


Rehabilitation following Microfracture of the Knee

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Kevin E. Wilk¹, Leonard C. Macrina¹, and Michael M. Reinold²

Abstract

Postoperative rehabilitation programs following articular cartilage repair procedures will vary greatly among patients and need to be individualized based on the nature of the lesion, the unique characteristics of the patient, and the type and detail of each surgical procedure. These programs are based on knowledge of the basic science, anatomy, and biomechanics of articular cartilage as well as the biological course of healing following surgery. The goal is to restore full function in each patient as quickly as possible by facilitating a healing response without overloading the healing articular cartilage. The purpose of this article is to overview the principles of rehabilitation following microfracture procedures of the knee.

Keywords

knee, rehabilitation, microfracture, arthroscopy

Introduction

Articular cartilage defects of the knee are a common cause of pain and functional disability in orthopedics and sports medicine. The avascular nature of articular cartilage predisposes the individual to progressive symptoms and degeneration due to the extremely slow and oftentimes inability of the cartilage to heal.¹⁻⁵ Nonoperative rehabilitation is frequently unsuccessful, and further treatment is required to alleviate symptoms. This presents a significant challenge for patients, particularly young and more active individuals who present without gross degenerative changes but rather focal cartilage defects.

Postoperative rehabilitation programs will vary greatly among patients and are individualized based on lesion specifics (size, depth, location, containment, quality of tissue), patient specifics (age, activities, goals, body mass index, general health), and surgical specifics (exact procedure, tissue involvement, concomitant surgeries). Thus, the development of an appropriate rehabilitation program is challenging and must be highly individualized to ensure successful outcomes. These programs are designed based on knowledge of the basic science, anatomy, and biomechanics of articular cartilage as well as the biological course of healing following surgery. The goal is to restore full function in each patient as quickly as possible without overloading the healing articular cartilage.

In this article, we will discuss the principles of rehabilitation following the microfracture procedure and outline a course of treatment based on several fundamental principles.

Rehabilitation Principles

Several principles exist that must be considered when designing a rehabilitation program following articular cartilage repair procedures. These key principles have been designed based on understanding the basic science and mechanics of articular cartilage.

Individualization

The quality of each individual's articular cartilage is the result of several factors, including age, body mass index, general health, nutrition, and history of previous injuries (**Table 1**). The composition of articular cartilage undergoes a gradual degeneration that results in a breakdown of tissue matrix and a reduction in the load-bearing capacity of the cartilage.⁶ The specific factors that contribute to this deterioration remain controversial, but it appears that age, obesity, poor nutrition, joint malalignment (such as a varus knee), history of injury (such as ligamentous or meniscal injury), and a history of repetitive impact loading (through

¹Champion Sports Medicine, American Sports Medicine Institute, Birmingham, Alabama, USA

²Boston Red Sox, Major League Baseball, Boston, Massachusetts, and Department of Orthopedic Surgery, Division of Sports Medicine, Massachusetts General Hospital, Boston, Massachusetts, USA

Corresponding Author:

Leonard Macrina, MSPT, SCS, CSCS, Champion Sports Medicine, American Sports Medicine Institute, 805 St. Vincent's Drive, Suite G100, Birmingham, AL 35205, USA
Email: lenmac08@yahoo.com

Table 1. Variables That Must Be Considered when Designing Postoperative Rehabilitation Protocols following Articular Cartilage Procedures

Lesion:	Location
	Size
	Depth
	Containment
	Quality of surrounding tissue
Patient:	Age
	Body mass index
	General health
	Nutrition
	Quality of articular cartilage
	Previous activity level
	Specific goals
Surgery:	Motivation level
	Repair procedure
	Tissue involvement
	Concomitant procedures

work or sport activities) may result in osteoarthritic changes.⁶ Thus, younger patients with isolated defects and relatively healthy surrounding articular cartilage oftentimes are able to progress their rehabilitation more rapidly than older individuals with more degenerative changes and less dense cartilage structure. Furthermore, the patient's motivation and previous activity levels must be considered when determining the rehabilitation approach to ensure that the goals of each patient are addressed. The rehabilitation program should be individualized to the specific demands of each patient's activities of daily living, work, and/or sport activities.

There are also several variables to consider with regard to the lesion that may have a dramatic effect on the rehabilitation process. Most importantly is the exact location of the lesion. Rehabilitation of lesions on a weightbearing surface of a femoral condyle must attempt to avoid deleterious compressive forces and require a different approach than for lesions located within the trochlea or retrosurface of the patella, where excessive shear forces should be minimized. The size, depth, and containment of each lesion must also be considered. Lesions that are large, deep, or have poor containment with healthy surrounding articular cartilage may require a slower rehabilitation progression than smaller, shallower, or well-contained lesions.

