A Comparison of 2 Continuous Passive Motion Protocols After Total Knee Arthroplasty

A Controlled and Randomized Study

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Abstract: Effect of continuous passive motion (CPM) protocols on outcomes after total knee arthroplasty. In this prospective randomized controlled study, 147 patients were assigned to 1 of 3 treatment groups: CPM from 0° to 40° and increased by 10° per day, CPM from 90° to 50° (early flexion) and gradually progressed into full extension over a 3-day period, and a no-CPM group. The CPM was administered twice a day for 3 hours over a 5-day period. All patients participated in the same postoperative physiotherapy program. Patients were assessed preoperatively, day 5, 3 months, and 1 year postoperatively. The early flexion group had significantly more range of flexion than both the standard and control groups at day 5. There was no significant difference between the groups for any other variable tested at any time frame. **Key words:** total knee arthroplasty, CPM, rehabilitation, outcomes.

Continuous passive motion (CPM) can be applied to the knee joint by a mechanical device that moves through a preset range of motion (ROM) at a selected velocity. Salter [1-3] researched and developed the concept of CPM after experiments in rabbits where he demonstrated that articular cartilage defects and intra-articular fractures healed better when CPM was used. He believed that immobilization was detrimental to joints, motion was beneficial, and CPM minimized forces across damaged joint surfaces. For motion to be continuous, it has to be applied passively, as muscles would fatigue with continuous active movement of a joint [1-3].

Continuous passive motion devices have been widely used as an adjunct to physiotherapy after total knee arthroplasty (TKA) for the past 2 decades [4]; however, there is controversy as to whether it is useful. Numerous studies have been carried out on the effects of CPM after TKA. Parameters such as knee ROM, length of stay (LOS), wound healing, and knee function have been evaluated with contradictory results. Some [4-12] recommend CPM, whereas others [13-18] have found it to be of little value in rehabilitation of the knee after TKA. The differences in outcomes can be explained partly by variations in study design and methodology. Differences in the duration of application of CPM ranging from as little as 4 hours a day [15] to almost 24 hours per day [19] have been reported. Some studies [13,15,19-21] have included small samples, which may affect validity.

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The primary motions of the knee joint are flexion and extension [22]. Traditionally, CPM has been administered by moving the knee from full extension through increasing degrees of flexion [19]. For the purposes of this paper, we refer to this method as standard CPM. More recently, an early flexion regime has been advocated in which the knee is progressively moved from flexion to extension [21,23-25]. Jordan et al [23] conducted a non-randomized trial comparing standard and early flexion CPM after primary TKA. Early flexion resulted in decreased LOS, decreased hospital costs, and increased ROM at 1 year. On the other hand, MacDonald et al [24] found no statistical differences, at any measured interval, between standard and early flexion CPM regimes and a no-CPM group. Their randomized trial evaluated cumulative analgesic requirements, ROM, LOS, and Knee Society scores. The authors acknowledge, however, that a longer trial of CPM may have benefited these patients as CPM was only utilized for a maximum of 24 hours postoperatively. Our study is the first prospective randomized controlled trial comparing 2 CPM protocols where the CPM has been administered over a significant period of time.

Aims of The Study

The aims of the research were to assess

1. The effect of CPM after TKA on knee ROM, length of hospital stay, wound healing, knee function, and perceived health status.
2. Whether early flexion CPM produces a better outcome than a standard CPM regime or control with no CPM.

Hypotheses

1. Early flexion CPM would be more effective than standard CPM and no CPM in achieving 90° flexion and 0° extension of the knee, decreasing LOS, and improving knee function.
2. There would be no difference in wound healing between the 3 groups.

Materials and Methods

Study Design

Patients were allocated by a block randomization procedure into 1 of 3 groups:

- Group A: Standard CPM regime
- Group B: Early flexion CPM regime
- Group C: No CPM (the control group).

