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The Continuous Passive Motion Device for the Knee: An Imperfect Solution to an Extinct Problem (Immobilization)

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RESEARCH STUDY

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By

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ABSTRACT

The CPM has been a staple of knee rehabilitation for more than 40 years. The device did not emerge in a vacuum, but came about because an important debate: motion vs rest, was drawing to close. Ironically, this debate had been resolved by the military decades earlier with active motion and exercise the clear winners[1]. On the civilian side of orthopedics, as late as 1992, patients spent 15 days in the hospital and 18 hours a day lying on their back while the CPM moved their legs[2].

The CPM was primarily designed to encourage cartilage growth and based upon studies of rabbits, which unlike humans can regenerate cartilage. Thus, the CPM was literally based upon an inappropriate animal model.[9, 91]

How did the CPM go from exceeding the human control group by 32.8 degrees of flexion, in ten days in 1982[3] to: "The effects of continuous passive motion (CPM) on range of motion (ROM), pain, function and quality of life are too small to justify its use and costs but the effects of CPM on participants' global assessment of treatment effectiveness are unclear…The effects of CPM on participants' risk of manipulation, risk of adverse events, length of hospital stay, swelling and quadriceps strength remain unclear although there is very low-quality evidence to indicate that CPM reduces the risk of manipulation under anesthesia." (Cochrane Review) in 2014[4]?

The first part of the answer is a simple theory and experimental design flaw: The CPM was invented in 1978 and the common practice then was to immobilize the leg following knee surgery—to let it rest. Compared to immobilization, any movement of the knee improved ROM. However, as the era of immobilization ended, and the CPM was compared to no machine at all, the difference between treatment and control group disappeared. The CPM was not efficacious—immobilization was harmful.

Nevertheless, the machine's efficacy was grandfathered into modern orthopedics despite the numerous modern level 1 studies that resounding demonstrated that the machine does not enhance ROM and the results on MUAs are inconclusive. And, the overwhelming majority of studies supporting the use of the CPM suffer numerous other design problems; in short supporting studies are level three, four, or five studies. Whereas, studies not supporting the use of the CPM typically are level one and two studies.

The CPM is still used today because it is a, common, and sometimes patient-requested adjunct to knee surgery. It's like putting on an old pair of slippers that were inherited during the surgeon's residency. Other surgeons prescribe it because it allows them to appear to do something, even though the machine achieves nothing and may actually harm the patient by prolonging bedrest (which is not benign), and still others use it because colleagues do, and patients expect it.

The machine suffers other problems: 1) the alignment between patient and machine cannot be maintained—the machine wanders over the bed and patients do too. It is uncomfortable to lay motionless for hours, days, and for days to weeks. Ritter tried bolting the machine to the bed to keep it from moving.[5] The alignment cannot be maintained—the joint is moved inappropriately potentially causing tissue trauma, inflammation and pain associated with CPM use.[6]

2) Pain has been a problem since the inception of the CPM. Pain reduces patient compliance, and patients resent being tethered to a painful machine. To counteract this, O' Driscoll, who advocated only allowing patients out of bed to use the bathroom, argued that patients should receive all the pain medication required to keep them comfortable during the more than 20 hours a day of being strapped to the CPM.[7]

3) The patient's leg does circumscribe the machine arc, i.e., the leg often experiences less than 70% of the machine's arc.[8]

4) Ironically, no study has ever established optimal CPM usage, and because the CPM does not enhance ROM in the modern world of knee rehabilitation (no immobilization)—whatever duration, angle, speed, arc etc. that is prescribed is equally ineffective-- whether it is 24 hours of use/day or 30 minutes/day—the machine is equally ineffective at all settings and durations of usage.

5) Equally important, while the CPM flexes the leg, patients are suffering the ill effects of too much bedrest. Modern norms of treatment have reduced hospital stays, patients ambulate the day of surgery and physical therapists argue for a more active recovery. A pattern the military established in WWI. If the decision to use or not use the CPM was based on quality of supporting evidence (e.g., level 1and 2), then it would no longer be used today

6) Given, contradictions in the origins of the theory, lack of standardized parameters, and the lack of positive outcomes the cost is simply unjustifiable.

I. History of the Debate: Rest vs. Motion

Joint injuries and surgeries have been important to people for more than 2000 years. Hippocrates, (460-370 BCE) argued that the joint needed rest following trauma, or in our parlance, immobilization.[9] Aristotle (384-322 BCE) argued to the contrary that the joint needed to move following trauma or surgery.[6,10] The "rest" side of the debate had a simple theory, let the joint rest and heal. The motion side held that moving the joint returned the patient to full function faster and reduced adhesions. The debate persisted for over 2000 years, and was brought to end for the U.S. military in WWI.

The First World War, saw the birth of modern physical therapy and rehabilitation medicine.[1,11-12] Here is how the U.S. treated joint injuries in that war, "Since in all such injuries ultimate function is the chief requisite treatment having for its purpose the restoration of function should be instituted as soon as possible, and for this purpose, it is desirable that cases of such injury be transferred, as soon as the primary wound treatment has been given, to the orthopedic service. It is important that such transfer be made before unnecessary adhesions have formed so that the restoration of function can be obtained in the least possible time. In all such functional restoration, it should be clearly understood that while motion is to be encouraged at the earliest possible moment, it should consist entirely of active motions, performed by the patient, in which case the reflex muscular contraction will protect the joint from undue injury. **All passive motion should be avoided"**[12] (emphasis added). Thus, the American military medicine resolved the debate in the clear favor of actively moving joints quickly following injury/surgery.

With the end of the war there was some retrogression, but Dr. Rusk reintroduced active rehabilitation to US Army Air Corps in the 1940s.[1] He observed, "that men did not get ready for full duty by playing black jack or listening to music... patients were deconditioning and bored" Consequently, after their initial discharge, patients had a high rate of readmissions because they were unable to meet the demands of being a soldier. Rusk introduced early ambulation and exercise following surgery. At same time scientific studies started to indicate early activity had greater benefits than prolonged bed rest. By 1944 the American Medical Association had a symposium entitled, "The abuse of rest in treatment of disease".[13] After the war in 1952 Professor George Perkins in an address to the British Orthopaedic Association stated, "in making a choice between rest and motion, we are largely biased by tradition". He went on to advocated **intermitted active motion** for the **first few days** after open reduction and internal fixation were the best treatment[14] (emphasis added). Motion after surgery became the military regime—but not the civilian.

