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Continuous passive motion (CPM): Theory and principles of clinical application

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Abstract—Stiffness following surgery or injury to a joint develops as a progression of four stages: bleeding, edema, granulation tissue, and fibrosis. Continuous passive motion (CPM) properly applied during the first two stages of stiffness acts to pump blood and edema fluid away from the joint and periarticular tissues. This allows maintenance of normal periarticular soft tissue compliance. CPM is thus effective in preventing the development of stiffness if full motion is applied immediately following surgery and continued until swelling that limits the full motion of the joint no longer develops. This concept has been applied successfully to elbow rehabilitation, and explains the controversy surrounding CPM following knee arthroplasty. The application of this concept to clinical practice requires a paradigm shift, resulting in our attention being focused on preventing the initial or delayed accumulation of periarticular interstitial fluids.

Key words: *bleeding, continuous passive motion (CPM), edema, fibrosis, granulation tissue, joint stiffness.*

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INTRODUCTION

Von Riemke, in his presidential address to the Danish Surgical Society in 1926, stated that, "All joint affections...should be moved. Movement should begin on the first day, should be very slow, and as much as possible it should be continuous." Salter, who invented the concept of continuous passive motion, which has come to be known as simply "CPM," derived this concept on the basis of a series of experimental investigations and well thought-out rationale. Salter and Field (1) showed in 1960 that immobilization of a rabbit knee joint under continuous compression, provided by either a compression device or forced position, resulted in pressure necrosis of the cartilage. In 1965, Salter et al. (2) reported deleterious effects of immobilization on the articular cartilage of rabbit knee joints and the resultant lesion that they termed "obliterative degeneration of articular cartilage." Salter (3) believed that "The relative place of rest and of motion is considerably less controversial on the basis of experimental investigation than on the basis of clinical empiricism." He reasoned that because immobilization is obviously unhealthy for joints, and if intermittent movement is healthier for both normal and injured joints, then perhaps continuous motion would be even better. Because of the fatigability of skeletal muscle, and because a patient could not be expected to move his or her own joint constantly, he concluded that for motion to be continuous it would also have to be passive. He also believed that CPM would have an added advantage, namely that if the movement was reasonably slow, it should be possible to apply it immediately after injury or operation without causing the patient undue pain. This idea was based on the gate-control theory of pain by Melzack and Wall (4,5), that with competing afferent sensory stimulation, painful stimuli would be inhibited. The concepts, tested in patients since 1978, have proven to be feasible (6).

Originally, development and subsequent research regarding CPM was driven primarily by the theory that joint motion would promote the healing and regeneration of articular cartilage (7,8). Although cartilage healing and regeneration continues to be an active area of research, the major clinical use of CPM today is to avoid arthrofibrosis following trauma or surgery on joints that are prone to stiffness, such as the knee, elbow, and joints of the hand.

Interestingly, CPM has found its greatest clinical use in rehabilitation following total knee arthroplasty, despite a relevant body of literature that appears confusing and contradictory (9–22). Indeed, there is substantial debate regarding whether CPM has any clinical utility at all in this setting (11,12). The methods of CPM application have differed among many of these studies, and all have differed in their approach to the use of postoperative CPM from that of the inventor, Salter, who recommended that it be continuous and through a full range of motion. To sort through the controversy and confusion, it is necessary to understand the potential implications for the method of CPM application.

To understand how CPM could be helpful in maintaining joint range of motion following trauma or surgery, one must understand the pathophysiology of joint stiffness. This paper describes a theory regarding the etiology and evolution of joint stiffness. Using this theory as a conceptual framework, the principles of CPM use in preventing joint stiffness are developed, and elbow rehabilitation is described as a paradigm. In order to elucidate the potential benefits of CPM following knee arthroplasty, a critical review of the literature is conducted, and interpreted within the framework of the joint stiffness theory. Based on this analysis, the general principles of CPM application and recommendations for its use following total knee arthroplasty are described.

PATHOPHYSIOLOGY OF JOINT STIFFNESS

The Four Stages of Stiffness:

1. Bleeding
2. Edema
3. Granulation Tissue
4. Fibrosis

Stage 1: Bleeding

The first stage, occurring within minutes to hours following articular surgery or trauma, is caused by bleeding, which results in distension of the joint capsule and swelling of the periarticular tissues. Depending on the individual joint, the capsule achieves a maximum potential volume at a certain joint angle. In the knee, the maximum capacity of the joint capsule has been found to occur at approximately 35º of flexion (23–26); in the elbow, it occurs at 80º of flexion (27). Any attempt to flex or extend a joint beyond its position of maximum capacity, when the joint and/or periarticular tissues are markedly swollen, creates extremely high hydrostatic pressures within the joint and periarticular tissues. Associated with these high pressures are severe pain and a marked increase in resistance to motion. Immediately following injury or surgery to the joint, the natural tendency is to hold the joint in the position of maximum articular volume to minimize painful stretching of the joint capsule and the pressure of the intra-articular hematoma.

Stage 2: Edema

The second stage of stiffness, which occurs during the next few hours or days, is very similar but progresses less rapidly. It is due to edema, caused by inflammatory mediators that are released by platelets and dead and injured cells. These mediators cause nearby blood vessels to dilate and leak plasma, resulting in swelling of the periarticular tissues, thereby diminishing their compliance. With swollen and less compliant tissues surrounding it, the joint becomes physically more difficult to move and movement becomes more painful (24,27). Up to this point, stiffness and loss of periarticular tissue compliance are simply due to the accumulation of fluid. In the next two stages, fluid is replaced by extracellular matrix deposition, marking a significant transition.