The operating surgeon and the independent assessor were blinded to the group allocation of the subjects, and the subjects were blinded to the study hypotheses. To determine the number of subjects required to achieve statistical significance, a power analysis was performed. The sample size was based on 3 pairwise comparisons of the groups each at a significance level of 1.7% (=5%/3) at 5 days after operation. To detect a difference of 7° knee ROM between groups with an SD of 10° within each group, the study needed to recruit 43 subjects per group to achieve 80% power. It is generally accepted that goniometric measurements of the knee have an error rate of ±5° [26]. If a 7° ROM difference existed in our study, this would represent a true difference between the groups A, B, and C rather than a difference due to measurement error.

Study Cohort

One hundred forty-eight patients were initially recruited into the study. One patient was subsequently excluded from the study, as we were unable to achieve 90° knee flexion on the CPM device in recovery. Results were analyzed for the remaining 147 patients. They were admitted to The

Table 1. Demographic Information

Group	A (Standard CPM)	B (Early flexion CPM)	C (No CPM)	Total
Patients (N)	47	48	52	147
Gender (% female)	72.3	64.6	67.3	
Mean age (y)	70.7	71.4	71.7	
Genesis I prosthesis (N)	7	5	7	19
Genesis II prosthesis (N)	40	43	45	128
Cruciate retained (N)	43	41	46	130
Posterior stabilized (N)	4	7	6	17
Patella resurfaced (N)	22	24	28	74
Patella not resurfaced (N)	25	24	24	73

Table 2. Physiotherapy Program

Commencing day 1 postoperatively
Ankle dorsi flexion/plantar flexion
Static quadriceps progressing to quadriceps over a fulcrum (active-assisted to active)
Static gluteals
Gentle active/active-assisted hip knee flexion on a powder board
Chest care as indicated
On day 2
Exercises as above progressing to independent straight leg raise
Transfer out of bed and sit out of bed in a chair if tolerated
On day 3
Exercises as above
Knee flexion over the side of the bed
Ambulation with gait aids, full weight bearing initiated
Day 4 onward
Knee flexion and extension ROM and strength, gait reeducation, and steps practiced. Patients with a quadriceps lag greater than 10° ambulated with EKS until adequate knee control obtained
Program conducted half an hour twice a day except on weekends when patients were seen once a day

Alfred, Melbourne, between January 1997 and July 2000 for surgery using a Genesis I or II prosthesis (Smith and Nephew, Memphis, Tenn). All had a primary diagnosis of osteoarthritis. Those excluded had bilateral TKA performed at the same time, revision of TKA, rheumatoid arthritis, or hemophilia. Demographic information is described in Table 1.

Surgical Procedure

Initially, Genesis I TKA prostheses were used exclusively in the study, but this protocol changed to Genesis II when the prosthesis became available. Ten experienced surgeons working in 2 surgical units at The Alfred performed the operations. Trainee registrars supervised by the senior surgeons performed some procedures. An anteromedial or midline incision was used, and the knees were approached through a medial parapatellar capsular incision. Cruciate retaining and posterior-stabilized prostheses were again used at the discretion of the operating surgeon (Table 1). The patella was not routinely resurfaced, at the discretion of the treating surgeon (Table 1).

Two Redivac drains were inserted and later removed at 48 hours. An attempt was made to standardize the anesthetic protocol, but because of individual patient requirements this was not possible. There was no significant difference between the groups A, B, and C according to anesthetic techniques.

Physiotherapy Program

All patients participated in a standardized physiotherapy program (Table 2).

CPM Protocols

Group A: Standard

Day 1 (operative day): CPM machine applied in the recovery room set at 0° to 40° for 3 hours. The CPM was removed and extension knee splint (EKS) applied to maintain the knee in extension overnight.

Day 2: CPM machine applied early in the morning at 0° to 45° for 3 hours and reapplied late afternoon at 0° to 50° for 3 hours. Extension knee splint applied overnight.

Days 3 to 6: CPM increased 5° twice a day until ceased on day 6. Extension knee splint applied overnight.

Group B: Early Flexion

Day 1 (operative day): CPM machine was applied in the recovery room at 90° to 50° knee flexion. The CPM machine was cycled between 90° and 50° flexion for 3 hours. Knee rested at 90° flexion on the machine overnight.