Despite the influx of ideas from the military and rare opponents, bedrest and immobilization of the knee remained the preferred civilian mode of recovery well into the 1990's. Indeed, Dr. David Halley, a resident with Dr. Sir John Charnley while Charnley was perfecting joint replacement, noted that, knee patients "Were put into casts for three weeks" (Pers. Comm)

II. CPM Theory & History:

The theory of the CPM is seductive, the patient is put into the machine which then flexes the knee through a prescribed arc, at a given rate, and angle; for a prescribed period of time each day, for days to weeks on end. The machine is supposed to pump fluid from the knee, thereby enabling the ability of the knee to bend further and removing the constituents of edema that promote scar tissue.[7] The predicted patient outcomes are an acceleration acquiring early range of motion (ROM)[5,25,31-33,38,42], a shorter hospital stay[34-35,37-38,53,57], and reduction in: arthrogenic muscle inhibition[5,49,53-54,92] (and consequently a quadriceps strength deficit), the formation of scar tissue[7], adverse events (wound infections, pulmonary emboli, knee hematoma and apatellar rupture.)[32,34-35,43,57], swelling[5,17 ,38,53,16] manipulations under anesthesia[3,24,28,32-34,40,48] , and overall hastening in the patients' ability to carry on the activities of daily living. For these reasons, Medicare and other insurance companies approve the CPM for up to 3 weeks after a TKA. However, most disturbing though is that in our review of level I studies (See Appendix 1), and the Cochrane Review's study, ***the CPM achieved none of its goals.***

Robert Salter is generally regarded as the inventor of the CPM in 1978 and we have reviewed his contributions in Appendix 2. Salter theorized "We can look on rest and motion as a spectrum. At one end is continuous immobilization or rest, as in a cast. In the middle is intermittent motion- either active or passive- and at the opposite end is continuous motion which, because of the fatigability of skeletal muscles, must be passive rather, than active"[97]. The theory was first invalidated in 1988, in a study where there was no difference found between using the knee CPM for 5 hours compared 20 hours.[30] Salter's "theory" asserts the movement must be continuous, therefore the CPM would have to be used 24 hours a day as it was in the first CPM studies.[3,24] In reality, the CPM should have been discontinued as theory were not backed by any data. However, we must note that passive motion machines were commonly used in the 19th century, and Salter was not the first to add electricity making motion continuous, but his machine did become the model upon which modern machines are based. What's most startling is the rationale behind Salter's CPM theory. His theory was solely based upon his clinical observations, experiments utilizing rabbits, an inappropriate animal model for humans,[91] and his own personal beliefs (Appendix 2-3). Salter's CPM theory and original research with rabbits is not analogous to humans, in order for Salter's CPM to be applicable to humans, patients would need to hang vertically with their ankle fixed to the machine moving their ankle up and down as the rabbits did in Salter's research. In reality, it was Coutts who describes the progression of three CPM knee models for humans (Appendix 2, Figure 2). Additionally, O'Driscoll was the one who further developed and elaborated the biology component of the CPM theory. Salter, was primarily interested studying the regeneration of rabbit cartilage after drilling holes in the subchondral bone (cartilage that will regenerate regardless of motion unlike humans). Shockingly, Salter's supporters stated "the impossible dream has, in a real sense, now become reality".[14]

Coutts et al., (1982)[3], were the first to use a CPM following a TKA. Coutts argued that patients did not mind 20 to 24 hours of enforced bedrest, because "patients were introduced to CPM and the mechanical device and its intended effect long before their total knee surgery…by time the patient awakened in the recovery room, the patient was well acquainted with the device".[15] However, in 1989 Ritter reports patients resented their mobility being restricted for 20 to 24 hours a day while they used the CPM.[5] It was difficult to enforce bed rest for more than a few hours, patients were not compliant because they resented the enforced immobility [16-18] and there were other problems. Bed rest promotes: contractures and loss of normal motion to joints, atrophy of muscles (15% loss per week of inactivity), calcium is lost from bones, the heart is deconditioned, poor circulation, increased infection in the urinary tract, increased ulcers, and increased depression and anxiety.[19-23] (Table 1).

Table 1. (Unnecessary Disabilities Due to Bed Rest)

Joints	Contractures: loss of normal range of motion
Muscles	Disease atrophy: 15% loss per week of inactivity
Bone	Osteoporosis; pathologic fractures
Urinary tract	Infection; calculosis
Heart	Deconditioning: decreased cardiac reserve; decreased stroke volume; resting and postexercise tachycardia
Circulation	Orthostatic hypotension; thrombophlebitis
Lung	Pulmonary embolism; atelectasis; pneumonia
Gastrointestinal	Anorexia; hospital-acquired malnutrition; constipation, impaction
Skin	Decubitus ulcer
Psyche	Anxiety, depression; disorientation

Coutts and those that followed him compared the CPM to immobilization. Coutts did not include a treatment of allowing motion (active) nor early ambulation without the CPM. The most direct way to test if the CPM has any efficacy is to add a third treatment group, "nothing—no CPM". This did become the control until decades after Salter & Coutts did their seminal work. In fact, most level 1 and 2 studies do use "nothing" as the control. It is immobilization that has been dropped from recent studies as it is now rightly out of favor (Table 6).

Compared to immobilization the CPM appeared to have a huge effect (Table 3 and 7). However, when the control group changed to no CPM, the CPM had little or no effect—this is particularly true of Level I studies (Table 6 and Appendix 1). We can now reinterpret the results of earlier studies. Immobilization is harmful. This does not mean that treatment with the CPM was helpful. It merely means that some motion is helpful. In humans, not being tethered to a CPM, allows enough motion that there is no difference between the CPM and no CPM group (Table 3). We have examined in table 7 the incidence of MUAs. Again, when the control was immobilized legs, the CPM appeared efficacious. However, when the control is no CPM there is little direct evidence that indicates that the CPM has any positive effect. Over time the length of hospital stays, amount of immobilization, and hours per day the CPM was used have all decreased as has discharge ROM (Table 3).We also reviewed how physical therapy protocols have changed to emphasize active exercises and movement (Table 2).

The most obvious overall trend is that patients are spending less time in the hospital, less time in bed, they ambulate the day of surgery, hospital physical therapy protocols have less immobilization and more active motion. Yet, despite this consistent progression towards the military's position of active motion, the CPM remains commonly prescribed and this is an anathema to the modern trends. Why must patients take to their beds for protracted periods of time (Table 6, see column total CPM hours) which achieve nothing and ill serves the patient as established above?