Stage 3: Granulation Tissue

The third stage consists of the formation of granulation tissue. This occurs during the first few days or weeks following trauma or surgery. Granulation tissue is a highly vascularized, loosely organized tissue with material properties somewhere between a highly organized blood clot and loose areolar fibrous tissue. As this granulation tissue appears within and surrounding the joint, the stiffness previously due to fluid accumulation becomes increasingly due to the deposition of a solid extracellular matrix.

Stage 4: Fibrosis

The fourth stage of stiffness represents fibrosis. During this stage, the granulation tissue matures, forming dense, rigid scar tissue. This scar tissue has a high concentration of collagen type I fibers in its extracellular matrix.

Evolution of Joint Stiffness

To understand how a joint ends up permanently stiff, it is necessary to understand how the stiffness evolves, and how one stage ushers in the next. Let us consider the example of a total knee arthroplasty. At the completion of the procedure (with the patient still anesthetized), when the wound has been closed, the knee has a certain range of motion. If one were to bring the patient back to the operating room from the recovery room 2 hours later and reexamine the patient's knee under general anesthesia, it would not move through the full arc of motion found intraoperatively. This is because the accumulating blood in and around the knee causes distention and loss of compliance of the periarticular tissues. However, if this blood were forced out of the periarticular region (or better still, not permitted to accumulate), mobility of the knee would immediately be restored.

One to 2 days later, if one were to examine the patient's knee again under general anesthesia, it would certainly not move through a full arc of motion based on current practices of rehabilitation following total knee arthroplasty. This loss of motion is due to accumulation of fluid, representing the second stage of stiffness, edema. It is still possible to eliminate this fluid from the periarticular tissues, but that requires sustained "milking" of the fluid away from the region of the joint.

Several days later, the knee definitely has a feel of stiffness that cannot be overcome by milking the fluid out of the region. In this third stage of granulation tissue deposition, extracellular matrix is being deposited in the tissues around the knee joint, causing them to thicken and greatly lose their compliance. A knee at this stage is still amenable to "manipulation" under anesthesia, but a degree of force is required to overcome the blocked motion. Several weeks to months later, when fibrosis is occurring during the fourth stage of stiffness, the extracellular matrix and granulation tissue are being replaced by dense, collagenous scar tissue. This provides great resistance to mobility, and the loss of motion cannot be overcome, even with manipulation.

One tends to think of stiffness as the final stage four—when the patient presents with an apparently irrecoverable loss of motion. Understanding the evolution of stiffness, however, should readily permit one to understand that the ultimate goal in its prevention and treatment is to prevent accumulation of fluid in and around the periarticular tissues. This is accomplished by minimizing bleeding and edema formation as well as by milking this blood and edema fluid away from the region of the joint. By preventing intra-articular and periarticular fluid collection, one prevents excess deposition of granulation tissue and fibrosis in the periarticular tissues. By the same logic, failure to achieve a full range of motion in the immediate or early postoperative period, combined with permitting the accumulation of even relatively small amounts of periarticular blood and edema, naturally permits extracellular matrix and collagenous scar tissue to be deposited, such that the full range of motion may never be recovered.

Principles of CPM Application

Using this theory, the role of CPM in preventing joint stiffness can be clarified. In the first few days following injury or surgery, CPM is useful primarily to minimize joint hemarthrosis and periarticular edema; CPM has been found to increase the clearance of a hemarthrosis from a rabbit knee (28). In the presence of a joint effusion, movement of the knee away from the position of maximum volume and compliance causes an increase in intra-articular pressure. The greater the effusion, the greater the pressure generated at a certain degree of joint flexion (23–27). CPM causes a sinusoidal oscillation in intra-articular pressure (29), as shown in **Figure 1** (30). This accelerates the clearance of a hemarthrosis (**Figure 2**). The enhanced clearance of blood from within the joint

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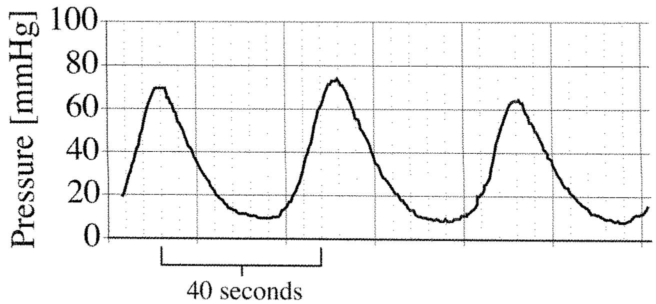

Figure 1.
An actual tracing of the intra-articular pressure in one knee during CPM reveals that, with 2 ml of fluid in the joint, the pressure oscillates in a regular sinusoidal fashion. This results in a "pumping effect" which is responsible for clearing blood and edema fluid from the joint and periarticular tissues. (Reproduced with permission from O'Driscoll et al. J Rheumatol. 10:360–3, 1983.)

