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ORIGINAL ARTICLE

Actual Knee Motion during Continuous Passive Motion Protocols is Less Than Expected

Jesse E. Bible BS, Andrew K. Simpson MD, MHS, Debdut Biswas BA, Richard R. Pelker MD, PhD, Jonathan N. Grauer MD

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Abstract Investigations of the usefulness of continuous passive motion (CPM) after TKA have yielded mixed results, with evidence suggesting its efficacy is contingent on the presence of larger motion arcs. Surprisingly, the range of motion (ROM) the knee actually experiences while in a CPM machine has not been elucidated. In this study, the ability of a CPM apparatus to bring about a desired knee ROM was assessed with an electrogoniometer. The knee experienced only 68% to 76% of the programmed CPM arc, with the higher percentages generated by elevating the head of the patient's bed. This disparity between true knee motion and CPM should be accounted for when designing CPM protocols for patients or investigations evaluating efficacy of CPM.

Introduction

For more than 25 years, the CPM machine has been used to facilitate rehabilitation after TKA and other joint reconstructions [1, 11, 21, 22, 25, 27, 31]. The concept of CPM, initially introduced by Salter et al. [25–28], was based on findings that immobilization of a joint after surgery gave rise to detrimental effects on articular collagen healing. The major clinical application of CPM in modern practice is as a modality to avoid arthrofibrosis after arthroplasty or other surgery involving joints prone to motion loss, such as the knee and elbow.

The short-term efficacy of CPM has been established by numerous clinical studies. When compared with physical therapy alone, the addition of CPM increases active knee flexion in the weeks after arthroplasty [3, 7, 12, 13]. In a meta-analysis of 952 patients, Brosseau et al. [2] reported the length of hospital stay was shorter in patients who received postoperative CPM. Furthermore, the addition of this modality to physical therapy also reduced the number of patients requiring postoperative knee manipulations [2, 7, 12, 22, 30, 31].

The literature addressing long-term clinical efficacy of CPM for rehabilitation after TKA, however, is more equivocal. Studies showing the superiority of CPM over physical therapy alone used regimens with larger motion arcs (eg, 70°–90°) continued for a longer duration of time (eg, > 48 h) [9, 17, 20]. Conversely, clinical investigations that failed to record an increase in knee ROM in conjunction with CPM used more limited motion arcs, which typically were started between 30° and 40° and increased by 10° to 20° each day [4, 11, 22, 30, 31]. In a direct comparison of these various CPM protocols, implementation of higher motion arcs brought about greater ROM, which remained evident 1 year after surgery [9].

Collectively, these studies suggest the magnitude of knee flexion and the overall motion arc of a CPM regimen are key determinants of its efficacy. Given the important role larger motion arcs seem to play in determining short- and long-term ROM after TKA, it is surprising there is a

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J. E. Bible, A. K. Simpson, D. Biswas, R. R. Pelker,
J. N. Grauer (✉)
Department of Orthopaedics and Rehabilitation, Yale University
School of Medicine, PO Box 208071, New Haven,
CT 06520-8071, USA
e-mail: jonathan.grauer@yale.edu

lack of data regarding the actual ROM the knee experiences in a CPM machine. Although many clinicians likely surmise the knee travels through a smaller ROM than the CPM, this assumption has not been investigated. Therefore, to optimize the clinical efficacy of CPM after TKA and accurately access the correlation between passive motion protocols and functional outcomes, the amount of motion the knee is subjected to while in a CPM device needs to be quantified.

In this study, we asked (1) how accurate CPM is in producing the desired knee ROM and (2) how patient positioning and knee bandaging techniques affected the accuracy of CPM.

Materials and Methods

We recruited 20 asymptomatic subjects and determined the amount of flexion in both knees by applying the electrogoniometer to each joint (Fig. 1). The midthigh and calf circumferences were 21 ± 3 and 15 ± 2 inches, respectively. The CPM machine then was passed through a series of motion arcs starting at 0° to 10° and progressing in 10° increments until a CPM motion arc of 0° to 90° was reached. This same series of nine measurements was conducted on both legs at three different head of bed settings (0°, 30°, 60°) and with the subjects' knee bare or with cast padding and compression wrap applied. The knee motion measurements then were compared with the programmed CPM motion arc. Institutional Review Board approval was obtained for these experiments before initiation of this study.

