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ΕΡΕΥΝΗΤΙΚΗ ΕΡΓΑΣΙΑ

The efficacy of continuous passive motion after total knee arthroplasty A three-group randomized controlled trial

OBJECTIVE To determine the effects of continuous passive motion (CPM), in conjunction with standard physiotherapy, after total knee arthroplasty (TKA), on the active range of motion of the knee and postoperative pain. **METHOD** The trial was conducted on 75 patients aged 50–80 years (Clinical Trial Identifier: ISRCTN91125056). The patients were allocated randomly into three groups of 25. The control group followed only the standard in-hospital postoperative physiotherapy intervention. The two study groups followed the physiotherapy intervention, and in addition a 6-day-application of CPM, for 30 minutes twice daily in the first group (CPM-30), and for 60 minutes twice daily in the second group (CPM-60). The range of knee's flexion and extension were recorded preoperative, and post-operative, at the 1st week (post-intervention) and 4th week (follow-up). The post-operative pain levels were evaluated on the 2nd (pre-intervention) and 8th (post-intervention) postoperative days, using the Pain Visual Analogue Scale (VAS). **RESULTS** At the 1 week postoperative, only the CPM-60 group had significantly greater flexion by 7.55° ($p=0.029$) than the control group. At the 4th postoperative week, the degrees of flexion in both intervention groups were statistically higher than in the control group (CPM-30 by 5.42° [$p=0.011$] and CPM-60 by 13.38° [$p<0.001$]). The CPM-60 group had a 7.96° greater range of active flexion compared to the CPM-30 group ($p<0.001$). No difference was observed between the three groups regarding the range of active extension or post-operative pain. **CONCLUSIONS** After TKA, the implementation of CPM for 60 minutes twice daily, in addition to the standard physiotherapy intervention, may significantly increase postoperative active knee flexion, but with no effect on knee extension or the pain levels.

Total knee arthroplasty (TKA) is recognized as the most effective and beneficial treatment of end-stage knee osteoarthritis.¹ TKA surgery is deemed successful when the patient's pain is reduced and the ability to perform daily activities is improved, postoperatively.² Patients who achieve pain-free mobilization and an adequate range of knee motion early after the operation, have been shown to attain a higher level of performance of functional activities.³ Physiotherapy intervention is initiated in the acute postoperative period,⁴ aimed at ultimately facilitating the return of the patients to an active lifestyle.⁵

Continuous passive motion (CPM) was introduced in the early 1980s,^{6–8} since when it has been added to the post-TKA physiotherapy intervention. The reported benefits of CPM

include reduction of postoperative pain, improved local circulation, and reduction of swelling and of the incidence of adhesions.⁹ Furthermore, the passive exercise provided by the CPM promotes early mobilization and an improved range of knee flexion; consequently, it enables active exercise and greater muscle strengthening.^{10–12} These benefits remain controversial, however, as the literature on CPM has not conclusively confirmed these results. Some studies demonstrated neither clinical differences between patients on whom CPM was used and those receiving standard physiotherapy,^{13–15} nor evidence of reduction in the level of postoperative pain.^{16–20} A Cochrane review²¹ reported evidence that the beneficial effects of CPM on the range of knee motion in the post TKA period are too small to be practically relevant.²¹ As the authors pointed out, however,

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ΑΡΧΕΙΑ ΕΛΛΗΝΙΚΗΣ ΙΑΤΡΙΚΗΣ 2020, 37(3):341–353

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Η αποτελεσματικότητα της συνεχούς παθητικής κινητοποίησης μετά από ολική αρθροπλαστική γόνατος: Τυχαίοποιημένη ελεγχόμενη δοκιμή 3 ομάδων

Περίληψη στο τέλος του άρθρου

Key words

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the trials included in this review implemented many different protocols for the administration of CPM.²¹ In some trials CPM was initiated directly after the TKA surgery,^{16,18} while in others it was applied days later.^{15,19,22} The CPM settings also differed between trials; in some trials, the settings were dictated by a protocol^{15,16,18,19} whereas in others they were determined either by the patient's comfort or at the discretion of the clinician.²² Moreover, the time duration of CPM application differed, ranging from 23 hours¹⁷ to 15 minutes.¹⁹ All these variables may have influenced the observed effects of CPM and could therefore prove difficult to generalize and apply to current clinical practice.²¹ There has been a lack of trials that compare the active range of knee motion between patients receiving standard physiotherapy and patients receiving both physiotherapy and CPM application.²³ The controversy surrounding the use of CPM in the acute postoperative period prompted us to evaluate the practice of CPM use and its effectiveness.

The preminent objective of the present clinical trial was to study the effects of a specific CPM protocol, in conjunction with physiotherapy intervention, on the acute postoperative range of active knee motion and on postoperative pain, after TKA. In addition, the probability of the duration of the study CPM protocol affecting the postoperative active range of knee motion and postoperative pain (pre-intervention versus post-intervention) was also explored.

MATERIAL AND METHOD

This was a 3-group randomized controlled trial (Clinical Trial Identifier: ISRCTN91125056), conducted in accordance with the ethical principles stated in the Declaration of Helsinki and its later amendments.²⁴ The study protocol was approved by the research committee of the Technological Educational Institute of Athens (current University of West Attica) and by the Scientific Research Council of the "KAT" General Hospital of Attica, Athens, Greece.