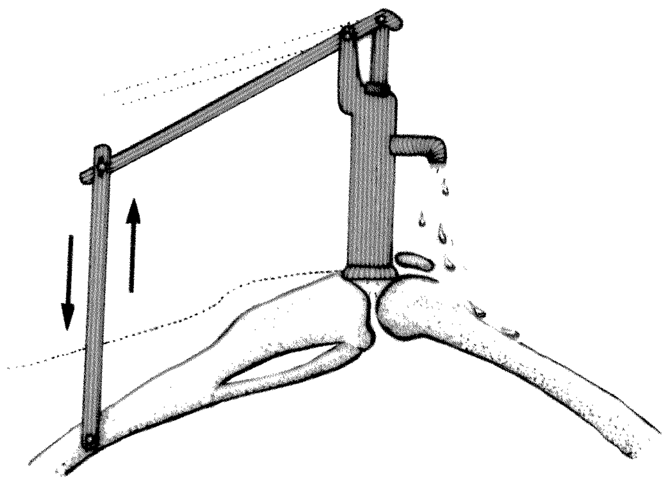

Figure 2.
Alternate flexion and extension of the joint by CPM raises and lowers the hydrostatic pressure in the joint and periarticular tissues resulting in a "pumping effect" that forces fluid out of the joint and periarticular tissues.

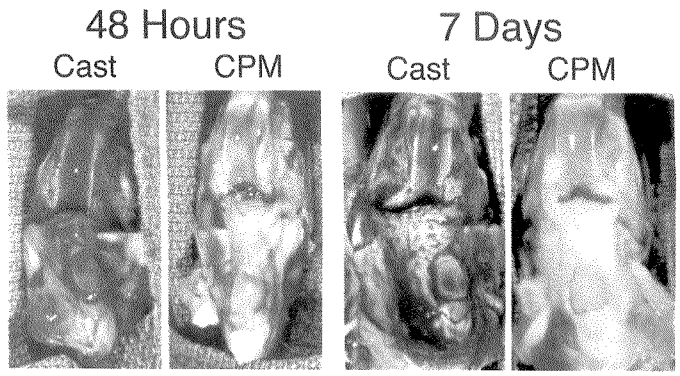

Figure 3.
Effect of CPM on clearance of a hemarthrosis. CPM rapidly accelerates the clearance of blood from the joint in the periarticular soft tissues, as seen in these comparison photographs at 48 hours and 7 days following injection of 2 cc of blood into both knees of a series of rabbits. The rabbits were treated by immobilizing one knee in a cast and moving the other knee on a CPM machine immediately following surgery and then continuously for 7 days. At 48 hours, the knee that had been immobilized in a cast (left) was still grossly bloody, whereas the opposite knee (right) treated by CPM was almost free of blood. At 7 days, the cast knee contained free blood in the joint while the CPM knee from the same rabbit was clear. In contrast to the immobilized knees, most of which contained small amounts of blood in the synovium at 7 days, all of the CPM knees appeared normal.

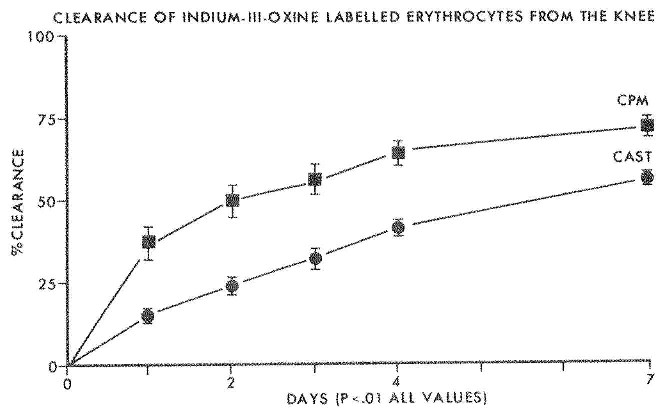

Figure 4.
Treatment with CPM enhanced the rate of hemarthrosis clearance by more than 100 percent. Values expressed as mean;pm1 standard error of the mean. (Reproduced with permission from O'Driscoll et al. Clin Orthop 176:305–11, 1983.)

(**Figure 3**) as well as the clearance of blood from the periarticular tissues (**Figure 4**) due to CPM has been documented and quantified by tracking radiolabeled erythrocytes. By effectively pumping fluid away from the area of the joint (28,30), CPM similarly prevents further accumulation of edema in the periarticular soft tissues (**Figure 5**). Thus, CPM is of maximum benefit and importance in the first few hours and days following surgery (i.e., the first and second stages of stiffness). CPM is less effective in the third stage of stiffness and ineffectual in the fourth. Sustained stretching of the periarticular tissues, through the use of splints, may be needed in the granulation stage, and fibrosis may only be amenable to aggressive splinting or surgical treatment.

