by statistically significant results in one medium-quality RCT[b] ***or***
	Provided by inconsistent[a] statistically significant pooled results in SMD or OR derived from multiple RCTs, including at least one medium-quality RCT[b]
Conflicting	Provided by inconsistent[a] statistically nonsignificant results in SMD or OR derived from multiple RCTs regardless of quality

RCT randomized controlled trial, *SMD* standard mean difference, *OR* odds ratio

Established in accordance with the "best-evidence synthesis," adapted by Dorrestijn et al. [12] from van Tulder's criteria [43]

[a]Pooled results are considered consistent if no statistically significant heterogeneity (I^2, $P > 0.05$) is identified and inconsistent if statistically significant I^2 ($P < 0.05$) is identified

[b]Methodological quality of a study is rated based on PEDro score as high (≥ 7/10) and medium (< 7/10)

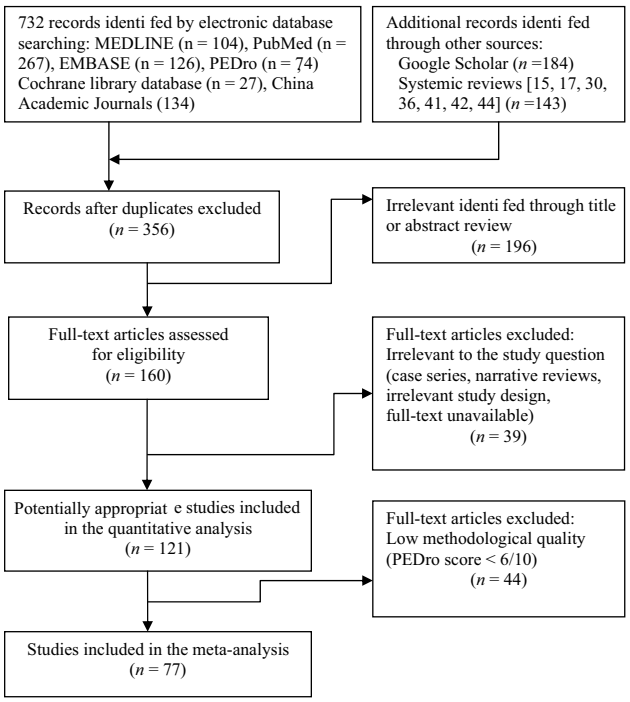

Fig. 1 PRISMA flow chart of randomized controlled trials enrolled in the meta-analysis study

were identified for full-text assessment. The final sample comprised 77 RCTs, which included 93 comparisons between CPM group and the control group receiving RNC or AET. Characteristics of the included RCTs are presented in Table S2 and are summarized in Table 2.

Study characteristics

In total, 6038 patients with mean ages ranging from 52.0 to 74.2 years (overall mean age 65.7 years). These patients experienced symptoms for a mean duration of 110.2 months (range 4–264 months). The 77 RCTs included populations from Americas (709 patients), Asia (4395 patients), Europe (692 patients), and Oceania (144 patients) (Table 2).

CPM application parameters and treatment protocols are summarized in Table S3. All included RCTs applied a CPM intervention protocol that was initiated on POD 0–14 with an initial flexion ROM of 30°–90°, a daily ROM increment of 5°–20° as tolerable by patients, a daily application time of 0.5–12 h, and an intervention duration of 1–21 days.

Risk of bias in the included studies

A summary of the PEDro scores of the included RCTs is presented in Table 3. The individual PEDro scores and the rated quality levels are listed in Tables S4 and S2, respectively. Regarding the cumulative PEDro score, interrater reliability was acceptable, and the intraclass correlation coefficient was 0.97 (95% CI 0.95–0.98, $P < 0.001$). Of the included RCTs, 20.8% and 79.2% were classified as high and medium, respectively, with an overall mean (range/total) PEDro score of 6.4 (6–8/10). The risk of bias as assessed using the Cochrane Collaboration risk of bias tool (Fig. S1) was generally low or unclear. An overall summary of the risk of bias among the included RCTs is presented in Fig. 2. Selection, blinding, attrition, and agenda biases were considered the greatest potential risks of bias in the included RCTs.