Day 2: CPM between 90° and 40° for 3 hours. Continuous passive motion was turned off but remained in situ with the knee resting in 90° flexion on the machine. Continuous passive motion applied

Table 3. Mean Knee Flexion

CPM Group	A (Standard)		B (Early Flexion)		C (None)	
Knee ROM	Active Flexion	Passive Flexion	Active Flexion	Passive Flexion	Active Flexion	Passive Flexion
Time						
Preoperative	102.5°	108.3°	102.5°	108.6°	102.6°	108.8°
Day 5	*69.4°*	*75.3°*	*78.7°*	*86.6°*	*64.9°*	*71.2°*
3 mo	95.0°		95.8°		93.7°	
1 y	102.7°		102.5°		102.9°	

Table 4. Mean Passive Knee Extension (Fixed Flexion Deformity) and Quadriceps Lag

CPM Group	A (Standard)		B (Early Flexion)		C (None)	
Knee ROM	Quadriceps Lag	Passive Extension	Quadriceps Lag	Passive Extension	Quadriceps Lag	Passive Extension
Time						
Preoperative	2.0°	9.3°	2.2°	9.7°	1.8°	10.0°
Day 5	12.1°	6.2°	11.6°	7.7°	12.9°	6.5°
3 mo	2.3°	7.2°	3.2°	8.7°	1.6°	6.4°
1 y	1.0°	3.6°	1.5°	3.4°	0.1°	4.1°

late afternoon at 90° and 30° flexion for 3 hours, and the knee was rested in 90° flexion overnight.

Day 3: CPM between 90° and 20° for 3 hours in the morning and between 90° and 10° for 3 hours in the afternoon. The CPM was then removed and EKS applied overnight.

Day 4: CPM between 90° and 0° for 3 hours in the morning and afternoon. The CPM was removed and the EKS applied overnight.

Days 5 to 6: CPM between 90° and 0° for 3 hours in the morning and afternoon. Extension knee splint in bed at night. Continuous passive motion ceased at the end of day 6.

Group C: No CPM

EKS in theater and remained in situ when in bed overnight and removed during the day. The patient received no CPM.

Measurements

Data were collected from each patient in the preoperative period (at a preadmission clinic) and postoperatively at 3 months and 1 year.

1. Knee flexion, extension, and quadriceps lag were measured in degrees with a standard universal goniometer [26]. These measurements were also taken on the fifth postoperative day.
2. Knee function was assessed using the functional component of the Knee Society Clinical Rating System [27].
3. Perceived health status of each patient was assessed using the Short-Form 12-Item Health Survey (SF-12) [28].

On the fifth postoperative day, wound healing was evaluated using the following classification system: aseptic wound discharge, aseptic wound dehiscence, superficial infection, or deep infection [8]. Wound healing was considered to have failed if there was infection or aseptic dehiscence of the wound.

Hospital (inpatient) LOS was recorded in days in the acute and rehabilitation settings.

Analgesic requirements were not controlled in this study. If one patient group experienced significantly more pain than the others, this could influence postoperative recovery and, hence, have an impact on the results. However, a specialized pain team monitored these patients postoperatively, and pain levels were recorded using a visual analogue scale twice a day when the machine was not cycling, for the first five postoperative days.

Data Analysis

Means and standard errors were computed for each group at each time point (baseline, 5 days, 3 months, 1 year). Univariate analysis was conducted using χ^2 tests for categorical variables and analysis of variance for continuous normally distributed data. Where data were found to be log-normally distributed (LOS, passive extension, and quadriceps lag), a log transformation was performed before analysis. Multivariate analysis was conducted using a repeat measures analysis of covariance adjusting for baseline prognostic factors. Wound healing and perioperative anesthetic requirements were evaluated using χ^2 tests for equal proportion. Perceived health status, measured on an ordinal scale, was evaluated using nonparametric analysis.

