Efficacy of Continuous Passive Motion Following Total Knee Arthroplasty: A Metaanalysis

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ABSTRACT. ***Objective.*** The objective of this metaanalysis is to examine the effectiveness of continuous passive motion (CPM) following total knee arthroplasty (TKA).

Methods. This metaanalysis used the methodology proposed by the Cochrane Collaboration.

Results. This review of 14 studies (952 patients) found significant improvements in active knee flexion and analgesic use 2 weeks postoperatively with the use of CPM and physiotherapy (PT) compared to PT alone. In addition, length of hospital stay and need for knee manipulations were significantly decreased in the CPM group. Not enough data were available to compare the degree of knee flexion applied or number of hours of application of CPM. However, significant results were not found for other comparisons such as short term CPM application versus longterm CPM application and wide treatment range versus small treatment range for the outcomes of active knee flexion, passive knee flexion and extension, presence of a fixed flexion deformity, use of analgesic, or total knee range of motion.

Conclusion. CPM combined with PT may offer beneficial results for patients post-TKA. However, the potential benefits will need to be carefully weighed against the inconvenience and expense of CPM. More research is necessary to assess the differences in effectiveness with different characteristics of application such as total duration of treatment and intensity of CPM interventions. (J Rheumatol 2004;31:2251–64)

Key Indexing Terms:
THERAPEUTIC EXERCISE   TOTAL KNEE ARTHROPLASTY   METAANALYSIS
CONTINUOUS PASSIVE MOTION   REHABILITATION   OSTEOARTHRITIS
RHEUMATOID ARTHRITIS

Knee arthroplasties (KA) are surgical procedures that have become more common in the last few decades in part due to the aging population. Rheumatoid arthritis (RA) and osteoarthritis (OA) are the 2 main reasons for KA. Historically, immobilization has been the postoperative treatment of choice for many orthopedic surgeries[1]. However, over the years clinical trials have shown that immobilization of a specific joint following surgery can have detrimental effects on collagen tissue healing, articular cartilage nutrition, and joint stiffness[2]. This insight into the disabling results of postoperative immobility has stimulated an interest in early mobilization[1].

Recent studies show that early movement is beneficial for the recovery of range of motion (ROM) in an immobilized joint[3]. Adequate ROM of the knee, particularly in flexion, is important for mobility and activities of daily living (ADL) in patients who have undergone KA[4]. If patients have improved ROM, their ability to perform functional tasks increases[4,5]. As a result of these findings, early postsurgical mobilization has become standard practice.

Continuous passive motion (CPM) is an external motorized procedure that enables a joint to move passively through a predetermined range of motion[6]. It is one technique whereby patients can achieve early postsurgical mobility. CPM was first introduced in the 1970s by Salter, who initiated trials using rabbits and demonstrated enhanced healing of cartilage using CPM[7]. Passive exercise such as CPM is thought to be helpful in maintaining ROM and reducing edema, whereas active exercise promotes muscle strengthening[8].

Studies on CPM have produced conflicting results. CPM has been shown to have positive effects on soft tissue healing, swelling, hemarthrosis, and joint function[2]. During the normal healing process, collagen fibers grow randomly, pro-

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ducing resistance to free movement[7]. CPM is proposed to work at the cellular level by decreasing random fiber growth and diminishing postoperative scar formation[7]. It has also been found that the use of CPM can decrease the incidence of postoperative deep vein thrombosis and thromboembolitic disease[9]. Several studies have claimed that the use of CPM can significantly increase the amount of knee flexion by the time of discharge from hospital[4,10,11]. Other research has reported that CPM decreases the rate of manipulation under anesthesia post-KA[12]. However, a retrospective study comparing CPM and physiotherapy (PT) to PT alone found no significant difference in knee ROM between the CPM and the non-CPM treatment groups[13]. Studying the use of CPM, some disadvantages have also been noted: (1) patients remain in bed while the machine is utilized; (2) studies show early knee ROM improvements require up to 20 hours of CPM application daily, which is time consuming and costly; (3) patients require technical support from nursing staff to operate the machines; (4) increased costs are associated with safe operation of the units and regular maintenance[14,15].

Despite the recorded benefits of CPM on knee flexion post-KA, it is clear that consensus has not been attained about the longterm efficacy of the procedure[16]. Although controversial, CPM has been used by many surgeons as part of a standard postoperative management of patients having undergone surgical KA[4,14]. It has been stated that the widely conflicting findings are due to inconsistencies in the variables being studied[7]. Little information exists to enable the clinician to select optimal CPM parameters, such as the most appropriate number of degrees per day to advance the CPM device or the optimal daily treatment duration[1,7]. Coutts, *et al* reported on the effectiveness of CPM following KA and suggested that 20 hours of CPM daily increased ROM and decreased edema and effusion[17]. Similarly, Davis reported increased ROM by using the CPM following a 3-day delay in the initiation of treatment[18]. However, Young and Kroll concluded that the CPM did not offer additional benefits from conventional PT alone[19], while others only used CPM for 6 hours a day and obtained positive results[20].

The objective of this metaanalysis was to determine the effectiveness of CPM following knee arthroplasty. CPM is compared to standard PT treatments conducted on patients after a total KA. Standard PT treatment, as defined by this analysis, consists of any combination of the following interventions: ROM exercises (ROM), muscle strengthening exercises (isometric, dynamic), functional exercises, gait training, immobilization, and ice. The outcome measures of interest for this metaanalysis were active and passive knee ROM, length of hospital stay, pain, swelling, fixed flexion deformity, and quadriceps strength at end of treatment and during followup.

MATERIALS AND METHODS

This metaanalysis used the methodology proposed by the Cochrane Collaboration[21].

Literature identification. The literature was searched up to and including December 2003 according to the sensitive search strategy outlined by the Cochrane Collaboration for randomized controlled trials (RCT)[22], with modifications proposed by Haynes, *et al*[23]. Additional terms for study design were used to identify observational studies, including: case-control, cohort, comparative study, clinical trial. Medline, Embase, Healthstar, Sports Discus, CINAHL, the Cochrane Controlled Trials Register, the PEDro database, the specialized registry of the Cochrane musculoskeletal group, and the Cochrane field of physical and related therapies were searched using a keyword and text word search strategy (Appendix). As well, reference lists of included trials were searched and content experts were contacted for additional studies. The details of the search strategy are given in the Appendix.

Eligibility criteria. The titles and abstracts of the trials identified by the search strategy were examined by 2 independent reviewers (VR, LB) to determine whether these selected trials met the inclusion criteria. All trials classified as relevant by at least one of the reviewers were retrieved. The retrieved articles were reexamined to ensure they met the inclusion criteria.

Only trials meeting the following conditions were included: subjects 18 years of age or older and having a presurgery diagnosis of degenerative joint disease, intervention and control groups of 5 or more individuals each, and measuring rehabilitative outcomes. Both the experimental and control groups received PT. In addition to the PT intervention, the experimental group received CPM.

According to an a priori protocol, all comparative controlled trials, including RCT, controlled clinical trials without randomization (CCT), case-control, and cohort studies were included. Trials that used the same patients as their own control were not accepted. The results were graded according to the strength of the study design. Both English and French RCT were considered. Peer-reviewed abstracts were accepted.

Acceptable interventions included any form of fitness exercise. Placebo, untreated, or active interventions were all acceptable control groups.

The large number of studies in this review measured a variety of outcomes. The outcomes were as follows: active and passive knee ROM; length of hospital stay; pain; swelling; and quadriceps strength.

Data extraction. Two independent reviewers (HD, JD) examined the titles and abstracts of the trials identified by the search strategy to select trials that met the inclusion criteria. All trials classified as relevant by at least one of the reviewers were retrieved. The retrieved articles were reexamined to ensure they met the inclusion criteria.