Table 2 Summary of study characteristics

Items	CPM intervention				Control				Total		
	Trials (*n*)[a]	Group (*n*)	Patients (*n*)	Mean[b]	Trials (*n*)[a]	Group (*n*)	Patients (*n*)	Mean[b]	Trials (*n*)[b]	Patients (*n*)	Mean[b]
Age, years	49	61	1971	65.3	49	51	1792	65.4	76	5936	65.8
BMI, kg/m^2	12	16	551	30.2	12	12	411	29.1	12	992	29.6
Onset time, mo	6	9	370	95.3	6	6	208	77.2	11	971	110.2
Sex, *n*											
Male	46	58	1189		46	48	1061		74	3626	
Female	46	58	700		46	48	656		74	2159	
Population area											
Americas	9	13	344		9	11	365		9	709	
Asia	56	64	2297		56	56	2098		56	4395	
Europe	10	10	339		10	10	353		10	692	
Oceania	2	3	144		2	2	98		2	242	
Arthroplasty type											
TKA	75	88	2089		75	77	2881		77	6030	
UKA	1	1	5		1	1	3		1	8	
Operated knee, *n*											
Unilateral	60	70	4082		60	62	2137		65	4284	
Bilateral	9	11	60		9	9	54		14	207	
Diagnosis, *n*											
OA	53	65	2077		53	55	1908		77	5452	
RA	11	11	111		11	11	106		30	511	
Others[c]	3	3	11		3	4	11		12	75	
Preoperative ROM, degree	40	47	1675	85.8	40	42	1588	85.2	61	4834	90.9
Preoperative function											
WOMAC	7	9	334	50.0	7	7	282	49.3	7	616	49.7
KSS Function	7	8	425	50.0	7	7	395	48.8	7	820	49.5
HSS	21	21	831	48.9	21	21	814	48.8	26	1645	48.8
Methodological design Intervention design Control type											
Monotherapy CPM	36	45	1507						36	1507	
RNC control					22	22	857		22	857	
AET control					17	18	559		17	559	
Adjuvant therapy	41	45	1617						41	1609	
RNC control					12	12	423		12	423	
AET control					29	30	1083		29	1083	

TKA total knee arthroplasty, *UKA* unicompartmental knee arthroplasty, *BMI* body mass index, *OA* osteoarthritis, *RA* rheumatoid arthritis, *WOMA* Western Ontario and McMaster Universities Osteoarthritis Index, *KSS* Knee Society Score, *HSS* Hospital for Special Surgery Knee Scoring, *RNC* regular postoperative nursing care, *AET* active exercise training

[a]Number of trials reporting the indicated item

[b]Summations were calculated based on the values reported in the included trials, where it can be estimated

Table 3 Summary of methodological quality crossing the included trials

Rated item[a]	Quality level (PEDro score)	
	High (≥ 7/10, 16 RCTs)	Medium (< 7/10, 61 RCTs)
	Trials, *n* (%)[b]	Trials, *n* (%)[b]
Eligibility criteria	16 (100)	52 (85.2)
Random allocation	16 (100)	61 (100)
Concealed allocation	12 (75)	0 (0)
Similarity at the baseline	16 (100)	61 (100)
Participant blinding	0 (0)	0 (0)
Therapist blinding	0 (0)	0 (0)
Assessor blinding	11 (68.8)	2 (3.3)
Adequate follow-up	16 (100)	61 (100)
Intention-to-treat analysis	15 (93.8)	59 (96.7)
Between-group comparison	16 (100)	61 (100)
Point and variability measures	16 (100)	61 (100)

PEDro Physiotherapy Evidence Database, *RCT* randomized control trial

Individual PEDro scores are listed in online supplementary Table S4 and the rated quality levels are shown in Table S2

[a]Details of each item and guidelines of rating criteria are available from the Physiotherapy Evidence Database (https://www.pedro.org.au/english/downloads/pedro-scale/)

[b]Percentage of the same quality level

Publication bias

Visual inspection of the funnel plots of ROM regain did not reveal substantial asymmetry (Fig. 3). In addition, Egger's linear regression test provided no evidence of reporting bias among the trials (n.s.).

