Cartilage Rehabilitation: Global Concepts for Successful Joint Restoration

Editorial / Introduction

Rehabilitation presents a critical component on the path to successful articular cartilage restoration. Its clinical importance is well recognized by the practitioners involved in the care of patients with articular cartilage injury and has been a continued focus of the ICRS.

Since initial cartilage rehabilitation concepts were primarily empirical, the ICRS has been supporting the development of systematic and evidence-based scientific concepts of cartilage rehabilitation. Starting with the first ICRS Rehabilitation Meeting in Zurich in 2007 continued organized efforts included the formation of the ICRS Sports and Rehabilitation Workgroup in 2008 with subsequent publications and regular presentations and rehabilitation sessions at ICRS meetings.

Despite its recognized clinical relevance, scientific knowledge about cartilage rehabilitation is still developing. Cartilage rehabilitation presents a complex field that requires a comprehensive understanding of the biological, biomechanical, anatomical, and surgical technique aspects of cartilage restoration. An improved knowledge of the basic science and clinical details of cartilage rehabilitation will help to improve success. This has been confirmed in several recent studies that demonstrated that cartilage-specific rehabilitation can significantly improve joint function and decrease recovery time after cartilage repair. While these results are encouraging, the rapid development and innovation in the field of cartilage repair demands a similar continued evolution of cartilage rehabilitation.

This newsletter presents a continuation of the ICRS efforts to promote the development of cartilage rehabilitation by facilitating a global exchange of established and developing concepts for cartilage rehabilitation. With a broad spectrum of contributions from 13 countries from 4 continents, the highly active member participation in this rehabilitation newsletter emphasizes the great international focus and scientific relevance of this topic around the world. The newsletter provides a global perspective and overview on ongoing research as well as trends and developments in the field of cartilage rehabilitation. Furthermore, it facilitates international communication between all groups of cartilage researchers and practitioners from different backgrounds. We greatly appreciate the excellent contributions of all the members and hope this ICRS newsletter will help to further stimulate and develop multidisciplinary collaborations to advance knowledge about this critically important aspect of restoring joint function and returning the patient with articular cartilage injury to unrestricted activity.

Kai Mithoefer and Karen Hambly
Co-Chairs, ICRS Sports and Rehabilitation Committee

Part 1 – Reviews

Principles of Rehabilitation after Articular Cartilage Repair in the Athlete

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Articular cartilage injury is observed with increasing frequency in both elite and amateur athletes and results from the significant acute and chronic joint stress associated with impact sports. Treatment of articular cartilage defects in the athletic population presents a therapeutic challenge due to the high mechanical demands on the joint in the athlete. Several restorative and reparative surgical techniques for articular cartilage repair techniques have shown comparable success rates in restoring articular cartilage surfaces and to return athletes even to high-impact sports. Rehabilitation following cartilage repair surgery presents a critical co mponent in the process of returning the athlete to sports activity. The concepts of current cartilage repair rehabilitation in the athlete are based on a combination of basic science data, empirical information, and limited clinical studies. Returning the athlete to sport can generally be achieved by using the systematic three-phase approach (Table 1). The described principles can be applied to every cartilage repair technique currently available and can be extended to most of the developing new surgical techniques. The progression through the individual phases is determined by the biology of the repair technique, characteristics of the cartilage injury, clinical symptoms, radiographic findings, and individual athlete's sport-specific demand. The biological phases of each cartilage repair techniques can be matched to the corresponding three rehabilitation phases (Table 1). The biology of the healing process in the first phased is differs between restorative (osteochondral auto- and allograft) and reparative techniques (marrow-based and chondrocyte-based techniques). With reparative techniques the early, soft repair tissue is vulnerable to mechanical overload and requires more protection than restorative techniques which rely primarily on bone-to-bone healing. High compressive and shear stresses during the first rehabilitation phase can decrease chondrocyte metabolic rate and should be avoided for both reparative and restorative techniques. However, low mechanical forces promote repair cartilage formation and nutrition as well as bone-to-bone healing and are encouraged. Due to the differences introduced by different cartilage repair techniques, lesion characteristics, and concomitant adjuvant procedures, the initial limit and progression of weight bearing activities should be individually determined by the surgical and rehabilitation teams for each athlete. Consequently, the duration and activities of the protection phase may be variable for each individual athlete. For example, active joint motion may be allowed in the range of motion that is outside of the range of articulation of the repaired defect. Athletes with defects in the patellofemoral joint can weight bear immediately while femoral defects need to be protected. To assure optimal care, the rehabilitation team should be familiar with the surgical and biologic principles that determine the initial protection of the postoperative joint and apply them for each individual athlete's unique set of circumstances.

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Using a criteria-based approach, clinical symptoms are used to individually guide the progress of the athlete through rehabilitation. Pain and particularly joint effusion following the rehabilitation exercise should be avoided as they can lead to quadriceps inhibition with its negative effect on neuromuscular joint control, joint biomechanics and resultant increase in joint reaction force in the area of the cartilage repair. While mild to trace joint effusion is normal during the first 4-6 weeks after articular cartilage repair, extensive efforts should be made to limit and reduce effusion by avoiding overly aggressive rehabilitation. Recurrent joint effusion indicates overload of the repair cartilage and premature progression during rehabilitation and should be avoided.

During the second phase, controlled gradual increase of the mechanical stress on the primary repair tissue stimulates cellular metabolism, proteoglycan and collagen deposition. This strengthens the cartilage repair tissue and makes it more resilient to increasing mechanical stress and more complex joint loading patterns. Restoration of neuromuscular control is critical during the second phase for restoration of joint function and return to athletic activity and should include the entire kinetic chain of the extremity with core, hip, thigh, and calf musculature. Neuromuscular and proprioceptive re-education has important implications for dynamic joint alignment and helps preventing new or re-injury.[45,58] Plyometrics effectively restore neuromuscular joint control and optimize joint biomechanics and load distribution under increased impact conditions. Analogous to individualized weight bearing during the initial rehabilitation phase, neuromuscular and proprioceptive exercises should be designed in a gradually progressive fashion to allow for optimal adaptation of the repair cartilage tissue in each patient.

During the final rehabilitation phase further organization and maturation of the cartilage repair tissue occurs by adapting to the even more demanding joint stresses associated with athletic impact and pivoting activities. Adaptations include increased rigidity of the matrix due to further proteoglycan deposition and crosslinking, collagen production and cellular orientation and organization within the neocartilage tissue. Gradually increasing impact and sport-specific movement patterns during this phase prepare the athlete to return to the high mechanical stresses associated with sports without overloading the repair tissue and potential repair tissue deterioration. At this point is not known how the repair tissue quality affects joint function and ability to return to sport. However, prospective data indicates that repair cartilage quantity can affect joint function after cartilage repair as limited repair tissue volume has been associated with a higher failure rate.[56] Sport-specific, on-field rehabilitation is a final and critical step in the return to sport after cartilage repair and also follows criteria-based for progression. Before advancing to simulated sports activities, MRI evaluation is recommended to evaluate repair cartilage volume, exclude graft hypertrophy or subchondral bone marrow edema which may indicate risk for graft failure or graft delamination. On-field rehabilitation is organized into gradually increasing sport-specific exercises which progress from in line running and jumping to acceleration and deceleration drills, progressive pivoting and cutting manoeuvres at increasing speeds, and gradual incorporation of sport-specific equipment and movement patterns. Progression is always criteria-based requiring the absence of pain, swelling, and limited ROM with the increasing activity. Using these principles for an individualized approach throughout all rehabilitation phases with close communication between athlete, surgical and rehabilitation staff, return to even demanding high-impact sport and continued sports participation can be successfully achieved with a high rate of success.

Table 1

Biologic and Rehabilitation Phases after Articular Cartilage Repair		
Phase	**Biology**	
	BIOLOGIC PHASE	REHABILITATION PHASE
Phase 1	Graft Integration and Stimulation	Protection and Joint Activation Phase
Phase 2	Matrix Production and Organization	Progressive Loading and Functional Joint Restoration Phase
Phase 3	Repair Cartilage Maturation and Adaptation	Activity Restoration Phase

Knowledge Translation for Articular Cartilage Repair Rehabilitation

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The translation of knowledge to practice has traditionally been a complex and prolonged process. Researchers are primarily knowledge creators but there is also an important role in the translation of this knowledge into practice. The translation of research into practice needs to accelerate to keep pace with rapidly changing fields such as articular cartilage repair. Therapists want to increase their use of evidence[3] but are often inadequately prepared to access, interpret and integrate research findings into their clinical practice.[4] There is a need for the synthesis of evidence into accessible formats that can guide clinicians and inform evidence-based practice (EBP).[5] The Knowledge to Action Process is a model that 'funnels' knowledge derived from research into an action cycle which translates the knowledge into a form to match the unique needs of the user.[6] A breakdown or gap in the Knowledge to Action Process results in important knowledge that could be used for the benefit of patients not getting through to practitioners

Generic rehabilitation protocols and guidelines are frequently used following articular cartilage repair (ACR). However, ACR populations are heterogeneous and in order to optimise post-operative management rehabilitation should reflect the individual context. This requires the rehabilitative team to be familiar with the surgical and biological principles of cartilage repair and to apply them for each individual's circumstances. Considerations for the individualisation of ACR rehabilitation are often either omitted or are poorly communicated within current generic protocols and guidelines. There is a need for the pragmatic application of research to ACR rehabilitative practice. It is proposed that a clinical decision support system

(CDSS) that provides easily accessible and current information on the considerations for ACR rehabilitation will overcome some of the barriers to EBP (see Figure 1). The goal is to create a simple knowledge-based system that can facilitate clinician learning and guide practice for the benefit of the patient whilst complementing, rather than supplanting, existing generic rehabilitation protocols.

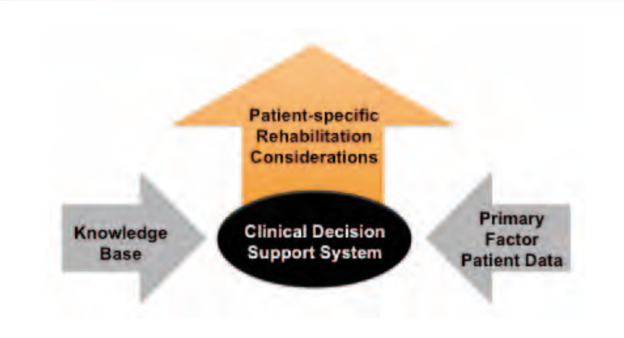

Figure 1: *Overview of the inputs and outputs of a clinical decision support system.*

A CDSS is being developed by the University of Kent in the UK utilising three components integral to the Knowledge to Action Process – the knowledge base, the inference engine and the communication mechanism. The knowledge base embedded in the CDSS was derived from published literature. A heuristic approach was adopted for the inference engine with the input of individual patient data triggering specific guidance based on rules constructed from the knowledge base (data-directed inference). Heuristics provide guidelines and problem-solving strategies that permit more individual variation than an algorithmic approach where a rigid sequence of ordered steps results in a list of instructions for a solution. Clinicians are autonomous professionals and as such should be allowed to determine the relevance of the research to their individual clients.4 Problems are frequently not clearly defined in rehabilitation so it was considered important to knowledge translation that the clinician is presented with considerations for how they may wish to individualise rehabilitation rather than specific rigid instructions. The communication mechanism was developed to deliver these rehabilitation considerations in an accessible format that provides the opportunity for the clinician to further evaluate the evidence-base underpinning each of the considerations.

Review of the evidence-base resulted in the identification of eleven primary factors implicated in the ACR rehabilitation process. A branch logic approach produced a multi-level hierarchy with each primary factor having a branched pathway. The number of logic pathways meant it was not conducive to hard copy format and resulted in the selection of a web-based format on a dedicated website www.cartilagerehabilitation.info. An expert system shell has been identified and an iterative design cycle of testing, consultation and refinement will take place prior to the launch of CDSS as an "on demand" system in summer 2012. The development of this CDSS, as with any decision aid, presents considerable opportunities but also many challenges.[7] There is the assumption that the integration of research into EBP will result in improved patient outcomes and this still needs to be established with respect to articular cartilage repair. Future studies will evaluate the access to and use of the CDSS and to assess changes in practice.