In each case, ROM was assessed with the same CPM machine with the knee positioned according to the manufacturer's directions. In addition, a metal clamp was affixed to the distal end of the CPM machine to prevent the CPM machine from sliding and subsequent position changes. The CPM machine then was programmed to progress through the series of nine motion arcs as described above. After each 10° increment, the CPM machine was placed in the 0° position to verify the knee was in its original location of 0° flexion. The series of nine measurements were repeated on both knees in six different scenarios: a bare leg with the head of the bed set at 0°, 30°, and 60° and the same leg covered with cast padding and an elastic wrap (ie, compression bandage) with the head of the bed elevated at the same angles. Each knee was dressed using the standard technique used at our institution after TKA; starting from the ankle and moving toward the middle portion of the thigh, the cast padding overlapped by 50% so the entire knee was covered with two layers. The compression bandage then was wrapped over the cast padding in a similar fashion.

One CPM machine (The Phoenix™ Series, Model 1850 Knee CPM; McKelor Technologies, Ltd, Grove City, OH) was used throughout the duration of this study. The ROM for the CPM device was adjusted with a handheld digital display unit. Accuracy of the CPM display was assessed initially using a flexible electrogoniometer directly mounted on the lateral side of the swing arm of the CPM machine, which is located across from the axis point of the knee.

The CPM machine was set to move through a series of motion arcs starting at 0° to 10°, which were increased progressively by 10° until a total ROM of 0° to 90° was reached. At each 10° increment, the amount of flexion measured on the electrogoniometer was compared with the ROM setting listed on the CPM display. This calibration process was done at the beginning of the study and also throughout the study at regular intervals (after every five subjects) to show consistency between measurements.

Fig. 1 A photograph shows a subject's leg with the electrogoniometer affixed along with the digital output unit and the CPM machine.

With these data, average CPM motion at each 10° increment on the CPM display unit was used to construct a calibration curve to which actual knee ROM measurements could later be compared.

The electrogoniometer measuring system (SG150; Biometrics Ltd, Gwent, UK) consists of a thin, flexible, strain-gauged strip (also known as a shin), which includes two lightweight plastic plates attached at each end (Fig. 1). The transducer measures angles in two planes of movement: flexion-extension and abduction-adduction. The electrogoniometer is lightweight, flexible, and noninvasive, allowing it to be secured to the knee without inhibiting joint movement. The output data were observed in real-time using a handheld digital display unit.

Other groups have used this measuring system to evaluate knee motion [14–16, 23, 24, 29, 32] and have validated several modifications (described in detail below) to the device to reduce the amount of error in measuring knee flexion and extension to less than 1°. In accordance with these studies [14–16, 23, 24, 29, 32], the same modifications were made to the system used in our study. Long, flexible plastic strips, fastened to the goniometer were applied with double-sided tape to the skin of the lateral side of the knee to minimize motion between the transducer and the underlying skin and subcutaneous tissue. Any changes in body shape along the lateral border of the leg were accommodated by placing pliable foam blocks beneath the end of the plastic strips adjacent to the knee [23]. This permitted a neutral (ie, nonabducted or nonadducted) configuration in the lateral plane to be achieved, which served to prevent any additional error secondary to interference between the abduction-adduction and flexion-extension channels. The outputs designating the flexion-extension and abduction-adduction angles of the knee then were recorded from the unit's digital display (Fig. 1).

To validate accuracy and reliability of the specific electrogoniometer used, ROM measured by the electrogoniometer was compared with that of a manual goniometer. This calibration process was repeated after each subject and the electrogoniometer readings were consistently accurate. Furthermore, the electrogoniometer was affixed to the lateral side of one subject's legs as described previously, and plain radiographs were acquired on three separate occasions at 0°, 30°, 60°, and 90° each time so the electrogoniometer measurements could be compared with those provided by the measuring tools of the digital radiographic system. Using this in vivo technique, the electrogoniometer was determined to be accurate within 1.8° ± 1.7° (mean ± standard deviation).