Results

Range of Motion

Preoperatively, there were no statistically significant differences between the 3 groups in mean

Table 5. Length of Hospital Stay (Acute) in Days

Group	N	Geometric Mean LOS
A (Standard CPM)	47	8.8
B (Early flexion CPM)	48	8.1
C (No CPM)	52	8
P	.51	

Table 6. Length of Hospital Stay (Rehabilitation) in Days

Group	N	Geometric Mean LOS
A (Standard CPM)	32	18.7
B (Early flexion CPM)	29	17.8
C (No CPM)	39	15.8
P	.58	

passive or active flexion (Table 3), or in quadriceps lag or passive extension (Table 4). At day 5 postoperatively, there were significant differences between the groups in active flexion (P = .008 and P < .0001) and passive flexion (P = .007 and P < .0001) (Table 3). At 3 months and 1 year postoperatively, there were no significant differences between the groups in active flexion, passive extension, and quadriceps lag. (Tables 3 and 4).

Length of Stay

Patients were discharged home when the multidisciplinary team assessed them as being able to manage safely in their home environment. Some patients were transferred to a rehabilitation facility for ongoing therapy before discharge. Length of acute hospital stay (in days) for the 3 groups was 8.8 for group A, 8.1 for group B, and 8.0 for group C. There was no significant difference between the groups (P = .51) (Table 5). One hundred patients went to a rehabilitation facility. Of these, 32 were in group A (geometric mean LOS = 18.7 days), 29 were in group B (geometric mean LOS =17.8 days), and 39 were in group C (geometric mean LOS =15.8 days). There was no significant difference between the groups (P = .58) (Table 6).

Table 7. Visual Analogue Scale Scores

Group	Day 1	Day 2	Day 3	Day 4	Day 5	Mean Score Over 5 days
A (Standard CPM)	4.1	3.7	3.5	3.4	3.2	3.6
B (Early flexion CPM)	3.2	2.9	2.5	2.3	2.4	2.6
C (No CPM)	3.5	3.1	3.1	3.1	2.9	3.1
P						<.0001

Table 8. Wound Healing

Wound Healing (5th Postoperative Day)	Yes	(N)	No	(N)
A (Standard CPM)	93.5%	43	6.5%	3
B (Early flexion CPM)	98%	47	2%	1
C (No CPM)	92.3%	48	7.7%	4
P	.44			

Pain

The mean of the 10 visual analogue scale scores for each patient was calculated; hence, a score out of 10 was determined. There are statistically significant differences in mean pain scores between groups A and B (P < .0001), groups B and C (P = .005), and groups A and C (P = .013) (see Table 7). These differences are, however, not clinically significant as they represent less than or equal to 1 point on a 10-point scale.

Wound Healing

Healing rates for the groups are represented in Table 8. A χ^2 analysis revealed that there was no significant difference between the groups in wound healing rates (P = .44).

Knee Function

Knee function was assessed using the Knee Society Clinical Rating System [29]. There was no significant difference between the 3 groups preoperatively, at 3 months or at 1 year (Table 9).

Perceived Health Status Measure SF-12

The SF-12 is a shorter version of the SF-36 used to reproduce its Physical Component Summary (PCS) and Mental Component Summary (MCS) scores [28]. There was no significant difference between the groups in PCS and MCS preoperatively, nor at 3 months and 1 year postoperatively.

Table 9. Knee Society Scores: Function (Means and SEs)

CPM group	A	B	C
Preoperative	40.1 (3.0)	42.1 (3.0)	45.3 (2.8)
3 mo	51.9 (3.6)	52.2 (3.2)	56.0 (3.0)
1 y	57.9 (3.6)	59.6 (3.4)	58.1 (3.1)

Discussion

Flexion: Early Postoperative Phase

The present study demonstrated a significant improvement in active and passive knee flexion at day 5 postoperatively in group B compared to groups A and C. McInnes et al [9] reported that standard CPM significantly increased active flexion at 1 week postoperatively but not at 6 weeks. Harms and Engstrom [4] found knee flexion was increased in a standard CPM group when compared with a no-CPM group. Yashar et al [25] found a significant difference in passive knee flexion in favor of an early flexion group. Other studies have reported no significant differences [19-21].

