

Peer-Reviewed Studies Evaluating Outcome Measures for the Efficacy of CPM Following Cartilage Repair

Clinical Study	Purpose of Study	Duration of Use	Results	Primary Finding
Improvement in Bone Homeostasis following Autologous Chondrocyte Implantation: Halbrecht et al (2006, Orthopedics)	A retrospective review and clinical follow-up evaluating the effectiveness of autologous chondrocyte implan-tation of the knee including CPM for passive motion.	Four weeks or more.	The mean Lysholm score improved from 43.58 to 71.42 & the modified Cincinnati knee score improved from 3.21 to 6.92. A mean follow-up at 26.5 months.	The results of this study indicate that autologous chondrocyte implantation of the knee followed by CPM demonstrate statistically significant (p<.05) improvements in function and pain reduction.
The Treatment of Osteochondral Lesions using a combination of Autologous Chondrocyte Implantation and Autograft; Three Year follow-up: Sharpe et al (2005, JBJS)	In this study a combination of ACI & the osteochondral autograft transfer system followed by CPM was evaluated as a treatment option for repair of large areas of degenerative articular cartilage.	Not reported.	After one year the patients had a significant improvement in symptoms and after 3 years this improvement was maintained in 10 out of 13 patients.	The authors conclude that the hybrid ACI/OATS technique provides a promising surgical treatment followed by CPM for passive motion for the treatment of patients with large degenerative osteochondral defects.
Treatment of Deep Cartilage Defects of the Patella with Periosteal Transplantation: Lorentzon et al (1998, Knee Surg Sports Traumatol Arthrosc)	26 patients who suffered from an isolated full-thickness disabling knee pain were treated with autologous periosteal transplantation with out chondrocytes.	CPM was initiated immediately post-op.	After a mean follow-up at 42 months 17 patients were graded as excellent (no pain), 8 patients as good (pain with strenuous loading) and 1 patient as poor (pain at rest).	Patients with full-thickness cartilage defects of the patella and disabling knee pain can be treated with autologous periosteal transplantation followed by CPM for passive motion with satisfactory clinical results.
Chondrocyte Transplantation: Minas et al (1997, Operative Techniques in Orthopedics)	This review evaluated autologous chondrocyte transplantation (ACT) followed by the use of a rehabilitation program that included CPM.	Used CPM for 6 weeks for 6-8 hours a day.	ACT results in reproducible satisfactory results with return to high-level activities including sports in over 90% of patients.	CPM is instituted as soon as cell attachment has occurred (after 6 hours or the next day) and is used to regain motion and enhance the quality of repair tissue (based on experimental and clinical studies that have shown an increase in repair tissue).
Fresh Osteochondral Allografts for Post-traumatic Knee Defects; Surgical Technique: Gross A (1997, Operative Techniques in Orthopedics)	Fresh osteochondral grafts followed by early mobilization with a CPM device have been performed on 126 knees in 123 patients with an average follow-up of 7.5 years	Not reported.	Survivorship analysis showed a 95% success rate at 5 years, 71% at 10 years and 66% at 20 years.	Osteochondral grafting with the use of CPM to facilitate cartilage nutrition and prevent stiffness has proven successful at our institution.
The Physiologic Basis of Continuous Passive Motion for Articular Cartilage Healing and Regeneration: Salter B (1994, Hand Clinics)	An overview of the author's first 23 years of experience with basic research relevant to the biological concept of continuous passive motion (CPM) of synovial joints in vivo, as well as the first 15 years of experience with clinical application of CPM.	Six to eight hours of use per day appears to offer the best benefits. This summary of studies did not report duration of CPM as part of the summary.	Basic research demonstrated the safety of CPM and benefits that included: regeneration of hyaline cartilage, improved fracture healing, improved motion, anti-inflammatory effects, & thicker/stronger tendon healing. Clinical benefits include: decreased pain, increased motion, high compliance, faster wound healing, no complications and reduced rehabilitation.	This summary of extensive research has led to the following accepted uses of CPM following: stable fractures, arthroscopy, capsulotomy, arthrolysis, synovectomy, biological resurfacing, acute ligament repair, tendon graft for ligament repair, tendon repair, osteotomy and prosthetic joint replacement.