We determined differences in the motion between the CPM and knee motion arcs, at different bed elevations and with and without knee dressings, using one-way analysis of variance with post hoc Bonferroni analysis. To compare knee motion between differing bed elevations, we used repeated-measures analysis of variance with post hoc Bonferroni analysis. This test also was used to evaluate for differences in knee motion attributable to presence or absence of dressing material for each motion arc of the CPM device. We used SPSS® 17.00 (SPSS Inc, Chicago, IL) for all analyses.

Results

With every motion arc tested, the average amount of motion actually experienced by the knee was less ($p < 0.001$ for each) than the average ROM of the CPM machine, regardless of the angle at which the bed was elevated and whether the leg was bandaged (Fig. 2). Thus,

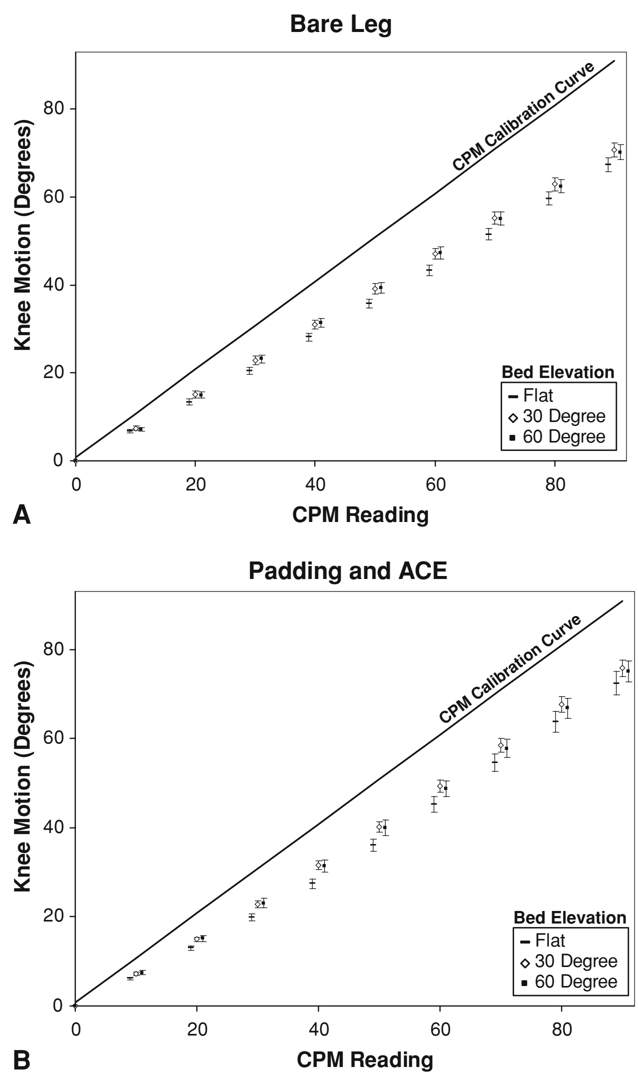

Fig. 2A–B The average knee motion at the three different bed elevations are shown for (**A**) the bare knee and (**B**) the bandaged knee. Error bars = 95% confidence intervals.

Table 1. Knee motion as a percentage of CPM

Leg preparation	Bed elevation	Knee motion*
Bare leg	0°	67.9 (0.5)
	30°	73.9 (0.5)
	60°	73.8 (0.5)
Bandaged leg	0°	68.9 (0.6)
	30°	76.1 (0.5)
	60°	76.1 (0.6)

* Values expressed as means, with standard errors in parentheses.

in every scenario, the knee was subjected to a considerably smaller motion arc than the CPM machine. Depending on the position of the head of the bed, the bare and bandaged knees were exposed to an average of only 68% to 74% and 69% to 76%, respectively, of the ROM of the CPM machine (Table 1).

