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A Prospective Study on Knee Function Recovery After Total Knee Arthroplasty: A Comparison of Active and Passive Exercise and Pain Assessment

Yixuan Liu *

Harbin Medical University, Harbin, China

* Corresponding Author Email: liuyanting@seu.edu.cn

Abstract. Purpose: The purpose of this study was to determine whether postoperative pain levels decreased and to examine the impacts of active and passive exercise on knee function recovery following total knee arthroplasty (TKA). Method: With a prospective study design adopted, the 204 patients who underwent TKA at our hospital were randomly assigned to either the Continuous Passive Motion (CPM) group or the Controlled Active Motion (CAM) group, with 102 patients in each group. Both groups accepted standard exercise protocols which were identical for both groups. All patients were assessed preoperatively, postoperatively, and after discharge. Assessment indicators included Range of Motion (ROM), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Visual Analogue Scale (VAS), Knee Society Function Score (KSS), and the Short Form Health Survey (SF-36). Results: At 1.5 and 3 months postoperatively, there was a statistically significant difference in flexion angles between the two groups ($P<0.05$). At three and six months postoperatively, the results showed a difference of statistical significance ($P<0.05$) in the groups' pain scores using the WOMAC score. Other indicators showed improvement in both groups. Conclusion: Both the CAM and CPM groups significantly improved patients' recovery after TKA; however, the CAM group demonstrated superior outcomes in terms of knee flexion, pain relief, and quality of life improvements.

Keywords: Total Knee Arthroplasty; Rehabilitation; Kinesitherapy.

1. Introduction

Osteoarthritis (OA), a degenerative disease, has gradually become one of the most common joint diseases worldwide [1]. To patients with knee osteoarthritis who experience no relief from conservative treatment, Total Knee Arthroplasty (TKA) is an extremely effective surgical option. The number of TKA cases is predicted to rise by 85% by 2030, to 1.26 million cases [2]. However, 80% of patients post-TKA encounter barriers performing daily activities such as squatting and climbing stairs, which are imperative for daily life satisfaction and independence [3]. As TKA is the final treatment option for these patients, they naturally expect to regain adequate knee ROM within an acceptable time postoperatively to alleviate functional limitations. To achieve postoperative ROM improvement, Salter et al. introduced CPM aiming to enhance joint mobility through passive motion [4]. Some studies have confirmed the benefits of CPM in improving ROM and reducing pain, leading to its widespread application in postoperative rehabilitation following TKA. However, despite its extensive use, most research have not found benefits in improving ROM, pain levels, or life satisfaction. On the contrary, many studies emphasize the necessity of implementing CAM postoperatively, making the effects of CPM in TKA rehabilitation controversial [5-7]. Moreover, Bade MJ et al. found that within the first 6 months after TKA patients still experienced persistent functional impairments despite standard rehabilitation protocols, consisting of a 51% decrease in stair climbing speed, an 18% decrease in walking speed, and a 40% fall in quadriceps strength [8]. This highlights the demand for more effective rehabilitation methods to help patients maximize functional recovery and alleviate pain post-TKA.

Therefore, this study adopts a prospective design to compare functional recovery and pain relief in patients undergoing CPM and CAM postoperatively with the goal of identifying a more optimal rehabilitation strategy.

2. Materials and Methods

2.1. Patients Selection

This study comprised 204 OA patients in total, who were divided into two groups at random using a random number table. In the CPM group (n=102), there were 65 females and 37 males, with an average age of (62.68±9.79) years and the body mass index (BMI) is (25.89±4.55) kg/m². The average hospital stay was 11.44±2.95 days. In the CAM group (n=102), there were 67 females and 35 males, with an average age of (62.41±9.24) years and the BMI is (25.32±2.91) kg/m². The average hospital stay was 11.61±2.77 days. The two groups' initial features were similar, and there were no appreciable variations in either group's gender, age, BMI, or length of hospital stay. As seen in Table 1.