It was estimated that a sample size of 25 patients per group was required to ensure an 80% probability of detecting a difference of greater than 5 degrees (°) in the range of active knee flexion between the groups, at the 8th postoperative day, with a <1.7% significance (Bonferroni correction) in two-tailed testing. The analysis of the covariance model, with baseline measurements of the range of active flexion as covariate, having an $R^2=0.250$, was used for analysis. The sample size estimation was calculated using the PASS 11.0.8 program.

Every patient aged over 50 years with end-stage knee osteoarthritis, admitted to the Orthopedic Department to undergo primary TKA was invited to participate in the study. Patients were excluded if they had previously undergone osteotomy or arthroscopy of the affected knee joint, suffered from diabetes mellitus (DM), peripheral vascular disease, musculoskeletal disorder or cognitive

impairment, or were on corticosteroid medication. After recruitment, any patient that experienced postoperative complications, such as incision wound healing problems, increased postoperative knee swelling or pulmonary embolism, was also excluded from the study¹⁵ and was then replaced by another patient who satisfied the inclusion criteria. Patients were informed that their enrollment in the study entailed a stay in hospital of 8 days, in order to complete the postoperative CPM protocol/physiotherapy program and the post-intervention measures. On acceptance of the study conditions, and prior to surgery, the participants gave their written informed consent. Their demographic and clinical characteristics, and the preoperative active flexion and extension of the affected knee joint were recorded.

All participants underwent hybrid TKA through a medial parapatellar approach,²⁵ performed by the same team of orthopedic surgeons, and the implanted prosthesis had similar specifications and technical characteristics in every case. The patients were randomized into three groups (one control group and two research groups) by an independent clinician, according to each patient's admission date. Specifically, the first selected patient was enrolled in the control group, the second selected patient in the first research group and the third selected patient in the second research group and so forth. The participants were not blinded to their group allocation.

For all three study groups, the in-hospital physiotherapy intervention, which was based on the rehabilitation protocol²⁶ presented in the appendix, was initiated on the 1st postoperative day and continued until discharge (8th postoperative day). The control group followed only the standard physiotherapy intervention. The two research groups followed the same in-hospital physiotherapy intervention, in conjunction with CPM application. In the first research group (CPM-30), the CPM was implemented for 30 minutes twice per day,¹⁷ while in the second research group (CPM-60), the CPM was applied for 60 minutes twice per day. The CPM application for the CPM-30 and CPM-60 groups was initiated after the removal of the surgical drain (2nd postoperative day) and continued until the evening of the 7th postoperative day. For both groups, the morning application of CPM was programmed after the physiotherapy session and in the evening it followed a 5-minute warm-up.^{15,22} The same CPM device was used for all patients (fig. 1). A physiotherapist was responsible for both the physiotherapy intervention and the CPM application in all groups.

According to the study protocol, the range of knee motion during the application of the CPM was initially set at 0–40°, and was increased by 10° of flexion per day, aimed at reaching the range of knee motion at the 7th postoperative day of 0–90°. Given the fact that the actual knee motion during CPM application was found to be 24–32% less than the programmed CPM arc,²⁷ the CPM device was regulated to have 28% greater range of motion than that required. The CPM study protocol applied to both research groups is reported in table 1.

Following discharge, the patients of all three groups were encouraged to continue their individualized program every day

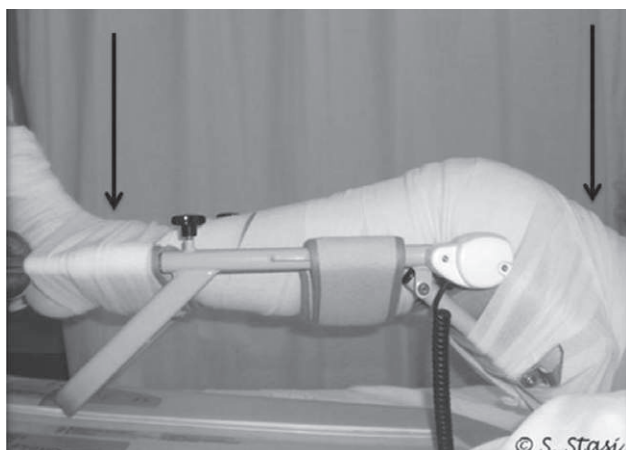


Figure 1. Application of continuous passive motion (CPM): The limb was positioned on the CPM device and stabilized with bandages (arrows). During CPM session, the patient was lying in supine position with no bed elevation.

Table 1. The continuous passive motion (CPM) protocol of the study on total knee arthroplasty.

CPM application per day	Programmed CPM arc ^{*,**}	Range of knee motion ^{*,**}
2nd postoperative day	0–51.5°	0–40°
3rd postoperative day	0–64°	0–50°
4th postoperative day	0–77°	0–60°
5th postoperative day	0–89.5°	0–70°
6th postoperative day	0–102.5°	0–80°
7th postoperative day	0–115°	0–90°

*CMP-30 group: 30 min twice per day; **CMP-60 group: 60 min twice per day

until the end of the 4th postoperative week, according to the detailed instructions they were given for the correct and safe performance of the exercises.

Outcome measures were obtained at three time points: Pre-operative (baseline), after the end of the physiotherapy session on the morning of the 8th postoperative day (1st postoperative week), and again during the first follow-up postoperative appointment at the end of the 4th postoperative week (follow-up measurement). All assessments were carried out by the same examiner, who was not involved in any way with the rehabilitation program and was blinded with respect to the group assignment. The goniometric measurements of active knee flexion and extension were performed according to the previously described technique.²⁸

In order to evaluate whether the CPM application could affect the postoperative pain level, we recorded pre-intervention versus post-intervention pain in the three study groups, using the 10-point pain Visual Analogue Scale (VAS).²⁹ The intensity of pain was evaluated twice, at the 2nd postoperative day (pre-intervention) and at the 8th postoperative day (post-intervention).