Raising the head of the bed from a flat position (0°) to either 30° or 60° increased ($p < 0.001$ for both) joint motion for each motion arc with the bare and bandaged knees (Fig. 2). However, there were no differences ($p = 0.469$ to 1) in knee motion noted between the 30° and 60° positions with any of the motion arcs (Table 2). The addition of cast padding and elastic wrapping to the knee increased joint motion (ie, improved the accuracy of the CPM machine for producing the desired knee ROM) ($p < 0.001$ to 0.891), although this effect was evident only among the larger motion arcs (Table 2).

Discussion

Previous studies suggest using CPM in a limited motion arc is less effective in clearing blood and edema from the joint [18, 19] and is unlikely to provide any impact on long-term ROM achieved by the patient after TKA [4, 11, 22, 30, 31]. Similarly, it has been suggested improved postoperative ROM might be seen if greater CPM motion arcs were used, because the periarticular tissues would experience an increased pumping effect, reducing hemarthrosis and stasis of inflammatory mediators helping to maintain long-term periarticular tissue compliance [17]. Given these findings, determining the amount of motion the knee actually experiences during CPM protocols is essential to further investigate and optimize the clinical efficacy of CPM. We therefore evaluated the accuracy of CPM in producing the desired knee ROM and how patient positioning and knee bandaging affect this accuracy.

We acknowledge this study is not without limitations. The primary limitation is that we evaluated the accuracy of only one brand of CPM machine and did not account for potential variability between CPM machines from different manufacturers. The majority of CPM machines in current clinical use, however, are predicated on a similar design and concept. We calibrated the CPM machine before all measurements to avoid potential discrepancy and inaccuracy related to manufacturer variability.

Our data show ROM of the knee is less than would be expected relative to the motion arc of the CPM. On average, the knee experienced only 68% to 76% of the CPM motion. This translates into reduced motion arcs and subsequent reduction in the pumping effect in and around the knee. Because the maximum capacity of the knee capsule occurs at 35° flexion [5, 6, 8, 10], others have hypothesized that attempts should be made to flex the joint beyond this position to create hydrostatic pressures, facilitating the prevention and/or elimination of edema in the joint and periarticular tissues [17]. Given our results, a CPM motion arc greater than 50° would have to be reached before the knee would begin to experience the pumping effects of flexion greater than 35°. In addition to other variables such as treatment duration, this major discrepancy between the CPM motion arc and actual ROM of the knee may at least partially account for the inconsistent results reported by other groups who have evaluated the efficacy of postoperative CPM protocols.

One method that seemed to enhance the accuracy of CPM protocols was raising the head of the bed. Increasing the angle of inclination to 30° and 60° brought about major improvements in knee motion for every motion arc tested, suggesting some amount of bed elevation is optimal, but the exact amount is not critical. Elevating the head of the bed may facilitate greater knee flexion by positioning the patient's pelvis and proximal thigh more securely in the CPM machine, thus preventing sliding of the patient's leg

Table 2. P values from repeated-measures analysis of variance comparing different bed elevations and leg preparations

Comparison	CPM reading								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
0° vs 30° bed elevation	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
0° vs 60° bed elevation	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
30° vs 60° bed elevation	1.000	1.000	0.940	1.000	1.000	1.000	1.000	0.469	0.555
Bare vs bandaged leg	0.453	0.785	0.572	0.891	0.449	0.049	0.007	< 0.001	< 0.001

relative to the CPM machine and the resultant decrease in knee flexion. Additionally, with higher motion arcs, the mean ROM associated with knees covered with cast padding and an elastic wrapping was considerably greater than that observed with bare knees. During these higher motion arcs, a bare leg has a tendency to shift in the CPM machine, which may decrease ROM of the knee. However, addition of the compression bandage provides an additional frictional component that seemed to help prevent the leg from sliding.

Our data indicate the ROM the knee experiences in a CPM machine is considerably less than initially anticipated. According to our findings, a CPM motion arc of 0° to 90° may only give rise to 60° to 70° of actual knee motion. Additionally, raising the head of the bed marginally improves the ability of the CPM machine to generate a specified knee ROM. In general, it is important that the discrepancy between the motion arc of the CPM machine and the true ROM of the knee is recognized by clinicians who currently recommend postoperative CPM for their patients, and this disparity also should be considered when designing protocols for investigation of CPM efficacy.

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