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Part 2 – Basic Science Application to Rehabilitation

Rehabilitation – *in vitro* investigations at the cellular level

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There have been numerous studies focusing on the use of mesenchymal stromal cells (MSCs) for the repair of acute cartilage defects. Most follow the structure of classical tissue engineering, investigating implant properties at the biochemical level, or structure/function in in vivo studies. In comparison, relatively few studies have investigated the role of biomechanics on stem cell fate decisions. When considering the clinical situation it is likely the rehabilitation protocol, and hence biomechanical stimulus applied, after cellular implantation will influence the final outcome. Studies investigating mechanical regulation have focused mainly on hydrostatic[1], uniaxial compression[2, 3] and multiaxial (shear and compression) loading [4, 5]. To more accurately mimic the in vivo environment it is likely that complex multiaxial loading will be required. Using a custom built bioreactor[6] which is able to apply compression, shear or a combination of the two (Figure 1) we have been investigating the role of the individual stimuli and the combination of the two on fibrin- polyurethane constructs seeded with human bone marrow derived stromal cells[7]. Within this system we are able to simulate a more natural kinematic environment using clinically relevant cells within a hydrogel familiar to orthopaedic surgeons (fibrin).

We have recently shown that shear appears to be a critical requirement for mechanically induced chondrogenesis of

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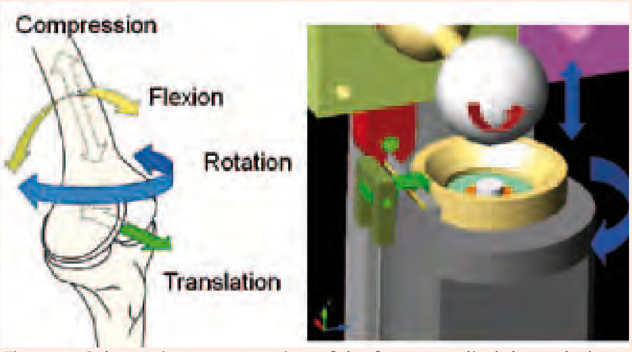

Figure 1: Schematic representation of the forces applied through the knee joint (left). The bioreactor used during these studies is able to apply similar multiaxial forces (right).

human MSCs within this system. In agreement with other studies, compression alone did not induce chondrogenesis, however shear superimposed on compression lead to a more robust chondrogenic response[7]. As the study did not include exogenous TGF-β, any chondrogenic induction was as a result of the mechanical stimulation applied. This would suggest that mechanical stimulation alone is able to direct human MSCs towards a chondrogenic phenotype. In a previous study we had shown that the chondrogenic response is modulated by the frequency and amplitude of the multiaxial load applied, suggesting that this model can be used to pre-screen rehabilitation protocols *in vitro*[8]. Within this system, the application of multiaxial load leads to endogenous production of TGF-β which then leads to the chondrogenic induction[5].

The influence of different modes of mechanical load has been investigated not only with respect to MSC differentiation; several studies have shown stimulating effects on articular chondrocytes seeded into 3D scaffold systems. Results from these studies may have implications for optimizing physical therapy concepts after chondrocyte transplantation treatments. For example, different studies have revealed that application of dynamic shear to the surface of chondrocytes-seeded scaffolds up-regulates the gene and protein expression of the cartilage superficial zone protein (Figure 2), which is also known as lubricin or proteoglycan-4 [9, 10]. Lubricin is an important component of normal synovial fluid which is specifically expressed at the articular surface, and has a major role for maintaining low friction joint articulation. Looking at different motion paths and loading frequencies, it was found that both the type of motion, such as flexion, rotation, or translation, and the sliding velocity affected the cellular response[9]. Furthermore, it was shown that not only articular but also nasal chondrocytes were responsive to specific loading patterns that simulate joint articulation[11]. Hence it is possible to test the reaction of cells from different sources, embedded in suitable biomaterial matrices, under addition of anabolic factors if requested, to relevant mechanical forces.

While the device is not a complete reproduction of the in vivo environment, it can offer insights into the role of various biomechanical stimuli on stem cell fate decisions, (re-)differentiation of chondrocytes, and cartilaginous tissue development. Use of such a device enables controlled in vitro studies to investigate duration, frequency, amplitude and the timing of

Figure 2: Bovine chondrocytes were seeded into a fibrin/polyurethane scaffold and cultured under various conditions for 3 weeks. Free-swelling controls (A) did not display any staining for lubrin. Samples exposed to compression alone also were negative for lubricin (B). However, samples cultured with shear, superimposed on compression, displayed intense lubricin staining at the surface of the construct.

initiation and the load applied. This would include whether an initial period of shear alone, as applied during continuous passive motion, is beneficial at the cellular level when compared to early application of both shear and compression, as experienced during partial load bearing. Moreover, the impact of specific biochemical supplements during regeneration can be determined in a controlled biomechanical environment. Due to the compliance issues these studies are difficult to perform in vivo and due to immunological issues any in vivo study would likely use animal cells and not those from adult humans. We hope this system can provide a valuable insight into potential rehabilitation protocols and that information gained can be translated into a clinical setting.

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CPM or not CPM after autologous chondrocyte transplantation?

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So far, autologous chondrocyte transplantation (ACT) has been employed widely in many countries for the treatment of large size articular cartilage defects. Several disputes still exist; one is the cells quantity versus how to keep the cells phenotype in culture condition for a quite long period. In general, the shorter in culture, the better cells phenotype. Some centers expand chondrocytes in large quantity, and then the cells will be under the dedifferentiation condition, it is hardly believed such cells will re-differentiate to normal chondrocytes after transplantation in vivo. The second is culture medium; to avoid using fetal calf serum is a main concern in order to get rid of any contamination by animal serum.

Scaffold is the most important element for successful transplantation; the communication between cells and matrix plays the key role for the property of new forming tissue. Unfortunately, there are very limited choices for scaffold for ACT. In the early stage periosteum was the only option of scaffold, in recent years a collagen membrane consisting of collagen type I and III replaced periosteum as the scaffold. Cultured chondrocytes are either injected underneath the scaffold which is sutured on the defect area first or loaded on the scaffold then glued on the defect. All the scaffolds mentioned above do not resemble real articular cartilage either in composition or structure. Collagen type I and III do not exist in normal articular cartilage and the arrangement of these collagen fibers does not behave like real hyaline cartilage as well. Chondrocytes grow on such structures, but lack normal communication between cells and matrix, and it is impossible to harvest real hyaline cartilage after transplantation.

We are using our own scaffold with two characteristics, the scaffold is made by the matrix of human articular cartilage, the most of the composition of scaffold is collagen type II and proteoglycans. On top of it, the scaffold preserves hyaline cartilage structure and the collagen fibers and proteoglycans are directionally arranged as perpendicular columns to resist pressure more effectively.

Continuous passive motion (CPM) is a useful tool for rehabilitation after joint surgery. However, for cartilage transplantation, different centers use different protocols, some report good outcomes after using CPM, but some have had negative experiences. We have used CPM in our rehabilitation protocol routinely for ACT patients after our animal experimental study. A special designed CPM was used for goat knee joint after ACT (fig 1-2). The results of the CPM protocol were superior to the no CPM protocol. Then we started using CPM for our patients who had undergone ACT. The clinical outcome also showed a benefit in using CPM.

For the first week of CPM, the purpose is to let the patient adapt to the treatment and give slight pressure on the transplanted tissue. The loading pressure is applied to the defect area gradually by control of the moving angle of the knee joint. If the repair area is between the patella and femoral trochlea, the moving angle should be controlled from 0-30 degrees for the first 7 days, and then the angle increases 5 degrees every 2 days until the range reaches 0-90 degree. The 0-90 degree moving range should continue until the end of 8th week. If the defect area is in femoral condyle, the starting angle should be from 0-45 degrees for the first 7 days, and then the angle also increases 5 degrees every 2 days until the range reaches 0-110 degrees. The 0-110 degrees moving range should continue until the end of 8th weeks as well.

According to our experience, CPM should be applied at least 1 hour each time, 2 times per day will be adequate. After CPM, an ice pack should be put on the joint for 30 minutes. CPM for our patients with autologous chondrocytes transplantation has a good outcome and we recommend it for the rehabilitation. Adequate pressure applied gradually on the defect is necessary

Fig 1: CPM leads goat knee flexion. (From the front)

Fig 2: CPM leads goat knee extension. (From the front)

Part 3 – Clinical Experiences

Challenging but necessary standardization of rehabilitation during cartilage repair clinical trials

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Current orthopaedic efforts towards improving evidence-based treatment algorithms in cartilage repair should also recognize post-treatment rehabilitation as a critical covariate in the analysis and understanding of outcome success. At the same time, manuscript reviewers and regulatory agencies are expecting to see standardized rehabilitation data in their submissions. However, the standardization and control of patient rehabilitation offers unique challenges, particularly in multicenter studies of large or varied geographic scale, and even more so for those intended to meet regulatory requirements and conducted under GCPs.

The first challenge is represented by the rehabilitation protocol itself. Unfortunately, rehabilitation has not been well-studied in the context of cartilage repair, and in some cases orthopaedic surgeons have developed their own preferred programs with little or no scientific basis, or patients are relegated to follow programs established by the therapist themselves. Therefore, the design of new cartilage repair studies should carefully weigh the choice of rehabilitation protocols, their implementation and the type of data that will be collected. Study protocols should dictate the selection of the appropriate therapeutic modalities and post-operative timeframe, such as the period of restricted weight bearing, or the use of continuous passive motion (CPM). Furthermore, clinical trials which compare cartilage repair therapies that differ in their repair mechanisms- as with an osteochondral graft device and microfracture- might call for different protocols altogether.

Choosing specific rehabilitation parameters and the extent of data collection can represent an excellent, albeit challenging, opportunity to understand how a rehabilitation protocol influences repair outcomes. Even simple variables like patient compliance, the progression of ROM and weight bearing and physical knee characteristics could be informa-

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tive, as well as more complex data obtained from functional tests of gait or proprioception. The extent of the data and the method of collection should be established with the therapists prior to treatment. Electronic data capture facilitates this collection and permits real-time tracking of both therapists and progression of patients. On the other hand, special consideration should be made as to the role that rehabilitation plays within a study protocol and its relationship to study endpoints. Regulatory requirements have not been clear regarding the level of statistical analysis and correlation to treatment outcomes which must be carried out. This issue needs to be clarified at an agency level- particularly if poor rehabilitation compliance or progression is viewed as a study protocol deviation with direct consequences on final endpoint statistical analyses.

Selection and training of therapists is also an essential step in successfully implementing a standardized rehabilitation program. International studies offer the challenge of multiple languages and may need to employ therapists with differing educational backgrounds but who have appropriate experience. Direct training and communication with all therapists is critical, especially with regards to study treatment, lesion size and location or other unique study components. Furthermore, the logistics and financial management, if needed, of such a relationship with the clinic or hospital providing the rehabilitation service, needs to be well established in advance of patient treatment.

Patients should be well informed regarding the importance of protocol compliance (e.g. attending sessions, weight bearing requirements) to both the health of their knee as well as the clinical study. Encouragement should not only come from the clinical site and the investigator, but also from the participating therapists. The objective of an unbiased study rehabilitation program should try to avoid the situation where compliance becomes a function of the efficacy of treatment, or of the willingness or ability to pay.

The energy and resources needed to overcome the intrinsic challenges of a well thought-out and implemented rehabilitation program with experienced therapists will certainly serve to normalize cartilage repair outcome data, while at the same time focusing much needed attention on the specific rehabilitation modalities currently used but for which there is little scientific evidence. Concurrently, such a program in clinical trials supporting regulatory submissions will meet the expectations for management and tracking of post-treatment care. Consequently, cartilage repair patients will benefit from rehabilitation protocols with valid scientific basis.