The VAS scale was explained to each patient and was given to him(her) for self-completion.

Statistical analysis

Data were expressed as mean±standard deviation (SD) for continuous variables and as frequencies (n) and percentages (%) for categorical data. The Kolmogorov-Smirnov test was used for normality analysis of the continuous variables. Homogeneity between groups was examined using the one-way ANOVA model and the Chi-square (χ^2) test.

The comparison of variables between groups at each time point was performed using the one way ANOVA model. Pairwise comparisons were performed using the Bonferroni test.

The one-factor repeated measures ANOVA model was used for the comparison of different time measurements of variables for each group. Pairwise multiple comparisons were performed using the method of Tukey critical difference.

The analysis of covariance model (ANCOVA) was used to compare the evaluation of variables (active flexion and active extension) on the 8th postoperative day (1st postoperative week) and at the end of the 4th postoperative week between the three groups. In order to control any preoperative differences between groups, the absolute values of active flexion and extension at the 1st and 4th postoperative weeks (dependent variables) were adjusted to preoperative values (covariates).

We followed the same procedure for the analysis of VAS variable between the three groups, using as dependent variable the absolute value on the 8th postoperative day (1st postoperative week) and as covariate the pre-intervention value on the 2nd postoperative day.

All tests are two-sided and statistical significance was set at $p < 0.05$. All analyses were carried out using the Statistical Package for Social Sciences (SPSS), version 21.0 (IBM Corporation, Somers, NY, USA).

RESULTS

Patient recruitment lasted from April 2013 to February 2015, by which time the required number of participants had been reached. The recruitment procedure is depicted in the flow diagram in figure 2. There was homogeneity between the three groups regarding the demographic and clinical characteristics at baseline (tab. 2).

The comparisons between the degrees of active knee flexion in the three groups at each time point are shown in table 3. In the measurements at the 1st postoperative week, only the CPM-60 group had significantly greater adjusted-to-preoperative mean of the degrees of knee flexion, by 7.55° (0.37–14.73) ($p = 0.029$) than the control

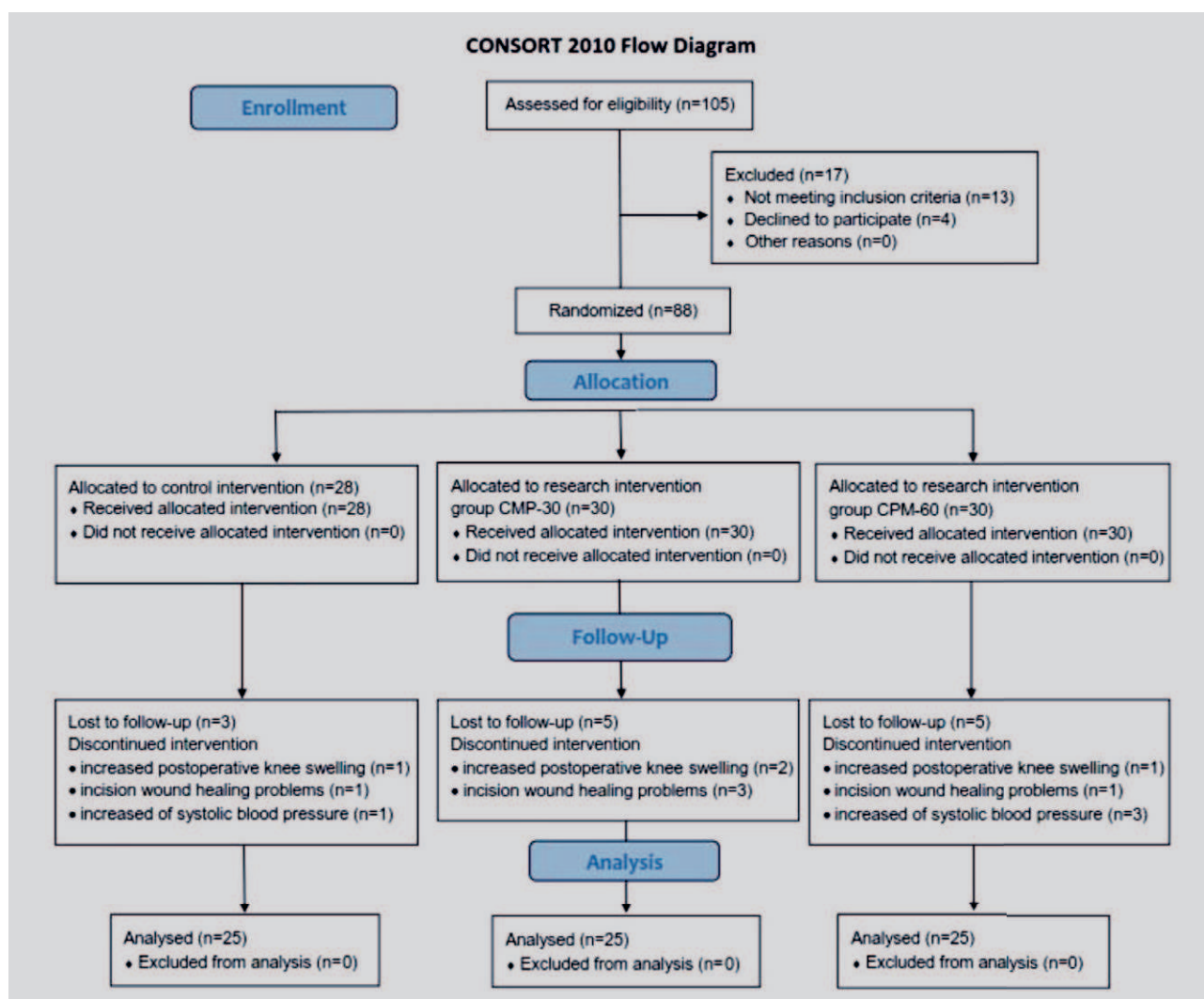


Figure 2. Flow diagram of the study on continuous passive motion (CPM) after total knee arthroplasty (TKA).