Table 1. Preoperative Information

	CPM (n=102)	CAM (n=102)	T (p)
Gender (male/female)	37/65	35/67	0.021 (0.884)
Age (year)	62.68±9.79	62.41± 9.24	0.550 (0.580)
BMI (kg/m²)	25.89±4.55	25.32±2.91	1.040 (0.300)
Length of Stay (day)	11.44±2.95	11.61±2.77	-0.420 (0.680)

CPM: Continuous Passive Motion; CAM: Controlled Active Motion; BMI: Body Mass Index

2.2. Surgical Procedure

All knee arthroplasties were performed by the same team of orthopedic surgeons. During preoperative conversations, all patients were informed about the surgical process, potential postoperative complications, and postoperative rehabilitation strategy. Both groups had drainage tubes placed after surgery, and rehabilitation plans were initiated on the first day after the removal of the drain (usually 6-12 hours post-surgery).

2.3. Postoperative Intervention

2.3.1. Continuous passive motion.

Patients in the CPM group underwent passive rehabilitation exercises using a CPM machine postoperatively. Patients were positioned supine with their knees fully extended. With assistance from a doctor, the CPM machine was securely placed under the knee to ensure the patient's stability and comfort. For the first exercise, the range of knee motion was set between 20° and 30° for a 5-minute adaptation exercise. The range of motion was then adjusted based on the patient's self-tolerance, with an increase of approximately 10° per day. Each subsequent practice began at an angle 15°-25° lower than the previous exercise's maximum. The training lasted 1 hour, twice daily.

2.3.2. Controlled active motion.

In the CAM group, patients were instructed to start toe movements on the day of surgery with the goal of emphasizing dorsiflexion. On postoperative days 1 and 2, patients practiced isometric quadriceps contractions while lying in the bed, holding the contraction for 15 seconds followed by relaxation, combined with ankle plantarflexion and dorsiflexion exercises. On postoperative days 3 and 4, posterior thigh muscle exercises were introduced, with patients contracting for 15 seconds and then relaxing. Posterior thigh tension exercises involved pressing the patient's heel downward while lying supine, maintaining a 10-second muscle contraction. Straight leg raising training were performed with the assistance of a doctor, who supported the Achilles tendon with one hand while

gently pressing the lower third of the thigh with the other hand to assist the patient in lifting the leg, aiming to achieve approximately 40° of hip flexion. The position was held for 15 seconds before lowering the leg. From postoperative days 5 to 7, knee flexion and extension exercises were performed, with the healthy leg assisting the operated leg in movement. Each exercise was repeated 10-20 times, three times per day.

2.4. Outcome Measures

2.4.1. Primary outcome measurement.

Range of Motion (ROM): Both groups were assessed preoperatively, on postoperative days 3, 5, and 7, and at 1.5, 3, and 6 months postoperatively. ROM plays a critical role in evaluating knee function recovery after TKA, and exercises targeting ROM have been proved to accelerate knee function recovery [9]. Therefore, in this study, ROM was selected as the primary indicator for knee function recovery. In this context, ROM refers to the range of angles through which the knee joint can move, from full flexion to full extension. ROM was measured using a universal goniometer with the patient in a prone position. The lateral condyle of the femur served as the fulcrum, with the stationary arm aligned along the femoral longitudinal axis pointing towards the greater trochanter, and the movable arm aligned along the fibular longitudinal axis pointing towards the lateral malleolus. Under the guidance of a doctor, patients were instructed to perform maximal flexion and extension of the knee. The measurement was repeated three times, and the average value was recorded.

2.4.2. Secondary outcome measurement.

These indicators included the Visual Analogue Scale (VAS) for pain assessment and patient-reported outcomes such as the Knee Society Score (KSS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and the Short Form-36 Health Survey (SF-36). The pain dimension of the WOMAC was also used to assess patients' pain levels.

VAS Score: In this study, VAS scores were recorded for both groups preoperatively, on postoperative days 3, 5, and 7, and at 1.5, 3, and 6 months postoperatively. The VAS is a commonly used tool for assessing pain intensity. Patients were given a 10-cm scale, where "no pain" was marked at one end and "worst possible pain" at the other. In order to adequately characterize the level of their agony, patients were asked to indicate the location., and the result was recorded as a number between 0 and 100. Higher numbers indicated more severe pain.