Clinical, radiological and biomechanical outcomes of a randomized comparison of conservative and accelerated approaches to post-operative weight bearing rehabilitation following MACI® Jay R. Ebert PhD; William B. Robertson PhD; Michael Fallon MBBS, FRANZCR; David G. Lloyd PhD; M.H. Zheng DM, PhD, FRCPath; David J. Wood BSC MBBS, MS, FRCS, FRACS; Timothy Ackland PhD, FASMF.

While surgical and cell culturing methods with respect to autologous chondrocyte implantation (ACI) have improved over the past 10 years, it is well known that research into post-operative rehabilitation, an important component for achieving optimal surgical outcome, is still in its infancy. At present, best patient outcome appears limited by a lack of knowledge regarding how to progressively increase weight bearing (WB) and exercise post-surgery. This research project sought to ascertain the impact of accelerated WB rehabilitation, compared with a more conservative WB approach, in patients following MACI implant. Recruitment for the project spanned two years from 2005-2007, culminating in several scientific publications,[1-5] as well as documented rehabilitation protocols[6] published in collaboration with Genzyme.

A randomized controlled study design was used to investigate clinical, radiological and biomechanical (gait) outcomes in 70 patients following MACI implant, in conjunction with either ‘accelerated’ or ‘conservative’ approaches to post-operative WB rehabilitation. Both interventions sought to protect the implant for an initial period, and then incrementally increase WB. Under the ‘accelerated’ protocol, patients reached full WB at 8 weeks post-surgery, compared to 11 weeks for the ‘conservative’ group (Table 1). Outcomes have been undertaken thus far pre-surgery and at 3, 6, 12 and 24 months post-surgery.

Patients in the ‘accelerated’ group demonstrated significantly greater ($p<0.05$) six minute walk distances and daily activity

Conservative Group											
Weeks Post-surgery	2	3	4	5	6	7	8	9	10	11	12
Weigwht bearing (%BW)	≤ 20%				50%	60%	70%	80%	90%	100%	
Crutches	2				1	1	1	1	1	1	0
Brace	Y				Y	Y	Y	Y	Y	Y	N
Accelerated Group											
Weeks Post-surgery	2	3	4	5	6	7	8	9	10	11	12
Weight bearing (%BW)	≤ 20%	30%	40%	50%	60%	80%	100%				
Crutches	2	2	2	2	1	1	1	0			
Brace	Y	Y	Y	Y	Y	Y	Y	N			

TABLE 1: The load bearing gradients followed by MACI patients in the traditional and accelerated rehabilitation groups.

levels, as well as a significantly better ($p<0.05$) improvement in knee pain, when compared to the ‘conservative’ group at 3 months post-surgery.[4] While both patient groups improved significantly to 24 months post-surgery, the accelerated group reported significantly less severe pain (Figure 1) and demonstrated superior six-minute walk distances (Figure 2) over the two-year period.

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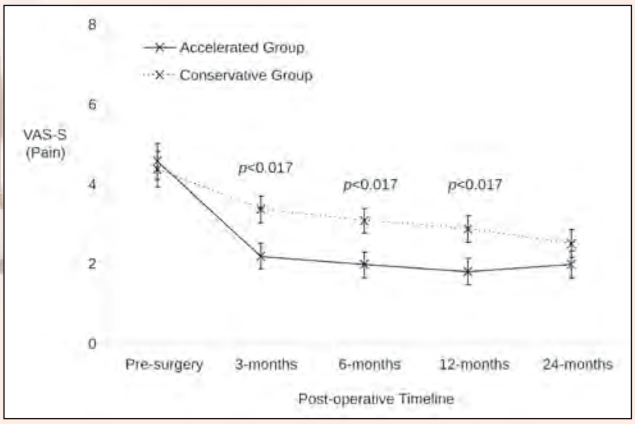

Figure 1: Change in pain severity for the accelerated and conservative patient groups, over the 24-month period.

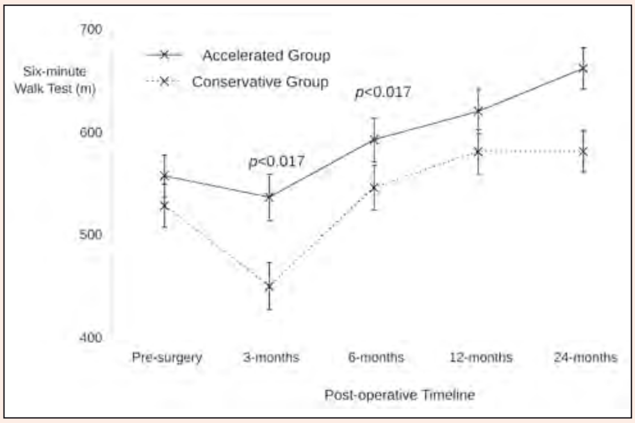

Figure 2: Change in six-minute walk distance (m) for the accelerated and conservative patient groups, over the 24-month period.

With regard to radiological outcomes, regardless of the rehabilitation protocol employed, no patient suffered any adverse effect to the implant as assessed by magnetic resonance imaging (MRI) at three months,[4] indicating graft tolerability to the faster return to full WB. Both groups significantly improved ($p<0.05$) in an MRI composite score and pertinent descriptors of graft repair throughout the post-operative period, up until 24 months post-surgery.[1] There were no differences ($p>0.05$) observed between the two groups. However, patient age, body mass index, defect size and the duration of pre-operative symptoms were all significantly correlated ($p<0.05$) with several MRI-based outcomes at 24 months.[1]

Three-dimensional gait analyses at 3, 6 and 12 months post-surgery demonstrated significantly reduced ($p<0.05$) knee extension moments in both patient groups up to, and including, 12 months, when compared with control subjects.[2] However, while the conservative WB group demonstrated significantly reduced ($p<0.05$) knee adduction moments at 3, 6 and 12 months, and a significantly reduced knee flexion moment at 3 months, no differences in these knee moments were observed between the accelerated patient group and controls.[2] Overall, a higher level of gait dysfunction was observed in patients who underwent a more conservative rehabilitation approach. These gait analyses also provided insight into the variables (in addition to ground reaction forces) that contribute to these knee moments,[3] which has improved the accuracy in prescribing and implementing progressive WB protocols for MACI implant patients.

Overall, the 'accelerated' WB approach that reduced the length of time spent ambulating on crutches produced comparable, if not superior clinical outcomes up to 24 months post-surgery in the accelerated rehabilitation group, without compromising graft integrity. This 'accelerated' regime is safe, effective and demonstrates a faster return to normal function post-surgery, and may reduce post-operative muscle loss, intra-articular adhesions and associated gait abnormalities.

This project has been undertaken in association with the University of Western Australia (School of Sport Science, Exercise and Health and the School of Surgery) and the Hollywood Functional Rehabilitation Clinic. We are now nearing completion of assessment at five years post-surgery and, based on the encouraging outcomes thus far, have initiated a new trial, part funded by a National Health and Medical Research Grant (APP1003452). This trial aims to compare our current 'best-practice' WB approach (8 weeks) with a further accelerated gradient of 6 weeks, in patients following both open and arthroscopically performed MACI implant to the WB femoral condyles and tibial plateau. The *'Accelerated Rehabilitation Guidelines for the Knee Using MACI', and associated 'Exercise Companion Guide'*, can be obtained through requests to your local Genzyme representative or by filling out the contact form at www.maci.com/contact.aspx.

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Cartilage Rehabilitation: Clinical Experiences

Progressive Joint Loading after Cartilage Repair with Autologous Matrix-Induced Chondrogenesis (AMIC) with Platelet Rich Plasma (PRP) Augmentation: Clinical Experience in 220 Patients Alberto Sciliari, Italy

Rehabilitation after articular cartilage surgery is widely recognized as critical to long-term outcome but the use of new techniques, like Autologous Matrix-Induced Chondrogenesis (AMIC), have simplified this part of the treatment. In my experience of 220 procedures I have used AMIC with a scaffold (Chondrotissue®) and PRP as glue and source of growth factors.

With this technique the patient is discharged after a few hours and encouraged to move the knee immediately following a specific rehabilitation protocol after the procedure. The first rehabilitation phase, which lasts two weeks, starts 6 hours after surgery with active motion exercises. The surgical procedure is entirely done arthroscopically so the post-operative pain is minimized and continuous passive movement is not necessary.

The patient is encouraged to actively move the knee and to use some simple static quadriceps exercises. The only limitation for range of movement is post-operative pain, which is usually minor, and joint effusion. In this first phase no weight bearing is permitted to protect the matrix from tangential forces that may injure the implant. In this period, the highly hydrophile scaffold (Chondrotissue®) allows for circumferential layer lubrication that helps the PRP–glue to maintain the implant in place. Lane (1) has observed a dramatic increase in the cartilage coefficient of friction (COF) that can potentially damage chondrocytes when the patient begins articulating the joint after surgery. Such injuries may affect the ability of the repair cartilage to heal fully.

Reducing the elevated COF with lubricating materials is recommended. After two weeks, in the second phase, the patient is allowed to walk with crutches using partial weight bearing for one week. This period is necessary to recovery a correct gait pattern and to permit initiation of hydrodynamic lubrication, so-called because the dynamic motion of the weight bearing areas produces an aqueous layer that separates and protects the contact points. This kind of lubrication physiologically occurs with load of cartilage and the cyclical loading is probably useful for an effective growth of the new cartilage tissue.

Papachristou (2) demonstrated that functional cartilage loading induces the AP-1 and Runx2 transcription factors through the JNK and ERK MAPK cascades. Since the above signaling mediators/effectors are considered to be crucial in the differentiation/maturation process of cartilage tissue, Papachristou proposes that functional mechanical loading of condylar cartilage serves to “fine tune” chondroblastic differentiation/maturation. Saadat (3) concludes that cyclical in vivo joint loading increases the proteoglycan content of the cartilage deep zone via signal transduction stimulated by increased hydrostatic pressure. This is clinically significant because the biomechanical properties of cartilage, and therefore its function, depend to a large extent on its ability to maintain hydration and tissue thickness under mechanical stresses with normal physiological loading. Proteoglycans provide the osmotic resistance necessary for cartilage to resist compressive loads. Kupcsik (4) observed that mechanotransduction of mesenchymal stem cells in a three dimensional scaffold increases synthesis of sulfated glycosaminoglycans (GAGs). Bian (5) demonstrated that dynamic mechanical loading enhances functional properties of tissue-engineered cartilage using mature canine chondrocytes. Hardmeier (6) concluded that mechanical stress is associated with cellular signalling communication and the preservation of N-terminus procollagen moieties, which regulate both collagen synthesis and the diameter of the fibre. This structural difference also affects actin stabilization, cytoskeleton remodelling and proteoglycan assembly. These effects seemed to be dependent on the magnitude and duration of the physical stress.

All these experimental studies enforce the idea that an early load is favourable for cartilage healing. After the partial weight-bearing period, the load is increased up to normal weight bearing and the patient is encouraged to start gentle swimming and cycling exercises. Complete weight bearing is reached at 4 weeks after surgery. Complete recovery of functional daily activities begins usually after 6 weeks.

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Customised postoperative therapy has a crucial impact on the outcome of cartilage surgery Eric Reiss, MD and Catherine Kessler-Schär, Graduate Physiotherapist, Orthopraxis Oftringen, Switzerland

To what extent can the rehabilitation process be optimised through customised adjustments of postoperative therapy? What impacts do “touch qualities” such as patient guidance have? What is the surgeon's role in postoperative therapy? To answer some of those questions, we have started to analyse adjustments in postoperative care and their impact on outcome in our clinic and would like to share with you first results.

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So far, we analysed a total of 28 patients (average age 38 years) who underwent cartilage repair surgery and postoperative therapy in-house, all with a sports background. Their femorotibial and/or femoropatellar cartilage defects (> 2 cm^2) were treated with the AMIC® surgical procedure. The Autologous Matrix Induced Chondrogenesis (AMIC®) is a single step procedure based on micro fracturing in combination with Chondro-Gide®, a bilayer collagen matrix. In all cases, the indication and contraindication criteria were invariably observed.