Table 2 (Rehab and Health Reimbursement Changes in Total Knee Replacements)

Time	Total Knee Replacement Rehab Protocol	LOS	Health Reimbursement Changes
Pre 1980s	Cast for two weeks. Start range of motion exercises two weeks later	2-3 wks	• Birth of physical medicine and rehabilitation • Research methodology beginning stage
1980s	Bed rest for a week, then start ambulation/ PT 1 week later	2 wks	• Prospective payment pushed for early ambulation and discharge. Meta-analysis medicine emerges
1990s	Shift from bed rest to active motion on day 2-3	7-10 days	• TKA protocols must be beneficial and cost-effective • Evidence based medicine born
2000s	Focus on immediate mobilization to decrease hospital stay. Total and partial knee replacements become outpatient procedures.	3-5 days	• Clinical research becomes necessary in health policy decisions • Levels of evidence introduced • Bundle payment (lump sum payments), gain sharing (reward cost-effective surgeons) accountable health care originations (reward quality) are introduced

Early CPM studies also suffered from the low quality of design. Many early CPM studies were level 3 due to being retrospective[3,24-36], and non-randomized[5,24-29,32-33,37-41], nor blinded[16,42-43].However, prior to the 1970s doctor's opinion and experience determine not only what interventions would be prescribed but also a patient's diagnosis. Thus, a patient's safety and the procedure used depended upon the surgeon's opinions and beliefs.[44] (Table 6) Hence, the popularity of the CPM was based upon not results.

Common Abbreviations

LoE= Levels of Evidence

IM= Immobilization

X= missing

"-"= N/A

Table 3 (Range of Motion at 2 weeks in immobilization or no CPM v. CPM)

Ref.	LoE	Year	CPM v. IM Statistics	CPM v. IM (ROM Values)	Total Diff.	CPM v. no CPM Statistics	CPM v. no CPM (ROM Values)	Total Diff.
1	3	1982	X	100.6° v. 67.8°	32.8°	-	-	-
2	3	1983	X	97° v. 79°	18°	-	-	-
3	3	1984	p<.05	X	X	-	-	-
4	3	1985	p=0001	X	X	-	-	-
5	3	1986	n.s.	95° v. 90°	5°	-	-	-
7	3	1987	-	-	-	n.d	77° v. 76°	1°
8	3	1987	-	-	-	n.s.	X	X
9	2	1987	-	-	-	n.s.	92.2° v. 89.7°	2.5°
11	3	1988	-	-	-	n.d.	65° v. 67°	-2°
12	3	1988	p<.02	90.2° v. 87.7°	2.5°	-	-	-
13	2	1989	n.s. p=0.1055	80.65 v. 78.3	2.35°	-	-	-
14	2	1989	-	-	-	p<.05	87° v. 78°	9°
16	2	1990	n.s.	80°v. 78°	2°	-	-	-
17	3	1990	p<.01	93.2° v. 86.5°	6.7°	-	-	-
21	2	1992	no p value	76° v. 67°	9°	-	-	-
23	2	1992	-	-	-	n.s.	93° v. 90°	3°
24	3	1993	-	-	-	n.s. (p=0.69)	88.32° v. 91.84°	-3.52°
25	3	1995	-	-	-	n.s.	X	X
27	2	1995	-	-	-	p<.0001	81.3°v. 71.2	10.1°
29	2	1996	-	-	-	n.s.	77° v. 76°	1°
36	1	2000	-	-	-	n.s. (p=0.41)	87° v. 90°	3°
40	2	2001	p<.05	75° v. 56°	19°	-	-	-
41	2	2003	-	-	-	n.s. (p=0.163)	90.2° v. 83.7	6.5°
46	1	2008	-	-	-	n.s. (p=0.06)	83.6° v.78.6 °	5°
47	1	2009	-	-	-	n.s.	85° v. 83°	2°

*Note references correspond with Appendix 1 References

CPM Settings & Efficacy

The CPM has several parameters that must be determined or require an operator to set: When should use begin following surgery, for how many days or hours per day, and days overall, the arc, alignment of patient and machine, rate of motion, angle of the patient's head and torso, how much the arc should increase each day (Table 4 and 5). Despite over 40 years of study, no one has produced an optimal protocol for the machine (Table 4,5,6). The studies differ markedly for all mentioned parameters (Table 6). Bible et al., (2009)[8] have argued that patient's the leg does not go through the same arc as the machine. Jordan et al.[39] suggested large arcs should pump more periarticular fluid out. However, large arcs are more painful.

Table 4 (Common CPM Variables)

CPM Start	•Recovery room •Post operative Day 2 or 3
Hours	•Short: 1-5 hours •Long: 10-24 hours
Flexion Arcs	•Standard:0-30/40° advance 10-15° per day •Early Flexion: 0 to 70/90° or 90-50° advanced by 10-20° per day

Table 5. Forgotten Biomechanic Variables

Flexion Arc		Position of Arc to Joint		Rate of Motion	
Standard	Early Flexion	Anatomical	Free Linkage	Slow	Moderate
1-2, 5,10-12	26, 28, 31-32, 35, 38, 42, 47, 50	13,30	None	4-5,7,10,15,18,29	13

*Note references correspond with Appendix 1 References

Even if the CPM did not keep patients in bed and the flexion arc moved the leg through the full arc, we would still need to have standardized CPM protocols that stipulate: the appropriate flexion arc, how to maintain position of arc to the joint, the rate of motion, when to start and end the CPM, or how long to use it, and how much the arc should be increased each day.[6,9]

Table 6 (Parameters Tested in CPM Studies

Key:

LoE= level of evidence

PoD= Postoperative

C= CPM was compared to 1) immobilization 2) no CPM/ standard PT 3) CPM combined with alternate intervention 4) alternate intervention.