The results of the individual trials were extracted from each of the included trials using predetermined extraction forms by 2 independent reviewers (HD, JD). The data were cross-checked by a third reviewer (LB). The extraction forms were developed and pilot-tested based on other forms used by the Cochrane musculoskeletal review group. Data of interest were grouped in either subject characteristics (age, sex, diagnosis, etc.) or CPM therapeutic application (hours/day, increments in degrees/day, etc.). The outcome measures collected were length of hospital stay, ROM (passive and active knee flexion and extension), extension lag, fixed flexion deformity, pain (on visual analog scale, VAS), pain medication intake, swelling, and quadriceps strength. These outcomes were considered pertinent to PT intervention by 3 of the authors (HD, JD, MJN). The final data values were based on consensus of the 2 reviewers.

Quality assessment. The quality of each study was assessed by 2 independent reviewers. Quality assessment examined the extent to which the RCT design, data collection, and statistical analysis minimized or avoided biases in its treatment comparisons[24]. The Jadad scale was used to perform the quality assessment[25,26]. The scale includes items pertaining to description of randomization, appropriateness of blinding, dropouts and withdrawals, and followup. Differences in scoring were resolved by consensus. A third reviewer (LB) was consulted when necessary. The quality assessment was pilot-tested on 4 unrelated articles prior to data extraction.

Statistical analysis. Results were analyzed to compare CPM combined with

PT versus PT alone. Results on individual treatment techniques were analyzed separately. Data relative to the outcomes from each trial were pooled to arrive at an overall estimate to determine the effectiveness of each procedure. Where possible, the analyses were based on intention-to-treat from the individual trials. In cases where trials reported outcomes with graphs, the mean scores and standard deviations were estimated from the graphs. Subgroup analyses were attempted to determine the effects of the method administration, methodological quality, and the intervention duration on outcomes. For continuous data, results were presented as weighted mean differences (WMD), where the difference between the treated and control groups was weighted by the inverse of the variance. For dichotomous outcomes, results were presented as an odds ratio or relative risk (RR). Standardized mean differences (SMD) were used when different scales were used to measure the same concept (e.g., pain). SMD were calculated by dividing the difference between treated and control means by the pooled estimate of the baseline standard deviation. Fixed effects models were used throughout, unless statistical heterogeneity was proved by the Cochrane Q test ($p < 0.05$). Where heterogeneity was significant, random effects models were used. For outcomes where it is desirable to have a lower score (e.g., pain), a negative value indicates a positive effect of the intervention procedure. For outcomes where a larger value is desirable (e.g., range of motion), a positive value indicates benefits.

RESULTS

Summary of the trials

The literature search and hand-searching identified 178 articles. Of the 178 articles, 58 trials were screened for relevance and inclusion into this metaanalysis. Of the 58 screened, 14 were in accord with the inclusion criteria: Chen, *et al* 2000[4], Chiarello, *et al* 1997[7], Colwell and Morris 1992[27], Harms and Engstrom 1991[1], Johnson 1990[28], Kumar, *et al* 1996[29], MacDonald, *et al* 2000[14], May, *et al* 1999[16], McInnes, *et al* 1992[5], Montgomery and Eliasson 1996[30], Nielsen, *et al* 1988[31], Pope, *et al* 1997[32], Vince, *et al* 1987[33] and Walker, *et al* 1991[34]. For inclusion, subjects were 18 years of age or older and were hospitalized following knee arthroplasty procedures. Presurgery diagnosis for all subjects was classified as degenerative joint disease, OA, or RA. The length of treatment in individual studies varied from 18 hours to 2 weeks. Daily CPM treatment time varied from 5 hours daily to 20 hours daily. All 14 articles included both male and female patients. A total of 952 patients were included for analysis. A summary of all trials is given in Table 1. Trials were excluded for several reasons including: no clinical outcomes of interest; not a clinical trial; subjects did not undergo knee arthroplasty; no variance reported on outcomes. Excluded trials and specific reasons for exclusion are tabulated in Table 2.

The primary diagnosis was degenerative joint disease. OA was present in over 89% of cases and RA represented no more than 8% of the subject diagnoses.

Methodological quality of the studies. The median methodological quality was 2 out of a maximum of 5 points. The quality scores ranged from 1 to 3. Of the 14 RCT, 3 scored full points for randomization, Harms and Engstrom 1991[1], Kumar, *et al* 1996[29], and MacDonald, *et al* 2000[14]. No studies were described as double blinded and 3 failed to provide a description of dropouts: Chen, *et al* 2000[4], Harms and Engstrom 1991[1], and Johnson 1990[28]. For the main comparison of CPM combined with PT versus PT alone, the median methodological quality was 2. Eight articles obtained a score of 2: Chiarello, *et al* 1997[7], Colwell and Morris 1992[27], Harms and Engstrom 1991[1], McInnes, *et al* 1992[5], Montgomery and Eliasson 1996[30], Nielsen, *et al* 1988[31], Vince, *et al* 1987[33], and Walker, *et al* 1991[34], while one obtained a score of 3, Kumar, *et al* 1996[29]. Eight articles provided a description of withdrawals and dropouts: Chiarello, *et al* 1997[7], Colwell and Morris 1992[27], Kumar, *et al* 1996[29], McInnes, *et al* 1992[5], Montgomery and Eliasson 1996[30], Nielsen, *et al* 1988[31], Vince, *et al* 1987[33] and Walker, *et al* 1991[34]. Only one article, Harms and Engstrom 1991, received full points for randomization[1].

Pooled analysis. Pooled analyses were possible for the comparison of CPM combined with PT versus PT alone at the end of treatment (approximately 2 weeks). Nine trials were included in this comparison (Chiarello, *et al* 1997[7], Colwell and Morris 1992[27], Harms and Engstrom 1991[1], Kumar, *et al* 1996[29], McInnes, *et al* 1992[5], Montgomery and Eliasson 1996[30], Nielsen, *et al* 1988[31], Vince, *et al* 1987[33], Walker, *et al* 1991[34]). Treatment was initiated on the first postoperative day for all trials except one in which CPM was started on the second postoperative day. For the outcome of active knee flexion, 4 studies were included in the pooled analysis, for a total of 286 patients (Chiarello, *et al* 1997[7], Harms and Engstrom 1991[1], McInnes, *et al* 1992[5], Montgomery and Eliasson 1996[30]). Overall, CPM combined with PT significantly increased active knee flexion at 2 weeks post-KA (WMD 4.30, 95% CI 1.96 to 6.63; Figure 1). In addition, a clinically important benefit was found for active knee flexion at 3 days (relative difference 23%; Table 3), 2 weeks (relative difference 22%; Table 3), and one week of followup (relative difference 25%; Table 3). Further, patients receiving CPM achieved 90° of knee flexion on average 4.7 days faster than patients receiving PT alone (4.7 days difference, Vince, *et al* 1987[33]).

Statistically significant results were also obtained for length of hospital stay. Six studies were included in the analysis with a total of 382 patients (Colwell and Morris 1992[27], Harms and Engstrom 1991[1], Kumar, *et al* 1996[29], McInnes, *et al* 1992[5], Montgomery and Eliasson 1996[30], Walker, *et al* 1991[34]). The treatment groups receiving CPM and PT were found to have a significantly shorter time to discharge (WMD –0.69 days, 95% CI –1.35 to –0.03; Figure 2) than those receiving physiotherapy alone. Discharge criteria varied among trials, and only 3 trials (Colwell and Morris 1992[27], Harms and Engstrom 1991[1], Kumar, *et al* 1996[29]) actually specified their criteria. Although length of stay was found to produce a statistically significant result, no clinically important benefit was found.