In 16 of the 28 patients, simultaneous valgisation, varisation or cruciate ligament surgery was performed to correct axis, instabilities and accompanying pathologies.

The surgical procedures were performed by the same team of surgeons and subsequently all patients received postoperative therapy supervised by the same physiotherapists. During the postoperative phase, the surgeon and the physiotherapists formed a team, continuously assessing the joint in order to allow adaptation to the therapy.

Postoperative therapy is closely accompanied by physiotherapist and surgeon and is adapted to the specific clinical situation and patient requirements.

Data were collected using the Geistlich Registry. This internet-based database allows recording and analysis of clinical results including medical history, clinical diagnosis, the Lysholm knee score, VAS pain scale and MRT analysis. We additionally monitored the progressive pain reduction, strength development and the increase in mobility utilising a goniometer. Thorough analysis of all data allowed correlating combination procedures, location, size and depth of the defect with postoperative criteria such as edema, tendency to swelling, pain and improvement of mobility.

At the start of the observation process, the team applied the post-operative guidelines recommended by Geistlich Pharma AG for "AMIC® Knee patients". We then modified these on the basis of the gained experience. As a result, the postoperative therapy focused increasingly on soft tissue techniques such as freedom of movement rather than on developing strength and coordination.

Based on our observations, we developed an adapted "4-Phase Model" (see Table 1), which has now become an established standard at our clinic.

Phase 1: Inflammatory phase	Week 1–2	Swelling/pain/metabolism Limitation of flexion in most cases 30°
Phase 2: Remodelling phase	Week 3–4	Proprioception/isometry/TENS/active motion splint at home (e.g. CAMOped)/Progressive weight bearing Flexion limitation 60°
Phase 3: Load progression	Week 7 – 3rd month	Full load/two-leg stance without retropatellar pressure/diversified ground surfaces /ergometer/gait therapy/strength (closed chain) Flexion limitation 90°
Phase 4: Back to life	From 4th month	Build-up of resistance on leg press/squats/ sport-specific training Free range of motion

Table 1: 4-Phase Model. The focus of treatment changes over the course of the rehabilitation

Our experience confirms the fact that rehabilitation of patients with retropatellar and femoral trochlea cartilage defects is more complex than of patients with femorotibial defect locations. While patients with retropatellar and femoral trochlea defects presented pain syndromes of longer duration and tendency to swelling up to 3 months after surgery, a rapid increase of mobility and decrease of pain was observed in those with femorotibial defects. It was also detected, that coordination and isometry were decreased in patients with retropatellar defects. In this group a marked hypotrophy of the femoral quadriceps muscle measuring up to 4 cm was visible during the 3 months follow-up.

The most rapid rehabilitation and best results in terms of pain, tendency to swelling, VAS pain scale as well as return to the former level of sports was achieved by the patients in whom an indicated simultaneous tibial valgisation osteotomy was performed.

Despite the low number of cases investigated, we are convinced that close cooperation between the surgeon, the physiotherapist and the patient during rehabilitation has a crucial impact on the quality of the cartilage repair. It is only with the help of such holistic and accompanying postoperative therapy that the healing process can be optimally adapted not only to the specific clinical situation, but also to the patients' requirements for optimal results. Since almost no evidence-based data are available on this topic, we would like to encourage the cartilage community to investigate this further.

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ACL Reconstruction with concomitant actifit meniscus implant as a prevention of cartilage damage Emilia Kurowska, Maciej Piatkowski, Konrad Slynarski, Sports Medicine Center CMS Warsaw, Poland

The literature is showing more and more studies documenting meniscus implants with the use of scaffold, however, the rehabilitation process has not been documented yet (in particular with concomitant ACL reconstruction). In such cases it is believed that the future results of ACL reconstruction rely on the meniscus treatment.

Damage to the avascular part of the meniscus is of significant importance due to the low ability to recover. Hence, meniscectomies were a gold standard when treating damages of such size. Menisci are of fundamental importance in the knee joint, thus, a partial or total meniscectomy may lead to irreversible degenerative arthritis and, as a consequence, to damage the joint. Taking a longer perspective it can result in varus knee as well as significant overload and degeneration of the articular cartilage. ACL reconstruction only improves the stability of knee joint and does not solve the problem regarding the joint surfaces. Actifit is a biodegradable meniscal implant. It is a porous scaffold made of aliphatic polyurethane providing optimal mechanical strength, biocompatibility and safe degradation (Fig.1). The blood transports cartilage repair cells and other nutrients that initiate the growth of new meniscus-like tissue. We believe that patients would benefit from a concomitant ACL reconstruction with arthroscopic medial meniscus repair and such a procedure will act as prevention from cartilage damage.

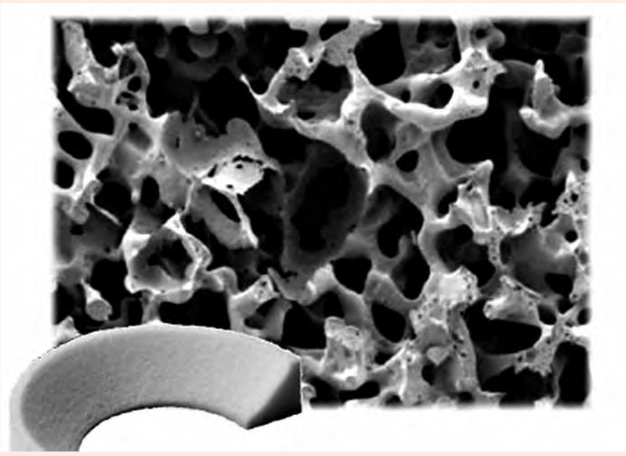

Fig. 1 Actifit implant

The study includes cases of 10 patients after ACL reconstruction with a concomitant arthroscopic medial meniscus repair with the use of a polyurethane implant (Actifit). In order to protect both the ACL, implant and the new fragile cartilage tissue the patients undergo a conservative rehabilitation process. Protecting the meniscus implant is of particular importance, thus, the rehabilitation programme is delayed compared with rehabilitation after an isolated ACL reconstruction. It focuses mainly on the range of motion (ROM), weight bearing status and, consequently, recovery to daily life activities and sports (Fig.2). Both level of pain and swelling need to be under constant control.

THE SPECIFIC PARAMETERS AFTER ACL AND ACTIFIT SURGERY

	ACL	Actifit
Prevention of pain and effusion	1 week	1 week
CPM	1 week	1 week
Isometric QF exercises	1 week	1 week
Patella mobilization	1 week	1 week
QF electrostymulation	1 week	1 week
Prioproception in standing (balance exercises)	2-4 week	9 week (with full WB)
Stationary bike	2 week	9-10 week
Stepper	4-5 week	12-14 week
Treadmil	10 week	14 week
Jumping	12 week	18 week (or later)
Return to sport activities	16-17 week	25 week
Return to training with opponent	32-35 week	36_40

Fig. 2

Patient compliance with activity modification, weight-bearing status, cryotherapy and therapeutic home exercises programme is emphasized. The rehabilitation programme begins immediately after surgery, to achieve full extension. Loss of extension following surgery can result in an abnormal gait, increased patellofemoral symptoms and quadriceps weakness. Patellar mobilization should be performed by the therapist to assist in reestablishing normal patellar mobility. If a patient has a deficiency in quadriceps contraction, a biofeedback unit or electrical stimulation can be used in conjunction with quadriceps setting exercises to improve facilitation of the quadriceps reeducation. A straight leg raise (SLR) is performed with the postoperative brace locked at 0 degrees until not only a sufficient quadriceps control is reached, but also the person is able to perform the SLR without pain or quadriceps lag. Range of motion, weight-bearing status and exercises are adapted individually to the patient's condition. Patients had 3–5 rehabilitation sessions per week with a single session lasting for 2 hours and a total duration of rehabilitation of 6 months.

Patients were evaluated with KOOS score, but their individual opinion was also taken into consideration. The patients were reported to significantly recover in terms of pain during a 12-month observation. They were assessed preoperatively and postoperatively, after 3, 6 and 12 months respectively. The outcomes of the KOOS score for pain have improved significantly from 62 preoperatively to 90 postoperatively. Their activities of daily life improved from 54 to 91. Similarly, the other three components of KOOS score rose: symptoms from 64 to 91; sport from 42 to 89 and quality of life from 55 to 90. From the patient's point of view we need to accelerate the rehabilitation programme as soon as possible but meniscus implant needs limitations of both ROM and weight bearing status. Regarding the necessity to protect the meniscus implant this rehabilitation programme is slower than the one following ACL reconstruction. Finally, our observations were that the time when the patients return to full physical activity after ACL reconstruction with concomitant meniscus implantation does not differ from that found after isolated ACL reconstruction. In our opinion, good clinical results allowing our patients to return to normal activities of daily living and sports without pain validate the proposed surgery followed by personalized rehabilitation. The problem regarding instability of the knee joint along with cartilage damage is common knowledge due to the fact that it consequently leads to damage of articular cartilage. When taking into consideration promising outcomes of studies on 10 patients, we have been working on making the rehabilitation programme faster and more perfect in order to restore the functions of knee joint and avoid pain or its instability at the same time.

Functional knee assessments in patients with meniscal cartilage injury: A comparison of performance-based and patient-reported measures.

Dennis C. Crawford, MD, PhD and Micah B Naimark, BS, USA

Meniscus injury is a known risk factor for the development of knee osteoarthritis. Assessing knee function in patients with meniscus injury is important not only to guide treatment decisions and rehabilitation for this common pathology, but also to collect longitudinal data about physical dysfunction associated with meniscal injury and the potential future development of knee osteoarthritis.

Outcomes for patients treated for meniscus cartilage injury are frequently assessed with standardized questionnaires. As patients with meniscus tears may alter their activities or movements to avoid pain and compensate for their injury, questionnaires based on patient perception may not accurately reflect joint function. Furthermore, questionnaire responses can be influenced by other psychosocial factors unrelated to the injured joint, including depression, fatigue, and cognition.[1,2] While questionnaires identify symptoms that are relevant to the patient, performance-based measures may provide additional information about the actual mechanical function of the joint.[2,3]

We developed a battery of performance-based assessments designed to reproduce knee movements required for everyday living. The battery consisted of nine test-items: active range of motion, passive range of motion, sit-to-stand, stair ascent, stair descent, step-ups, step-downs, star lunges, and 6-minute timed treadmill travel (Figure). In addition to capturing objective measurements of performance, patients were asked to rate their pain and difficulty on a visual analog scale after completing each task.

Fifty patients diagnosed with isolated torn menisci and scheduled for arthroscopic meniscus surgery underwent the test on three occasions: twice pre-operatively to assess reproducibility and once post-operatively to determine response to treatment. Questionnaire data including the Knee Injury and Osteoarthritis Outcome Score (KOOS) and International Knee Documentation Committee (IKDC) Subjective Form were also obtained. Results of our initial study to validate this battery were recently presented at the Osteoarthritis Research Society International's (OARSI) 2011 World Congress on Osteoarthritis and have been submitted for publication.[4]

Top row left to right: Active/passive range of motion, sit-to-stand, stair ascent, and stair descent. Bottom row left to right: step-ups, step-downs, star lunges, and 6-minute timed treadmill travel.

All performance-based assessments demonstrated strong interrater and intrarater reproducibility. The greatest reproducibility was observed with star lunges and treadmill travel, the two tasks with the highest motion complexity. On questionnaires, patients had a 53% improvement in IKDC subjective scores and substantial increases in all 5 KOOS subscales, with the highest improvement of 65% in the KOOS quality of life scale. Patients reported similar improvements in pain and difficulty with the performance-based battery of tests. Objective measures also revealed an improvement, but to a lesser degree. The greatest change in performance was seen with activities that placed high loads on the knee joint such as stepping and stair tasks. Patient performance on these tasks improved on average 10–15% after surgery.