Flexion: Late Postoperative Phase

At 3 months and 1 year postoperatively, there was no significant difference between the groups in active or passive knee flexion in our study. This is in agreement with the findings of other studies at 3-, 6-, and 12-month evaluations [17,19,24,25]. In contrast, Jordan et al [23] in a nonrandomized study reported that an early flexion CPM regime produced increased flexion ROM at 1 year compared with standard CPM.

The average active range of knee flexion in our study, at 1 year postoperatively, was 103° for all groups. This value is lower than the 112° average knee flexion reported by MacDonald et al [24] and Yashar et al [25]. The likely explanation for this difference is that postoperative ROM is influenced by preoperative ROM [30]. In our study, the patients were all public hospital patients and mean preoperative active flexion was 102.6° (Table 3). In a cohort treated privately, the average preoperative flexion was 111.5° and the postoperative flexion was 111.6°. MacDonald et al [24] reported a mean preoperative range of 106°, whereas Yashar et al [25] reported a mean preoperative ROM of 110°. The mean age of patients in our study was 71 years. In the study of MacDonald et al [24], the mean age was not stated, but patients older than 80 years were excluded, as were those with a greater than 15° fixed flexion deformity. In the study of Yashar et al [25], the mean age was 69 years. In our study, increased patient age and stiffer knees preoperatively may have contributed to the reduced range of movement.

Extension

We found no statistically significant differences between the groups in passive extension in the first postoperative week, as did previous authors [9,21]. In contrast, Harms and Engstrom [4] found that CPM resulted in a significant improvement in knee extension. In our study, we found no significant differences between the groups in passive knee extension at 3 months nor at 1 year. Other authors have reported the same finding [10,19,24,25].

Quadriceps Lag

We found no significant differences between the groups in quadriceps lag at day 5, 3 months, and 1 year postoperatively. Other authors [23-25] did not examine quadriceps lag in their publications. Ng and Yeo [21] found no significant differences between groups in active extension on the fifth postoperative day.

Length of Stay

There were no significant differences between the groups in acute or rehabilitation hospital inpatient LOS, which is in agreement with Yashar et al [25] and MacDonald et al [24], but is in contrast to the findings of the nonrandomized study on 100 TKA patients by Jordan et al [23]. The latter authors reported that the early flexion resulted in decreased LOS and decreased hospital costs and improved ROM at 1 year. Our acute hospital LOS for all groups was higher than that reported by MacDonald et al [24]. There are a number of possible reasons for this including patient demographics. MacDonald et al [24] excluded patients older than 80 years and those who were unable to ambulate 30 m and climb 10 steps. In our study, age was not an exclusion criterion and some of our patients were virtually wheelchair bound before surgery because of a long waiting list. These are important factors in outcome. Furthermore, MacDonald et al [24] excluded patients if they had fixed flexion deformities greater than 15°, whereas in our study 17 patients had deformities of that magnitude. Thus, over 10% of our subjects had severe degenerate disease of the knee preoperatively, which would have contributed to a slower recovery. Johnson [7,8] found LOS was significantly reduced after the use of standard CPM compared with control. However, others [4,9] have found no significant difference in LOS between standard and control groups. Local discharge policies and the availability of rehabilitation facilities also affect length of acute hospital stay.

Wound Healing

Johnson [7] reported that transcutaneous oxygen tension on the lateral aspect of the incision decreased as the knee flexed past 40°; hence, we were somewhat concerned about the risk of wound breakdown in the early flexion group. In the present study, the early flexion group knees were maintained in 90° flexion overnight for 2 nights, but there were no significant differences between the groups in wound healing when assessed on the fifth postoperative day, which agrees with Yashar et al [25]. Our early flexion group had fewer wound complications than the control or standard groups (Table 8). Ververeli et al [12] also found that there was no significant difference in wound healing between standard and no-CPM groups.