Meta-analyses

Treatment success rates and general outcomes

Treatment success rates (TSRs) for pain severity and global outcomes were mostly assessed using a Likert scale [7, 34] (Table S2). In the overall follow-up duration, the CPM group had a higher TSR than the non-CPM or active control group in the random-effects model (OR 3.64, $P < 0.00001$; LoE, moderate; Fig. S2).

Effect of CPM on postoperative pain

During acute stay, SMDs for pain reduction after CPM therapy were observed from POD 3 (SMD = − 0.87, $P = 0.005$) to POD 14 (SMD = − 0.70, $P = 0.002$) without significant heterogeneity among follow-up time frames ($I^2 = 0\%$) (Fig. S3), and an overall SMD of − 0.96 ($P < 0.0001$; LoE, moderate) favoring CPM was observed (Fig. S4).

During postacute follow-up, SMDs were observed only for short-term effects on pain reduction at 1-month follow-up (SMD = − 0.56, $P = 0.01$), favoring CPM; there was significant difference in heterogeneity among time frame subgroups ($I^2 = 64\%$) (Fig. S5). In the overall postacute follow-up duration, a significant SMD of − 0.64 favoring CPM ($P = 0.005$; LoE, moderate) was observed (Fig. S6).

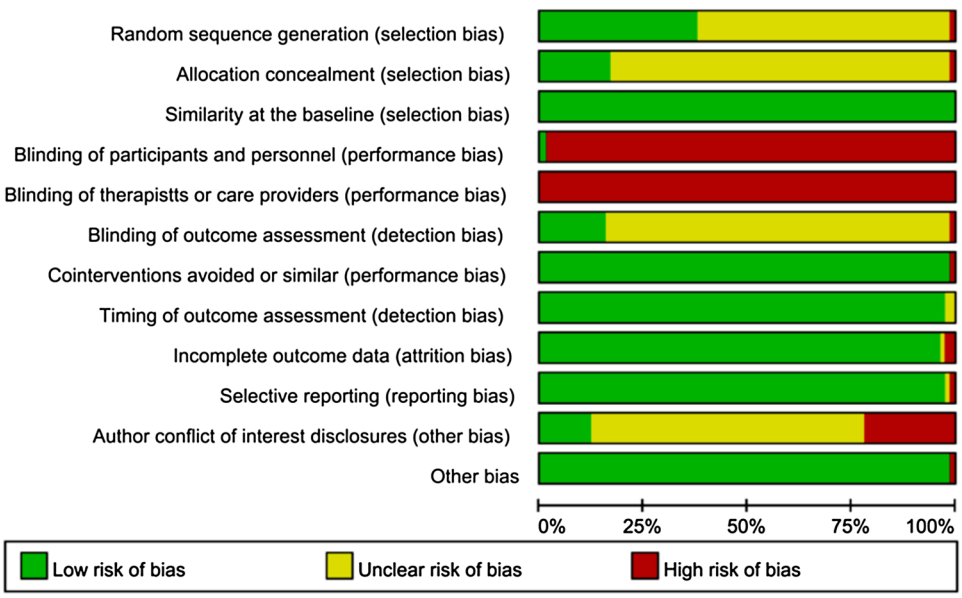

Fig. 2 Risk of bias summary across the included randomized controlled trials

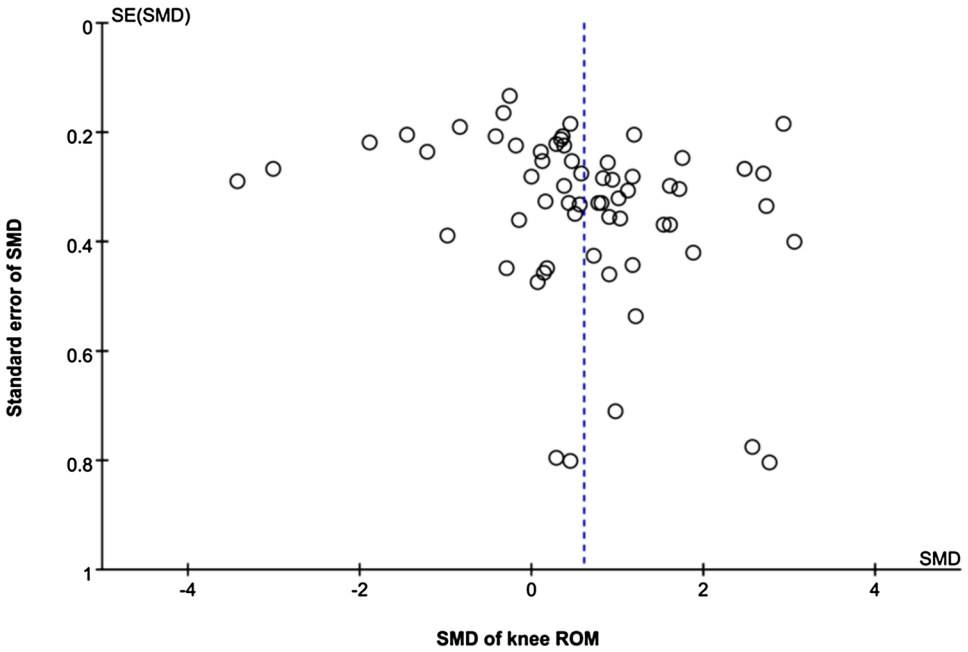

Fig. 3 Publication bias plot. Funnel plot for effect size of knee ROM. The SMDs of knee ROM is plotted on the *x*-axis and standard error of SMD is plotted on the *y*-axis. The vertical dotted line indicates the mean value of the SMDs. Visual inspection of the funnel plot of the SMDs of pain score did not reveal substantial asymmetry. Egger's linear regression test results indicated no evidence of reporting bias among the studies (n.s.). *ROM* range of motion, *SMD* standard mean difference