LOS= length of stay

Ref.	LoE	Year	C	CPM Start	Deg. of Initial Arc	Deg. Advanced	Total HRs in CPM (Bed)	Times X Hrs.	Stopped	CPM LOS	Control LOS
1	3	1982	1	?	Never < 30°	?	20	1	Discharge	×: 12	×: 15
2	3	1983	1	?	Never < 30°	?	20	1	Discharge	×: 14	×: 18
3	3	1984	1	PoD 0	0-90°	?	18	1	?	?	?
4	3	1985	1	Recovery Room	30 to 90°	Slow Increase	?	?	×:5.4	?	?
5	3	1986	1	Recovery Room	0-30°	10-15°	20	1	?	×:16	×:20
7	3	1987	2	3rd PoD	0 to 35°	5 to 10°	3	3 X 1 hrs	Discharge	×:19	×:22
9	2	1987	2	Recovery Room	0-30°	?	20	1	?	15	16.7
10	2	1988	2	Recovery Room	0-30°	10°	7-17	1	7	×:10	×: 10
11	3	1988	2	2nd PoD	0-25°	5-10°	4	2 x 2hrs	12th PoD	?	?
12	3	1988	1	Recovery Room	0-30°	10-20°	10 to 20	1	Discharge	×:15	×:16
13	2	1989	1	2nd PoD	**?**	?	20	1	5	?	?
14	2	1989	2	Recovery Room	0 to 40°	10°	12 to 18	On 3 off 1 or On 2 off 2	Discharge	×:12	×:12
16	1	1990	2	Recovery Room	0 to 30°	?	24	1	8th PoD	×:11	×:14
17	3	1990	1	Recovery Room	0 to 35°	10°	10	?	Discharge	×:15	×:15
18	2	1991	1	Recovery Room	0-40°	10°	6	1	?	×:17	×:18
19	3	1991	3	Recovery Room	0-40°	10°	?	?	Discharge	×:10	×:11
20	2	1992	1	Recovery Room	0-40°	10°	24	1	Discharge	×:10	×:11
21	2	1992	1	Recovery Room	0-40°	10°	16-20	1	7	×:15	×:20
22	1	1992	2	PoD 1	?	?	9	1	?	×: 10	×:10
23	2	1992	2	Recovery Room	0-30°	15°	16	2 on off 1	?	?	?
24	3	1993	2	?	Per patient's passive ROM	?	3 to 4	1	?	×:19	×:20
25	3	1995	2	PoD 0	0 to 25-30°	5-10°	4 to 6	?	?	?	?
27	1	1996	5	Recovery Room	0-90°	?	10	1	?	×:12	×:12
28	2	1996	2	Recovery Room	?	?	9	3 x 3hrs	?	×:7	×:6
34	3	1999	4	?	Per patient tolerance	?	3-5	1	8	×: 8	×:8
36	1	2000	2	PoD 1	10° < passive flexion	?	5	1	?	?	?
40	2	2001	1	PoD 1	0-60°	?	23	1	6	?	?
41	2	2003	2	PoD 1	Per patient tolerance	?	4	1	4	×:4	×:4
44	1	2006	2	PoD 1	0-30°	10°	2	2 X 1hr	?	?	?
46	1	2008	2	Recovery Room	?	?	4	2 X 2hrs	17	?	?
47		2009	2	PoD 0	PoD 1: 70- 100° PoD 2: 0-100°	?	PoD 1: 4 PoD 2: 6	PoD 1: 2 X 2hrs PoD 2: 3 X 2 hrs	?	×:7	×:7
49	2	2010	2	PoD 0	90-70°	10° in 4 hrs	6	3 x 2 hrs	3	×:2	×: 2

52	3	2013	2	PoD 1	?	?	6	3 x2 hrs	Discharge	×:3	×:3
54	1	2014	2	PoD 0	Per patient tolerance	Per patient tolerance	2	1	?	×: 8 (IRF)	×:9 (IRF)
55	1	2014	4	PoD 2	?	?	1	2 X 30 min.	1 day prior to Discharge	×: 11	×: 10
57	1	2015	2	PoD 1	0-30°	10°	2	2 x 1 hr	Discharge	×: 6	×: 9
58	1	2015	2	PoD 0 or 1	Per patient tolerance	Per patient tolerance	6	3 x 2hrs	Discharge	×: 3	×: 4

*Note references correspond with Appendix 1 References

As far back as O'Driscoll (2000), in a review paper on the CPM theory, he asserted that if the CPM had been used according the inventor's recommendations then it would have worked.[7] But, Dr. Salter never published any CPM knee biomechanics or user parameters recommendations. Rather, he did publish many reviews of his "basic research and proposed clinical applications", but none of his papers tell the clinicians how to appropriately and safely the device.[9,94-95] Most recent CPM papers concern only two issues: Does the CPM significantly enhance the range of motion (ROM), and does it lead to a reduction in manipulations under anesthesia.

According to O'Driscoll CPM use should begin in the recovery room, with initial arc set at 0-40° and advancing 10° per day (standard parameters). Elsewhere though, he argued more flexion (70-100° and advancing 20° per day[10]) would pump more fluid out of the knee but still requiring the CPM use to begin in the recovery room. Further, the majority of studies fail to mention the arcs utilized, and the actual arc used is based upon what the patient can tolerate.[61,92-93]

Pain appears to be a problem. O'Driscoll's conflicting suggestions about CPM settings, immediately raises questions and concerns regarding uncontrollable pain. Pope et al. [43] reported patients experienced increased pain when the early flexion/ more aggressive arcs are utilized. "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"O'Driscoll[7]. This atypical response to pain clearly shows the commitment O' Driscoll had to the theory.

While supporters of the CPM have touted flexion, the machine did not allow patients to achieve extension. Some investigators mention the issue[17,29] and others attempted to rectify the issue by using a bolster under the heel to gain full extension.[32]

Why are optimal setting not known? Multivariate optimization has been around at least since Newton, Gauss, Fermat, and Lagrange.[45]It is not as if finding the optima was a particularly vexing scientific challenge. Ardent prescribers of CPMs may argue that the optima is likely to differ for each patient—a proposition that is difficult, if not impossible, to test; the more parsimonious answer to why the optimum problems has not been solved is no optima exists. The CPM's ineffectiveness is independent of the hours used,[3,17,28,96] whether the CPM is started in the recovery room or first postoperative day,[26-27] whether alignment is maintained or not[5,17], the speed of the CPM (an arbitrary number based of rabbit model).,[9] All of the above suggests there are serious issues with the theory and original research Further, as Tabor stated "This is the optimum time to question our rehabilitation practice and strive for a more evidence-based approach." Clearly, the CPM is not supported by high quality evidence due the fact CPM theory is based of Salter's level 5 clinical observations and inappropriate animal model.

Hospitals, physical therapist, and modern rehabilitation protocols have clearly moved from a passive patient at rest or with their leg immobilized to an active patient that generates less motion—CPM usage is counter to this trend indicating that is a hard habit to break.