KSS Score: KSS scores were recorded preoperatively, on postoperative day 7, and at 3 and 6 months postoperatively. The KSS primarily assesses functional abilities in daily activities, such as walking distance and stair climbing. It further distinguishes between lateral and anteroposterior instability, providing separate scores, as well as an independent functional score. This makes the KSS more objective and detailed, allowing for a better reflection of postoperative quality of life and independence.

WOMAC Score: The WOMAC is a questionnaire specifically designed for osteoarthritis patients and was used in this study to evaluate knee function preoperatively, on postoperative day 7, and at 3 and 6 months postoperatively. The scale is divided into three dimensions: pain, stiffness, and physical function. The total WOMAC score is the sum of the scores from these three dimensions, with lower scores indicating less pain, stiffness, and functional impairment, and better knee function.

SF-36: The SF-36 was used to evaluate overall health status and quality of life preoperatively, on postoperative day 7, and at 3 and 6 months postoperatively. The SF-36 is a widely used self-reported questionnaire that covers multiple dimensions of both physical and mental health. It consists of 36 items, grouped into 8 health domains, such as physical functioning, bodily pain, and social functioning and so on. Every domain is assigned a number between 0 and 100, where higher values correspond to greater health. The overall score can be calculated by averaging the weighted scores of each domain.

3. Statistical Analysis

Statistical analyses were performed using SPSS version 2.0. To confirm that the variables were normal, the Shapiro-Wilk test was utilized, ensuring that all variables were in a normal distribution. Chi-square tests were used to assess gender differences between the two groups, while independent t-tests were used to compare age and BMI, expressed as means and standard deviations (x±s). Independent t-tests were performed to find differences between the groups, and paired t-tests were employed to examine changes within each group before and after the intervention. Statistical significance was defined as a p-value of 0.05 with a 95% confidence interval.

4. Results

4.1. ROM

Analysis of preoperative and postoperative knee flexion angles revealed that the preoperative ROM in the CPM group was 61.44±11.98°, while in the CAM group it was 59.51±11.33°, with no statistically significant difference between the two groups (t=1.18, P=0.24). At postoperative days 3, 5, and 7, there was no statistically significant difference between the groups (P>0.05). However, significant differences were observed at 1.5 and 3 months postoperatively (P<0.05), but by 6 months, there was no statistically significant difference between the two groups (P>0.05).

The analysis of preoperative and postoperative knee extension angles showed that the preoperative extension angle in the CPM group was 171.96±6.92°, while in the CAM group, it was 171.42±6.35°. The difference in extension angles between the two groups was not statistically significant (t=0.58, P=0.56). No statistically significant differences were observed at any other postoperative evaluation time points (P>0.05). As seen in Table 2.

Table 2. Comparison of Preoperative and Postoperative ROM between CPM and CAM

ROM		CPM (n=102)	CAM (n=102)	T (p)
ROM-Flex(°)	Pre-	61.44±11.98	59.51±11.33	1.180 (0.240)
	Post-3d	42.61±1.61	42.39±1.30	1.080 (0.280)
	Post-5d	60.82±1.64	61.10±1.79	-1.170 (0.240)
	Post-7d	89.21±4.44	90.45±5.72	-1.740 (0.080)
	Post-1.5M	92.68±1.54	95.85±3.66	-8.080 (0)
	Post-3M	103.60±1.54	114.95±3.01	-33.890 (0)
	Post-6M	115.25±0.68	116.36±0.69	-1.090 (0.280)
ROM-Ext(°)	Pre-	171.96±6.92	171.42±6.35	0.580 (0.560)
	Post-3d	184.68±5.93	186.06±5.56	-1.730 (0.090)
	Post-5d	184.75±5.91	185.52±5.63	-0.950 (0.340)
	Post-7d	184.73±5.89	185.51±5.66	-0.970 (0.330)
	Post-1.5M	184.72±5.90	185.49±5.67	-0.940 (0.350)
	Post-3M	184.81±5.94	185.47±5.67	-0.800 (0.420)
	Post-6M	184.82±5.93	185.44±5.71	-0.770 (0.440)

ROM: Range of Motion; CPM: Continuous Passive Motion; CAM: Controlled Active Motion; Flex: Flexion; Ext: Extension

4.2. VAS

The preoperative VAS score in the CPM group was 22.21±12.98, while in the CAM group was 23.79±14.60. There was no statistically significant difference between the two groups preoperatively (P=0.413). There were no statistically significant differences at any other postoperative time points. As seen in Table 3.