group. In the follow-up measurements (4th postoperative week), the adjusted-to-preoperative mean of degrees of knee flexion of both intervention groups were statistically higher (CPM-30 by 5.42° [0.99–9.85]; $p=0.011$ and CPM-60 by 13.38° [8.96–17.83]; $p<0.001$, respectively), than that of the control group; the CPM-60 group had a 7.96° (3.55–12.40) ($p<0.001$) greater range of active knee flexion compared with the CPM-30 group (tab. 3).

Significant association was demonstrated between CPM application and postoperative degrees of active knee flexion. The time duration of CPM application also affected the range of motion of active knee flexion.

The comparison of the degrees of active knee extension between the three groups at each time point revealed no statistically significant differences (tab. 4).

The pre-intervention and post-intervention pain levels (VAS values) in the three groups are shown in table 5. No statistically significant differences were revealed, indicating that postoperative pain levels were not affected by CPM application. It is of note that during CPM application, no patient discontinued the CPM sessions because of severe pain.

DISCUSSION

In the present study, the implementation of the proposed CPM protocol was found to increase the degrees of postoperative active knee flexion, but the CPM application had no affection on the postoperative active knee extension or on the pain levels.

The comparison between the results of the two CPM

Table 2. Demographic and clinical characteristics of the three groups of the participants in the study of continuous passive motion (CPM) after total knee arthroplasty (n=75).

Characteristics	Values*			p-value
	Control group (n=25)	CPM-30 group (n=25)	CPM-60 group (n=25)	
Age (year)	72.64±6.15	75.04±4.61	71.72±6.24	0.113
Height (m)	1.62±0.05	1.66±0.06	1.64±0.07	0.208
Weight (kg)	83.84±17.83	79.68±11.32	81.96±12.39	0.584
Body mass index (kg/m ²)	31.81±6.76	29.00±3.72	30.49±5.12	0.204
Sex				
Men/women	3 (12)/22 (88)	9 (36)/16 (64)	7 (28)/18 (72)	0.139
Affected knee				
Right/left	14 (56)/11 (44)	13 (52)/12 (48)	15 (60)/10 (40)	0.850
Use of assistive device				
No/yes	13 (52)/12 (48)	11 (44)/14 (56)	13 (52)/12 (48)	0.808
Assistive device use frequency				
Always/sometimes/rare	8 (66)/2 (17)/2 (17)	7 (50)/4 (29)/3 (21)	7 (58)/3 (25)/2 (17)	0.936
Type of assistive device				
Cane/Walker	11 (92)/1 (8)	14 (100)/0 (0)	10 (83)/2 (17)	0.290
Preoperative active knee flexion (degrees)	97.48±15.32	99.48±13.84	99.28±11.27	0.849
Preoperative active knee extension (degrees)	10.36±5.31	10.10±4.97	10.76±4.58	0.889

The values are expressed as mean±standard deviation (SD) for continuous variables and as frequencies (n) and percentages (%) for categorical variables. Homogeneity between groups was examined using one-way ANOVA model and Chi-square (χ^2) test

Table 3. Comparison of active knee flexion in degrees (°) during the observation period after total knee arthroplasty.

Patients' groups	Values*			Within group p-value	Adjusted mean** (95% CI)	
	Preoperative measurement	1st postoperative week	4th postoperative week		1st postoperative week	4th postoperative week
Control	97.48±15.33	56.80±11.09 [#]	83.84±6.83 ^{#,§}	<0.0005	57.26 (53.13–61.39)	84.18 (81.63–86.73)
CPM-30	99.48±13.84	59.00±11.57 [#]	89.80±7.09 ^{#,§,¶}	<0.0005	58.74 (54.61–62.86)	89.60 (87.06–92.15) [§]
CPM-60	99.28±11.28	65.00±11.47 ^{#,§}	97.72±8.00 ^{§,†,‡}	<0.0005	64.81 (60.68–68.93) [†]	97.56 (95.03–100.12) ^{†,‡}
Between groups p-value	0.849	0.036	<0.001		0.029	<0.001

* The values are expressed as mean±standard deviation (SD); ** Adjusted for preoperative value using the analysis of covariance model (ANCOVA)

[#] p<0.005 versus preoperative; [§] p<0.005 versus 1st postoperative week; [¶] p<0.05 versus control; [†] p<0.005 versus control; [‡] p<0.005 versus CPM-30

CPM-30: Application of continuous passive motion (CPM) for 30 min twice daily, CPM-60: Application of continuous passive motion for 60 min twice daily, 95% CI: Confidence interval 95%

Table 4. Comparison of active knee extension degrees (°) during the observation period after total knee arthroplasty.