Effect of CPM on range of motion

The meta-analysis for knee ROM during acute hospital stay revealed that irrespective of the application protocol and methodological design, CPM significantly improved knee ROM on POD 5 with an SMD of 0.75 ($P = 0.001$); similar results were observed on POD 10 and POD 14 (Fig. 4 and Table S5) and no significant heterogeneity among time frames was observed during acute stay (Fig. S7).

During postacute follow-up, significant effects on knee ROM were only observed at 3-month follow-up (SMD = 0.80, $P < 0.00001$; LoE, moderate) (Fig. 4 and Table S6); however, no significant heterogeneity was observed among time frames (Fig. S8).

Effect of CPM on functional outcome

During acute stay, the effect of CPM on pooled functional scores was significant with an SMD of 1.59 ($P = 0.03$) on POD 5, and similar results were observed on POD 10 and POD 14, irrespective of the application protocol and methodological design (Fig. 4 and Table S5); however, significant differences were observed among time frames during acute stay ($I^2 = 79.2\%$) (Fig. S9).

Similar results were observed at 3-month (SMD = 0.86, $P < 0.00001$), 6-month (SMD = 1.02, $P = 0.004$), and 12-month (SMD = 1.08, $P = 0.009$) follow-up (Fig. 4 and Table S6); no significant differences were observed among time frames during postacute follow-up ($I^2 = 0\%$) (Fig. S10).