Table 3. Comparison of Preoperative and Postoperative VAS Scores Between CPM and CAM

VAS	CPM (n=102)	CAM (n=102)	T (p)
Pre-	22.21±12.98	23.79±14.60	0.820 (0.413)
Post-3d	40.52±10.91	41.75±10.42	-0.820 (0.413)
Post-5d	31.84±16.49	30.96±11.55	0.440 (0.659)
Post-7d	15.38±5.63	14.95±6.83	0.490 (0.623)
Post-1.5M	12.53±3.96	12.07±5.26	0.710 (0.480)
Post-3M	5.84±3.68	5.19±3.73	1.270 (0.207)
Post-6M	5.11±3.05	5.25±3.11	-0.320 (0.751)

VAS: Visual Analogue Scale; CPM: Continuous Passive Motion; CAM: Controlled Active Motion

4.3. KSS

The preoperative KSS score in the CPM group was 37.67±6.83, and in the CAM group, it was 36.00±6.24, with no statistically significant difference preoperatively (P=0.07). There was no statistically significant difference in KSS scores on postoperative day 7 (P=0.95). At 3 months postoperatively, the CAM group showed significantly better KSS scores compared to the CPM group (t=-5.61, P<0.05), but by 6 months, there was no statistically significant difference between the two groups (t=-1.18, P=0.24). As seen in Table 4.

Table 4. Comparison of Preoperative and Postoperative KSS Scores Between CPM and CAM

KSS	CPM (n=102)	CAM (n=102)	T (p)
Pre-	37.67±6.83	36.00±6.24	1.820 (0.070)
Post-7d	79.23±5.28	79.18±5.69	0.070 (0.950)
Post-3M	84.70±1.51	86.33±2.53	-5.610 (0)
Post-6M	86.39±2.92	86.64±2.51	-1.180 (0.240)

KSS: Knee Society Function Score; CPM: Continuous Passive Motion; CAM: Controlled Active Motion

4.4. WOMAC

Function dimension: The preoperative WOMAC function score in the CPM group was 52.18±9.73, and in the CAM group, it was 51.79±8.95, with no statistically significant difference (t=0.29, P=0.77). At all postoperative time periods, there were no statistically significant differences between the two groups (t<0, P>0.05).

Stiffness dimension: The preoperative stiffness score in the CPM group was 5.84±1.58, and in the CAM group, it was 5.25±1.50, with no statistically significant difference (t=1.50, P=0.14). There were no statistically significant differences between the groups at any postoperative time points (P>0.05).

Pain dimension: The preoperative WOMAC pain score in the CPM group was 16.43±2.92, and in the CAM group, it was 15.41±3.08, with no statistically significant difference. On postoperative day 7, there was no statistically significant difference between the groups (P=0.40), but at 3 and 6 months postoperatively, there were significant differences between the groups (P<0.05). As seen in Table 5.

Table 5. Comparison of Preoperative and Postoperative WOMAC Scores Between CPM and CAM

WOMAC		CPM (n=102)	CAM (n=102)	t(p)
Function	Pre-	52.12±9.73	51.79±8.95	0.290 (0.770)
	Post-7d	28.00±5.81	28.17±5.88	-0.200 (0.840)
	Post-3M	25.82±4.15	25.90±4.53	-0.130 (0.900)
	Post-6M	21.53±6.52	21.71±5.79	-0.200 (0.840)
Stiffness	Pre-	5.84±1.58	5.25±1.50	1.500 (0.140)
	Post-7d	5.88±1.51	5.78±1.51	0.460 (0.640)
	Post-3M	4.37±1.51	4.71±1.48	-1.590 (0.110)
	Post-6M	1.84±1.00	1.85±1.01	-0.070 (0.940)
Pain	Pre-	16.43±2.92	15.41±3.08	1.610 (0.110)
	Post-7d	6.87±0.69	6.95±0.71	-0.850 (0.400)
	Post-3M	6.56±0.88	6.04±0.86	4.290 (0)
	Post-6M	6.05±0.84	5.33±0.84	6.160 (0)

WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; CPM: Continuous Passive Motion; CAM: Controlled Active Motion

4.5. SF-36

On postoperative day 7, there was a statistically significant difference between the two groups in the Physical Component Summary (PCS) score (P=0.049). At 3 months postoperatively, there were statistically significant differences in the Physical Function (PF) and Role-Physical (RP) domains (P<0.05). As seen in Table 6.