Patients' groups	Values*			Within group p-value	Adjusted mean** (95% CI)	
	Preoperative measurement	1st postoperative week	4th postoperative week		1st postoperative week	4th postoperative week
Control	10.36±5.31	10.48±5.45	2.44±1.75 ^{#,§}	<0.0005	10.49 (8.49–12.50)	2.44 (1.76–3.12)
CPM-30	10.08±4.97	11.40±6.08	1.88±1.78 ^{#,§}	<0.0005	11.52 (9.52–13.53)	1.91 (1.24–2.59)
CPM-60	10.76±4.58	11.48±4.37	2.04±1.74 ^{#,§}	<0.0005	11.34 (9.34–11.35)	2.00 (1.32–2.68)
Between groups p-value	0.889	0.764	0.515		0.744	0.499

* The values are expressed as mean±standard deviation (SD); ** Adjusted for preoperative value using the analysis of covariance model (ANCOVA)

[#] p<0.005 versus preoperative; [§] p<0.005 versus 1st postoperative week

CPM-30: Application of continuous passive motion (CPM) for 30 min twice daily, CPM-60: Application of continuous passive motion for 60 min twice daily, 95% CI: Confidence interval 95%

Table 5. Comparison of pre-intervention versus post-intervention values on the Pain Visual Analogue Scale (VAS) of patients undergoing total knee arthroplasty.

Patients' groups	Values*		Within group p-value	Adjusted mean** (95% CI) 1st postoperative week
	2nd postoperative day	1st postoperative week		
Control	6.12±2.24	4.76±1.88	0.002	4.77 (4.23–5.31)
CPM-30	6.64±1.85	4.40±1.73	<0.0005	4.14 (3.60–4.69)
CPM-60	5.64±2.10	3.92±1.47	<0.0005	4.17 (3.62–4.71)
Between groups p-value	0.239	0.223		0.190

* The values are expressed as mean±standard deviation (SD); ** Adjusted for preoperative value using the analysis of covariance model (ANCOVA)
CPM-30: Application of continuous passive motion (CPM) for 30 min twice daily, CPM-60: Application of continuous passive motion for 60 min twice daily, 95% CI: Confidence interval 95%

groups demonstrated that the time duration of CPM application affected the active flexion of the knee. Specifically, at the immediate post-intervention measurement (1st postoperative week), the group to which CPM was applied for 30 minutes twice daily (CPM-30) showed no significant differences from the control group; statistically significant difference was observed only at follow-up at the 4th postoperative week. The group in which CPM was applied twice daily for 60 minutes (CPM-60) revealed significant statistical differences in flexion measurements at both time periods, and at the 4th postoperative week the CPM-60 patients nearly reached the preoperative active knee flexion.

These data confirm those of other studies in which the respective measurements were carried out 5–10 days after TKA.^{10,11,22,30,31} In those studies, CPM application in addition to standard physiotherapy intervention had a positive effect on the active range of knee flexion (63–80°), similar to the CPM-60 group here.^{10,30–32} In addition, the improvement in active knee flexion of their CPM groups, ranged from 2–3°, compared with their control groups. In one study only,²² in which the CPM application was continued until the 17th postoperative day, a 5° improvement was observed in the intervention group. This difference was non-significant ($p=0.06–0.07$), which may be explained by the fact that the CPM application was determined by patient comfort or clinician discretion,²² and not based on a specific protocol, as in our study.

A relevant Cochrane review²¹ concluded that more than 5 additional degrees in the range of knee flexion is required to justify the added time, cost and inconvenience of CPM.²¹ Ours is the first study in which clinically meaningful differences (i.e., more than 5°) between standard physiotherapy and standard physiotherapy combined with CPM are reported. Thus, patients may benefit from our CPM protocol (60 minutes twice daily), as the passive exercise provided by the CPM in the immediate postoperative period following TKA helps to maintain the range of motion, while

subsequently, the increased range of motion enables active exercise and greater strengthening.¹²

Our results also indicated that the CPM benefits in range of knee flexion, gained in the 1st postoperative week resulted in additional range of motion by the 4th postoperative week. Previous studies have reported no such long-term advantages from CPM,^{10–12,16} in these studies, however, it was not reported whether the participants followed any specific physiotherapy program after discharge. The findings of the present study may be due to the policy that the patients in all groups were encouraged to continue their individualized exercise program. Thus, the flexion achieved during the in-hospital CPM application combined with physiotherapy after discharge led to further improvement of active knee flexion, as measured at the 4th week follow-up. It has been reported that the short- and long-term outcomes after TKA may be related to the type and intensity of postoperative rehabilitation.³³

One of the effects that could possibly be observed with the application of CPM after TKA is a lack of either active or passive range of knee extension motion. In our study, the post-intervention active knee extension deficit was similar in all groups (tab. 4). Comparable, knee extension deficits (4–10°) have been observed in other studies, where measurements were carried out 5–14 days after TKA.^{10,11,32} Difficulty in performing knee extension postoperatively could be explained by weakness of extensor muscles, knee swelling, pain, stiffness in the flexor muscles, or a combination of these factors, given the acute-stage condition.¹⁵ Typically, after 4 weeks, these symptoms are minimized and knee extension is maximized, and on follow-up measurement, active knee extension reaches the expected postoperative levels (6–2°),^{23,31} as in our study's patients.