Positive results were obtained for the number of patients requiring manipulation post-KA. According to data pooled from 3 trials (Harms and Engstrom 1991[1], McInnes, *et al*

Table 1. Summary of included trials on efficacy of continuous passive motion after knee arthroplasty.

Author / Year	Sample size (n)	Population details	Age (yrs) Mean (sd or range)	Treatment	Comparison Group	Concur. Therapy	Session / week No. Of weeks	Follow-up	Quality R,B,W
Chen B 2000	Randomized Single-blinded Gr 1 : 23 Gr 2 : 28	Exclusion : bilateral TKA, intolerance of CPM machine, significant wound drainage or wound infection, TKA revision, weight >= 240 lbs (to ensure proper fitting in a standard CPM machine) Gender : Gr 1 : 6M/17F Gr 2 : 9M/19F	Male : 72 (46-91) Female : 65 (40-86)	Gr 1 : CPM + PT : CPM started within 24 hrs of admission; initially set from 0° to approx. 60° (10 ° less than passive knee flex); knee flexion increased daily as tolerated by patient. Also PT. Gr 2 : PT only : 2 hrs per day of PT and 1 hr per day of OT	Gr 2 : PT only : 2 hrs per day of PT and 1 hr per day of OT	PT (not described)	5 hrs per day, until D/C (i.e. approx. 8 days)	3 days (approx. mid-treatment) Approx. 1 wk (end of treatment)	1,0,0
Chiarello CM 1997	Randomised open, 46 Gr1: 10 Gr2: 8 Gr3: 9 Gr4: 8 Gr5: 11	Patients with degenerative joint disease undergoing primary and unilateral TKA 34F / 12M	Gr1: 70.9 (9.7) Gr2: 74.2 (9.1) Gr3: 74.2 (6.3) Gr4: 71.2 (9.8) Gr5: 62.7 (10.3)	Treatment started on either POD 1, 2 or 3. Gr1: CPM 4.3hrs/day (SD=1.5), ROM increment 7.0dgrs/day (SD=5.3) Gr2: CPM 4.1hrs/day (SD=1.0) ROM increment 6.0dgrs/day (SD=5.0) Gr3: CPM 6.6hrs/day (SD=4.4) ROM increment 6.0dgrs/day (SD=5.0) Gr4: CPM 8.0hrs/day (SD=3.1) ROM increment 7.0dgrs/day (SD=7.8)	Gr5: Concurrent treatment only	PT: gait training, transfers, education, moist heat, and strength & ROM exs.	Treatment until D/C or 2 weeks post-surgery	None	1, 0, 1
Harms M 1991	Randomised open 113 Gr1: 55 Gr2: 58	Diagnosis of OA or RA, primary TKA, knee flex contracture <40dgrs, pre-surgery condition—able to walk 10m within 2min with walking aid, able to rise from chair with arm rest and seat height of 18in. Excluded: Revision, concurrent knee surgery, condition comprising treatment. Gr1: 43F/12M Gr2: 54F/4M	Gr1: 69 (9) Gr2: 71(10)	Gr1: CPM initiated in recovery room, 0-40° x 1st 48 hrs post-surgery, 2°/sec. Increment 10°/day, as tolerated. Immobilised in splint or back slab while off CPM.	Gr2: Concurrent treatment only	All patients familiar to the exs programme before surgery. POD1: Splint, static quads contraction progressing towards SLR, ankle + gluteus exs. POD2: mobilise with splint POD3: active knee flex, inner range quads exs, splint removed POD5: mobilise without splint if dynamic control of knee ext or proper SLR	CPM 6hrs/ day applied until 80° of flex achieved (~17-18 days). Concurrent treatment 2x/ day, minimum of 10 min/ session	None	2, 0, 0
Haug J 1988	27 pts (28 knees) Gr1: 13 pts (14 knees) Gr2: 14 pts (14 knees)	Diagnosis of degenerative joint disease or RA (26/2)	Gr1: 67 (9) Gr2: 71 (8)	Gr1: CPM + NMS Pt placed on CPM unit after surgery. Initial setting at 0-40dgrs. NMS POD1: actives electrodes over vastus medialis distally & femoral nerve proximally; inactive electrode equidistant between both active ones. Intensity: max level of tolerance. Asym biphasic wave, 300msec, 35 pulses/sec, 2sec ramp time, 1sec fall time, 15sec on (0-40dgrs), 45 stimulations/hr, 20 sec rest at 40° setting, 65 sec rest at 90 sec setting	Gr2: CPM only	PT: AROM, Quads femoris setting, flex/ext stretches, ambulation.	CPM + NMS: 3x/day 1hr/session 8 days treatment	None	0, 0, 1

R: randomization; B: blinding; W: withdrawals; NA: not available; ADL: activity of daily living; AROM: active range of motion; CPM: continuous passive motion; exs: exercise; POD: postoperative day; PROM: passive range of motion; PT: physiotherapy; Rx: treatment; TKA: total knee arthroplasty.

Table 1. Continued.

Author / Year	Sample size (n)	Population details	Age (yrs) Mean (sd or range)	Treatment	Comparison Group	Concur. Therapy	Session / week No. Of weeks	Follow-up	Quality R,B,W
Johnson DP 1990	Randomised controlled 102 Gr1: 50 Gr2: 52	Primary replacement of the knee. Excluded: infective focus, diabetes, peripheral vascular disease, corticosteroid therapy, scars. Gr1: 13RA/37OA Gr2: 12RA/40OA	N/m	Gr1: CPM ROM 0-10 ° on 1st day, increased of 10°/day until 90° reached (on 6th day). Exs involving full knee ext. Active knee flex & ext allowed on 7th day.	Gr2: Splint (knee flex not allowed before 7th day). SLR exs.	Weight bearing starting on 3rd day	CPM: 20hrs first 3 days and 16hrs x following 4 days. Splint- 7days Exs (both groups) performed 2x/ day. Treatment for 7 days	2, 6wks; 3, 6 & 12 months	1, 0, 0
Kim JM 1995	Randomised open 47 patients 68 knees Gr1: 34 Gr2: 34	57.4% OA 42.6% RA 39F/8M	21-30 y/o: 6pts 31-40 y/o: 2pts 41-50 y/o: 2pts 51-60 y/o: 15pts 61-70 y/o: 19pts 71-80 y/o: 3pts	Gr1: CPM immediately after surgery. 60° flex increased to 110°. Then CPM discontinued and AROM exs encouraged.	Gr2: Ant plaster splint post-op at 110-120 ° knee flex x 24 hrs alternated with post slab in full ext x 24 hrs.	Quads exs encouraged whenever possible and full weight bearing allowed 2 wks post-surgery	CPM: from 1-3 wks Splinting: from 2-5 days as tolerated.	42 months	1, 0, 1
Kumar PJ 1996	Randomised open 73 patients 83 knees Gr1: 40pts (46knees) Gr2: 33pts (37knees)	OA pts, TKA Gr1: 23F/17M Gr2: 22F/11M	Gr1: 69.3 (52-86) Gr2: 68.1 (42-88)	Gr1: CPM initiated in recovery room at 0 - 90°. Immobilization at night.	Gr2: (Drop & Dangle) post-op immobilisation. POD1: immobilisation removed, PROM, 90° flexion achieved at each session.	PT daily x 2 hrs: isometric exs, PROM, A-AROM, gait training (including stairs) FES if extensor lag >30° or if no independent SLR performed on POD3.	CPM: 10hrs/ day PROM: 20min (progressed to 30-45 min), 2x/ day. Treatment until D/C, max 5 days (if criteria not met, pt sent to rehab).	6 wks, 3 & 6 months	2, 0, 1
MacDonald SJ 2000	120 Gr 1 : 40 Gr 2 : 40 Gr 3 : 40	Inclusion : Less than 80 yrs of age with primary OA, no previous surgery on the knee, normal functioning ipsilateral hips, ability to tolerate NSAIDs and marcaine, ability to ambulate 30m preoperatively, ability to climb 10 steps Exclusion : RA, greater than 15° valgus or fixed flexion deformity Gender : N/A	N/A	Gr 2 : CPM from 0°-50° : 0°-50° initially then progressive increment changes of 10° each hour as tolerated by patient Gr 3 : CPM from 70°-110° : 70°-110° with no increment changes CPM initiated immediately in the recovery room, discontinued day after surgery	Gr 1 : No CPM Day after surgery, all patients began a standard PT regimen, twice daily for 6 wks : active flexion and extension, PROM exercises, mobilized as tolerated using walker or crutches	Standard dose of intra-articular marcaine (30mL 0,5% with 1:200000 epinephrine in saline solution)	18-24 hrs of CPM, initiated in recovery room, for one day PT : 2x/ day for 6 wks	Approx. 1, 6, 52 wks	2,0,1
May LA 1999	Gr 1: 12 Gr 2: 7	Patients admitted to the GRH who had undergone a primary total knee arthroplasty. Less than 14 days post-op	Gr 1: 72.8 yrs (3.7) Gr 2: 66.3 yrs (9.4)	Gr 1: CPM for knee flexion/extension 3 to 5 hrs/ day, 7 days/ wk, set at full extension and the maximal flexion was set at the maximum tolerated. The therapist sets the CPM and increases it daily with tolerance.	Gr 2: Lower Limb Mobility Board (LLiMB) 5 to 10 mins per session, 6 sessions per day, 7 days/wk, those without full active flexion and extension were given instruction on auto-assisted exercises while using LLiMB,	Physical therapy, 1 to 1 1/2 hrs/ day, except on wkds. The treatment consisted of ice, active and auto-assisted ROM and strengthening exercises, gait training and pool therapy twice per week for 30 mins.	Gr 1: 3 to 5hrs/ day, 7days/ wk until discharged Gr 2: 5 to 10 mins per session, 6 sessions per day, 7 days/ wk until discharged Concurrent therapy: 1 to 1.5 hrs/day, except on the weekends	End of treatment – 1 month	1,0,1