Table 6. Comparison of Preoperative and Postoperative SF-36 scores Between CPM and CAM

SF-36	Pre-			Post-7d		
	CPM	CAM	T (p)	CPM	CAM	T (p)
PF	21.62 ±4.00	20.76 ±3.92	1.538 (0.485)	26.81 ±1.74	27.76 ±2.21	-1.099 (0.062)
RP	6.59 ±1.19	6.44 ±1.18	0.886 (0.776)	6.56 ±1.33	6.26 ±1.46	1.506 (0.639)
BP	5.08 ±1.05	4.97 ±0.86	0.776 (0.107)	10.09 ±2.53	10.29 ±2.50	-0.554 (0.523)
GH	20.56 ±1.83	20.40 ±1.87	0.605 (0.885)	23.03 ±1.37	23.25 ±1.47	-1.135 (0.213)
VT	17.69 ±5.53	16.10 ±6.05	1.957 (0.229)	17.16 ±6.65	16.41 ±6.13	0.832 (0.365)
SF	8.54±1.65	8.13 ±1.75	1.728 (0.665)	5.19 ±1.06	5.11 ±0.98	0.548 (0.341)
RE	5.12 ±1.02	4.74 ±1.11	2.568 (0.093)	5.21 ±0.84	5.39 ±0.79	-1.639 (0.376)
MH	27.63 ±3.87	27.88 ±3.16	-0.515 (0.095)	27.71 ±3.38	27.65 ±3.73	0.118 (0.351)
PCS	51.19 ±8.95	49.25 ±8.47	1.587 (0.511)	63.73 ±4.29	63.80 ±5.08	-0.111 (0.049)
MCS	58.98 ±8.68	56.82 ±8.21	0.476 (0.681)	55.19 ±8.13	54.66 ±7.73	0.476 (0.681)

SF-36	Post-3M			Post-6M		
	CPM	CAM	T (p)	CPM	CAM	T (p)

PF	27.76 ±2.21	28.81 ±1.54	-3.931 (0.000)	29.46 ±1.11	29.36 ±1.03	0.655 (0.724)
RP	7.41 ±0.84	7.68 ±0.53	-2.700 (0.000)	7.81 ±0.39	7.78 ±0.46	0.493 (0.255)
BP	10.51 ±2.10	10.57 ±2.08	-0.174 (0.829)	11.38 ±1.21	11.32 ±1.29	0.374 (0.319)
GH	23.33 ±1.30	23.62 ±1.20	-1.621 (0.251)	17.94 ±3.24	17.04 ±3.10	2.032 (0.559)
VT	16.01 ±6.29	16.72 ±6.53	-0.786 (0.419)	16.96 ±5.92	17.31 ±5.60	-0.437 (0.407)
SF	8.48 ±2.31	8.80 ±2.26	-1.013 (0.941)	8.95 ±2.05	9.14 ±2.00	-0.658 (0.710)
RE	5.28 ±0.85	5.30 ±0.96	-0.154 ±0.152	5.29 ±0.92	5.35 ±0.89	-0.466 (0.504)
MH	27.58 ±3.96	27.97 ±3.23	-0.775 ±0.103	26.93 ±4.97	27.28 ±4.42	-0.536 (0.313)
PCS	68.72 ±3.16	70.35 ±3.01	-3.769 ±0.982	72.02 ±2.06	72.04 ±2.13	-0.066 (0.714)
MCS	57.34 ±9.22	58.82 ±9.64	-1.121 ±0.569	58.17 ±8.81	59.13 ±8.40	-0.797 (0.541)

SF-36: Short Form-36 Health Survey; CPM: Continuous Passive Motion; CAM: Controlled Active Motion; PF: Physical function; RP: Role-physical; BP: Body pain; GH: General health; VT: Vitality; SF: Social function; RE: Role emotional; MH: Mental health; PCS: Physical component summary; MCS: Mental component summary