Improvement of Full-Thickness Chondral Defect Healing in the Human Knee after Debridement and Microfracture using Continuous Passive Motion: Rodrigo et al (1994, Amer J of Knee Surg)	Since 1985, 298 patients have been studied after treatment of full-thickness articular surface defects of the knee. A CPM group was compared to a non-CPM group including different duration variables.	The duration that resulted in the most success was 8 weeks of CPM for 6 hours per day.	The mean improvement in grade (1-5) for the CPM group (2.67) was statistically superior to the non CPM (1.67) group (p=.003). Only 15% of the CPM group had no improvement in grade, whereas 45% of the non-CPM group failed to improve (p=.0065)	The statistical significant improvement in the CPM group was the same whether the lesion was patellofemoral or tibiofemoral, large or small, or in a young or old person. The authors conclude that CPM for 6 hours a day for 8 weeks result in better gross healing of the lesion when evaluated by arthroscopic visualization compared with the same treatment without CPM.
Surgical Technique for Articular Cartilage Transplantation to Full-Thickness Cartilage Defects in the Knee Joint: Stone et al (1997, Operative Techniques in Orthopedics)	Since 1992, 60 patients have undergone autogenous articular cartilage grafting followed by CPM.	CPM was used for 4 weeks.	The authors mix of articular cartilage and cancellous bone followed by CPM led to decreased and gross healing in all lesions examined by second arthroscopy. Knee arthrometer scores for reconstructed ACL patients improved from 4 to 1.25mm while repaired ACL patients improved from mean of 4 to 2 mm.	The authors believe that this procedure and the use of CPM post-operatively offers pain relief and articular cartilage regeneration for patients with painful chondral lesions.
Autologous Chondrocyte Implantation Compared with Microfracture in the Knee: Knutsen et al (2004, J Bone Jt Surg)	This study compared the results of autologous chondrocyte transplantation with microfracture technique in a randomized trial. CPM was used following both procedures.	CPM was initiated the first post-operative day.	According to the SF-36 physical component score at 2 years post-op, the improvement in the microfracture group was significantly better than that in the autologous chondrocyte implantation group (p=0.004).	Both methods, including the use of CPM post-operatively, had acceptable clinical results.
Superior Results with Continuous Passive Motion Compared to Active Motion after Periosteal Transplantation; A Retrospective Study of Human Patella Cartilage Defect Treatment: Alfredson et al (1999, Knee Surg Sports Traumatol, Arthrosc)	Fifty-seven patients with isolated full-thickness cartilage defect of the patella & disabling knee pain of long duration were treated by autologous periosteal transplantation to te cartilage defect. Group A was treated with CPM and group B was treated with active motion. Follow-up was at a mean of 51 months.	CPM was initiated the first post-operative day.	Only one patient out of 26 had an unsatisfactory result in the CPM group while nine out of 19 patients had an unsatisfactory result in the non-CPM group.	"Our results, after performing autologous periosteal transplantation in patients with full-thickness cartilage defects of the patella and disabling knee pain, are good if CPM is used postoperatively. The clinical results using active motion post-operatively are not acceptable, especially not in patients with chondromalacia of the patella.
Effects of Continuous Passive Motion and Immobilization on Synovitis and Cartilage Degradation in Antigen Induced Arthritis: Kim et al (1995, J Rheumatol)	To determine the effects of continuous passive motion and immobilization on synovitis and cartilage degradation in an experimental model of chronic inflammatory, antigen-induced arthritis.	Not applicable	The articular cartilage degradation was significantly greater in the immobilized knees compared to its opposite CPM treated knees. Five of 12 immobilized knees had articular surface erosion compared to none in the CPM treated knees. Loss of cellularity was also significantly greater in the immobilized knees.	Articular cartilage was better preserved in the knees treated with CPM than immobilization at six weeks.
The Arthroscopic Implantation of Autologous Chondrocytes for the Treatment of Full-Thickness Cartilage Defects of the Knee Joint: Erggelet et al (2003, J. Arthro & Rel Surg)	The authors compare and then describe their technique for arthroscopic implantation of autologous chondrocytes followed by the use of CPM for rehabilitation.	Not reported.	The authors report that the arthroscopic technique for the implantation of autologous chondrocytes eliminates a substantial amount of side effects and speeds post-operative rehabilitation.	Arthroscopic autologous chondrocyte implantation followed by CPM opens new horizons for the treatment of cartilage defects.
Experimental Study on the Repair of Full Thickness Articular Cartilage Defects; Effects of Varying Periods of Continuous Passive Motion, Cage Activity, and Immobilization: Shimizu et al (1987, J Orthop Res)	In order to clarify the dose/response characteristics of CPM, the repair process of full thickness articular cartilage defects was studied in a rabbit model. The following CPM combinations & immobilization (immob) were tested: CPM 24 h/day, CPM 8/hr-immob 16/h, CPM 2/h-immob 22/h, and immob 24 h/day.	Not applicable	The CPM 24 h/day & CPM 8 h/day groups demonstrated better repair than the other groups with more chondrocytes in the repair tissue. The CPM 2 h/day group only showed slightly better repair than the immob group. CPM following initial mobilization was not able to overcome the harmful effect of immobilization.	The authors conclude that CPM for 8 or 24 h/day is effective for adequate cartilage repair even with some immobilization. CPM application should be 8 hours a day. If CPM is delayed for a week following immobilization, the effect of CPM on cartilage will be reduced.