Elbow Rehabilitation as a Model of CPM Use

We have successfully used CPM to rehabilitate elbows following trauma and reconstructive procedures. The principles of CPM use are applied and readily appar-

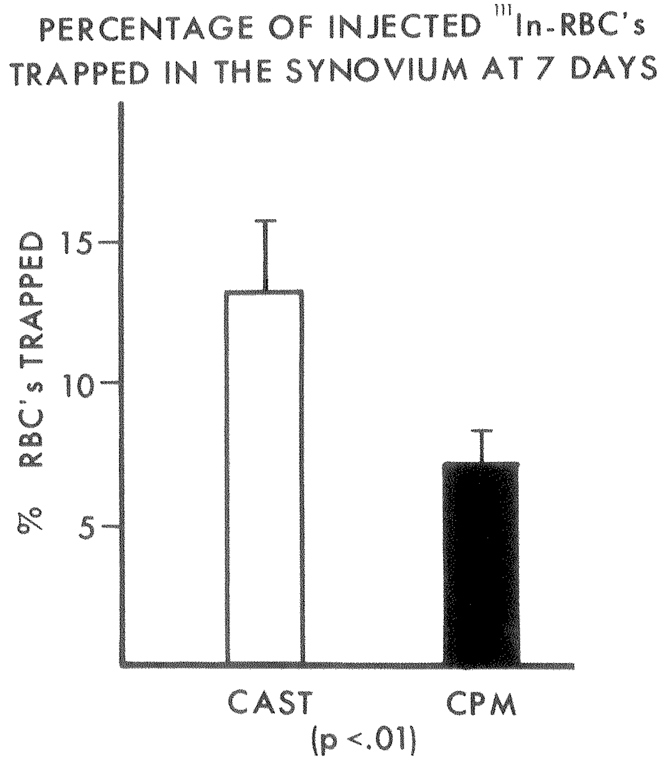

Figure 5.
The bars represent the percentages of the injected, labeled erythrocytes that remained trapped in the synovium after 7 days. Treatment by CPM decreased this trapping by approximately 50 percent, which would decrease the thickening and inflammatory response in the periarticular soft tissues, thereby improving compliance of the joint overall. Values are expressed as mean;pm1 standard error of the mean. (Reproduced with permission from O'Driscoll et al. Clin Orthop 178:305–11, 1983.)

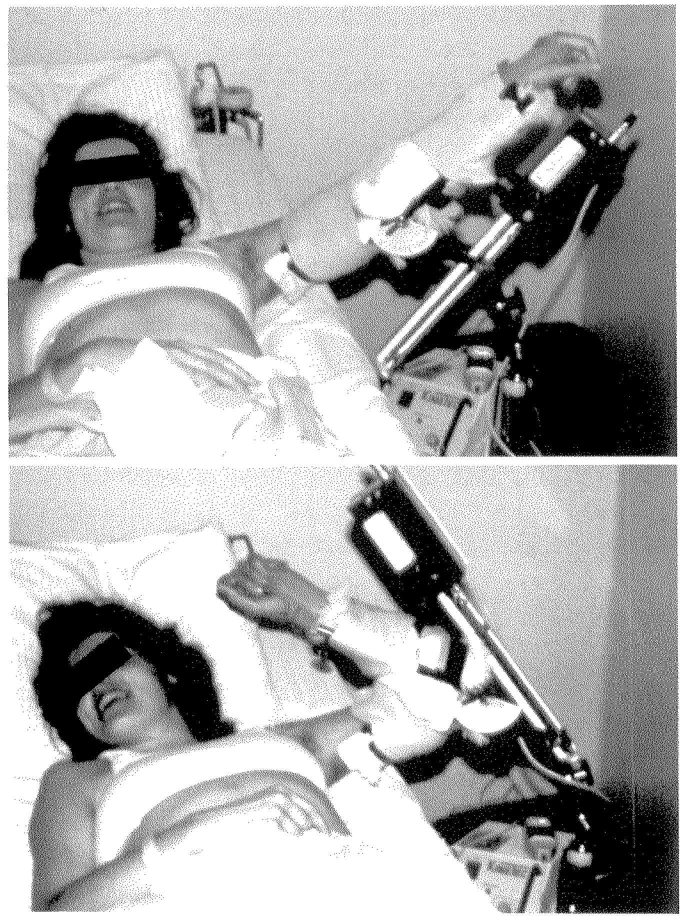

Figure 6.
Photographs taken on the same day of surgery in a young patient operated on for posttraumatic arthritis and stiffness of the elbow. This was treated by distraction interposition arthroplasty and immediate commencement of a full range of motion on a CPM machine. Pain was controlled with an axillary indwelling catheter for brachial plexus block anesthesia. This particular machine does not permit a full range of motion of the elbow, which can be accomplished by augmenting the motion with wedges placed alternately beneath the wrist or elbow to enhance flexion or extension, respectively.

ent in our standard protocol for elbow rehabilitation. Motion should commence as soon as possible following surgery, ideally in the recovery room. As this is not always practical, it may be preferable to elevate the arm in full extension and keep it wrapped in a compressive Jones dressing to minimize swelling until motion is started. A drain is used to prevent accumulation of blood. Prior to starting CPM, all circumferential wrappings (Jones, cling, etc.) are removed and replaced with a single elastic sleeve. This is essential to prevent excessive stress being applied to the skin, which can result in shearing and damage to the wound.

Once CPM is started, it is necessary to utilize the full range of motion (**Figure 6**). Essentially, the periarticular tissues are being stretched and compressed alternately in flexion and extension. By this mechanism, CPM causes a sinusoidal oscillation in intra-articular pressure (29,30), which squeezes out excess blood and fluid and prevents further edema from accumulating (28). In the first 24 hours, swelling due to bleeding can develop in minutes, so CPM should be continuous. Only bathroom privileges are allowed. As the number of days following surgery increases, the amount of time required for swelling to develop also increases, so that longer periods out of the machine are permitted.

CPM requires close supervision by someone skilled with its use, so it is mandatory that the patient and family are involved and educated from the beginning regarding the principles of use and how to monitor the limb.