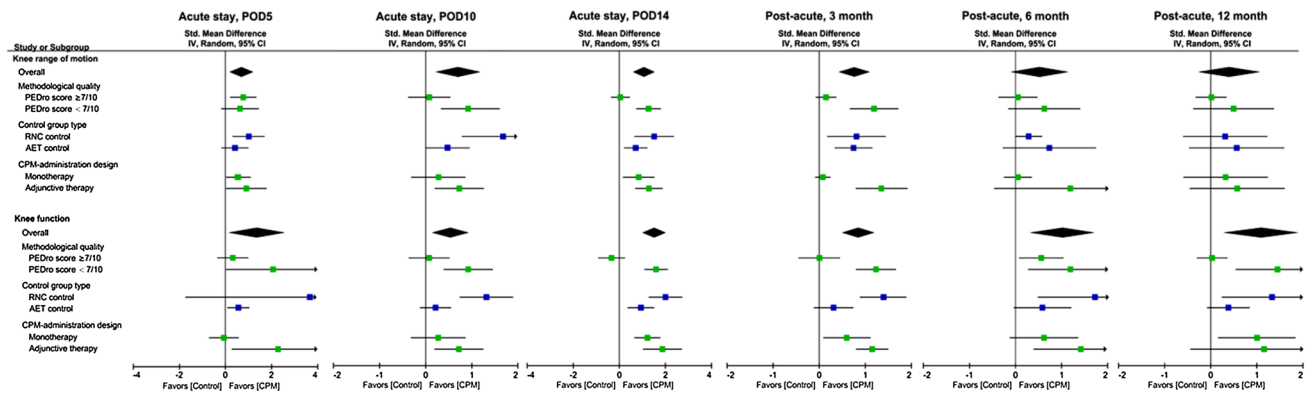

Fig. 4 Forest plot of CPM therapy. Subgroup analyses for knee range of motion and functional recovery during the follow-up periods. Subgroup results plotted on the right-hand side indicate effects favoring CPM, and the combined effects are plotted using black diamonds. *CI* confidence interval, *IV* inverse variance, *Random* random-effects model, *CPM* continuous passive motion, *POD* postoperative day, *PEDro* Physiotherapy Evidence Database, *RNC* regular nursing care, *AET* active exercise training

Subgroup analysis

During acute stay, all kinds of subgroups, except CPM intervention designs during all acute stay time frames, showed significant group differences in knee ROM as well as function (Fig. 4 and Table S5).

During postacute follow-up, significant differences in knee ROM effect were observed between the quality-level, population-area, control-type, and intervention-design subgroups at 3-month follow-up only (Fig. 4 and Table S6). At 3-month and 12-month follow-ups, significant differences in knee function effect was also observed in quality-level and population subgroups.

Metaregression analysis

Determinants of CPM efficacy

Young age ($R^2 = 18.9\%$, $P = 0.001$), low BMI ($R^2 = 30.3\%$, $P = 0.04$), and less preoperative ROM ($R^2 = 20.3\%$, $P = 0.006$) predicted greater effect sizes of knee ROM, pain, and functional outcomes during acute stay (Table S7); similar results were observed in knee ROM at postacute follow-up (Table S8). After all time frames were pooled, patients with a preoperative ROM of < 100°achieved a positive effect size of knee ROM following postoperative CPM therapy ($\beta = -0.05$; 95% CI −0.07, −0.03; $P < 0.001$) (Fig. 5).

Regarding CPM application parameters, a greater daily ROM increment ($R^2 = 47.5\%$, $P < 0.001$) and longer duration of CPM application ($R^2 = 18.3\%$, $P = 0.003$) significantly predicted larger effect sizes of postoperative ROM and functional recovery during acute stay (Table S7). At postacute follow-up, CPM application parameters had no effect on outcomes, except that an earlier POD of CPM initiation ($R^2 = 9.9\%$, $P = 0.048$) significantly predicted greater function recovery (Table S8). In addition, the POD of CPM initiation ($R^2 = 22.7\%$, $P = 0.02$) and daily ROM increment ($R^2 = 61.6\%$, $P < 0.001$) were also predictors of the effect size of treatment success.

The control type and CPM intervention design were significantly associated with the effect sizes of knee ROM at acute stay and postacute follow-up, respectively (Tables S7 and S8); similar results were observed in knee function. Follow-up duration was not associated with effect sizes of outcomes at acute stay and postacute follow-up (Tables S7 and S8).