R: randomization; B: blinding; W: withdrawals; NA: not available; ADL: activity of daily living; AROM: active range of motion; CPM: continuous passive motion; exs: exercise; POD: postoperative day; PROM: passive range of motion; PT: physiotherapy; Rx: treatment; TKA: total knee arthroplasty.

Table 1. Continued.

Author / Year	Sample size (n)	Population details	Age (yrs) Mean (sd or range)	Treatment	Comparison Group	Concur. Therapy	Session / week No. Of weeks	Follow-up	Quality R,B,W
McInnes J 1992	Randomised controlled single-blind 102 Gr1: 51 Gr2: 51	Primary TKA, diagnosis of RA or OA (OA defined by roentgenogram), not more than 20° knee flex contracture, passive knee flex of at least 90°. Excluded: cognitive or sensory deficit, did not understand or speak English, undergoing another surgical procedure prior or during TKA, weight >136kg. Gr1: 33F/18M 37OA/14RA Gr2: 33F/18M 45OA/6RA	Gr1: 65.7(11.1) Gr2: 70.2(8.7)	Gr1: CPM initiated within 24 hrs of surgery (device: Sutter 9000 or 2000) Increment as tolerated.	Gr2: Concurrent treatment only	Quads strengthening (from POD1), A-AROM & PROM exs (flex, ext) (from POD2), gait training, bicycling.	Actual CPM hrs/day (mean): POD1-3:12.4 POD4-7:8.9 Concurrent treatment: 1-2x/ day, 7 days/ wk. Treatment until discharge (Average 10.8 days)	6 wks	1, 0, 1
Montgomery F 1996	Randomised open 68 Gr1: 34 Gr2: 34	Diagnosis of gonarthosis, primary TKA Gr1: 24F/10M Gr2: 24F/10M	Gr1: 74(5) Gr2: 76(6)	Gr1: CPM initiated POD1, increment until level of pain, speed adjusted to level of pain (2-6 min/ cycle)	Gr2: Active PT initiated POD1: AROM + PROM	Patients instructed to self-train actively and instruction on gait	CPM: 3 hrs/ session, 3 sessions/ day, 7 days/ wk until D/C PT: 30 min session 2 sessions/ day, 5 days/ wk until D/C D/C criteria: AROM min. 70°, ability to walk and climb stairs, independent with ADL) Up to 2wks	None	1, 0, 1
Nielsen PT 1988	Randomised open 54 Gr1: 27 Gr2: 27	Primary TKA, uncemented ACG-2000 prostheses, diagnosis of arthrosis. Excluded: previous TKA in contra lat knee	Gr1: 71(40-83) Gr2: 72(37-83)	Gr1: CPM initiated POD2 at 0-25°, increment 5-10° /day	Gr2: Concurrent treatment only	Starting POD2: quads strengthening, AROM with full weight bearing	CPM: 2 hrs/ session, 2 sessions/ day Treatment duration: 12 days	None	1, 0, 1
Pope RO 1997	Randomised controlled 53 (57knees) Gr1: 17pts (18knees) Gr2: 18pts (20knees) Gr3: 18pts (19knees)	Diagnosis of OA or RA Excluded: fixed deformity >30° Gr1: 11F/6M Gr2: 9F/9M Gr3: 13F/5M 49knees with OA 8 knees with RA	Gr1: 72.5(61-84) Gr2: 72.7(63-82) Gr3: 69.6(57-79)	CPM initiated in recovery room with speed 1.5min/cycle, increased 10°/day Gr1: CPM 0-40 Gr2: CPM 0-70	Gr3: ext splint in recovery room, removed for concurrent treatment. Splint removed POD3	Static quads + gluteus contractions, SLR, AROM, ankle pumps, gait training starting POD3.	CPM: 2 days, at least 20hrs/ day Concurrent treatment: 2x/ day, 10 reps of each exs.	1 year	1, 0, 1
Walker RH 1991	Phase 1: 22 Gr1A: 12 Gr1B: 10	Patients who just had a total knee arthroplasty. Diagnosis: (OA/RA) GR1A: 11/1/0 Gr1B: 10/0/0	Gr 1A: (72,7,5,5) Gr 1B: (73,6,4,25)	Gr 1A: CPM The post-op regimen included CPM initiated in recovery room with range 0-40°, CPM throughout hospitalization with daily advancement of flexion by 10° to tolerance.	Gr 1B: No CPM Knee immobilization in extension initiated in the operating room and continued for three days. Different range of motion exercises until POD3.	Standardized post UTKA physical therapy initiated on post-operative day	N/A	Approx. 2 wks (end of treatment)	1,0,1

R: randomization; B: blinding; W: withdrawals; NA: not available; ADL: activity of daily living; AROM: active range of motion; CPM: continuous passive motion; exs: exercise; POD: postoperative day; PROM: passive range of motion; PT: physiotherapy; Rx: treatment; TKA: total knee arthroplasty.

1992[5], Vince, *et al* 1987[33]), subjects in the CPM group had a significantly lower incidence of post-KA manipulation (RR 0.12, 95% CI 0.03 to 0.53; Figure 3). However, no clinically important benefit was shown for the number of patients needing postoperative manipulation (5% to 18% relative difference, Table 4). All 3 trials began CPM treatment within 24 hours.