Reports regarding pain levels with CPM use have been conflicting, with some studies reporting increased pain,³⁴ and others^{35,36} less pain. In both CPM intervention groups in

our study, the postoperative pain levels were not affected by CPM application. This finding is of paramount importance, as increased pain in the immediate postoperative rehabilitation period could have a significant effect on the rate of recovery, by limiting exercise potential and delaying mobilization.¹⁷

Study limitations

The present study, which was a 3-group randomized controlled trial, has both strengths and limitations. A key strength is that all participants underwent the same operative protocol, namely TKA through a medial parapatellar approach²⁵ performed by the same team of orthopedic surgeons, and the same physiotherapist was responsible for the physiotherapy intervention in all three groups. Supervision and guidance from the physiotherapist during in-hospital physiotherapy/CPM sessions helped to ensure the patient adherence to the protocol. A zero drop-out rate was achieved by financially de-burdening the participants from the renting of the CPM device during the intervention period (the 8 day-hospital stay). All measurements were made by the same examiner, who was not involved in any part of the rehabilitation program and was blinded with respect to the group assignment. These factors added strength and statistical power to the results of this study.

Study limitations that should be mentioned include the fact that the patients were followed-up only until the 4th postoperative week; hence, there was no opportunity to observe whether the advantages of CPM application

were preserved over time. In addition, the study did not include other assessment, such as knee muscle strength and overall functional outcome, although, most of the other research on the effectiveness of CPM has also focused on range of motion as the primary outcome.^{18,22,23} Finally, the study population consisted of individuals who had preoperative active knee flexion of greater than 95° (tab. 2). It must be underlined that our findings, therefore, cannot be generalized to all patients with knee osteoarthritis, since the preoperative range of knee flexion is among the factors affecting the range of flexion achieved after TKA.³⁷

In conclusion, the study findings indicate that, after TKA, the implementation of the proposed CPM protocol for 60 minutes twice daily, in addition to the standard postoperative physiotherapy intervention, may significantly increase the range of active knee flexion without affecting the pain level. No effect was observed on knee extension. Further research is needed in order to confirm these results and to extend the measurements to other outcomes, including of knee muscle strength, overall functionality and patient satisfaction.

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ΠΕΡΙΛΗΨΗ

Η αποτελεσματικότητα της συνεχούς παθητικής κινητοποίησης μετά από ολική αρθροπλαστική γόνατος: Τυχαίοποιημένη ελεγχόμενη δοκιμή 3 ομάδων

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ΣΚΟΠΟΣ Η επίδραση της συνεχούς παθητικής κινητοποίησης (continuous passive motion, CPM), σε συνδυασμό με φυσικοθεραπευτική παρέμβαση, στην ενεργητική κίνηση του γόνατος και στον πόνο, μετά από ολική αρθροπλαστική γόνατος (ΟΑΓ). **ΥΛΙΚΟ-ΜΕΘΟΔΟΣ** Εβδομήντα πέντε ασθενείς (ηλικίας 50–80 ετών) συμμετείχαν στην παρούσα μελέτη (Clinical Trial Identifier: ISRCTN91125056). Μετεγχειρητικά, στην ομάδα ελέγχου εφαρμόστηκε μόνο η καθιερωμένη φυσικοθεραπευτική παρέμβαση. Στις δύο ερευνητικές ομάδες εφαρμόστηκε επί πλέον ένα πρωτόκολλο CPM 6 ημερών: στη μια ομάδα (CPM-30), η CPM συνεδρία εκτελούνταν 30 min δύο φορές ημερησίως, ενώ στη δεύτερη ομάδα (CPM-60) 60 min δύο φορές την ημέρα. Το εύρος της ενεργητικής κάμψης και έκτασης του γόνατος καταγράφηκε προεγχειρητικά, μετά την παρέμβαση (1η μετεγχειρητική εβδομάδα), και επαναληπτικά την 4η μετεγχειρητική εβδομάδα. Τα επίπεδα του μετεγχειρητικού πόνου αξιολογήθηκαν τη 2η και την 8η μετεγχειρητική ημέρα, με

την κλίμακα πόνου Visual Analogue Scale (VAS). **ΑΠΟΤΕΛΕΣΜΑΤΑ** Την 1η μετεγχειρητική εβδομάδα, μόνο η ομάδα CPM-60 εμφάνισε στατιστικά σημαντική διαφορά στο εύρος της ενεργητικής κάμψης κατά 7,55° ($p=0,029$), σε σχέση με την ομάδα ελέγχου. Στην επαναληπτική μέτρηση (4η μετεγχειρητική εβδομάδα), το εύρος της ενεργητικής κάμψης και των δύο ερευνητικών ομάδων ήταν περισσότερο [CPM-30 κατά 5,42° ($p=0,011$) και CPM-60 κατά 13,38° ($p<0,001$)] συγκριτικά με την ομάδα ελέγχου, ενώ συγκριτικά με την ομάδα CPM-30, η ομάδα CPM-60 είχε κατά 7,96° μεγαλύτερη ενεργητική κάμψη ($p<0,001$). Στην ενεργητική έκταση του γόνατος και στα επίπεδα του μετεγχειρητικού πόνου δεν εμφανίστηκαν στατιστικά σημαντικές διαφορές μεταξύ των 3 ομάδων. **ΣΥΜΠΕΡΑΣΜΑΤΑ** Μετά από ΟΑΓ, η εφαρμογή CPM για 60 min δύο φορές ημερησίως, σε συνδυασμό με φυσικοθεραπευτική παρέμβαση, μπορεί να αυξήσει σημαντικά την ενεργητική κάμψη του γόνατος χωρίς να επηρεάσει την ενεργητική έκταση, καθώς και τα επίπεδα του μετεγχειρητικού πόνου.