CPM application parameters are associated with CPM efficacy

Four iterations of multiple linear regressions were performed for data analysis (Table 4). After controlling for patient characteristics and methodological designs, greater daily ROM increment and early POD of CPM initiation independently predicted greater effect sizes of postoperative knee ROM; similar results were found for function and treatment success.

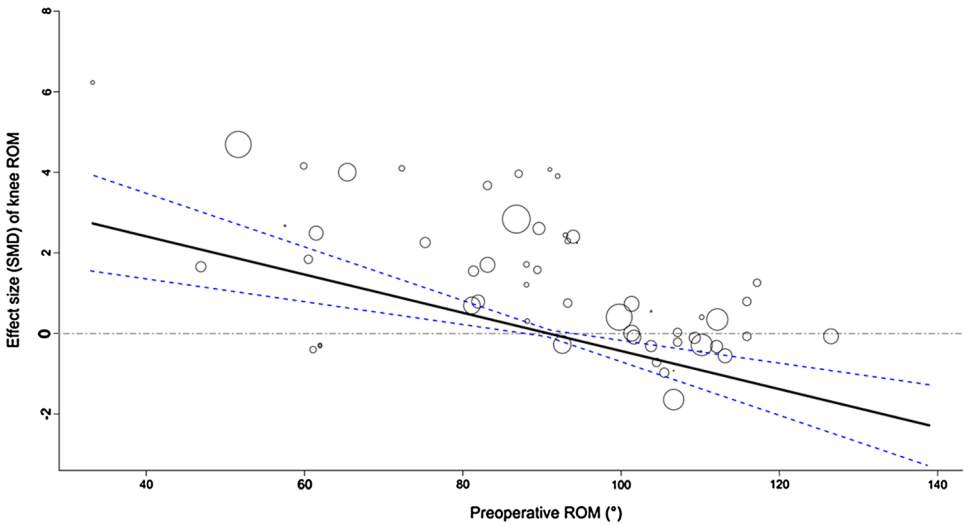

Fig. 5 Multivariate metaregression between preoperative ROM and effects of CPM on knee ROM. Each circle represents an independent comparison. The size of each circle is proportional to that study's weight (inverse-variance weighted). The regression prediction is represented by the solid line for effect size (SMD) of knee ROM ($\beta = -0.05$; 95% CI −0.07 to −0.03; $P < 0.001$). Dotted lines represent the 95% CI. The metaregression model was adjusted for age, methodological design and quality, and follow-up time of each comparison. *CPM* continuous passive motion, *ROM* range of motion

Discussion

The meta-analyses provided statistically significant moderate evidence supporting that CPM increased the TSR, reduced pain, restored the knee ROM, and enhanced functional recovery, regardless of the follow-up duration, application parameters, and methodological design. We further identified that patient's age and preoperative ROM significantly influenced the effect size of knee ROM after CPM therapy; in addition, CPM application parameters including POD of CPM initiation and daily ROM increment independently predicted effects on knee ROM and function.

In this meta-analysis, there was moderate evidence supporting that CPM exerted not only short-term benefits on postoperative knee ROM which is in line with previous systemic reviews [15, 36, 42, 44] but also long-term (12 months) effects on knee function which is conflicting to the previous results [17, 30, 41]. Unlike previous systemic reviews [15, 17, 30, 36, 41, 42, 44], in the current meta-analysis, RCTs without restrictions on publication year or language were selected, comparatively more RCTs with Asian populations were included, and RCTs with low methodological quality were excluded. The differences in the study selection and inclusion criteria may have contributed to the inconsistency between our results and previous systemic reviews.

Older age, knee stiffness, and obesity are risk factors for poor postoperative ROM [1, 14, 16, 22, 37] and rehabilitation outcomes during hospital acute stay and postacute follow-up [25–27]. In the present study, the results indicated that a lower preoperative ROM of < 100° can be predicted to achieve a positive effect size of knee ROM after CPM; this result is consistent with a previous study result indicating that patients with stiff knees before TKA surgery may experience greater gain in knee ROM postoperatively compared with those without knee stiffness [45].