Table 7 (Amount of MUAs Immobilization (IM) or Physical Therapy (PT) v. CPM)

Refs.	LoE	IM	CPM	PT	CPM
1	3	5	0	-	-
2	3	21% More	0	-	-
7	3	X	X	3	3
9	2	X	X	1	0
16	2	0	0	-	-
18	2	5	1	-	-
21	2	0	0	-	-
22	1	-	-	0	8
27	2	-	-	5	0
28	2	-	-	3	1
49	2	-	-	2	0

*Note references correspond with Appendix 1 References

Costs

Today, manufactures who claim to provide additional clinical or cost benefits to existing technologies are required to undergo economic evaluation and provide high quality scientific evidence to support their claim to health policy decisions makers and payers.[46-47] In the mid-1990s an evidence based and cost-effective reform were initiated in the total knee arthroplasty field as demands of decreasing the length of hospital stays and lowering hospital costs became paramount in health policy.[2,38,40,48-50] Reimbursement changes required and motivated hospitals to decrease time spent in the hospital starting in the 1980s, which is why the CPM seemed like an attractive solution. Salter et al. initially projected a savings of $2,000 to $4,000 per patient over a 6-month period using the CPM.[51] Many investigators[34,36,39-40,52-55] argued that the CPM was cost effective despite the absence of high quality evidence of patient outcomes and costs data to justify the belief that the CPM saves any money or influences hospital stay, manipulation under anesthesia (MUA) rate, or faster recovery of ROM (Table 3,6,7). This trend was noticed as early as the late 1980s and early 1990s. Indeed, in a review of the CPM by Morris noted "The findings discussed in this review on the possible benefits of the use of CPM after TKR have proved inconclusive…These trends are not strong enough to justify the CPM's regular use and may explain why the inclusion of CPM in post-operative rehabilitation programmes became so variable."[56] Many studies[5, 27, 37, 42, 57-61] and reviews[62-68] on the CPM noticed the same trend and recognized the CPM used resources in several ways, e.g. purchasing the devices and software, maintenance of the devices, training staff how to properly use the CPM, and nurse- time[18,61,69] While, many ardent supporters argued the CPM was cost-effective even when there were no significant differences between the CPM and no CPM in objectively measured parameters. Today, surgical approaches and early ambulation physical therapy protocols are now allowing patients fewer postoperative restrictions decreasing overall hospital stay.[70]The CPM which keeps patients in bed, is contrary to current practices.[18]

The price of keeping patients in bed does come at high cost. Although, the price of the daily rental fee for the CPM has decreased from $60 in 1995 to $16 today.[40] Even if the CPM was free, this does not dismiss the fact the machine requires patients lay in bed, inevitably deteriorating muscles and strength. It would be more cost effective to pay patients $16 a day to be active. Presently CPM costs are estimated at $235.50 per TKA.[61] Boese et al.[59] also reported if the CPM was dropped from their post-operative rehabilitation protocol, then their institution could have saved $22, 200 per year. The reality is, for the past forty years insurance companies and the government have paid CPM manufacturers large sums of money without the companies being able to provide high quality clinical evidence supporting cost effective claims and also have kept patients in bed. However, the lack of important clinical and research findings go unrecognized by surgeons, as many as 58% of orthopaedic surgeons admit to prescribing the CPM at the 2009 Annual Meeting of the American Association of Hip and Knee Surgeons (AAOS).[71]

Today, we have to be motivated by the high demand on health resources and low funds available. We have no choice but to pay closer attention to the clinical outcome per unit cost e.g., clinical and administrative personnel, drugs and other supplies, devices, space, and equipment.[72] Cost effective analysis is an important tool in the current health care crisis.[73] There seems to be complete lack of understanding how cost and outcomes interact in joint replacement because we are not efficiently or consistently objectively measuring costs and outcomes. Given that, baby boomers are aging rapidly[74-76], the obesity epidemic is increasing[77-79], and total knee patients are younger demand for high quality outcomes can only increase[73]. All these factors contribute to the projected 673% increase in TKRs with 62% of patients being less than 65 years old by the year 2030. In 2011 $14.8 billion was spent on OA, if we do not modify surgical and rehab protocols by 2030 this amount could easily be approaching $100 billion dollars.[80-81]

The reality is total knee replacements are as prevalent as congested hear failure.[82]Current solutions to the problem of cost and joint replacement include: A single lump-sum payment from Medicare to a health care delivery system (e.g., bundle payments)[83-85], rewarding efficient surgeons with a new medical device or research funding (e.g., gain sharing)[83], physician compensations for care provide to a particular patient population over time versus compensation for each procedure performed (e.g., accountable care organizations)[83], and cost benefit analyses (e.g., QALY)[84-85]. When we put all this into perspective we see that CPM has never fulfilled its clinical or cost-effective purposes, and it does not fit current health policy goals. Its continued approval wastes already strained resources.

What is most remarkable is that regulators, policy makers, and payers often struggle with insufficient data to make a determination of efficacy. This is not the case with the CPM there is a rich abundance of data to enable a decision—scientifically that decision has been made, but policy and politics are something else.

Conclusion

In the end, what are we left with? There is the compelling theory: Moving the joint should reduce the blood and edema in the joint and reduce adhesions. But, when studies that use no CPM as a control reach the same average range of motion as those that used the CPM, we have to question Salter's original assertion, as articulated by O'Driscoll that, "He (Salter) 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." This assertion is false. Patients without the CPM gain the same ROM as patients with a CPM. The motion need not be continuous; it can be episodic throughout the day. Without continuous motion, there is no logical reason why the motion, must of necessity be passive. Passive motion may initially help with neuromuscular re-education but as that re-education proceeds active motion is not only possible but is, as the Surgeon General's circular 46 noted… "desirable". There is no logical reason to pay to keep patients in bed to their determent.