Frequent checking and slight adjustments of position prevent pressure-related problems. Nurses do not always have sufficient time, or sometimes the experience, to look after these needs. The patients and their families develop a keen sense of responsibility very quickly and become an invaluable asset to the process.

Proper use of CPM, as described in this paper, immediately raises questions and concerns regarding uncontrollable pain. Achieving satisfactory pain control in these patients requires that we depart from traditional teaching; rather than adjusting the motion according to the level of pain, the analgesia is adjusted instead. This is no different than the principles of anesthesia for surgery. Some patients have more pain than others, and appropriate modifications need to be made for them.

There are essentially three options for pain control: 1) narcotic medication, either by injection or by continuous infusion using a PCA (patient controlled analgesia) pump; 2) local anesthetic by continuous infusion with an indwelling catheter and infusion pump; or 3) regional anesthetic, by brachial plexus block anesthesia in the upper limb, or nerve blocks or epidural in the lower limb. With upper limb surgery, we favor the use of an indwelling catheter for continuous brachial plexus block anesthesia (31–35). This permits a range from analgesia to anesthesia by varying the dose of bupivacaine, a long-acting local anesthetic. In many cases, the dose initially employed is sufficient to cause a complete or near-complete motor and sensory block. Motor blockade requires splinting of the wrist to protect it. Moderate or complete anesthesia, as opposed to analgesia with minimal anesthesia, requires careful attention to the overall status of the limb, as the patient's protective pain response is no longer present.

The catheter is left in place for 3 days in the hospital, then removed. At that time, the patient is usually able to maintain the same range of motion with either oral analgesics only or none at all. The goal is to have the patient leave the hospital capable of actively moving the joint through at least 80 percent of its normal motion without significant pain (**Figure 7**); of course, more is better. CPM should be used long enough to get the patient through the period during which he or she will be able to accomplish the full range of motion by him or herself. This can be several days to a month. As the home rental market for CPM machines is being served by at least two companies at the time of this writing, home use of CPM is practical. The typical requirement is in the range of 4 weeks for a joint that was stiff before surgery and 1 to 2 weeks for elbows requiring assistance to prevent stiffness from developing.

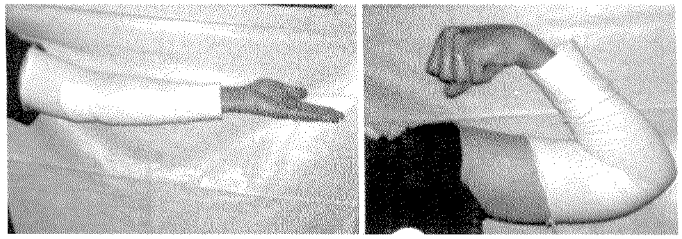

Figure 7.
Active range of motion 3 days following surgery in a patient with rheumatoid arthritis. Preoperatively, this patient had active and passive motion from 50 to 120º of flexion. Surgery consisted of a total synovectomy and capsulectomy. CPM treatment was given immediately postoperatively and continuously for 3 days: full motion was maintained on the machine continuously and the pain controlled with an indwelling axillary catheter for brachial plexus block anesthesia. Active motion at the time of discharge was painless throughout an arc of 10 to 135º of flexion. Final follow-up confirmed maintenance of this arc of motion.

CPM Use in the Knee Following Total Knee Arthroplasty

Understanding the theory and principles of proper CPM application in clinical practice, one is in a good position to review and interpret the literature concerning the use of CPM to facilitate rehabilitation following total knee arthroplasty, for which it has been employed since the early 1980s. In one of the earliest studies of CPM in this patient population, Coutts et al. (13,36) compared knees treated with CPM (begun in the recovery room, initially set at 0 to 40º and advancing by 10º per day) with knees immobilized for a period of 3 days postoperatively prior to beginning any motion. The knees treated with CPM were found to have improved motion 1 year postoperatively. In another study, comparing CPM use to 7 days of splinting following total knee replacement, CPM was again found to improve the flexion of the knee at 1-year follow-up by an average of 10º (14). These studies support the notion that early postoperative motion is better than prolonged immobilization following total knee arthroplasty.

Other investigators, comparing CPM with more limited periods of postoperative immobilization (2 to 6 days) prior to beginning range-of-motion exercises with a physical therapist, failed to observe a difference in knee range of motion at final follow-up (15–18,20). However, careful evaluation of the methods in these studies reveals that

CPM was not used according to the recommendations of the inventor or the principles outlined above. Instead, CPM was initiated through a very limited arc of 30 to 40º and advanced by 10 to 20º per day as tolerated by the patient. The control groups began knee range-of-motion exercises with the therapist 2 (20), 3 (16–18), or 4 to 6 days (15) postoperatively. What we can conclude from this set of studies is that such limited motion with a CPM machine is no more effective at achieving a final range of motion following total knee arthroplasty than the use of physical therapy in the early postoperative period. Furthermore, we can conclude that an adequate range of motion for typical activities of daily living can generally be obtained with or without the use of CPM.