This initial study suggests performance-based assessments can reproducibly assess knee function in patients with meniscal cartilage injury. Interestingly, patients tended to report large reductions in symptoms out of proportion to their improvement in physical performance. While performance-based assessments might require more effort to administer, they may offer data about underlying joint function that is distinct from patient-reported symptoms and questionnaires. We suggest performance-based assessments could be a useful clinical and research tool for monitoring cartilage injury, treatment, and rehabilitation. Similarly, these assessments may be useful for return to work guidelines or performance level criteria. Further investigations outlining necessary levels of function for commonly performed tasks could be of interest.

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Cartilage Rehabilitation: Clinical Experiences

Physiotherapy after cartilage repair: Experience from Clinica CEMTRO (Spain) Fernando García-Sanz[1], José Luis Lara Cabrero1, Pedro Guillén-García[2], Elena Rodríguez-Iñigo[2], Juan Manuel López-Alcorocho[2] [1]Physiotherapy Service, Clínica CEMTRO, Madrid, Spain, [2]Research Unit, Clínica CEMTRO, Madrid, Spain, e-mail: aure.castillejo@clinicacemtro.com

After autologous chondrocyte implantation, physiotherapy is essential for a good recovery of the joint and to reach functional capacity of the patient as soon as possible. However, postoperative rehabilitation should take into account the "biological time" to guarantee the fully viability of the implant. Therefore, our protocol of rehabilitation considers this issue. In this communication we are going to describe the protocol followed in Clínica CEMTRO after autologous chondrocyte implantation in the knee or in the ankle. Our protocol has been used in 334 cases in the knee and 35 cases in the ankle. First, we have to emphasize the advantages of the arthroscopic technique without immobilization versus the open surgery. In our protocol, we have established an initial unloading phase for 8 weeks to allow for the biological integration of the implant into the joint. The goal of this first phase is to recover the mobility of the joint. To achieve this goal, we routinely use continuous passive movement (CPM) (Figure 1) and manual interactive mobilization of the joint performed by the physiotherapist. With an individualized manipulation we can functionally dose the intensity of the rehabilitation based on clinical parameters such as joint effusion and hypertonic muscle response, which help to monitor how much load and activity the joint can bear. We believe that the early mobilization of the joint can avoid the complications associated with immobilization and aids the early recovery joint function while supporting chondrocyte physiology through movement of the synovial fluid.

Figure 1. Progressive load scale

In the second phase, we the joint is submitted to progressive mechanic load. The use of scales (Figure 2) allows us to quantify the progress in joint loading, always under the surveillance of both the physician and the physiotherapist working as a team to supervise any slight sign of overload of the joint. During this second phase, muscle-potentiation is initiated to recover the functional parameters of muscle strength as soon as possible. In order to respect the viability of the implantation, initial muscular work is performed in open kinetic chain exercises in a biomechanical position or range of motion which guarantees the minimum load of the repaired cartilage defect.

Figure 2. CPM therapy (continuous passive movement therapy)

The rehabilitation protocol ends with a third phase of patient re-adaptation to normal activity, but modulating this activity to the joint response. It is important to assess joint effusion to appropriately dose activity progression.

In conclusion, the rehabilitation process aims to recover the functional parameters and the patient's quality of life as soon as possible, without placing the implant in danger. To achieve this goal, it is necessary to respect the biology of the implant, to start early mobilization of the joint and to assure at all times the acceptance of the load by the joint using close surveillance of the team of treating physician and physiotherapist. We do not use local electro-thermotherapy because its effect on the cellular development in the implanted area is not known. However, we use moderate cryotherapy and manual therapy as the mainstay of our physiotherapy treatment.

On-Field Rehabilitation and Return to Sport after Cartilage Repair Della Villa Stefano and Ricci Margherita, Isokinetic Medical Group, FIFA Medical Centre of Excellence, Bologna, Italy

Rehabilitation following cartilage repair is a critical component in the achievement of full recovery and return to sport.[1] the rehabilitation protocol is made of five phases, each one with different clinical and functional goals to be reached.[2]

In this article we deal with On-field rehabilitation (OFR) which is the last phase of the rehabilitation process. Medical attention is usually very accurate during the first months after surgery. It gradually reduces and at that time the athlete often has to follow the advice of his athletic trainer or coach instead of going on with supervised rehabilitation. This could cause difficult situations such as complications or incomplete recovery. This is why we firmly believe in the importance of OFR as a way to return to sport and to prevent re-injuries. [3]

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The OFR takes place on a soccer field (grass or synthetic, outdoors or indoors) under the supervision of an experienced athletic trainer (Figure 1). Each session lasts about 90 minutes, from 3 to 5 times a week (depending on the athlete's activity level), for at least 10 weeks. It consists of progressive sport-specific exercises (Figure 2) and it gradually allows the athlete to return to sport.

A recent study showed that athletes treated with OFR and Isokinetic training after arthroscopic second-generation autologous chondrocyte implantation (Hyalograft C) had a faster return to normal training (8.6±1.7 months) and an earlier return to competition (10.6±2.0 months) compared to the control group (10.6±1.7 and 12.4±1.6 respectively).[4] These results and the significant improvement in the International Knee Documentation Committee (IKDC) subjective score (44.4±2.9 pre-operative; 84.7±11.7 at 1 year of follow-up; 90.7±11.7 at 5 year of follow-up) support our hypothesis that an intensive rehabilitation may allow an earlier return to sport without jeopardizing clinical and functional outcome over time.

The return to sport in term of time and clinical outcome is influenced by several factors such as the patient's characteristics (age, activity level, motivation, rehabilitation goals) and the type of surgery. In a study by Mithoefer et al[5] a bout return to competition after autologus chondrocyte transplantation, 83 % of high level soccer players returned compared to only 16 % of amateurs. As a matter of fact most of high level athletes are young, have shorter duration of symptoms and high motivation. They also generally follow a supervised rehabilitation.

Kon et al[6] recently compared the functional recovery in a population of soccer players after two different surgical techniques. The same step-based rehabilitation protocol was used. The microfracture (MF) group returned to team in 6.5 months and the arthroscopic second-generation autologous chondrocyte implantation (Hyalograft C) group in 10.2 months. The return to competition was after 8 and 12.5 months, respectively. IKDC subjective score showed similar outcome at 2 years follow-up in both groups (MF 86.8±9.7 vs. Hyalograft C 90.5±12.8), but significant better results in the Hyalograft C group after 5 years (MF 79.0±11.6 vs. Hyalograft C 91.0±13.9). So, microfracture allows a faster recovery with worst outcome over time, while Hyalograft C has a delayed return to competition with more durable clinical results.

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Rehabilitation protocol after cartilage repair with BMAC and a collagen-based matrix Georgios Karnatzikos, MD, Anup Kumar, MD, M. S. Somanna, MD, Alberto Gobbi, MD, O.A.S.I. Bioresearch Foundation, Gobbi N.P.O. , Via Amadeo 24 Milan Italy, Georgios Karnatzikos (giokarnes@gmail.com)

Cartilage has a limited healing potential due to the presence of few specialized cells with low mitotic activity and the lack of vessels and of undifferentiated cells that can promote tissue repair. Many surgical techniques have been utilized to improve cartilage lesions healing such as microfracture and autologous chondrocyte implantation (ACI). Gobbi et al[1] recently published their results on a single-step surgery utilizing autologous bone marrow aspirate concentrate (BMAC) containing mesenchymal stems cells (MSCs) and growth factors for cartilage repair in large osteochondral lesions, measuring even up to 22 cm^2 in size.

The goals of cartilage repair are to restore an articular surface that matches the biomechanical and biochemical properties of normal hyaline cartilage and to prevent the progression to

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osteoarthritis. Additionally, associated pathologies as ligament instability, meniscal absence and axis deviation should be treated before or in a concomitant procedure in order to achieve safe return to previous activities and prevent joint from high mechanical stresses and progressive degeneration. Rehabilitation: The rehabilitation protocol after cartilage repair with BMAC and collagen matrix patients should continue for 6-8 months and is similar to rehabilitation after second-generation ACI, based on current knowledge of the graft healing biology. Patient's program is ideally designed to take into account different factors such as site and type of lesion, surgical technique, associated pathologies or surgeries, patient's age, characteristics and expectations, psychological factors, social support and team work[2]. Therefore the rehabilitation program is individualized respecting joint reactions and specific criteria of progression between rehabilitative phases [3, 4, 5]. The rehabilitation program is divided in 4 functional phases [6] characterized by specific objectives and criteria of progression (proliferative, transitional, maturation, and functional recovery). Della Villa et al[7] went further to suggest that an intensive rehabilitation protocol following cartilage repair procedures which included isokinetic and on-field activities positively affected graft maturation and shortened return to play time.

Rehabilitation Progression: The rehabilitation protocol is based on recovery of full range of motion, strength, and sport specific skills without pain and swelling and allows a safe progression. Joint reactions and clinical signs should be considered together with functional criteria for load progression, under surgeon's supervision. Certain goals within each phase are expected to be achieved at a particular time-frame (Table 1). Any delays encountered demand close attention while progression from one phase to the next is allowed if cleared by the managing physician. Important issues related to weight-bearing, range of motion, strength and functional re-training are addressed at specified intervals and are the parameters used to judge the progression[8, 9].

Weight-bearing: While maturation of newly formed tissue would take time to be completed, protection against excessive stress and loads are emphasized especially during the immediate post-operative period and the early phases of rehabilitation [10,11]. In addition, patients should be advised regarding certain positions that should be avoided as determined by the defect size and location. Patients with anterior femoral condyle lesions would have to avoid loading the knee in extension; posterior condylar lesions should avoid loading at flexion angles greater than 45°; while trochlear lesions should not be loaded at angles greater than 30° of flexion. At this time, focus is shifted to strength training and neuromuscular exercises. Regaining muscular control and strength protect the graft site by effectively absorbing the forces that act through the joint surfaces and the treated lesion. [8, 9, 12, 13]

Bracing: The program should consider provisions that would allow patients to be mobile without compromising the delicate status of the graft. This is achieved with the use of a brace locked at 0° which together with the use of crutches would

Phase	Objectives	Criteria to Progress
1. Protection of the implant (0–6 weeks)	• Protect the transplant from excessive loads and shearing forces • Decrease pain and effusion • Gain full extension and gradual recovery of knee flexion • Retard muscle atrophy	• Full active knee extension • Knee flexion > 120° • No or minimum pain and swelling • No pain during weight-bearing • Adequate muscle recruitment (quadriceps)
2. Transition and recovery of gait (6–12 weeks)	• Return to normal gait pattern • Progressive recovery in daily functional activities • Increase the strength of the quadriceps and flexors • Recovery of full range of motion	• Normal gait • Recovery of nearly full ROM (full extension, flexion > 135°). • Adequate muscle tone and neuromuscular control • No pain or swelling
3. Maturation and recovery of running (12–24 weeks)	• Return to a correct running pathway • Further increase in strength of quadriceps and flexors muscles • Further increase in functional activities level	• Running without pain/swelling at 8 km/h for 10' • Adequate recovery of coordination and neuro--muscular control • Recovery of strength • > 80% contralateral limb • Single leg hop test: > 80% contralateral limb
4. Turnover and sport specific recovery (24–52 weeks)	• Sustain high loads and impact activities • Recovery sport specific skills • Prepare athlete for a return to team and competition with good recovery of the aerobic endurance • Maintain a good quality of life, avoiding excess of body fat and preventing risk of re-injury	• Running without pain/effusion at 10 km/h for 15' • Recovery of strength > 90% contralateral limb. • Single leg hop test: > 90% contralateral limb • Recovery of sport specific skills

Table 1: Rehabilitation phases, objectives and criteria to progress between phases.

permit non-weight bearing ambulation while protecting the graft. Most protocols recommend non-weight bearing for two weeks following the surgery. After two weeks, partial weight-bearing can be initiated for both condylar and patellofemoral lesions. However, for patients with trochlear lesions weight-bearing progression should primarily be conducted with the leg locked in full extension. As the strength of the quadriceps muscles are regained, the patient can shift to one crutch at around the fourth week. At the same time, the brace can be gradually released from a locked position at increments of 20°–25°. Progression in unlocking the brace has been demonstrated to be slower for those with trochlear lesions.