Millions of patients have had to endure a CPM. Some may have found it comforting, others found it painful, and it robbed them of their freedom. Moreover, it forced all of them to stay in bed with all the debilitating effects of bedrest, not to mention that it did not reduce the arthrogenic muscle inhabitation and so left them with a deep strength deficit (that are often not erased even a decade after their TKA.[86-90] Dr. Rusk was and is correct, "that men did not get ready for full duty by playing black jack or listening to music." He noted that in recovery time, (which was immobilization), patients were deconditioning and bored".[1] As we have argued above, immobilization is not the only means by which decondition and boredom are produced. Lying in bed for hours a day appears sufficient. Total Knee Arthroplasties are well on their way to become ambulatory surgery. If this is to be the case, then new ways of restoring range of motion, strengthening muscles and reducing AMI must be found. These new methods must actually work—not because of strong voices from prominent surgeons in high positions but because the very mechanics of the machine satisfy the theory that O' Driscoll described. Insurers and the government should stop paying for CPMs. The machine, however well-intentioned, is a failure and the tax payers and insurers need not pay because we are unwilling to break an old habit.

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Appendix 1: Review of CPM Studies and Levels of Evidence

Key: R= Retrospective, p= Prospective, RCT= Randomized Controlled Trial, PS= Pilot Study, and PT= Physical Therapy

CPM Studies in 1980s

Reference (lead author last name)	Year	Level of Evidence	Study Design	Randomized	Control Treatment	Supports CPM
1. (Coutts)	1982	3	R	N	Immobilization	Y
2. (Coutts)	1983	3	R	N	Immobilization	Y
3. (Davis)	1984	3	R	N	Immobilization	Y
4. (Fisher)	1985	3	R	N	Immobilization	Y
5. (Goletz)	1986	3	R	N	Immobilization	Y
6. (Basso)	1987	3	R	N	20 (Control) v. 5 hrs CPM	Y
7. (Gose)	1987	3	R	N	No CPM	Y
8. (MaChesney)	1987	3	R	N	No CPM	N
9. (Vince)	1987	2	P	Y	Standard PT/ no CPM	Y
10. (Lynch)	1988	2	P	Y	Standard PT/ no CPM	N
11. (Nielsen)	1988	3	R	Y	Active PT	N
12. (Romness)	1988	3	R	N	Immobilization	Y
13. (Ritter)	1989	2	P	N	Immobilization	N
14. (Schnebel)	1989	2	RCT	Y	Standard PT/ no CPM	N

*R= Retrospective, P= Prospective, RCT= Randomized Controlled Trial, PS= Pilot Study, PT= Physical Therapy

CPM Studies in 1990s

Reference (lead author last name)	Year	Level of Evidence	Study Design	Randomized	Control Treatment	Supports CPM
15. (Angulo)	1990	3	R	Y	Transcutaneous Electrical Nerve Stimulation (TENS) & CPM v. CPM only	Y
16. (Maloney)	1990	2	P	Y	Immobilization	Y
17. (Shih)	1990	3	R	N	Immobilization	Y
18. (Harms)	1991	2	P	Y	Immobilization	Y
19. (Walker)	1991	3	R	Y	TENS & CPM v. Cooling Pad & CPM v. CPM only	Y
20. (Colwell)	1992	2	P	Y	Immobilization	N
21. (Johnson)	1992	2	RCT	Y	Immobilization	Y
22. (McInnes)	1992	1	RCT	Y	Standard PT/ no CPM	Y
23. (Worland)	1992	2	P	Y	Standard PT/ no CPM	N
24. (Nadler)	1993	3	R	N	Standard PT/ no CPM	N
25. (Can)	1995	3	R	Y	Standard PT/ no CPM	N
26. (Jordan)	1995	3	R & P	N	Immobilization	Y
27. (Verveli)	1995	2	P	N	Standard PT/ no CPM	Y
28. (Kumar)	1996	2	P	Y	PT (Drop and Dangle)	N
29. (Montegmory)	1996	2	P	Y	Active PT	N
30. (Chiarello)	1997	3	R	Y	Standard PT/ no CPM v. 4 varying CPM settings	N
31. (Pope)	1997	2	P	Y	Immobilization v. 2 varying CPM settings	N
32. (Yashar)	1997	2	P	Y	None (2 varying CPM groups)	Y
33. (Worland)	1998	2	RCT	Y	Standard PT/ no CPM	Y
34. (May)	1999	3	PS	Y	Lower Limb Mobility Board	N
35. (Ng)	1999	3	R	Y	Standard PT/ no CPM v 2 varying CPM settings	Y

*R= Retrospective, P= Prospective, RCT= Randomized Controlled Trial, PS= Pilot Study, PT= Physical Therapy

CPM Studies in 2000s

Reference (lead author last name)	Year	Level of Evidence	Study Design	Randomized	Control Treatment	Supports CPM
36. (Chen)	2000	1	RCT	Y	Standard PT/ no CPM	N
37. (Lachiewicz)	2000	4	R	N	None (CPM patients only)	Y
38. (MacDonald)	2000	1	RCT	Y	Standard PT/ no CPM v 2 varying CPM settings	N
39. (Beaupre)	2001	1	RCT	Y	Standard Exercise (SE) & CPM v. SE & Slider Board v. SE only	N
40. (Lau)	2001	2	P	Y	Immobilization	Y
41. (Lenssen)	2003	2	P	Y	Standard PT/ no CPM	Y
42. (Bennett)	2005	1	RCT	Y	Standard PT/ no CPM v 2 varying CPM settings	N
43. (Denis)	2006	2	RCT	Y	Standard PT/ no CPM v 2 varying CPM settings	N
44. (Leach)	2006	1	RCT	Y	Standard PT + Slider Board/ no CPM	N
45. (Leonard)	2007	3	R	N	None (3 varying CPM groups)	Y
46. (Lenssen)	2008	1	RCT	Y	Standard PT/ no CPM	N
47. (Bruun-Olsen)	2009	1	RCT	Y	Active PT	N
48. (Ersozlu)	2009	2	P	Y	Standard PT/ no CPM v 2 varying CPM settings	N
49. (Alkire)	2010	2	P	Y	Standard PT/ no CPM	N
50. (Lan-Hui)	2012	2	P	N	Standard PT/ no CPM	N
51. (Maniar)	2012	2	P	N	Standard PT/ no CPM v 2 varying CPM settings	N
52. (Tabor)	2013	3	R	N	Standard PT/ no CPM depending on ROM on POD 1	N
53. (Boese)	2014	1	RCT	Y	Standard PT/ no CPM v 2 varying CPM settings	N
54. (Herbold)	2014	1	RCT	Y	Standard PT/ no CPM	N