Statistically significant results were also obtained for the

Table 1. Continued.

Author / Year	Sample size (n)	Population details	Age (yrs) Mean (sd or range)	Treatment	Comparison Group	Concur. Therapy	Session / week No. Of weeks	Follow-up	Quality R,B,W
Worland 98 1998	Randomized Single-blind trial. Sample size at entry: 91pts (114knees)	Patients with total knee replacement & OA diagnosis. Exclusion: Concomitant medical problems requiring additional days in the hospital, pts who needed serous drainage from their wounds requiring temporary use of a knee immobilizer. Gr1:15M / 23F Gr2: 12M / 30F	Gr1: 69.1(7) Gr2: 71.3(10)	Both groups had CPM applied in recovery room at 600, increasing 150/day until 900. Unilateral pts: CPM x 2hrs periods (6x/ day) alternating with 2hr periods of rest. Bilateral pts: CPM x 2hrs on (R) knee, CPM x 2hrs on (L) knee (4x/ day each knee), 2hrs of rest. After D/C: Gr1: CPM	After D/C: Gr2: PT; physiotherapist went to pt's home Continued with PT established during hospitalization.	Concurrent Rx: PT: POD1: isometric ankle DF/PF, quads, gluts, ambulation with walker as tolerated. POD2: Straight-leg raises, short-arc quads stretching, supine heel slides, passive hamstring stretching, sitting knee flexion as tolerated.	~3.5 days inpatients treatment (all CPM) Gr1 after D/C: 3 hrs/ day x 10 days Gr2 after D/C: 3x/ wk 1hr/ session, for 2wks.	6 wks & 6 months	1, 0, 1

R: randomization; B: blinding; W: withdrawals; NA: not available; ADL: activity of daily living; AROM: active range of motion; CPM: continuous passive motion; exs: exercise; POD: postoperative day; PROM: passive range of motion; PT: physiotherapy; Rx: treatment; TKA: total knee arthroplasty.

Table 2. Excluded trials.

Study	Reason for Exclusion
Aubriot[35]	No standard deviation
Beaupré[15]	Mixed population
Davis[18]	Not enough statistical data
Haug[36]	Combined electrical stimulation
Johnson[37]	No standard deviation
Kim[38]	Head-to-head
Lau[39]	No. of patients in each group missing
Lynch[40]	No standard deviation
Maloney[41]	Mixed population
Odenbring[42]	Not TKA subjects
Rasti[43]	Literature review
Simkin[44]	Not enough statistical data
Tremblay[50]	Not enough statistical data
Ververeli[45]	Not an RCT
Worland[46]	Both groups received CPM
Yashar[47]	Mixed population
Young[19]	Not enough statistical data

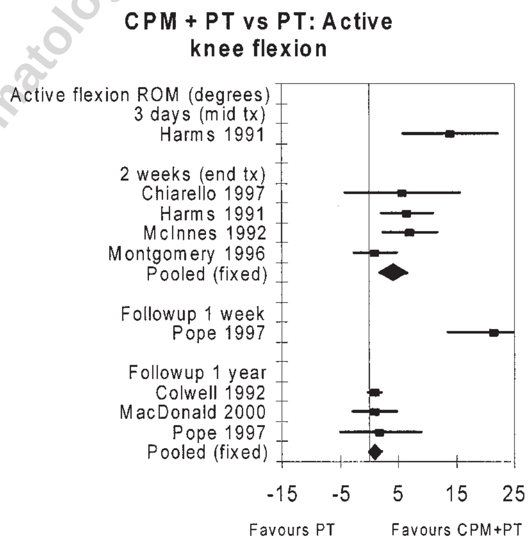

Figure 1. Statistical significance determined by a weighted mean difference and confidence interval of 95% for active ROM. tx: treatment.

outcomes of pain medication intake (WMD –4.18 mg, 95% CI –7.86 to –0.49) and knee swelling (WMD pooled –1.79, 95% CI –2.05 to –1.53)[5,30]. However, clinically important benefit was not achieved for any of the outcomes (analgesic use, 1–52 mg difference; knee swelling, 2–5% difference), and significant problems with heterogeneity of data existed for the comparison of knee swelling.

Pooled analysis revealed that CPM did not significantly improve passive knee flexion at end of treatment or at 6 weeks, 3 months, or 6 months of followup (Figure 4). For the outcome of passive knee extension, 3 trials were pooled (Chiarello, *et al* 1997[7], Kumar, *et al* 1996[29], McInnes, *et al* 1992[5]) and were homogeneous for comparison. Two trials (Chiarello, *et al* 1997[7], McInnes, *et al* 1992[5]) measured fixed flexion deformity, while the third measured passive knee extension (Kumar, *et al* 1996[29]). Passive extension and fixed flexion deformity were considered to be the same outcome as they both represent the limit of available knee extension. Results for passive knee extension at end of treatment were not found to be statistically significant (WMD 0.49°, 95% CI –0.99 to 1.97). For the outcome of active knee extension (Chiarello, *et al* 1997[7], McInnes, *et al* 1992[5]) only 2 trials could be pooled for analysis with 113 patients included. Neither result was found to be statistically significant (WMD –1.06°, 95% CI –7.53 to 5.40; Figure 5). However, a clinically important benefit was shown for passive knee extension (18% to 95% relative difference[27,30]) and flexion deformity (23% relative difference, Pope, *et al* 1997[32]) despite the statistical insignificance.

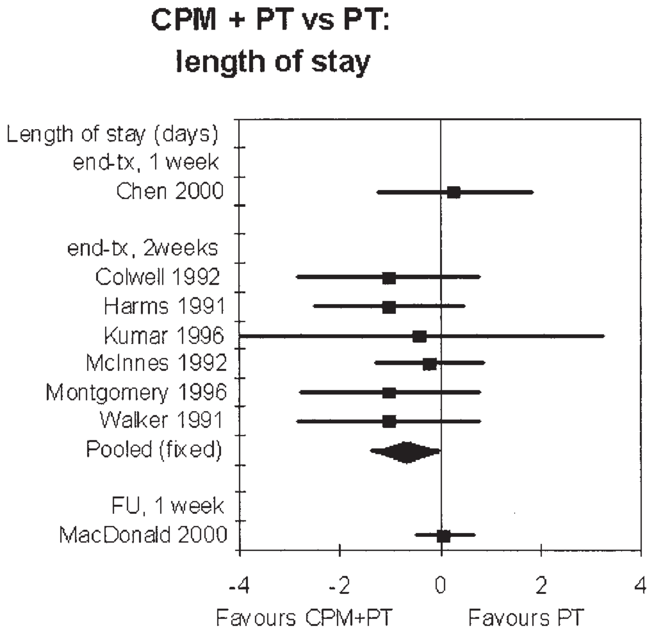

Figure 2. Statistical significance determined by a weighted mean difference and confidence interval of 95% for length of stay. tx: treatment.

Results from individual studies. Pooled analyses were not possible for several aspects of this review. CPM combined with PT versus PT alone produced statistically insignificant results for the outcome of pain as measured by a VAS at mid-treatment — one week (Montgomery and Eliasson 1996[30]) and end of treatment — 2 weeks (McInnes, *et al* 1992[5]) or as measured by the proportion of patients with pain at the end of treatment. In addition, no clinically important benefit was shown for pain at end of treatment as measured by a VAS (2% difference, McInnes, *et al* 1992[5]).