Λέξεις ευρητηρίου: Ολική αρθροπλαστική γόνατος, Πόνος, Συνεχής παθητική κίνηση, Τροχιά κίνησης, Φυσικοθεραπεία

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Appendix 1 (a)

Physiotherapy for Patients who Have Undergone Total Knee Arthroplasty

Intervention	Performance Guidelines
Timeframe: 1st week (Inpatient Rehabilitation)	
Respiratory Physiotherapy (If needed)	Diaphragmatic breathing. Exhale and cough instructions must be given for secretion drainage. Upper limb combined with respiratory exercises can be performed.
Trunk Exercises (If needed)	Supine position. Trunk extensors, individually modified abdominal exercises, pelvic elevation (pelvic bridge), etc.
Isotonic and resistive training of the contralateral limb (If needed)	
Ankle Pumps	Supine position. Two sets of 10 repetitions each for both limbs, alternately. (Note: Be alert for any signs of deep vein thrombosis, such as increased swelling, erythema, calf pain).
✓ Ankle dorsiflexion – plantar flexion with manual resistance	
Isometric contractions of hip extensor muscles	Supine position. Isometric contraction for 6 s followed by a rest interval of 20 s.
Active isotonic contractions of hip rotators	Supine position with knee joint in extension and ankle joint in dorsal flexion.
Hip abduction – adduction slides	Supine position. Neutral leg position (concerning hip rotation), with knee joint in extension and ankle joint in dorsal flexion. During the first postoperative days, the exercise is performed with assistance, if needed, later as active isotonic.
Lower limb stretching exercises	Mild stretching of hip flexors, extensors and adductors, knee extensors and dorsiflexors.
Activation of Knee's Extensor Mechanism	
✓ Isometric contractions of knee extensors	Supine position. Isometric contraction for 4 s, with adequate resting intervals. Gain knee extension equal to 0°.
✓ Isotonic knee extension (short arc)	Supine position. A towel roll is placed under the patient's knee so that in the initial position the knee joint is 30° flexed. The patient is asked to straighten the lower leg, lift the foot and extend the knee. The patient must hold and count to 5–6, then lower the foot slowly with the ankle joint in dorsal flexion position.
✓ Straight leg raise (SLR)	Supine position with the contralateral limb's knee flexed and the foot supported on the bed. During the first postoperative days, patients are encouraged to perform the exercise even if the extensor mechanism of the knee joint has not fully recovered. Ultimately, as the programme progresses with intensive activation of the extensor mechanism, the patients should be able to achieve SLR using full knee extension with strong quadriceps activation. The exercise can be started with isometric holding of the limb at a hip angle of 50–60°, followed by eccentric contraction of the hip flexors, and completed with concentric elevation of the limb with the knee fully extended.

Appendix 1 (b)	
Knee Flexion	
✓ Stretching and range of motion exercises	Seated position on the lateral side of the bed, with the contralateral foot supported on a footstool. During the first postoperative days, the exercise is performed with assistance, later on active isotonic contractions of hamstrings are performed, gradually increasing the range of knee flexion ($\geq 70^\circ$ on 5th postoperative day).
✓ Isometric – isotonic strengthening of knee flexors	Supine position. Isometric contraction for 6 s followed by a rest interval of 20 s.
Transfer Training	Patients are educated to perform bed mobility and transfers from bed to chair with the least amount of assistance, while maintaining appropriate weight-bearing precautions as individually tolerated.
Gait Training	The correct pattern of postoperative gait taught according to three-point ambulation: walker – operated limb – contralateral limb. (Note: Avoid torsion forces across the knee joint, especially when bearing weight on operated limb).
Training of ascent/descent stairs (If patient ambulated with walker without any other assistance)	Before discharge, patient is trained to ascend/descend stairs using the stair handrail and a forearm crutch. During ascent the contralateral limb is moved first, followed by the operated limb and by the crutch. During descending the crutch is placed on the front stair, followed by the operated limb and then by the contralateral limb. (Note: Avoid torsion forces across the knee joint, especially when bearing weight on operated limb).
Knee range of motion timeframe goal	<i>The goal is to gain a pain-free range of knee motion from 0° (full extension) up to 90° (knee flexion) 7 to 10 days after surgery</i>
Timeframe: 2nd–4th weeks (Outpatient rehabilitation)	
The 1st week's activities and exercises are continued and developed	Individualised progressive improvement of muscle strength, endurance (isometric \rightarrow isotonic \rightarrow resistive training).
Lower limb stretching exercises	Stretches of all muscle groups involved.
Patella-femoral joint mobilisation	Patella-femoral joint mobilisation as indicated, taking account of incision healing.
Activation of Knee's Extensor Mechanism	
✓ Isometric contractions of knee extensors	Supine position. Isometric contraction for 4 s, with adequate resting intervals.
✓ Isotonic knee extension (long arc)	Seated position on chair with armrests and seat-height 45–50 cm. The patient extends the knee joint ($90^\circ \rightarrow 0^\circ$). The patient must hold and count to 5, then lower foot slowly with the ankle in dorsal flexion position.
Knee Flexion:	
✓ Seated heel slides	Seated position on a high chair so that the feet barely touch the floor. The patient flexes the knee joint to achieve an active range of motion $>90^\circ$.
Balance exercises from short-sitting position on the bed	Seated position on the side of the bed, with the hips in abduction and the feet resting on the floor. The patient performs trunk and upper-limb exercises.