55. (Mau-Moller)	2014	1	RCT	Y	Sling Exercise v. CPM	N
56. (Alaca)	2015	3	R	Y	Progressive NMES v. CPM	N
57. (Baloch)	2015	1	RCT	Y	Standard PT/ no CPM	N
58. (Joshi)	2015	1	RCT	Y	Standard PT/ no CPM	N
59. (Liao)	2015	3	R	N	None (3 varying CPM groups)	Y

*R= Retrospective, P= Prospective, RCT= Randomized Controlled Trial, PS= Pilot Study, PT= Physical Therapy

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Appendix 2 Robert Salter and the History of Passive Motion and the CPM

Robert Salter, the presumptive inventor of the CPM did not have as his goals increasing ROM or decreasing MUAs, but in the era of knee replacement, these became the goals for the CPM use. Salter, is the person who determined that motion needed to be continuous. Salter strongly believed the CPM could have a role in at least 19 in articular cartilage and healing, which are 11 more applications then five years prior in another review paper (See Appendix 3).[2,17] What's more, the foundation of Salter's rationale behind the CPM is based off clinical observations, an inappropriate animal model, and personal experience. (See Appendix 4). Clearly, Salter's CPM theory was not based upon objective facts or science, but rather his own personal beliefs. Supporters of Salter's CPM theory have stated the theory "the impossible dream has, in a real sense, now become reality".[30]

O'Driscoll, restated Salter's theory for using the CPM, "He (Salter) 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. 'It was O'Driscoll who went on, "In the first few days following injury or surgery ...(the) CPM is useful primarily to minimize joint hemarthrosis and periarticular edema." Salter had nine distinct clinical applications[1] of the CPM (see below). However, Salter was most concerned with the application of continuous passive motion on the regeneration of cartilage. Salter, in a twenty-three year review asserted the CPM had nineteen applications in articular cartilage healing and regeneration (See Appendix 3).[2] In modern times Salter took full credit for the most modern knee CPM applications. [3]None of Salter's goals were ever achieved by the CPM.

Table 1.

	Salter's Clinical Application of CPM	Modern Knee CPM Application
1	Open reduction and rigid internal fixation of intraarticular fractures involving the ankle, knee, hip, elbow, or finger joints	Acceleration in early range of motion
2	Open reduction and rigid internal fixation of diaphyseal fractures involving the ankle, knee hip, elbow, or hand	Shorter hospital stay
3	Capsulotomy and arthrolysis for posttraumatic arthritis with restriction of motion of the ankle, knee, hip, elbow, or finger joints	Reduction in arthrogenic muscle inhibition (quadriceps strength)
4	Synovectomy for rheumatoid arthritis and hemophilic arthropathy	Reduction in the formation of scar tissue
5	Arthrotomy and drainage of acute septic arthritis	A reduction in complications
6	Surgical release of extra-articular contractures or adhesion (e.g. quadriceplasty)	Reduction in swelling
7	Metaphyseal osteotomy with rigid internal fixation of the tibia, femur,or humerus	Reduction in manipulations under anesthesia
8	Arthroplasty of the knee, hip, elbow, or fingers	
9	Reconstruction of an old tear of a medial collateral ligament of the knee using a semitendinosus tenodesis	

In Salter's time there was considerable interest in how immobilization influenced the recovery of cartilage. Many authors demonstrated cartilage after trauma/ surgery did not regenerate nor was joint restoration ever restored when immobilized immediately after injury/surgery in rat,[4-7] rabbit,[8-10] monkey,[9,11-12] dog[13-14], and human[15] models. In contrast, the positive effect of exercise of joints on articular cartilage in animal models was being recognized at the same time.[30] By "1965, **normal active motion** reportedly stimulated the 'healing process' of cartilage defects in the knees of monkeys whereas immobilization led to adhesions."[30] Indeed, 1965 Salter (1965)[16] reported that immobilization resulted in "obliterative degeneration of articular cartilage" leading led him to believe that because immobilization was unhealthy for joints, that the CPM should "enhance the nutrition and metabolic activity of articular cartilage" and stimulate healing or accelerate the healing of articular cartilage "due to mesenchymal cells to differentiate into articular cartilage due to the stimulation of pluripotential cells".[17]

In the 1950's Salter began pilot studies with monkeys.[18] However, monkeys do not regenerate cartilage, similar to humans or dogs.[19] Consequently Salter moved to rabbits for his later studies as they do regenerate cartilage.[16,18,20-21] In his most famous study Salter drilled holes through the rabbits' cartilage and into the bone.[21] He then examined how the rabbits' cartilage grew back.[17] Typically, Salter would immobilize a leg of one treatment group; the CPM group had their leg affixed to Salter's CPM with dental plaster. Specifically, the hind foot was held in place with the dental plaster, then the cup was driven up and down through a range of motion from 20 to 100 degrees according to Ogilvie-Harris[20] as Salter never mentioned these details in his review papers. [2,17,31] However, Salter never stated such details in his 10, 18, or 23-year review papers and in another paper it is cited the range of motion used was an arc of 70 degrees from 40 to 110 degrees of flexion (Figure 1). Both the treatment and control groups of rabbits were placed in slings affixed to Salter's electrified CPM for weeks (Fig. 1). Salter had a third group of rabbits that he allowed to move inside their cages. He then microscopically evaluated the quality of cartilage based upon an examination, using a 0-75 point subjective scale he invented.[17] (Salter's 1960 Classifications of Lesions in Articular Cartilage is in Appendix 3). Salter's stated purpose was to show that continuous passive motion was better than either immobilization, or limited mobility and his results reflected that view. Salter was convinced that his passive motion machine would aid in recovering from a large variety of orthopedic problems (Table 1 and Appendix 3). However, he was not the first to invent a machine to aid patients in knee recovery, nor the first to use passive motion.

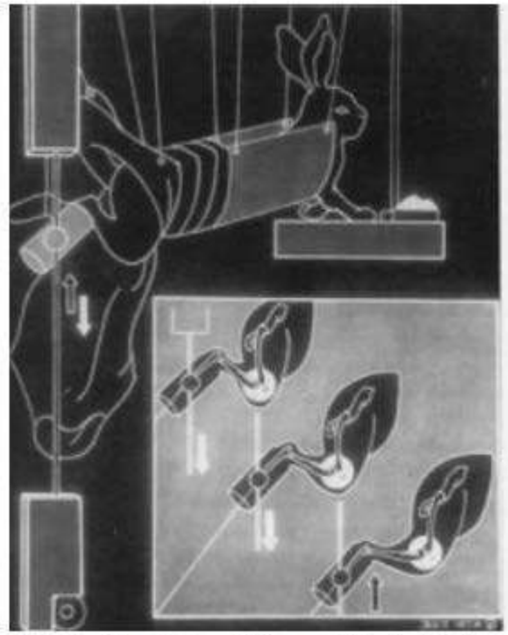

Figure 1. Schematic of a rabbit in a specially designed CPM apparatus, pr viding continuous passive motion of one knee joint. The range of motion us was an arc of 70 degrees (from 40 to 110 degrees of flexion).