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The Induction of Neochondrogenesis in Free-Articular Periosteal Autografts under the Influence of Continuous Passive Motion. An Experimental Investigation in the Rabbit: O'Driscoll & Salter (1984, J Bone Joint Surg AM)	The purpose of this study was to determine the chondrogenic potential of free intra-articular autografts of periosteum under the influence of joint mobilization compared with CPM.	Not applicable	After 3 weeks cartilage was the predominant tissue in only 8% of the grafts in immobilized limbs, compared with 59% of grafts exposed to CPM.	This investigation demonstrated the chondrogenic potential of free periosteal grafts in a synovial fluid environment and also the stimulating effect of CPM on periosteal neochondrogenesis.
Articular Cartilage regeneration of the Knee joint after Proximal Tibial Valgus Osteotomy: A Prospective Study of Different Intra- and Extra-Articular Operative Techniques: Schultz & Gobel (1999, Knee Surg Sports Trauma Arthrosc)	In this study high tibial osteotomy for medial gonarthrosis was performed in 95 patients (105 knee joints). Group 1: Arthroscopic surgery, immobilization & PT; Group 2: Surgery, internal fixation & PT; Group 3: Surgery, internal fixation, PT & CPM; Group 4: Surgery, internal fixation, Surgery, internal fixation, PT and CPM.	Not reported.	Arthroscopy and electron microscopy showed better cartilage regeneration in groups 3 & 4. Groups 1 & 2 showed only regeneration isles, sometimes not fixed to the underlying bone.	The CPM groups (3 & 4) demonstrated cartilage regeneration that was thicker, more stable and sometimes covered all of the pre-existing erosions, which were not seen in the non-CPM groups.
Biological Resurfacing of Full-Thickness Defects in Patellar Articular Cartilage of the Rabbit; Investigation of Autogenous Periosoteal Grafts Subjected to Continuous Passive Motion: Moran et al (1992, J Bone Jt Surg Br)	The authors compared CPM with intermittent active motion on the results of the resurfacing with autogenous periosteal grafts of full-thickness defects.	Not applicable	The quality of neochondrogenesis was statistically superior in the CPM group (p<0.05) compared to the intermittent group.	The addition of CPM after surgery was shown to improve every aspect of healing and resurfacing of the defect.
Outcomes of Microfracture for Traumatic Chondral Defects of the Knee; Average 11-year Follow-up: Steadman et al (2003, Arthroscopy)	Patients were treated with microfracture for chondral defects and a post-operative regimen of CPM or 8 weeks. At final follow-up all patients were evaluated with Tegner, Lysholm, WOMAC, and the modified SF-36.	CPM was used for 8 weeks.	At follow-up, all parameters indicated significant improvement. Most of the improvement occurred in the first year with continued improvement up to 3 years.	The authors stress that rehabilitation consisting of protected weight-bearing and CPM for 8 weeks is an essential component to achieve 90% good results with the microfracture procedure.
Functional Outcome of Knee Articular Repair in Adolescent Athletes: Mithofer et al (2005, Amer J Sport Med)	Adolescent athletes with full-thickness articular cartilage lesions were treated with autologous chondrocyte transplantation (ACT) followed by CPM. Outcome was evaluated via self-assessment scores, knee activity scores and level of athletic participation.		At 47 months, 96% reported good or excellent results with statistically significant (p<.001) increases in Tegner activity and Lysholm scores. Ninety-six % returned to high-impact sports & 60% to an athletic level = or > than pre injury.	ACT followed by CPM yields a statistically significant high yield of function in adolescent athletes.
Autologous Osteochondral Mosaicplasty for the Treatment of Full-Thickness Defects of Weight-Bearing Joints: Hangody & Fules (2003, J Bone Jt Surg)	The authors describe their results after ten years (831 patients) of clinical experience with autologous osteochondral mosaicplasty followed by the use of CPM post-operatively.		Good to excellent results were achieved in 92% of patients treated with femoral condylar implantations, 87% of those with tibial resurfacing, 79% with those treated with mosaicplasties and 94% treated with talar procedures.	Autologous osteochondral mosaicplasty followed by CPM post-op appears to be an alternative for the treatment of small & medium-sized focal and osteochondral defects.