The results of this meta-analysis revealed that CPM application parameters, particularly the POD of CPM initiation, daily ROM increment, and total days of application, were independent determinants of CPM clinical efficacy. Our findings are supported by previous studies [15] but are inconsistent with a recent Cochrane analysis [17]. It is believed that CPM demonstrated positive biologic effects on tissue healing, edema, hemarthrosis, and joint function [6, 35, 38]. Therefore, CPM may exert the greatest benefit with early initiation, greater progress in motion arc, and longer duration of application during acute hospital stay.

Several limitations of this study must be considered. First, although the data did not suggest substantial publication bias, heterogeneity was observed among the included RCTs, which may be attributed to the varying methodological designs and application protocols. Second, the nature of CPM intervention led to a high risk of blinding biases; however, all the included RCTs had good methodological quality (PEDro score ≥ 6). Finally, other confounding factors such as disease duration, surgery technique, prosthesis design, and postdischarge rehabilitation, which may have contributed to treatment efficacy [11], were not assessed when analyzing effect sizes of ROM and functional outcomes.

In this study, the clinically relevant results were identified that patient characteristics influenced the treatment effects of CPM therapy; in addition, an aggressive protocol of CPM application may predict greater treatment effects on postoperative outcomes. Such results may help clinical practitioners establish prompt and efficient rehabilitation protocols after knee arthroplasty in arthritis patients, especially for

Table 4 Association of CPM application parameters with knee joint ROM and function outcome at discharge and postacute follow-up

Covariate	Model 1†		Model 2§	
	β	SE	*β*	SE
Dependent variable = Treatment success (ln OR)				
Daily ROM increment (°)	0.092	0.013***	0.095	0.016***
CPM-initiated POD (*days*)	−0.494	0.205*	−0.515	0.347
Adjusted R^2	0.765		0.760	
Model *P* value	0.026		n.s	
Comparison, *n*	22		22	
Dependent variable = Knee ROM (SMD)				
Daily ROM increment (degree)	0.047	0.013**	0.037	0.012**
CPM-initiated POD (days)	−0.192	0.081*	−0.254	0.075**
Adjusted R^2	0.374		0.570	
Model *P* value	0.023		0.007	
Comparison, *n*	40		38	
Dependent variable = Knee function (SMD)				
Daily ROM increment (degree)	0.070	0.015***	0.119	0.022***
Application duration (days)	0.106	0.023***	0.037	0.052
Adjusted R^2	0.591		0.681	
Model *P* value	< 0.001		n.s	
Comparison, *n*	50		24	

ROM range of motion, *CPM* continuous passive motion, *POD* postoperative day, *ln OR* natural log transformed odds ratio, *SMD* standard mean difference

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

†Model 1: Stepwise linear regression variables included parameters of CPM application. The linear model coefficients were represented as *β* values with standard error (SE)

§Model 2: Stepwise linear regression variables included age, population area, preoperative ROM, intervention design, comparison type, follow-up duration, and variables from model 1. Population area was coded as Americas = 1, Asia = 2, Europe = 3, and Oceania = 4. Intervention design was coded as monotherapy = 1 and adjunctive therapy = 2; comparison type was coded as regular care = 1 and active exercise control = 2

those with older age, higher BMI, and poor preoperative ROM.

Conclusion

In this study, we provided moderate evidence indicating that postoperative CPM therapy exerted significant short-term effects on TSR, pain, and knee ROM and a long-term effect on functional recovery in patients with arthritis. In addition, patient characteristics and CPM applications may influence treatment efficacy. Owing to potential biases (blinding biases) in the included RCTs of this study, we recommend that CPM should be cautiously applied to achieve favorable postoperative outcomes.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest related to the publication of this article.

Ethical approval This study dealt with published data only, no ethical approval has been necessary since sensitive information has not been provided or utilized in this review.

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