Continuous Passive Motion (CPM): During the immediate post-operative period, the transplanted joint is immobilized with a brace. The use of a CPM (continuous passive motion) machine is commenced after 24 hours. The advantage of using one have been reported by Salter et al study[9] which demonstrated an enhanced modeling of the repair by influencing the integration and orientation of cells. The usual range by which the machine is set is from 0° to 40° initially which is increased by increments of 5° depending on the location of lesion. At four weeks post-operatively, patients should be expected to reach 90° to 110°.

Strength Training: Once the joint is pain-free and swelling has settled with full range of movement achieved, the rehabilitation can now be focused on strength training. Early quadriceps control is emphasized and should be achieved within the first week following the implantation. During this time, isometric quadriceps exercises with the knee locked in extension are commenced. Isometric closed kinetic chain exercises then follow which place sufficient demand on the muscles for progressive strength training without overloading the grafted areas.

Specific sports patterns: As the patient nears the completion of his rehabilitation, re-evaluation of specific activities that determine the type of physical demands that would constitute the patient's lifestyle is performed. The various components of these activities are broken down and incorporated in the patient's training. The end goal of which is to regain balance and the protective reflexes to prepare the patient for his gradual return to activities.

Conclusion: The rehabilitation protocol after cartilage repair with BMAC and collagen matrix represents an essential component of the treatment and is designed to facilitate the newly-formed tissue incorporation and to influence the successful outcome of the procedure.

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Post-operative Matrix-Induced Autologous Chondrocyte Implantation of the Talus Rehabilitation Christopher Kreulen MD*, Chris Carr M.Phys.*, Eric Giza MD**, Martin Sullivan MD*, *North Shore Private Foot and Ankle Clinic, Australia 2065,**UC Davis Department of Orthopaedics, Sacramento, USA, ckreulen@gmail.com

Introduction: MACI is a second generation autologous chondrocyte implantation technique used for the treatment of osteochondral defects. Specifically, harvested chondrocytes placed onto a 3-dimensional collagen matrix and implanted on the articular defect with fibrin glue[1-9]. This procedure has been performed at our institution with an arthrotomy[6] since 2003 and in 2008 this standardize rehabilitation protocol was instituted. The aim of this protocol is to provide a standardized outline of post-operative care for patients and their physiotherapists, as many patients are tertiary referrals and do not live near the clinic or the main physiotherapy office.

Rehabilitation Protocol: The short term goals (0–12 weeks) of this protocol work on slowly progressing weight bearing while preventing the deleterious effects of immobilization and rest, including arthrofibrosis, joint adhesions, muscle atrophy, and pain. During the first 6 weeks the rehabilitation is focused on decreasing swelling, improving range of motion, preventing adhesions, and conservatively increasing the weight-bearing status. The rehabilitation must begin to create the environment that encourages the cells to proliferate while preventing a certain amount of deconditioning.

At two weeks the dressing, splint, and sutures are removed (Fig. 2). The patient's ankle is placed into a CAM walker boot (Fig. 1) that is to be worn at all times except during physiotherapy, home exercises, and showering. The patient must maintain strict non weight-bearing (NWB) with crutches at this time. During the two-four week post-op period, plantarflexion-dorsiflexion, inversion and eversion ankle ROM exercises are started under the guidance of a therapist. The therapist also begins manual joint manipulations and gentle scar massage.

Figure 1: Example of the rehabilitation CAM walker boot used by patient after the two week point in the post-operative rehabilitation.

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At the four-six week post-operative period the patient begins hydrotherapy and isometric strengthening of the ankle. From our experience, hydrotherapy provides a great benefit in the rehabilitation process and we prefer to get the patient in chest high water for all exercises. These exercises include walking forwards, backwards, and sideways, heel rises, cycling in water, and single leg balance. Touch weight-bearing (TDWB) is started on week five.

At six-twelve weeks post-operative the aim is to increase weight-bearing, begin gait re-education, and restore ROM ankle to normal levels. At week six the transition to full weight-bearing (FWB) begins and Theraband strengthening exercises are initiated. Sliding foot stretching exercises, gait re-education, and low-speed no resistance exercise bike are started as well. Joint mobilizations and soft tissue massage should also continue during this time to continue to reduce the amount of swelling.
During week 12 to six months post operatively the goals of the rehabilitation protocol at this point are to gradually return to more functional activity, while avoiding high impact exercise such as running and jumping. Progressive proprioception and strengthening continue and exercises are mainly closed chain. During the 12–18 week period the patient is taken out of the boot but is not allowed to have more impact on the joint besides walking. Single leg balance on the floor and transitioning to a pillow are introduced to improve stability and proprioception. More focused stretching and strengthening of the gastroc-soleus, including eccentric and concentric calf-raises, are initiated.

Figure 2: Healing anteromedial arthrotomy incision used for placement of the MACI graft.

The 18–24 week period continues the previous activities and still limits impact exercises. A wobble board is begun and an increase in the time of walking exercises continues. At six months the graft will be stable enough to continue to increase balance training and start a gradual increase of impact activities with an aim for full impact activity at twelve months.

Experience: The MACI procedure previously described has been performed on over 80 patients at our institution since 2004. The current protocol was instituted in 2008 and has been used with 26 patients. There were 13 female and 13 male patients in this group. The average age was 38 years old. We have found that rehabilitation is important as this group of patients usually has had 2–3 previous surgeries to their ankle prior to the MACI procedure [6] and that the rehabilitation must also deal with the difficulties associated with a chronic injury. Our experience has shown us that patients will begin to have an increase in pain once they start their weight-bearing transition. The protocol may need to be adjusted and individualized to fit some of these patients' needs, although typically they continue to improve in a timely fashion. Overall, we have found our patients to perform well with this rehabilitation protocol and compliance is excellent.

Early Rehabilitation Following Microfracture in the Hip

Marc J. Philippon, MD, Diana Patterson, Teddy Fagrelius, The Steadman/Philippon Research Institute, Vail, CO, USA

Microfracture is a marrow-stimulating procedure that allows undifferentiated stem cells to heal chondral injuries. The procedure, developed by Steadman, accesses pluripotent marrow cells via small subchondral perforations created in the site of the defect.[1] A marrow clot forms in which stem cells will differentiate into stable, hybrid fibrocartilaginous tissue that covers the lesion.[1,2] While there are other surgical procedures to treat articular cartilage defects, the microfracture procedure continues to grow in popularity due to ease of use and cost.

Microfracture of the hip is indicated with focal and contained full-thickness defects, partial thickness lesions in which the cartilage scrapes off down to the bone when probed, and cases in which unstable cartilage flaps overlay intact subchondral bone.[3] It is crucial to have an adequate height of cartilage around the rim of the lesion as the rim functions to hold the clot in place. Contraindications for microfracture of the hip include partial thickness defects and chondral lesions related to a bony defect. Patients who are unwilling or unable to comply with postoperative rehabilitation protocols are contraindicated for this procedure.

The postoperative management parallels that established for microfracture surgery on the knee.[4] Care is taken to prevent disruption of the marrow clot (Figure 1) and thus protect the environment for marrow and mesenchymal cells to differentiate and grow.[3] Repaired defects in femoral condyles of horses showed at 8 weeks hyalinelike tissue in microfractured defects, increase in type II cartilage mRNA expression in repair tissue, and treated lesions contained more repair tissue filling the defect.[5] Initially, cold therapy is used to provide pain relief and to diminish the inflammatory response. Initial physical therapy efforts can begin on the day of surgery, and should focus on regaining range of motion and prevention of adhesion development, while protecting the surgical repair and healing cartilage. Continuous passive movement, circumduction, stationary biking, and aqua therapy are all utilized. Regaining muscle strength and neuromuscular balance of the hip and pelvis is critical to long-term success of the surgical repair.[6]

Candidates for microfracture surgery of the hip must be educated preoperatively that the rehabilitation protocol is a slow, involved process, as it must never be shorter than the necessary time for natural osseous healing and cartilage re-growth. Its success depends highly on the patient's expectations and commitment. Outcomes are not measured by the speed with which the patient returns to their prior activity, but their overall satisfaction and longevity of function.[7]

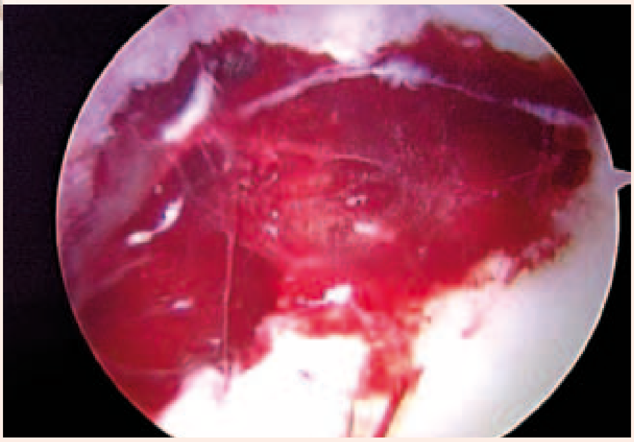

Fig. 1

In the weeks following arthroscopic microfracture surgery, flat-foot weight-bearing of 20lbs (9 kg) is maintained for the first 8 weeks. Reduced weight-load allows for osseus healing, and the flat-foot position is preferred over the toe-touch position to prevent a flexion contracture. A continuous passive movement machine is used for 6 to 8 hours per day during their weeks of weight-bearing restriction to prevent adhesions and, possibly, promote fibro-cartilaginous growth.[8] The CPM machine should place the hip in 10 degrees of abduction, move between 0 and 45 degrees of flexion, and be increased as tolerated.[8] Following each episode of CPM activity, the patient should lie prone for 30–60 minutes to prevent hip flexor contracture formation. Circumduction exercises are performed at 0 and 70 degrees of flexion in both the clockwise and counter clockwise directions. The leg is moved in a circular motion with the patella always facing upward and in line with the shoulder. Our use of circumduction (Figure 2) immediately postoperatively has reduced the formation of adhesions from 4% to 1.4% cases.[9]

Use of the stationary bike, set with no resistance on the operative leg and the seat set high enough to prevent excessive flexion, starts on the day of surgery. Resistance can be added as tolerated.[6] Aqua therapy is used regain ROM and strength in a low-impact non-weight-bearing environment. Sessions are limited to 10–15 minutes and monitored to keep the patient's ROM small. Patients walk in the pool to facilitate developing the proper walking gait and pelvic muscle strength while protecting the microfractured area from impact. When the patient is off crutches they can run in the pool starting with chest deep water and progressing to shallower water. Underwater treadmill running is not recommended as it introduces a secondary shearing force to the surgically repaired area.[10]

Regaining strength in the hip and core muscle groups and planes of motion is critical to the success of the rehabilitation and overall surgical procedure. Resolving maladaptive muscle patterns at this point in the athlete's life can help to prevent

Fig. 2

future problems with the surgically repaired hip and prolong careers. Exercises used to accomplish this goal start with sub maximal isometrics in the first days after surgery, and progress as tolerated. Significant work towards stabilizing the pelvic musculature and emphasizing correct firing patterns can be accomplished in the 8 weeks before weight-bearing, which enables the patient to progress more rapidly once normal gait exercises are begun.[6,10]

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Member's Experiences

Part 4 – Member's Experiences

Care should especially be taken concerning knee joint angle and the contact area in rehabilitation planned following autologous osteochondral grafting for knee cartilage lesions: A report of two cases. Hiroshi Kuroki[1], Toru Oka[2], Taizo Furukawa[2], Masahiko Kobayashi[3], Yasuaki Nakagawa[4]
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Autologous osteochondral grafting surgery is one of the recently evolved methods to create hyaline repair tissue in articular cartilage lesions. Recent studies showed that this surgery appears to be a promising alternative for the treatment of small and medium-sized focal cartilage lesions in both of weight-bearing and non-weight-bearing joint surfaces[1–4]. The knee joint, which consists of the weight-bearing lateral and medial tibiofemoral surfaces and the non-weight-bearing patello-femoral surface, is one of the most frequently treated joint by this surgery. Because size and location of cartilage lesions differ in each patient, successful management after the autologous osteochondral grafting to the knee has always been a challenge for rehabilitation specialists and orthopaedic surgeons.