The impact of limited-range CPM on swelling and fluid dynamics in the operated limb is somewhat variable. In a subset of patients in Coutts' study (13), pressure in the deep posterior compartment of the calf and venous flow velocity in the femoral vein were measured during CPM application. These measures were found to vary cyclically with the application of CPM. This finding is consistent with the previously described animal studies on intra-articular pressure and CPM, and with the concept described by O'Driscoll et al. (30) of CPM acting as a fluid pump to reduce edema in the limb. In four studies, knee circumference was measured to see if CPM use reduced knee swelling: three found a statistically significant reduction in knee circumference (9,22,37) and one did not (20). Perhaps relating to decreased knee swelling, studies have found CPM to facilitate a more rapid achievement of knee flexion (9,18,20) and to decrease the number of patients requiring postoperative knee manipulation (18,20,22).

Because CPM utilized in this limited way has not been found to reliably reduce knee swelling, one would predict, based on the theory presented thus far, that CPM used in such a limited fashion would result in little or no improvement in final range of motion. Furthermore, the studies presented to this point do not contribute significantly to answering the question of whether or not use of CPM as it was originally conceived might ultimately affect final range of motion following total knee arthroplasty.

Based on the discussion thus far, it could be anticipated that if CPM were used through a greater range of motion or higher in the flexion arc where tissue tension is greater, the effects would be more significant. Two studies compared more aggressive CPM range of motion with physical therapy. In one study, Pope and colleagues (21) divided 53 patients into 3 groups. The first had a "traditional" course of CPM with initial range set at 0 to 40º, advanced to 0 to 60º 24 hours later, and then discontinued after 48 hours. The second had a more aggressive course of CPM with initial range set in the recovery room at 0 to 70º and progressing to 0 to 90º 24 hours later. This group also had the CPM removed after 48 hours. In both CPM groups, traditional physical therapy, which included active knee flexion and extension through the maximum possible range, was begun after CPM was discontinued. The control group received traditional physical therapy beginning on the first postoperative day. In this study, CPM use did not cover the extent of the second stage of stiffness and there was no difference between the three groups with regard to range of motion at 1 year.

Because intra-articular pressure has been noted to progressively increase as knee flexion increases, one would expect that the pumping action of CPM would be greater with greater degrees of knee flexion. Jordan et al. (10) compared two different postoperative CPM protocols. In the first group, CPM was begun on the second postoperative day with a range of motion of 0 to 40º and progressed as tolerated in 10º increments. In the second group, CPM was begun in the recovery room and set at 70 to 100º of flexion. Extension was advanced by 20º on the first postoperative day and then to full extension by the second postoperative day. The authors found that range of flexion 1 year postoperatively was 111º in the first group and 120º in the second group, a statistically significant difference.

Thus, the literature is entirely consistent with what would be predicted based on the principles of CPM application formulated within the paradigm of the pathophysiology of swelling. In other words, limited use of CPM in a range that is ineffective in the prevention or elimination of blood and edema collection in and around the joint would be unlikely to have any permanent impact on the range of motion following total knee arthroplasty. On the other hand, by employing greater ranges of motion or utilizing CPM higher in the flexion portion of the arc, the pumping effect in the periarticular tissues would be expected to have a greater impact on soft tissue swelling and ultimate range of motion. Whether or not CPM, utilized through a full range of motion in the immediate postoperative period and continued long enough to guide the patient through the early stages, might prevent the third and final stages of swelling has not been addressed in the literature.

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COMPLICATIONS

Complications resulting from the application of CPM can and do occur. Most are not serious or permanent. The most common complication may be increased bleeding, but rarely is this sufficient to require a transfusion due to the marginal increase in blood loss. Although four studies found no difference in wound drainage or transfusion requirements with CPM use following total knee replacement (15,16,18,20), two found increased wound drainage with CPM (19,21). Some patients may require a return to the operating room for evacuation of hematoma under such circumstances.

The major concern in using CPM following major joint operations such as knee replacement relates to the wound itself. Among the literature on wound complications following knee replacement, three studies did not find an increase in wound healing complications with CPM use (14,20,22) but one study did (15). Interestingly, an experimental study in rabbits by van Royen et al. (38) showed that wound healing was accelerated by CPM postoperatively: skin wounds evaluated 3 weeks following arthrotomy displayed 200-percent increases in strength, stiffness, strain prior to failure, and energy absorption prior to failure.

Our clinical experience with CPM application to the elbow suggests that CPM does not have a negative impact on healing of the wound itself. The tension generated in the wound may be a problem if swelling is present when CPM is initiated or if swelling is permitted to occur. Under such circumstances, CPM must not be used through the full range of motion until the swelling has been reduced. This is accomplished by "working" the end-ranges of motion: the patient alternates flexion and extension through a small arc of motion at the limit of flexion (and then extension) to viscoelastically milk the fluid out of the joint and periarticular tissues. Two patients with extensive elbow procedures and large posterior skin flaps experienced wound dehiscence in the first 48 hours postoperatively, when their wounds had been closed with subcuticular stitches rather than staples or interrupted sutures.

However, there is concern about the impact on viability of the skin flaps, particularly over the extensor surfaces such as the knee and the elbow. On several occasions, a long posterior skin flap on the elbow has turned dark and its viability looked questionable. Those elbows were treated by placing them into a well-padded, cylindrical Jones dressing with an anterior plaster slab holding the elbow in extension, then elevating the arm for 2 to 4 days. None of these patients has required a procedure such as skin grafting or a free flap, although a few have had areas of necrosis that healed by secondary intention without surgical treatment. A word of caution is required concerning the required modification to dressings applied to a limb being treated by CPM: no circumferential wrapping (cling, etc.) should be left on the limb once the CPM is started. An elastic tube grip sleeve or fishnet is preferred as it can move freely with the joint. Failure to recognize this increases the likelihood of complications due to compressive and shear forces generated against the wound by a restrictive non-elastic dressing.