Additional comparisons of CPM combined with PT versus PT alone found varying results. At the end of treatment, no statistically significant differences were found for the outcomes of number of patients with ROM improvement (Nielsen, *et al* 1988[31]), presence of an extension lag (degrees) (Nielsen, *et al* 1988[31]), knee circumference (Chen, *et al* 2000[4]), or quadriceps strength (WMD 1.60, 95% CI –1.88 to 5.08) (McInnes, *et al* 1992[5]). For the outcome of extension/flexion deformity, statistically significant results in favor of CPM combined with PT were found at mid-treatment (WMD –1.42, 95% CI –2.69 to –0.15) and at the end of treatment (WMD –3.80, 95% CI –6.04 to –1.56) (Harms and Engstrom 1991[1], Figure 6). However, these results were not significant after one week or one year of followup (Pope, *et al* 1997[32], Figure 6). In addition, no clinically important benefit was shown for global extension/flexion deformity (5% relative difference, Harms and Engstrom 1991[1]).

A statistically significant benefit was also not demonstrated for the outcome of function as measured by a 0 to 70 scale (Pope, *et al* 1997[32]), or using the Knee Society Score (MacDonald, *et al* 2000[14]) at one year followup, or by the Health Assessment Questionnaire at 6 months followup (McInnes, *et al* 1992[5]). Meanwhile, statistically significant results in favor of the treatment group were found on time to achieve 90° flexion (days) at the end of 2 weeks of treatment (WMD –4.70, 95% CI –7.37 to –2.03, Vince, *et al* 1987[33]).

For the comparison of CPM combined with PT versus splinting combined with PT, one trial (Johnson 1990[28]) was included; 102 patients were included for comparison. Outcomes were assessed at end of treatment (one week), and followup (2 weeks, 6 weeks, 3 months, 6 months, and one year). Measuring ROM into knee flexion (Figure 7), statis-

Table 3. Example of a relative difference (clinical relevance) calculation for a weighted mean difference outcome.

Study	Treatment Group	Outcome	No. of Patients	Baseline Mean	End of Study Mean	Absolute Benefit	Relative Difference in Change from Baseline, %
Harms and Engstrom[1]	CPM + PT	Active knee flexion (degrees), mid treatment - 1 week	55	103.7	68	25.3	23
	Control		58	115.0	54.0		
Chiarello[7]	CPM + PT	Active knee flexion (degrees), end of treatment - 2 weeks	11	95.5	77.1	22.3	22
	Control		10	112.1	71.4		
Pope[32]	CPM + PT	Active knee flexion (degrees), followup - 1 week	18	101.8	78.3	25.5	25
	Control		18	105.8	56.8		

CPM: continuous passive motion; PT: physical therapy.

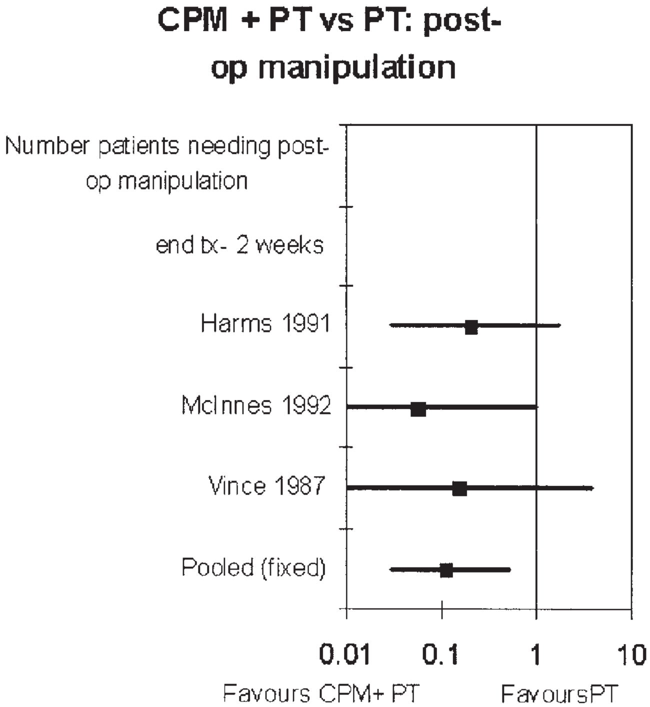

Figure 3. Statistical significance determined by a risk difference calculation for an odds ratio outcome: postoperative manipulation. tx: treatment.

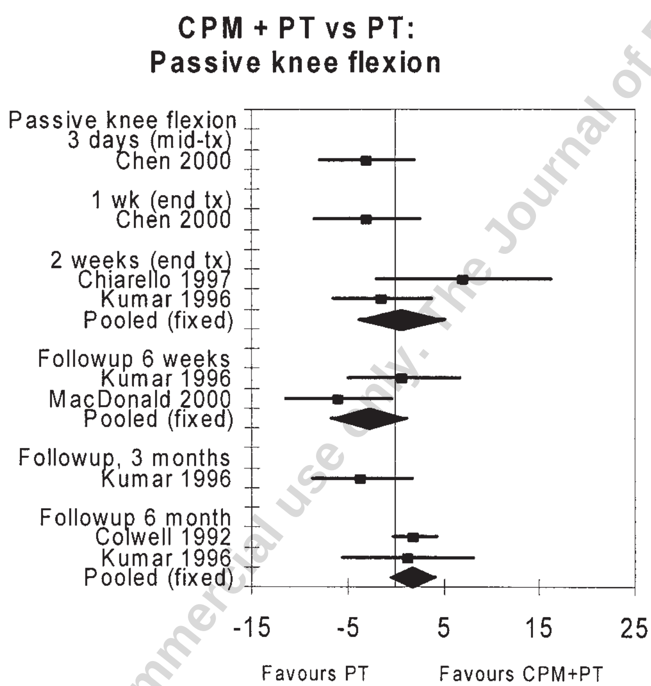

Figure 4. Statistical significance determined by a weighted mean difference and confidence interval of 95% for passive knee flexion. tx: treatment.

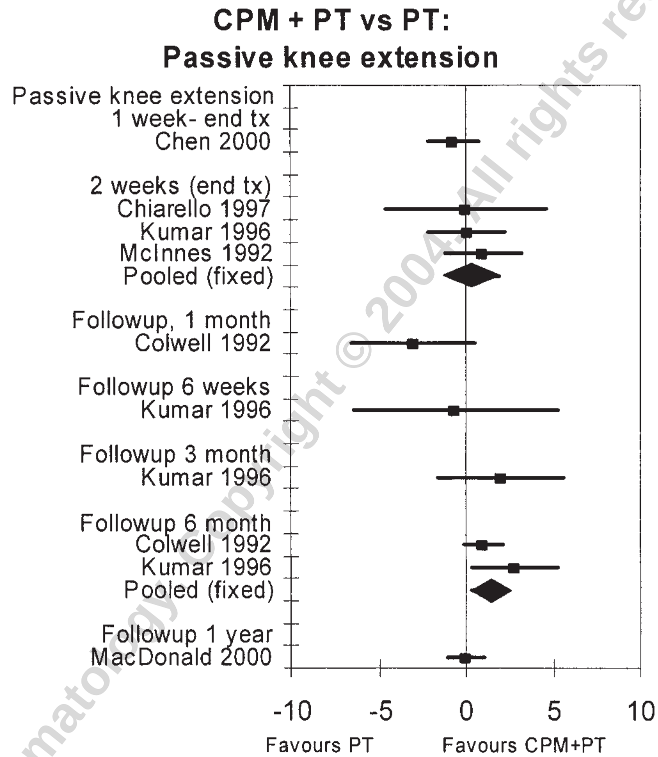

Figure 5. Statistical significance determined by a weighted mean difference and confidence interval of 95% for passive knee extension. tx: treatment.