The authors present two clinical cases of patients who had undergone autologous osteochondral grafting. Authors recommend that the return of weight-bearing is gradual, usually non-weight-bearing for the first 2 or 3 postoperative weeks, partial weight-bearing for 3 to 5 weeks postoperatively and return to full weight-bearing 5 to 8 weeks postoperatively. Strengthening using the open kinetic chain concept (OKC) and the closed kinetic chain concept (CKC) is applied in the first 3 weeks postoperatively and after 3 weeks, respectively. Because the program for each case respects both the period of non-weight-bearing and the knee angle without putting the osteochondral grafts at risk depending on size and location of the cartilage lesions, different postoperative rehabilitation programs should be planned for each case, especially in the strengthening program (Table).

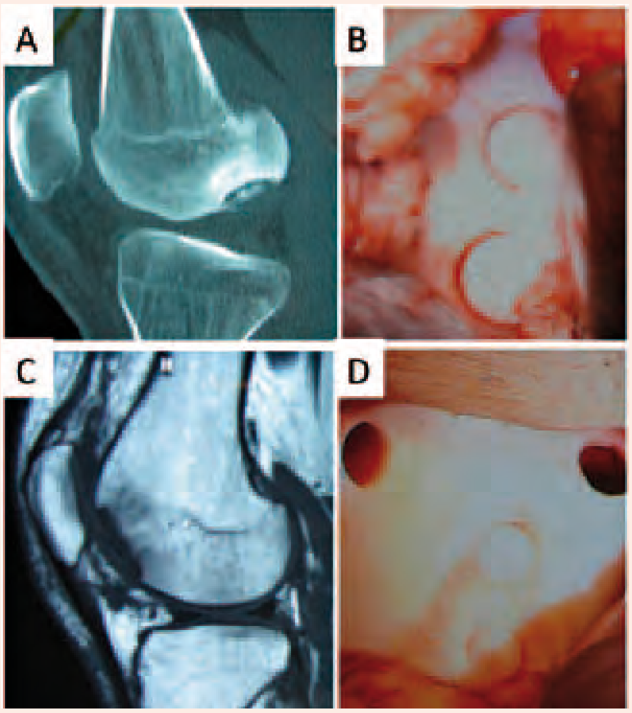

Fig. 1 Cartilage lesion was posterior of medial condyle in case 1 (A) and patellar groove in case 2 (C). Two plugs were grafted in each case (B, D).

Case 1 is a 15-year-old male with 2 osteochondral plugs (diameter 8 mm, length 15 mm) grafted to the cartilage lesion (size, 130 mm^2) on the posterior part of the medial femoral condyle (Fig. 1). Isometric strengthening at 0 degrees and isotonic strengthening at 0–30 degrees of knee flexion were applied in the first 3 weeks postoperatively so as not to increase contact pressure on the graft, paying careful attention to the contact area (Fig. 2, upper)(5). After 3 weeks postoperatively, CKC strengthening was added using a pneumatic chair exercise at 30 degrees of knee flexion and the squatting exercise at the 30–45 degrees of knee flexion. After 5 weeks postoperatively, the OKC exercise was unrestricted and the CKC of the squatting exercise was performed at between 0–45 degrees. The CKC exercise was unrestricted after 8 weeks postoperatively.

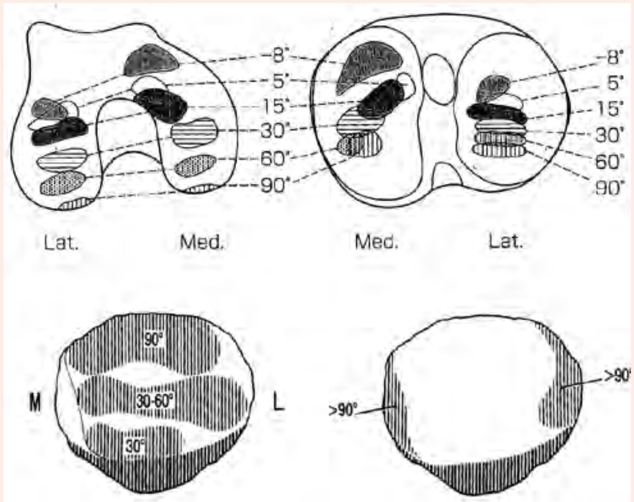

Fig. 2 Knee joint angle and contact area in the tibio-femoral surface (upper)(5) and in the patellar surface (lower)(6).

Case 2 is a 27-year-old male, with 2 osteochondral plugs (diameter 8 mm length 15 mm) grafted to cartilage lesion (size, 135 mm^2) on the central part of the patellar groove (Fig. 1). Isometric strengthening at 0 or 90 degrees of the knee and isotonic strengthening at 90 and 120 degrees was applied in the first 3 weeks postoperatively so as not to increase contact pressure on the graft, paying attention to the contact area (Fig. 2, lower).[6] After 3 weeks postoperatively, strengthening using the pneumatic chair exercise at 45 degrees and the squatting exercise between 0–45 degrees was performed. After 5 weeks postoperatively, the OKC exercise was unrestricted and the CKC of the squatting exercise was performed at the between 0–60 degrees. The CKC exercise was unrestricted after 8 weeks postoperatively.

Each case successfully recovers their muscle strength, range of motion and pain score using the numeric score and returns to activities of daily living and sports at postoperative 8

	Therapeutic exercise	Site of lesion: Patellar groove	Site of lesion: Condyle, anterior	Site of lesion: Condyle, posterior
Non-weight-bearing	OKC (isometric)	at 0 or 90 degrees	at 90 degrees *	at 0 degree *
(first 2 or 3 weeks postoperatively)	OKC (isotonic)	at the degree between 90 and 120	at the degree between 90 and 120 *	at the degree between 0 and 30 *
Partial weight-bearing (postoperative week 2 or 3 to 5 for 1/3 of body weight)	CKC (pneumatic chair)	at 45 degrees	at 45 degrees **	at 30 degrees **
(postoperative week 4 to 7 for 2/3 of body weight)	CKC (squatting)	at the degree between 0 and 45	at the degree between 45 and 60 **	at the degree between 30 and 45 **
	Bicycle ergometer	20 min or more		
Full weight-bearing (postoperative week 5 to 8)	OKC (isometric/isotonic)	at any degree		
	CKC (squatting)	at the degree between 0 and 60		at the degree between 0 and 45
Exercise to return to sports (postoperative week 12 –)		jog, jump, dash, cross-step, etc.		
Return to sports (postoperative week 20 –)		more than 80 % to maximum isometric strength of knee extension in the sound side		

*: In case of medial condyle, being conscious of vastus lateralis and keeping eversion position of the ankle and foot. In case of lateral condyle, being conscious of vastus medialis and keeping inversion position of the ankle and foot.

**: In case of medial condyle, keeping eversion position of ankle and foot and inner rotation of hip joint slightly. In case of lateral condyle, keeping inversion position of ankle and foot and outer rotation of hip joint slightly.

weeks and 6 months, respectively. The authors recommend that care should especially be taken concerning knee joint angle and the contact area when therapeutic exercise programs and gradual weight-bearing exercise programs are planned following the autologous osteochondral grafting for knee cartilage lesions.

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Medial patellofemoral ligament reconstruction and Autologous Matrix-Induced Chondrogenesis (AMIC): a case report

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Introduction: The treatment of traumatic chondral defects of the patella in young, active patients remains a challenge. The goal of treatment is to provide a well functioning, properly aligned knee that can endure a wide range of activity. Cartilage defects at the patella commonly occur in recurrent lateral patellar dislocation, subluxation and functional instability[2]. The importance of the medial patellofemoral ligament (MPFL) as the primary soft-tissue restraint to lateral displacement of the patella has recently been corroborated by several studies, and the MPFL is always injured to some extent during traumatic lateral patellar dislocation[5]. We present a case for combining Autologous Matrix Induced Chondrogenesis (AMIC) for cartilage repair and medial patellofemoral ligament reconstruction for patellar tracking. This report focuses on the rehabilitation program that needs to be adjusted when two operative procedures are combined.

Case report: A 22 y.o. female with a localized chondral defect at the patella presented in our clinic. She had a 4 year history of recurrent patellar dislocation. She reported that her knee functionally limited her and she felt that her patella would "pop out of place" during every day activity. A MRI scan was undertaken, reporting a shallow trochlea groove, a lateral patellar tracking and a cartilage lesion down to the subchondral bone at the medial patella. A MPFL repair in combination with an AMIC was recommended. At the time of surgery a diagnostic arthroscopy was performed and a cartilage lesion grade III-IV according to the Outerbridge classification was seen (Fig. 1a). For the treatment of the cartilage lesion ($2\ cm^2$) an AMIC procedure was performed (Fig.2a,b) was performed followed by an MPFL repair as prior described[3,7]. Behind the background of the MPFL repair, the patient was postoperatively placed in a knee immobilizer in 20° of flexion. Already on the day of surgery she was taught an exercise program including a limited range of passive knee flexion of up to 60° and how to begin walking using 2 elbow crutches with half body weight. In the first 2 weeks, passive range of motion was performed with the help of a physiotherapist and a continuous passive motion (CPM) device on a daily basis following the recommendations after cartilage repair procedures[4]. In an attempt not to unduly load the patellofemoral joint there was a bias towards closed-chain activities. After 2 weeks, leg raising and quadriceps setting exercises were instituted and range of motion was increased as tolerated with no restrictions. Although the patient was progressing well, she still had a limited knee extension at minus 10° and only 110° flexion limited by pain. Accordingly, she was transferred to our hydrotherapy class to improve pain

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and range of motion. The patient continued with her home exercise program on non-gym days and was discharged from the physiotherapy department 8 weeks postoperatively.

Results: Following this rehabilitation program after AMIC with concomitant patella realignment surgery, when reviewed 6 months postoperatively, the patient reported that her knee felt "stronger" with no recurrent patellar dislocation, and was completely satisfied with her surgery. She had increased confidence in the use of her knee, full range of motion and had returned to her normal home and work activities.

Discussion: This single-case study describes a patient following AMIC and concomitant MPFL repair and a tailor-made rehabilitation program. This patient reported a successful outcome with the resolution of patella instability and relieve of anterior knee pain.

The lack of a control group does not allow to establish whether one or the other procedure alone can provide both pain relief and functional improvement, but ethical reasons suggest that both conditions should be treated[2]. Our results are in line with a similar study combining a distal realignment and membrane-seeded autologous chondrocyte implantation (MACT) leading to good results with significant increases in all outcome scales[2].

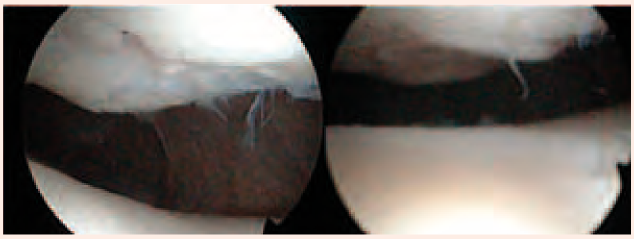

Fig. 1a,b: Arthroscopic view at the articular surface of the patella. Fig 1a demonstrates the chondromalacia graded as III - IV according to Outerbridge classification, while Fig. 1b shows a smooth articular surface after AMIC with the matrix in place at the end of surgery.

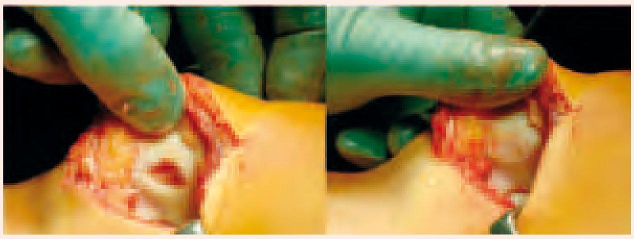

Fig 2a,b: Surgical access to the patella. Fig 2a shows the debridement of the patellar cartilage lesion. Intraoperative findings after AMIC (Fig. 2b).