Evaluation and Treatment of Articular Cartilage Lesions in the Knee, part 2: Gillogly (2003, Sport Med Arthrosc Rev)	Review of autologous chondrocyte implantation (ACI) including the use of CPM postoperatively.		ACI has proven to be a reliable treatment option for isolated articular defects of the knee.	Alignment, stability, meniscal function and compliance with post-operative rehabilitation which includes CPM are all important factors that need to be addressed to enhance outcomes.
Autologous Chondrocyte Transplantation for Reconstruction of Isolated Joint Defects; the Assaf Harofeh: Robinson et al (2000, IMAJ)	Biopsies were obtained from patients aged 18-45 who underwent autologous chondrocyte transplantation followed by CPM for passive motion. Follow-up was 6 months to one year.	Not reported.	MRI studies in all patients revealed that the defects were filled with tissue having similar signal characteristics to cartilage.	Chondrocyte implantation followed by CPM is a procedure capable of restoring normal articular cartilage in cases with isolated joint defects. Pain can be predictably reduced, while joint locking and effusion eliminated.
Fresh Osteochondral Allografts for Post-Traumatic Defects in the Knee, A Survivorship Analysis: Beaver et al (1992, J Bone Jt Surg Br)	Fresh osteochondral grafts were used to repair post-traumatic osteoarticular defects in 92 knees followed by the use of CPM for passive motion therapy. The average follow-up was 68 months in this survivorship study.	CPM began immediately after surgery.	There was a 75% rate at five years, a 64% success rate at 10 years and a 63% success rate at 14 years. The results in patients over 60 were poor (p=0.08).	The authors recommend this method with the post-operative use of CPM for the treatment of post-traumatic osteochondral defects in the knees of relatively young and active patients.
Rehabilitation after Surgical Treatment of Cartilage Lesions: Jopek & Grabowski (2001, Acta Clinical)	Rehabilitation programs after different articular cartilage procedures was evaluated. Eighteen patients had microfracture technique, 43 had osteochondral transfer (OAT), and seven underwent a periosteal flap with marrow cells plasty.	CPM is utilized during the protection phase 0-8 weeks post-op.	Maintaining of full or allowed motion is of great importance, because it leads to intra-articular pressure changes that are needed for proper cartilage nutrition.	The phase of cartilage healing in all procedures is 0-8 weeks which is the recommended duration for CPM therapy.
Perichondral Grafting for Cartilage Lesions of the Knee: Homminga et al (1990, J Bone Jt Surg Br)	Twenty-five patients with 30 chondral lesions of the knee were treated with an autogenous strip of costal perichondrium. The knee was immobilized for two weeks.	CPM began two weeks after the procedure.	The mean knee score improved from 73 to 90 after one year which was maintained in those evaluated year two. In 28 cases the defect was completely filled with tissue resembling articular cartilage.	The authors conclude that in most cases perichondral arthroplasty of cartilage defects of the knee followed by CPM gives good to excellent clinical results. The results were statistically significant at p<0.001.
Prospective Clinical Study of Autologous Chondrocyte Implantation and Correlation with MRI at Three and Twelve Months: Henson (2003, J Bone Jt Surg Br)	Fifty-seven patients who received an autologous chondrocyte implantation (ACI) followed by the use of CPM were evaluated at three and 12 months with MRI and knee function measures.	Not reported.	In this study 81% of knees improved in subjective scores, and 61% improved in the level of knee function. However the IKDC objective scoring may not be the ideal system of reporting for cartilage repair procedures.	MRI may be as accurate as arthroscope visual scoring and biopsy in determining graft maturation into hyaline articular cartilage.
Autologous Chondrocyte Implantation using a Bilayer Collagen Membrane: A Preliminary Report: Cherubino et al (2003, J Ortho Surg)	To present preliminary clinical experience with Matrix-induced autologous chondrocyte implantation (ACI), a new tissue-engineering technique for treatment of deep cartilage defects. Several scoring systems were used including MRI at six and 12 months. Membrane structure and cellular population were evaluated via light microscope, scanning electron microscope and electrophoresis before implantation.	Duration not reported. CPM was utilized immediately post-op.	All patients with a minimum follow-up of 6 months showed an improvement in clinical and functional status. MRI showed presence of hyaline-like cartilage and evidence of chondroblasts and type 11 collagen.	Matrix-induced ACI followed by CPM offers several advantages over traditional cultured cell procedure. They include technical simplicity, short operation time, minimal invasiveness and easier access to donor sites. It appears to be a reliable method for repair of deep cartilage defects.