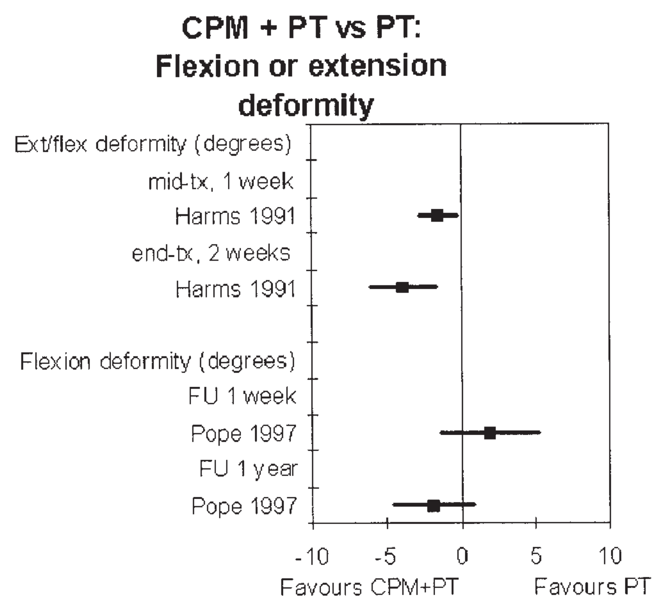

Figure 6. Statistical significance determined by a weighted mean difference and confidence interval of 95% for flexion and extension deformity. tx: treatment, FU: followup.

tically significant results favoring the CPM group were found at end of treatment (WMD –16.00°, 95% CI 10.52 to 21.48) and followup at 2 weeks (WMD –10.00°, 95% CI 4.35 to 15.65), 6 weeks (WMD –8.00°, 95% CI 1.32 to 14.68), 6 months (WMD –7.00°, 95% CI 0.60 to 13.40), and one year (WMD –9.00°, 95% CI 7.63 to 10.37). At 3

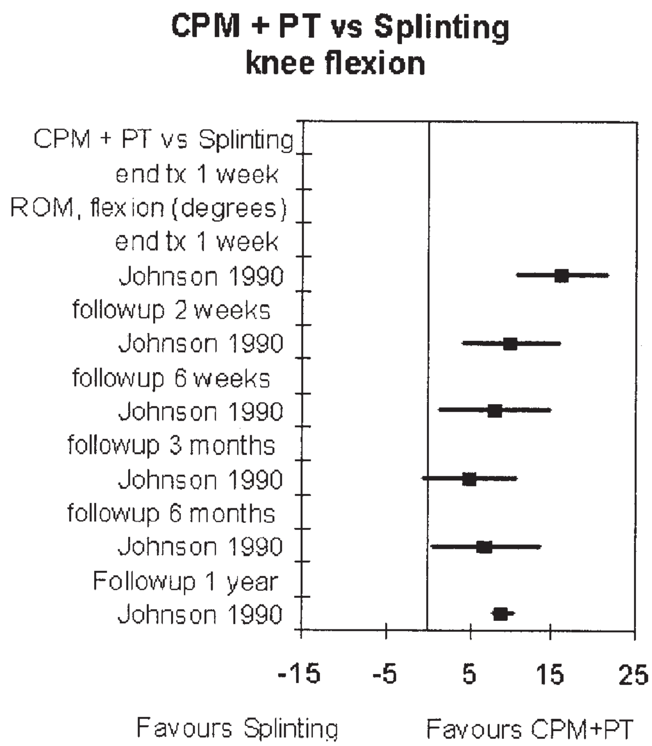

Figure 7. Statistical significance determined by a weighted mean difference and confidence interval of 95% for knee flexion. tx: treatment.

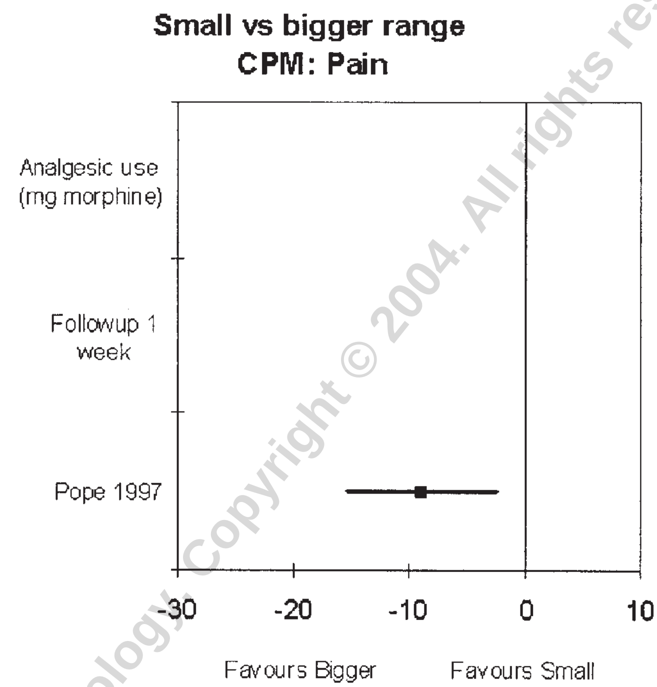

Figure 8. Statistical significance determined by a weighted mean difference and confidence interval of 95% for knee pain. tx: treatment.

months, results favored the CPM group (WMD –5.00°, 95% CI –0.64 to 10.64), but were found not to be statistically significant. Comparing CPM and PT versus splinting for flexion deformity and extension lag deformity, no statistically significant results were found.

For the comparison of short-time CPM application versus long-time CPM application (results not shown), no statistically significant results were found for the outcomes of active knee flexion, presence of a fixed flexion deformity, analgesic use, or total knee ROM at end of treatment (Chiarello, *et al* 1997[7]). However, only 20 patients were included in this comparison. As well, no clinically important benefits were found for flexion ROM in comparing short-time versus long-time CPM application.

For small-range versus big-range, no statistically significant results were found for active ROM into knee flexion, total ROM, flexion deformity, or function at one week and one year followup (Pope, *et al* 1997[32]). However, statistically significant results were obtained for analgesic use at one week followup favoring a larger range (WMD –8.90, 95% CI –15.36 to –2.44, Pope, *et al* 1997[32], Figure 8).

In addition, no statistically significant results were found comparing low-range CPM application to high-range CPM application for the outcomes of analgesic use, length of hospital stay, or knee range of motion at end of treatment or followup at 6 weeks and one year (MacDonald, *et al* 2000[14], Pope, *et al* 1997[32]). In addition, results for function as measured using the Knee Society Score (0–200: WMD 1.0, 95% CI –8.05 to 10.05, MacDonald, *et al* 2000[14]) were not significant. Despite the lack of statistical significance, a clinically important benefit was demonstrated for pain medication intake (16 mg difference, Table 5) favoring the high-range CPM group. However, no clinically important benefit was shown for knee flexion ROM (relative difference 2%) or length of hospital stay.

For the comparison of CPM versus lower limb mobility training combined with PT, no statistically significant results were found on the outcomes of pain, active knee flexion, active knee extension, passive knee extension, and gait speed (results not shown)[16]. However, only 19 patients were included for comparison. Results were measured at the end of treatment (one month).

DISCUSSION

The results from this metaanalysis suggest that CPM combined with PT interventions is effective at increasing active knee flexion 2 weeks post-knee arthroplasty relative to physiotherapy intervention alone[1,5,7,30]. However, the clinical significance of an additional 4° of knee flexion can be questioned. Adequate ROM of the knee, particularly in flexion, is important for performing mobility tasks such as walking, transfers, and activities of daily living. A minimum of 65° of knee flexion is required in the swing phase of normal gait, 90° of flexion is required to descend stairs, and at least 105° is required to rise from a toilet or low chair[12]. Due to its functional importance, knee ROM was a primary out-

Table 4. Example of a risk difference (clinical relevance) calculation for an odds ratio outcome.