Appendix 1 (c)

Body weight transfers from contralateral to operated lower limb	Upright position. The patient's lower limbs are positioned in slight hip-abduction with the back supported against the wall. The walking device is placed in front to provide a handhold for support. Initially, the load on the operated limb should be a maximum of 30% vs 70% on the contralateral. By the end of the 4th week, the patient should be able to perform the exercise with equal load on both limbs (50% vs 50%), without being supported by the wall and while maintaining the correct trunk and pelvic posture, always under the physiotherapist's supervision.
Standing toe raises	Upright position. When the patient acquires sufficient balance, can easily change direction during walking with assistance, and is able to turn safely while walking with the assistive device, training with exercises in the upright position may be commenced. The hands hold on to a firm surface to provide the patient with support.
SLR in 4 planes (abduction, adduction, flexion, hyperextension)	
Gait training	Gait training is continued in order to improve function and quality of operated limb performance during swing and stance phases. The patient is re-educated so that during the initial contact of the operated limb's stance phase the heel strikes the ground first, as in a normal gait pattern. After the 4th week, if the patient's postoperative muscle performance is adequate for weight-bearing acceptance, the walker is replaced by two forearm crutches or one cane, according to the surgeon's preference.
Knee range of motion timeframe goal	<i>The goal is to gain a pain-free range of knee motion from 0° (full extension) to 105–110° (knee flexion)</i>
Timeframe: 5th–8th week	
Lower limb stretching exercises	Emphasis on soft tissue stretching and joint flexibility.
Sit-to-stand exercise	Chair with armrests and seat-height 45–50 cm. The patient is seated with the knee joint at 90°. The patient rises from the chair by pushing off both armrests and then slowly sits down again. (Note: The patient must have regained an active range of knee motion of at least 80° to perform sit-to-stand transfers with minimal compensatory activity).
Forward Lunges 1/4	Upright position. A sturdy chair is placed on the contralateral side to provide the patient with handhold support. Keeping the back straight, the patient takes a small step forward with the operated limb, bending the operated knee.
Mini squats (knee flexion/extension)	Upright position with patient's back and shoulders against a wall. The feet are placed at shoulder width apart, about 15–20 cm from the wall, with the toes pointing straight ahead. From the upright position (knee extension 0°) the patient performs knee flexion up to 50–60° and then returns to upright with the legs straight. (Note: The patient is educated to perform the exercise with 40% weight on the operated limb and 60% on the contralateral limb).
Standing toe raises	Upright position. The degree of difficulty depends on how the patient is supported while performing the exercises. Initially, the patient uses both hands, then just the hand on the operated side, and is ultimately supported using only two fingers on the operated side.
SLR in 4 planes (flexion, abduction, adduction, extension)	
Lateral steps	Upright position. The patient is facing forward and performs lateral steps, starting from the operated side (initially 5 steps are performed for each side).
Balance and proprioceptive training	Standing with eyes open and then closed. Standing with one foot directly in front of the other. Stepping forwards/backwards, etc., as individually tolerated.
Knee range of motion timeframe goal	<i>The goal is to preserve knee extension 0° and gain knee flexion >110°</i>

Appendix 1 (d)**Timeframe: 9th–12th week**

Lower limb stretching exercises	Emphasis on soft tissue stretching and joint flexibility. Maximise postoperative range of motion (-10° to 115° plus).
Sit-to-stand exercise	Chair with armrests and seat-height 45–50 cm. The patient rises from the chair by pushing off both armrests and then slowly sits down again.
Knee extension resistive exercises	Sitting position. The exercises are performed with cuff-weights. (Note: The cuff-weight resistance training program gradually increases in difficulty, with the addition of 0.5 kg increments up to a maximum of 2.5 kg, as individually tolerated).
Knee flexion resistive exercises	
Lateral steps	Upright position. The patient is facing forward and performs lateral steps, starting from the operated side (initially 5 steps are performed for each side).
Step on an obstacle/forward step down	Increase height and/or width of obstacle, as individually tolerated.
Lateral stepping over obstacles	Starting from 5 obstacles to reach the maximum threshold of 10 obstacles.
Balance and proprioceptive training	Walking on uneven or soft surfaces, with eyes opened/closed, walking backwards. Sitting on Swiss Ball, standing on BOSU, etc., as individually tolerated.
Ascent/descent stairs (12th week)	<p>Criteria for step-over-step stair climbing</p> <ul style="list-style-type: none"> • Pain-free active range of knee motion • At least 4+/5 muscular performance based on Muscle Manual Test of all operated lower extremity muscle groups.

Recommendation Notes:

1. During the first postoperative days, a towel roll should be placed under the ankle of the operated limb to promote knee extension when patients are supine in bed.
2. During the first postoperative days, ensure that patients are premedicated with pain medication 30–60 minutes prior to each physiotherapy session and encourage them to use cryotherapy at least 5 times/day.
3. Until the 7th postoperative week, cryotherapy is also recommended following physiotherapy sessions to reduce pain, discomfort and swelling in the knee joint.
4. All patients are educated to breathe with a normal inhalation/exhalation rhythm while performing the isometric exercises, in order to avoid a Valsalva manoeuvre.
5. Isometric contractions should follow the BRIME (BRief Isometric EXercise) protocol suggested by Liberson et al, which consists of 6 s of isometric contraction, followed by 20 s of rest (purported to maintain normal pulse and blood pressure).
6. Monitor wound healing and consult with the orthopedic surgeon if signs or symptoms of infection are seen.
7. If the patient has any difficulty with a particular exercise, the programme can be modified accordingly.
8. Each exercise – apart from ankle pumps – starts with 1 set (5 to 10 repetitions), reaching a maximum of 2 sets of 10 repetitions, as individually tolerated.
9. It is strongly recommended that exercises involving a risk of falling should be performed only under the physiotherapist's supervision.