Knee Function

The functional component of the Knee Society Clinical Rating System [29] was used as a measurement tool in this study. It demonstrates good responsiveness when used to assess outcome after TKA [27]. Despite a 5-point difference in preoperative Knee Society function scores between control and standard CPM groups (Table 9), there were no statistically significant group differences preoperatively. In addition, there were no statistically significant differences at 3 months or 1 year between control and CPM treatment groups. Similarly, MacDonald et al [24] also found that there were no differences between the control and CPM groups preoperatively and at 1 year when evaluated using the Knee Society scoring system. McInnes et al [9] reported no significant differences between standard CPM and control groups in knee function at 6 weeks after TKA.

Perceived Health Status

The Medical Outcomes Study SF-12 includes 12 questions from the SF-36. No other authors evaluating the effects of CPM on TKA have used the SF-12. In the present study, we found no differences in SF-12 scores preoperatively, at 3 months or at 1 year between the 3 groups. However, the PCS for the control group was significantly worse at 1 year postoperatively compared to preoperatively (Table 10). The reason for this is not clear. The number of complications in the no-CPM group was not significantly different when compared to the CPM groups at 3 months and 1 year. Adequate test-retest reliability using the SF-12 was demonstrated by Ware et al [28]: PCS = 0.89 and MCS = 0.76. This measurement tool was designed for large group studies with patient populations greater than 500 [28]. Therefore, it may not be the most reliable tool to estimate perceived health status in clinical applications such as the present study.

Study Limitations and Suggestions for Future Research

Our patients attended a preadmission clinic where they received education, written information about TKA, and a personalized exercise program to be commenced before their operation. Attendance at this clinic may have influenced the results in favor of the no-CPM group. Postoperatively patients were given 2 half-hour sessions of physiotherapy daily during the week and 1 half-hour session on weekends. This intensive program is not readily available in all hospitals. The role of CPM in the early postoperative management of patients who are medically or psychologically impaired was not addressed in our study and may require further investigation. Colwell and Morris [19] found that isolating outliers made the LOS significantly different between a no-CPM group and a standard CPM group.

Statistical tests are for means and assess whether the means of different groups are statistically different. This conclusion fails to identify individuals or subgroups that may have benefited from the intervention. Thirty-three of the 147 patients evaluated in this study had a preexisting fixed flexion deformity (FFD) of 15° or more. We analyzed the day 5 postoperative results of these patients for the purpose of generating ideas for future research. Statistical analysis of this subgroup showed that these patients had statistically significant increases in quadriceps lag (P = .0005) and

Table 10. SF-12 Scores (Means and SEs)

Group	A (Standard CPM)		B (Early Flexion CPM)		C (No CPM)	
SF-12	PCS	MCS	PCS	MCS	PC	MCS
Preoperative	38.0 (2.0)	48.1 (1.8)	42.2 (2.0)	45.7 (1.8)	43.4 (1.8)	44.5 (1.7)
3 mo	39.4 (2.3)	50.4 (2.1)	38.4 (2.1)	53.3 (1.9)	39.5 (1.9)	54.1 (1.8)
1 y	43.8 (2.4)	54.3 (2.2)	40.0 (2.3)	54.4 (2.1)	37.8 (2.1)	54.3 (1.9)

passive extension loss ($P < .0001$) when compared to the rest of the group (patients with a FFD ≤10°). We also analyzed the FFD subgroup according to CPM group allocation (A, B, C). There were no statistically significant differences in quadriceps lag or passive extension loss between the groups. Unfortunately, the sample size was small and a larger sample of patients with clinically significant preexisting FFD would need to be evaluated to determine whether CPM makes a difference for some patients after TKA.

Conclusion

The results of this study show that an early flexion CPM regime is useful in achieving a better range of active and passive flexion in the early postoperative period after TKA, but did not result in decreased LOS. Length of stay is, however, multifactorial and influenced by social issues in addition to joint function. We were unable to demonstrate any significant difference between standard and early flexion CPM and control groups after discharge. There was no difference in wound healing rates, functional outcome, or perceived health status. From these results, we have been unable to justify the use of CPM as a routine rehabilitation tool in the public hospital setting after TKA. The role of CPM in the management of patients with difficult problems or in facilities where manpower is limited warrants further study.

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