Study	Group	Outcome	No. Observed	Total N	Risk Occurrence, %	Risk Difference, %
McInnes[5]	CPM + PT	No. patients needing post-operative manipulation	0	51	0	–18
	PT		8	51	18	

CPM: continuous passive motion; PT: physical therapy.

Table 5. Clinical relevance for low range versus high range continuous passive motion (CPM).

Study	Treatment Group	Outcome	No. of Patients	Baseline Mean	End of Study Mean	Absolute Benefit
MacDonald[14] 2000	Low range CPM (0 to 50 degrees)	Analgesic use (mg)	40	0	88	16%
	High range CPM (70 to 110 degrees)		40	0	72	

come. Results from this metaanalysis suggest, however, that although CPM may produce small changes in active knee flexion range in the short term it does not result in additional range over the long term, one or 2 years post-surgery.

Statistically significant results were also found for the outcome of length of hospital stay. This metaanalysis suggests that patients who receive CPM in addition to PT are discharged home from the hospital earlier than those who receive PT treatment alone. In the current age of hospital cutbacks and limited resources, even small reductions in length of hospital stay after a surgical procedure may be important. Length of hospital stay was also a primary outcome for this metaanalysis.

CPM in addition to physiotherapy intervention also reduced the number of postoperative knee manipulations required relative to PT alone. It has been suggested in related research that the greatest benefit of CPM appears to be its ability to decrease the number of knee manipulations[5]. Manipulation is used to facilitate the postoperative rehabilitation program for patients with painful, limited ROM of the knee[12]. However, manipulation is a painful process and an added complication to the initial surgery. Therefore, any reduction in the number of procedures required is beneficial to both the surgeon and the patient; however, the absolute reduction in risk will depend on the baseline risk.

No statistically significant difference was found for the outcome of active or passive knee extension. However, this is not surprising, as CPM was designed to improve knee flexion[7]. It has been suggested that an active hold at the point of maximum extension, activating the quadriceps, would be necessary while utilizing the CPM machine in order to enhance active extension[7].

Information on the outcome of pain is limited. It has been suggested that rhythmic joint movement inhibits the pain-spasm reflex[48]. However, these results were not supported by the limited data available in this metaanalysis.

Information biases were identified in several trials[28,30]. Heterogeneity of results was also a problem for several outcomes. In several trials the ROM measurements were not specified as being active or passive. These measures need to be performed and reported in a standardized manner to allow appropriate comparisons. Heterogeneity or variability may have been introduced in the outcomes measured, the type of implants used (cemented vs uncemented), and the patient diagnosis. Under ideal circumstances, interventions are to be delivered in a blinded fashion. However, in many instances it is impossible to blind patients or clinicians when using physical interventions. This, however, could introduce bias into the study. Due to the limited sample size, subgroup analyses could not be performed based on low methodological quality (2/5). This could introduce bias into the results.

Protocols were another area in which bias may have been introduced. Protocols differed from trial to trial and in some cases, treatment parameters were not reported adequately. For the main comparison of CPM combined with PT versus PT alone, 5 studies (Chiarello, *et al* 1997[7], Harms and Engstrom 1991[1], McInnes, *et al* 1992[5], Nielsen, *et al* 1988[31], Vince, *et al* 1987[33]) provided identical PT treatment to the experimental and control groups, while 4 studies (Colwell and Morris 1992[27], Kumar, *et al* 1996[29], Montgomery and Eliasson 1996[30], Walker, *et al* 1991[34]) were found to have provided one group additional PT. In addition, there is no consensus on the clinical application characteristics such as selected ROM for treatment, treatment duration, or intensity of application. Several studies (Chiarello, *et al* 1997[7], MacDonald, *et al* 2000[14], Pope, *et al* 1997[32]) attempted to compare CPM duration and treatment ROM. However, data could not be pooled and the sample size was low for individual trials. Finally, PT interventions were not uniform, since all studies provided a different PT intervention. It is not clear what effect these differences may have on the reported efficacy of CPM.

Another important factor that may influence results is the use of preoperative exercises as part of the rehabilitation protocol for KA. There is no consensus regarding the effect of preoperative PT in total KA; however, it has been suggested that the decrease in muscle strength observed postsurgery may be reduced through implementation of a preoperative PT regime[49].

The failure to use validated outcome measures is also a limitation of this analysis. No functional activities (sit to stand, supine to sit, ambulation, stair climbing, ambulation velocity, functional status) were assessed using validated outcome measure scales in any of the analyzed studies. Since the focus of PT treatment is aimed increasingly at functional activities, the outcome measures used to assess CPM should reflect this situation.

It has been stated by many orthopedic specialists that good surgical management and postoperative outcome of a patient are dependent upon proper rehabilitative input[8]. In other words, exercise is a key element in the success rate of hip and knee arthroplasty[8]. Whether it is the use of a CPM machine or a physical therapist, passive ROM exercises are suggested to begin the third postoperative day[8]. This act of passive ROM maintains extension/flexion activity in the knee and helps the muscles reeducate themselves[8]. Since full knee extension is one of the most difficult tasks for the patients to achieve, initiating exercise in extension and assisting knee flexion is more easily accomplished passively than actively attempting to achieve full extension[8]. The use of a CPM machine to achieve passive ROM is appropriate. During the second postoperative week, isometric exercises begin to strengthen both quadriceps[8]. These exercises are followed by gait training[8]. Here the benefits of CPM may come into play, since the importance of early adequate knee ROM determines the rate at which the patient achieves normal gait. It is clear that postoperative exercise plays a vital role in the rehabilitation rate of the patient. As long as the benefits of CPM outweigh the costs, it should be considered a viable rehabilitative intervention.

CPM combined with conventional PT may be utilized to produce small increases in active knee flexion ROM, to decrease length of hospital stay, and to reduce the risk of manipulation following total knee arthroplasty. These potential benefits will need to be carefully weighed against the inconvenience and expense of CPM. Further studies are required to assess the effectiveness of CPM by altering treatment variables. For example, modifying the total duration of treatment and the intensity of CPM interventions, and using different types of patients at various disease states would aid in defining the most efficacious CPM treatment regime. In addition, the effect of CPM combined with and compared to various other physiotherapy interventions should be studied further.

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APPENDIX

Search strategy for identification of studies

1 exp arthritis, rheumatoid/
2 arthritis, juvenile rheumatoid/
3 1 not 2
4 (rheumat$ adj arthrit$).tw.
5 3 or 4
6 osteoarthritis, knee/
7 osteoarthritis/
8 osteoarthritis.tw.
9 knee.tw,hw.
10 7 or 8
11 9 and 10
12 6 or 11
13 5 or 12
14 arthroplasty, replacement, knee/
15 knee prosthesis/
16 total knee.tw.
17 or/14-16
18 exp physical therapy/
19 motion therapy, continuous passive/
20 continuous passive motion.tw.
21 gait therapy.tw.
22 exercise therapy.tw.
23 (ice or cold).tw.
24 therapeutic exercise/
25 "heat/cold application"/
26 or/18-25
27 17 and 26
28 random$.tw.
29 control$.tw.
30 (compare or comparative).tw.
31 experiment$.tw.
32 exp clinical trials/
33 comparative studies/
34 exp prospective studies/
35 prospective.tw.
36 retrospective.tw.
37 cross-section$.tw.
38 cross sectional studies/
39 exp case control studies/
40 or/28-39
41 27 and 40
42 27 not 41

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