The Autologous Matrix Induced Chondrogenesis (AMIC) has proven to be a successful treatment and provides two major advantages; on the one hand it is a one-step procedure and on the other hand it is cost-effective with no need of in vitro cell expansion. In a case series of 27 patients we prior described a significant improvement in 4 different scoring systems after a follow-up of up to 36 months after AMIC[3]. MPFL reconstruction has become the first choice for treating recurrent patellar dislocation and good midterm clinical results with up to 97% patient satisfaction and up to 10 years of follow up have been reported[6].

As with all rehabilitation programs, the patient´s management should be tailor-made to meet patient´s, physiotherapist´s and surgeon´s objectives. Our rehabilitation protocol does not immobilize the knee, although movement is limited initially, and encourages the return to functional activities. By not immobilizing the knee, the likelihood of the detrimental effects of the immobilization such as joint stiffness, articular degeneration and muscle atrophy can be reduced. The initial limitation of movement is based on the fact that the MPFL has its maximal restraint against patella lateralization in 30% of knee flexion[1].

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Case report: patello femoral chondral lesion in a young female soccer player

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A 24 year old female medical student visited the department of physiotherapy 3 weeks after having suffered an injury during a soccer game. Presumably the kneecap was subluxated at the time of her injury. Magnetic Resonance Imaging (MRI) showed a grade 4 chondral lesion of the lateral trochlea of her left knee. The patient was scheduled for an autologous chondrocyte implantation (ACI). After consulting the orthopaedic department of the University Medical Centre Utrecht, the patient was sent to the department of physiotherapy for a preoperative screening. The importance of preoperative screening should be emphasized. It is important that the patient has a clear understanding of the postoperative process and involved exercise progression. Some important items of that process are the long duration of the rehabilitation and the continued motivation and dedication of the patient to the rehabilitation program. The patient presented with several favourable parameters: short duration of symptoms between injury and operation, young age, normal weight, high preoperative activity level with daily sports participation and positive motivation.

During the first arthroscopy, a second chondral lesion was seen: a defect of the patella. Conclusion: kissing lesions of the patella and trochlea. Two months after the first visit to the orthopaedic department, an autologous chondrocyte implantation of the trochlea and the patella was performed. After the operation, a bandage (tape) was applied distal and proximal from the knee joint. By using this tape method the contact between the opposite defects is minimalized (Fig. 1).

Fig. 1

The rehabilitation program for patello-femoral defects was used and MRI examination was performed to follow the morphology of the cartilage. Post operative rehabilitation included bracing in extension for 6 weeks. Full weight bearing with the brace was permitted after 3–4 weeks depending on the reaction of the joint and the controlled activation of the quadriceps. Continuous passive motion was used for 6 weeks, 6–8 hours a day. After 6 weeks it was permitted to take off the brace and resume a normal gait. Hydrotherapy was used as an ideal method to normalize the gait.

Rehabilitation after ACI must be a fine tuned therapy! Especially knowledge of the biological processes in the joint, combined with the loading of the joint during the different phases of the rehabilitation is essential. Load on the repaired structures at the different angles of joint loading should be considered depending on the location of the lesion. Biomechanical aspects of the patellafemoral and tibiofemoral joint should be well understood for ACI rehabilitation.

At 19 months postoperatively, the patient is doing very well. Mid- and high load exercises are tolerated without any problem and the patient is starting agility training and sports-related exercises in the upcoming months. It is difficult to predict when the patient will be ready too return to soccer. The combination of systematic rehabilitation and continued positive motivation and mental attitude increase her chance to return her to active sports participation.

Case Report: Rehabilitation and Isokinetic Testing after Cartilage Repair with Microfracture

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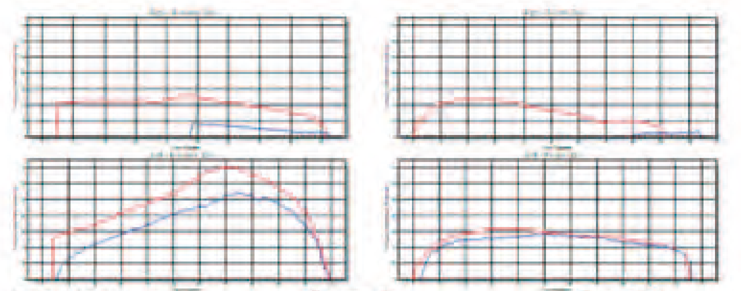
Articular cartilage damage has been heavily discussed in literature as surgical techniques and rehabilitation strategies evolve. The etiology of chondral injuries varies between trauma, degeneration, meniscal tears and even a poor biomechanical alignment. Even partial meniscectomy can be potentially detrimental for the cartilage tissue due to augmented contact pressures between femur and tibia. The ICRS has established an official classification for this cartilage lesion that is used worldwide. The treatment for cartilage injuries depends of their local defect characteristics and patient's activity level. The microfracture technique was described by Steadman in 2001 and has been used with good results following the rehabilitation guidelines proposed by Reinold et al (JOSPT 2006). In some cases, when chondral injury is extensive, exercise-induced pain during rehabilitation can present a challenge for patient and physical therapist. Below we present a case that describes treatment options for this kind of patient:

Case Presentation: A 36 year old businessman and recreational surfer involved in a car crash 10 years ago began complaining of knee instability and swelling over the last 5 years. The patient reported two previous knee surgeries for the same problem, performed in another Brazilian state, with no success. Clinical history, physical examination, X-ray and magnetic resonance imaging revealed an anterior cruciate ligament tear, grade IV chondropathy and partial medial and lateral meniscectomy. The patient underwent anterior cruciate ligament reconstruction with hamstrings graft, Steadman's microfractures of chondral defects located in the trochlea ($2cm^2$) and the lateral femoral condyle (7mm).

Platelet rich plasma clot (PRP) was applied to the chondral repair site. The patient began continuous passive motion (CPM) therapy on the first postoperative day until the second week when he started using the bicycle. Crutches were used without weight bearing for 6 weeks and the patient performed the majority of exercises commonly prescribed and recommended after cartilage repair. After 12 weeks of rehabilitation, the patient still complained of edema, weakness and marked pain - mostly while doing exercises. The regular rehabilitation protocol was interrupted. The patient received a hylan G-F 20 intra-articular injection and started an isokinetic strengthening (Cybex-HumacNorm) protocol for 8 weeks, as suggested by Petersen et al (2009). It consisted of 6-8 concentric sets of 10 repetitions at different angular velocities, tree times per week with one-day minimum rest between intervals. The first set, so called a "warming set" was performed at 180 degree per second with 20-30 repetitions and 60 second rest. The other 8 sets use slower velocities (120, 90, 60 and 30 degree per second, two sets for each velocity). The patient started with higher velocities and the progresses to slower velocities. After 6 weeks the patient should be doing 5-6 sets (two 120, two 90 and one or two sets at 60 degree per second). The wor-

Cartilage Rehabilitation: Clinical Experiences



Isokinetic Con/Con Speed 60/60 deg/sec 3 Reps	Extensors (Con) 31/03/2011	10/05/2011	Change	Flexors (Con) 31/03/2011	10/05/2011	Change
TORQUE PARAMETERS						
Peak Torque (Newton-Meters - Best Repetition)						
Right	18	50	208 %	7	47	600 %
Left	107	141	32 %	56	62	12 %
Deficit	[illegible]	[illegible]		[illegible]	[illegible]	
Work per Repetition (Newton-Meters - Best Repetition)						
Right	8	71	767 %	1	49	3500 %
Left	127	178	39 %	83	92	11 %
Deficit	[illegible]	[illegible]		[illegible]	[illegible]	
Average Power per Repetition (Watts - Best Repetition)						
Right	9	42	367 %	3	39	867 %
Left	70	95	36 %	45	48	7 %
Deficit	[illegible]	[illegible]		[illegible]	[illegible]	

kload was increased every Wednesday, introducing one extra set per week. Isokinetic testing was obtained at the beginning of training and after 8 weeks is shown below:

The two upper graphs represent the right leg and the two graphs below the left leg. At the right are the graphs of extensors muscles and at the left the graphs of flexor muscles. The blue lines show the contractile behavior of first evaluation (March, 03–2011) and the red lines represent the second evaluation (May, 10–2011).

Following the treatment protocol, isokinetic testing showed an improvement of 208% on extensor peak torque and 600% on flexor peak torque. The work produced by extensors and flexors improved 767% and 3500%, respectively. In comparison, during the first testing the patient was lacking total active extension against gravity. After 6 weeks of isokinetic training he cannot only achieve this feat but also without significant pain (EVA 02 compared with EVA 06 on the beginning of treatment).

The program of complex physiotherapeutic treatment of patients after arthroscopic reconstruction of cartilage by the AMIC method

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AMIC (Autologous Matrix-Induced Chondrogenesis) is an innovative biological method of cartilage reconstruction that stimulates the natural potential of the organism to rebuild focal cartilage and bone-cartilage surface damage of no more than 1–2 cm² [(1)]. The aim of this study is to demonstrate complex physiotherapeutic treatment of patients after arthroscopic cartilage reconstruction (joint surface) by AMIC method; based on case studies among patients of our clinic.

The first steps of rehabilitation: Patients are hospitalised for one day and equipped with an angle- adjustable orthosis stabilizing the knee at 15° angle for the first 24 hours after surgery. We recommend walking with crutches in a normal movement pattern, without loading of the limb for the first 4 weeks. Then, loading should be gradually introduced so that the operated limb can be fully loaded within approximately 6 weeks when the patient should be able to walk without elbow crutches. The patient should perform proprioceptive exercises from the first day after the surgery. Knee joint flexion is limited to no more than 90° for the first 4 weeks after surgery. Two weeks after arthroscopy all patients attend an appointment with their doctor, have their stitches removed and undergo physiotherapy treatments in our clinic. Once the knee range of motion and the quadriceps condition is considered adequate, patients can start to load the operated limb in full knee extension.

The first 12 weeks of rehabilitation: In our protocol the most important aspects of rehabilitation after arthroscopic cartilage reconstruction are proprioceptive exercises, the range of motion (ROM) and isometric exercise that stimulate the quadriceps.

The range of motion is performed using continuous passive motion machine (CPM) and on a stationary bike with no loading for the first 4–5 weeks. In the initial stage, exercises stimulating the quadriceps are only isometric, in weeks 5–6 squats are introduced but only up to 90° of knee flexion. The first proprioceptive exercises are in supporting conditions, after 5–6 weeks with full loading on unstable ground. During weeks 7–8 of the rehabilitation process the load is increased on the stationary bike, squats with additional weight are performed and exercises on one leg are introduced, along with exercise with an athletic trainer.

Biomechanical tests: We obtained, from objective measuring tools, results regarding the patient's recovery. The first (basic) biomechanical tests are performed in the 12th week after arthroscopy; they are composed of postural strategy and neuromuscular control evaluation of lower limbs and the spine, using DELOS system, the assessment of ground reaction forces and symmetry during loading on lower limbs movement performed on dynamometric MTD platforms, measurement of isokinetic muscles strength and functional tests of basic movements patterns according to Gary Cook's concept. Further rehabilitation activities are influenced by the results of these tests. If they meet the assumed criteria we introduce dynamic exercises, jogging training and advanced training with a physical education trainer. If the results do not meet the assumed criteria a patient returns to static exercises and the tests cannot be retaken for another 3 weeks. The tests are done in the 6th and 12th month after the arthroscopy and they are always composed of the same elements. Additionally, a Functional Movement Screen is performed after the 6th month.

Today in our clinic there have been 30 patients who have been operated with the AMIC method, 15 at the 3-month post-surgical evaluation, and 6 patients at 6 months post-surgical evaluation. Among the group is one patient who is professional athlete that has already returned to a training regime in his football club. Having observed patients in our clinic it seems that the rehabilitation protocol we have created for patients after reconstruction of cartilage defects in the knee with the AMIC method, is not only successful but also enables patients' recovery, and what is more, to full fitness.

References:

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