Patients may develop nerve compression palsies due to local pressure against the CPM device, particularly if regional anesthetic is used and the patient or staff does not recognize pressures. Frequent adjustments of position and close inspection of the set up on an ongoing basis can prevent this.

Another concern, particularly with operations of the lower limb, is deep vein thrombosis and pulmonary embolism. Preliminary work by Coutts and colleagues (20) revealed an increase in femoral vein flow with each CPM cycle, but this has not been shown to protect against pulmonary embolism. One study using venograms to screen for deep vein thrombosis showed a decreased incidence of thrombophlebitis below the knee but not above the knee (17).

Patients having knee arthroplasty are usually anticoagulated for prophylaxis against deep vein thrombosis. Although epidural anesthesia or analgesia provides excellent pain control, particularly with an indwelling epidural catheter, potential complications of prolonged epidural anesthetic in an anticoagulated, bedridden patient are of concern. For this reason, we have moved away from regional anesthetic to favor PCA pumps in these patients. The recent advent of local infusion pumps promises to be of potential benefit in these patients. Narcotic use following total knee arthroplasty and subjective sensation of pain with and without CPM has been studied, but the results are mixed and no clear conclusion can be drawn (9,16,20–22).

RECOMMENDATIONS FOR CPM USE

When utilized according to the principles described in this paper, CPM acts to reduce blood and fluid accumulation in and around joints that have been traumatized or undergone surgery. In this way, CPM is useful in avoiding the development of subsequent joint stiffness in the first few hours or days. Avoiding stiffness in the early stages minimizes its chances of progression to fibrosis of the joint and establishment of contracture. Long-term benefits, however, are predicated on preventing the accumulation of blood and/or edema fluid in the joint or periarticular tissues. This is accomplished by the immediate application of a full range of passive motion on CPM, or by briefly elevating and splinting the limb in a position that keeps the periarticular tissues stretched before instituting a full range of passive motion on CPM. In the event that the patient is temporarily prevented from using the machine due to other medical or technical factors (if, for example, the machine breaks down) and periarticular swelling does occur, it must be reduced by alternately stretching the joint at its limits of flexion and extension to work the fluid out of the periarticular region.

CPM is indicated to prevent stiffness and to maintain motion obtained at the time of surgery, particularly following joint replacement, synovectomy, contracture release, excision of heterotopic ossification, and fixation of intra-articular fractures. This is particularly true for joints that were stiff preoperatively. It is relatively contraindicated if the soft tissue constraints (ligaments) are insufficient, if the joint is unstable, or if rigid fixation of fractures has not been attained. By following these guidelines and adhering strictly to the principles of CPM use, one will increase the chances of obtaining maximum range of joint motion following trauma or surgery. It would be anticipated that proper application of CPM would, indeed, be cost effective, because it would decrease the need for physical therapy and joint manipulation under anesthesia, and later rehabilitation or surgical intervention to treat stiffness.

CONCLUSION

The principles on which the concept of CPM is based are twofold. First, joint motion is necessary for the maintenance of articular cartilage. Second, and relevant to the present discussion, joint homeostasis requires maintenance of normal periarticular soft tissue compliance. For CPM to accomplish this requires that the motion be full, and that the soft tissues be subjected to tension immediately following surgery in order to prevent swelling. It is this early maintenance of motion that is the key determinant of the joint's long-term mobility. The application of this concept to clinical practice requires a paradigm shift, resulting in the focus of our attention on preventing the initial or delayed accumulation of periarticular interstitial fluids.

REFERENCES

1. Salter RB, Field P. The effects of continuous compression on living articular cartilage. An experimental investigation. J Bone Joint Surg 1960;42–A:31–49.
2. Salter RB, McNeill OR, Carbin R. The pathological changes in articular cartilage associated with persistent joint deformity. An experimental investigation. In: Studies of the rheumatoid diseases. Third Canadian conference on research in rheumatic diseases. Toronto; 1965. p. 33–47.
3. Salter RB. Motion vs. rest. Why immobilize joints? J Bone Joint Surg 1982;64–B:251–4.
4. Melzack R, Wall PD. Evolution of pain theories. Int Anesthesiol Clin 1970;8(1):3–34.
5. Melzack R, Wall PD. Pain mechanisms: a new theory. Science 1965;150(699):971–9.
6. Salter RB, Hamilton HW, Wedge JH, Tile M, Torode IP, O'Driscoll SW, et al. Clinical application of basic research on continuous passive motion for disorders and injuries of synovial joints: A preliminary report of a feasibility study. J Orthop Res 1984;1:325–42.
7. Salter RB. The physiologic basis of continuous passive motion for articular cartilage healing and regeneration. Hand Clin 1994;10(2):211–9.
8. Salter RB. History of rest and motion and the scientific basis for early continuous passive motion. Hand Clin 1996;12(1):1–11.
9. Montgomery F, Eliasson M. Continuous passive motion compared to active physical therapy after knee arthroplasty: similar hospitalization times in a randomized study of 68 patients. Acta Orthop Scand 1996;67(1):7–9.
10. Jordan LR, Siegel JL, Olivo JL. Early flexion routine. An alternative method of continuous passive motion. Clin Orthop 1995(315):231–3.
11. Rorabeck CH. Continuous passive motion is a useful postoperative tool [see comments]. Orthopedics 1999;22(4):392.
12. Dorr LD. Continuous passive motion offers no benefit to the patient [comment]. Orthopedics 1999;22(4):393.
13. Coutts RD. A conversation with Richard D. Coutts, MD. Continuous passive motion in the rehabilitation of the total knee patient, its role and effect [interview]. Orthop Rev 1986;15(3):126–34.
14. Johnson DP, Eastwood DM. Beneficial effects of continuous passive motion after total condylar knee arthroplasty. Ann R Coll Surg Engl 1992;74(6):412–6.
15. Maloney WJ, Schurman DJ, Hangen D, Goodman SB, Edworthy S, Bloch DA. The influence of continuous passive motion on outcome in total knee arthroplasty. Clin Orthop 1990(256):162–8.
16. Colwell CW Jr, Morris BA. The influence of continuous passive motion on the results of total knee arthroplasty. Clin Orthop 1992(276):225–8.
17. Vince KG, Kelly MA, Beck J, Insall JN. Continuous passive motion after total knee arthroplasty. J Arthroplasty 1987;2(4):281–4.
18. Romness DW, Rand JA. The role of continuous passive motion following total knee arthroplasty. Clin Orthop 1988;226:34–7.