Photo taken from: Marchie A, Clarke MT, Lee PTH. Robert Salter and his organization of the biological concept of continuous passive motion (CPM). University of Toronto Medical Journal. 2004; 81(2): 140-143.

Passive motion was invented in the late 1800s by Championniere school and others.[22,23-24] The 1800s saw the evolution of a myriad of mechanical devices to assist in the application of passive motion Zander of Sweden popularized a technique of mechanico-therapeutic, which treated congenital and acquired joint deformities with machines.[25-26] After more than a decade of enthusiasm in both Europe and America, during which more than 50 international mechanic- therapeutic institutes were established they fell out of favor.[22] In the United States in 1960 Dr. Vernon Nickel, designed a form of **continuous** motion to restore mobility in the knee of a rheumatoid patient following knee synovectomy, however “The system was cumbersome. It required transfixion pins in the femur and tibia among other things. This experience was never published and received no further development”.[27-29] Shortly, after Dr. Salter believed the CPM to have a positive effect on the healing of damaged articular cartilage in rabbits, he collaborated with Saringer an engineer to develop CPM devices for humans in 1978. According to Dr. Coutts this machine was modified three times. The first was an upside down bicycle suspended from the patient's bed. However, patients found the device intolerable because of the pressure on the foot from the motorized pedal. The second was a motorized Thomas splint with a Pearson attachments. Patients found this device more comfortable, but the device had a tendency to wander off the bed. The third was similar to the machine that Salter and Saringer (1978) invented (figure 2, Bottom Left). Both Salter and Nichols electrified their final machines making them **continuous.**[29-30] Perhaps, the need to modify the CPM for humans is simply because the motion applied to rabbits is not analogues to humans because rabbits have a different anatomy, this is why the flexion arcs used in rabbits was twice the amount applied to humans. The model used on rabbits could never be analogous to humans as it is not ethical to fix patient's ankles to the machine with dental plaster and for the humans to experience the same motion the rabbits did, then humans would need to hang vertically with the device pulling their ankle forward and backwards. Finally, rabbit cartilage heals regardless if motion is or is not applied. Whereas, human cartilage will not automatically heal after a joint injury or trauma.

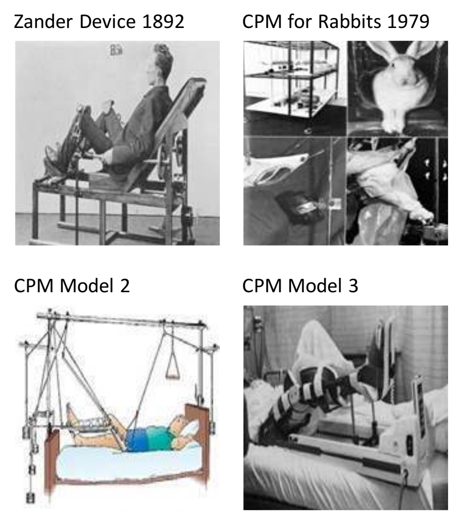

Figure 2.

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Appendix 3

According to Salter's first 23 years of research the CPM was to treat cartilage healing and regeneration:

1) Full-thickness defects in a joint surface- short term and long term (1 year)
2) Partial thickness defects in a joint surface
3) Intra- articular fractures short and long term (6 months)
4) Acute septic arthritis
5) Intra- articular fluid pressures
6) Clearance of hemathrosis
7) Wound healing
8) Muscle Atrophy
9) Tendon healing in partial thickness lacerations
10) Ligament healing in a tenodesis model and carbon fiber model
11) Free intra- articular periosteal autografts
12) Autogenous osteoperiosteal grafts for biological resurfacing of defects in a joint surface
13) Autogenous osteoperiosteal grafts for biological resurfacing of patellar groove defects
14) Durability of regenerated cartilage at 1 year
15) Celluar orgin of regenerated cartilage from periosteal autografts and allografts
16) Biologic resurfacing of patellar cartilage defects with autogenous periosteal grafts
17) Chondrogenic potential of autogenous and allogenic periosteal grafts
18) Cyropreservation of periosteum and the chondrogenic potential of cryopreserved periosteal allografts
19) Joint surface debridement : chondral shaving and subchondral abrasion

According to Salter's first 18 years of research the CPM was to treat treat cartilage healing and regeneration:

1. Full thickness defects (e.g, healing)
2. Intraarticular fractures
3. Acute septic arthritis
4. Partial thickness lacerations of the patellar tendon
5. Semitendinosus tendodsis to replace the medial collateral ligament
6. Autogenic osteoperiosteal grafts in major defects
7. Free autogenic periosteal grafts
8. Periosteal allografts

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Appendix 4

"First, clinical observations revealed deleterious effects of prolonged immobilization of synovial joints in patients: persistent stiffness and pain, muscle atrophy, disuse osteoporosis, and late degenerative arthritis with subsequent use of the involved joints.

Second, clinical observations showed the beneficial local effects of **early active motion** as opposed to prolonged immobilization of diseased and injured joints.

Third, original basic research had shown the harmful effects of immobilization of rabbit knee joints under compression produced either by a compression clamp or by immobilization of diseased and injured joints.

The author demonstrated a lesion of pressure necrosis of articular cartilage in the compressed area in 6 days. Subsequent use of a joint with this lesion led to degenerative arthritis.

Fourth, original basic research had also shown the harmful effects of prolonged immobilization (6 to 12 weeks) of the flexed knee joint of the rabbit without compression. The author demonstrated a lesion of obliterative degeneration of articular cartilage in the non-contact areas secondary to the adherence of the synovial membrane to the joint surface. Subsequent use of such immobilized joints led to degenerative arthritis.

Finally, **lessons** from cardia surgery (especially open heart operations), peripheral vascular surgery, and thoracic surgery showed that injured tissues do not need to be put to rest in order to heal. The costovertebral joints move continuously with every breath throughout the life span of an individual, and yet they are seldom the site of degenerative arthritis."

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