5. Discussion

After TKA, the recovery of knee flexion significantly impacts a patient's overall mobility. Many daily functional activities, such as sitting, standing, squatting, and climbing stairs, require a certain degree of knee flexion to perform. In contrast, knee extension is primarily associated with joint stability and gait, but the lack of sufficient flexion imposes a more significant limitation on patients' functional activities. Therefore, focusing postoperative rehabilitation on the recovery of knee flexion is imperative for a patient's ability to perform daily activities. Mau-Moeller et al. indicated that at least a 5° difference in ROM is clinically meaningful [10]. This study demonstrates that both CPM and CAM significantly improved ROM, but at 3 months postoperatively, the CAM group exhibited significantly better knee flexion than the CPM group, with a ROM difference greater than 5°, highlighting CAM's superiority in enhancing postoperative joint mobility.

Most patients turn to undergo TKA after conservative treatment fails, primarily to alleviate pain and functional limitations during daily activities. Therefore, effective pain management postoperatively is important. There was no discernible difference in the two groups' VAS scores in the study we conducted; however, both groups showed significant improvements compared to their preoperative scores. When evaluating pain using the WOMAC scale, significant differences were found at 3 and 6 months, which may be attributed to the subjective nature of VAS scores, as they rely on patient self-reporting and can be influenced by individual perceptions. Pain perception is determined by various factors, including physiological, psychological, environmental, and social influences. Fear of exercise following TKA has been recognized as a factor that negatively impacts knee function recovery [11]. Therefore, at 3 months postoperatively, the CAM group had better KSS scores, possibly due to more active and fearless engagement in exercise at home. Although both groups experienced pain relief, patients in the CAM group reported significantly lower pain levels than those in the CPM group, suggesting that CAM may play an important role in postoperative pain

management and patient comfort improvement. At the same time, SF-36 scale indicated that by postoperative day 7, both groups had improved in physical function, with the CAM group showing slightly greater improvements. At 3 months postoperatively, the CAM group had significantly higher scores in physical function (PF) ($t=-3.931$, $P<0.001$), suggesting that CAM was more effective in mid-term recovery.

In this study, the CAM group adopted a patient-centered approach under the supervision of doctors, allowing patients to control their exercises independently and engage in self-controlled active movements. This process requires patients to activate their muscles and knee joint dynamic stability to a higher level, along with more proprioceptors, enhancing the connection between the nerves and muscles (neuromuscular re-education). This helps to restore coordination between the nerves and muscles, thereby gradually improving the patients' functional recovery [7,12]. Moreover, exercises such as isometric contractions, muscle relaxation, and straight leg raise training promote static muscle contraction, strengthen muscle power, accelerate blood circulation, and improve nutrient metabolism at the injury site, contributing to the healing of damaged structures.

Based on the analysis of the outcome measurements in this study, it is evident that functional recovery after TKA should emphasize active rather than passive exercise. Patients in the CPM group were less motivated to exercise after discharge than those in the CAM group. Additionally, Jia et al. pointed out that CPM demands higher economic costs [13]. However, for patients unable to engage in active functional exercise, CPM remains a feasible option. It is important to note that active functional exercise should be supervised by a doctor to prevent patient complacency.

6. Limitations

There are several limitations in this study. First, more postoperative evaluation indicators could have been included, such as isometric muscle torque testing (IMTT) and other functional performance measures. Second, the follow-up period was relatively short. Existing studies suggest that patients usually reach a peak in recovery at 6 months postoperatively, with a decline in function occurring around 2 years postoperatively [14,15]. Therefore, longer-term follow-up is needed to better assess changes in joint function.

7. Conclusion

This randomized controlled trial evaluated ROM, pain, and function in patients undergoing TKA. Consistent with existing literature, our study demonstrates that while both CPM and CAM significantly improve patient conditions after TKA, CAM is superior in restoring knee flexion and relieving pain. Additionally, CAM reduces equipment and nursing costs. Consequently, these findings support the recommendation of CAM as the first choice for postoperative rehabilitation following TKA.

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