19. Kumar PJ, McPherson EJ, Dorr LD, Wan Z, Baldwin K. Rehabilitation after total knee arthroplasty: a comparison of 2 rehabilitation techniques. Clin Orthop 1996(331):93–101.
20. Ververeli PA, Sutton DC, Hearn SL, Booth RE Jr, Hozack WJ, Rothman RR. Continuous passive motion after total knee arthroplasty. Analysis of cost and benefits. Clin Orthop 1995(321):208–15.
21. Pope RO, Corcoran S, McCaul K, Howie DW. Continuous passive motion after primary total knee arthroplasty. J Bone Joint Surg Br 1997;79:914–7.
22. McInnes J, Larson MG, Daltroy LH, Brown T, Fossel AH, Eaton HM, et al. A controlled evaluation of continuous passive motion in patients undergoing total knee arthroplasty. JAMA 1992;268(11):1423–8.
23. Funk DA, Noyes FR, Grood ES, Hoffman SD. Effect of flexion angle on the pressure-volume of the human knee. Arthroscopy 1991;7(1):86–90.
24. Jayson MIV, Dixon ASJ. Intra-articular pressure in rheumatoid arthritis of the knee. III. Pressure changes during joint use. Ann Rheum Dis 1970;29:266–8.
25. Levick JR. The influence of hydrostatic pressure on trans-synovial fluid movement and on capsular expansion in the rabbit knee. J Physiol (Lond) 1979;289:69–82.
26. Favreau JC, Laurin CA. Joint effusions and flexion deformities. Can Med Assoc J 1963;88:575–6.
27. O'Driscoll SW, Morrey BF, An K-N. Intra-articular pressure and capacity of the elbow. Arthroscopy 1990;6:100–3.
28. O'Driscoll SW, Kumar A, Salter RB. The effect of continuous passive motion on the clearance of a hemarthrosis from a synovial joint. An experimental investigation in the rabbit. Clin Orthop 1983;176:305–11.
29. Breen TF, Gelberman RH, Ackerman GN. Elbow flexion contractures: Treatment by anterior release and continuous passive motion. J Hand Surg 1988;13–B:286–7.
30. O'Driscoll SW, Kumar A, Salter RB. The effect of the volume of effusion, joint position and continuous passive motion on intra-articular pressure in the rabbit knee. J Rheumatol 1983;10:360–3.
31. Stinson LJ, Lennon R, Adams R, Morrey B. The technique and efficacy of axillary catheter analgesia as an adjunct to distraction elbow arthroplasty: a prospective study. J Shoulder Elbow Surg 1993;2:182–9.
32. Brown AR, Weiss R, Greenberg C, Flatow EL, Bigliani LU. Interscalene block for shoulder arthroscopy: comparison with general anesthesia. Arthroscopy 1993;9:295–300.
33. Schroeder LE, Horlocker TT, Schroeder DR. The efficacy of axillary block for surgical procedures about the elbow. Anesth Analg 1996;83:747–51.
34. Rice ASC. Prevention of nerve damage in brachial plexus block. XVI Annual European Society of Regional Anaesthesia Congress; 1997. London: Permanyer, 1997. p. 60–3.
35. Gaumann DM, Lennon RL, Wedel DJ. Continuous axillary block for postoperative pain management. Reg Anesth 1988;13:77–81.
36. Coutts RD, Borden LS, Bryan RS, Hungerford DS, Stulberg B, Thomas WH, et al. The effect of continuous passive motion on total knee rehabilitation (abstract). Orthop Tran 1983;7:535–6.
37. Ritter M, Gandolf V, Holston K. Continuous passive motion *versus* physical therapy in total knee arthroplasty. Clin Orthop 1989;244:239–43.
38. Van Royen BJ, O'Driscoll SW, Dhert WJA, Salter RB. A comparison of the effects of immobilization and continuous passive motion on surgical wound healing in mature rabbits. Plast Reconstr Surg 1986;78:360–6