Finally, any concomitant procedures to address alignment, stability, or meniscal function may also alter the rehabilitation program because of the need to protect other healing tissues.

Create a Healing Environment

The next principle of articular cartilage rehabilitation involves creating an environment that facilitates the healing

process while avoiding potentially deleterious forces to the repair site. Through animal studies, as well as closely monitoring the maturation of repair tissue in human patients via arthroscopic examination, the biological phases of maturation have been identified following several articular cartilage repair procedures.⁷⁻¹² Knowledge of the healing and maturation process following these procedures will ensure that the repair tissue is gradually loaded and that excessive forces are not introduced too early in the healing process.

Two of the most important aspects of rehabilitation of articular cartilage procedures are weightbearing restrictions and range-of-motion (ROM) limitations. Unloading and immobilization have been shown to be deleterious to healing articular cartilage, resulting in proteoglycan loss and gradual weakening.¹³⁻¹⁶ Therefore, controlled weightbearing and ROM are essential to facilitate healing and prevent degeneration. This gradual progression has been shown to stimulate matrix production and improve the tissue's mechanical properties.^{1,5,17}

Controlled compression and decompression forces observed during weightbearing may nourish the articular cartilage and provide the necessary signals to the repair tissue to produce a matrix that will match the environmental forces.^{13,15,16} A progression of partial weightbearing with crutches is used to gradually increase the amount of load applied to the weightbearing surfaces of the joint. The use of a pool or aquatic therapy may also be beneficial to initiate gait training and lower extremity weightbearing exercises. The buoyancy of the water decreases the amount of weightbearing forces to approximately 25% of the individual's body weight when submerged to the level of the axilla and 50% of the individual's body weight when submerged to the level of the waist.¹⁸

A force platform is another useful tool during the early phases of rehabilitation when weightbearing is limited. This can be used to monitor the percentage of weightbearing on each extremity during exercises such as weight shifts, mini squats, and leg press (**Fig. 1**).

The pool and force platforms may be used during early phases of rehabilitation to perform limited weightbearing activities designed to facilitate a normal gait pattern and enhance strength, proprioception, and balance. The authors believe that beginning controlled weightbearing activities during the early protective stage of healing is a critical component to the overall rehabilitation process. Although the return to functional activities will differ for each patient, it is our opinion that early initiation of controlled exercise enables the individual to return to functional activities sooner than those who are immobilized and non-weightbearing.

Passive range of motion (PROM) activities, such as continuous passive motion (CPM) machines or manual PROM performed by a rehabilitation specialist, are also performed immediately after surgery in a limited ROM to



Figure 1. Initial weightbearing exercises such as a weight shift can be performed on a force platform that can measure the amount of weight distribution between each extremity.

nourish the healing articular cartilage and prevent the formation of adhesions.¹⁹⁻²⁶ Motion exercises may assist in creating a smooth low frictional surface by sliding within the joint's articular surface and may be an essential component to cartilage repair.^{19,20} It is the authors' opinion that PROM is a safe and effective exercise to perform immediately postoperatively, with minimal disadvantageous shear or compressive forces, if performed with patient relaxation. This ensures that muscular contraction does not create deleterious compressive pressures or shearing forces.

The use of CPM has been shown to enhance cartilage healing and long-term outcomes following articular cartilage procedures.¹⁹⁻²⁶ Comparing the outcomes of patients following microfracture procedures, Rodrigo et al.²⁷ reported an 85% satisfactory outcome in patients using a CPM machine for 6 to 8 h per day for 8 wk as compared with a 55% satisfactory outcome in those patients who did not use a CPM machine. PROM can also be performed on a bike with adjustable pedals that can alter the available ROM (Unicam Corporation; Fig. 2).

Biomechanics of the Knee

Knowledge of the biomechanics of the tibiofemoral and patellofemoral joints is essential to appropriately design



Figure 2. Bicycle riding on a Unicam machine (Unicam Corporation, Ramsey, NJ) that can adjust the pedal axis to alter the range of motion performed.

rehabilitation programs following articular cartilage repair procedures to ensure that exercises are selected and performed in a manner that does not cause deleterious forces to the repair site.

Articulation between the femoral condyle and tibial plateau is constant throughout knee ROM. Near full knee extension, the anterior surface of each femoral condyle is in articulation with the middle aspect of the tibial plateau. With weightbearing, as the knee moves into greater flexion, the femoral condyles progressively roll posteriorly and slide anteriorly, causing the articulation to shift posteriorly on the femoral condyles and tibial plateaus.^{28,29}

The articulation between the inferior margin of the patella and the trochlea begins at approximately 10° to 20° of knee flexion, depending on the size of the patella and the length of the patellar tendon.²⁹ With knee flexion, the

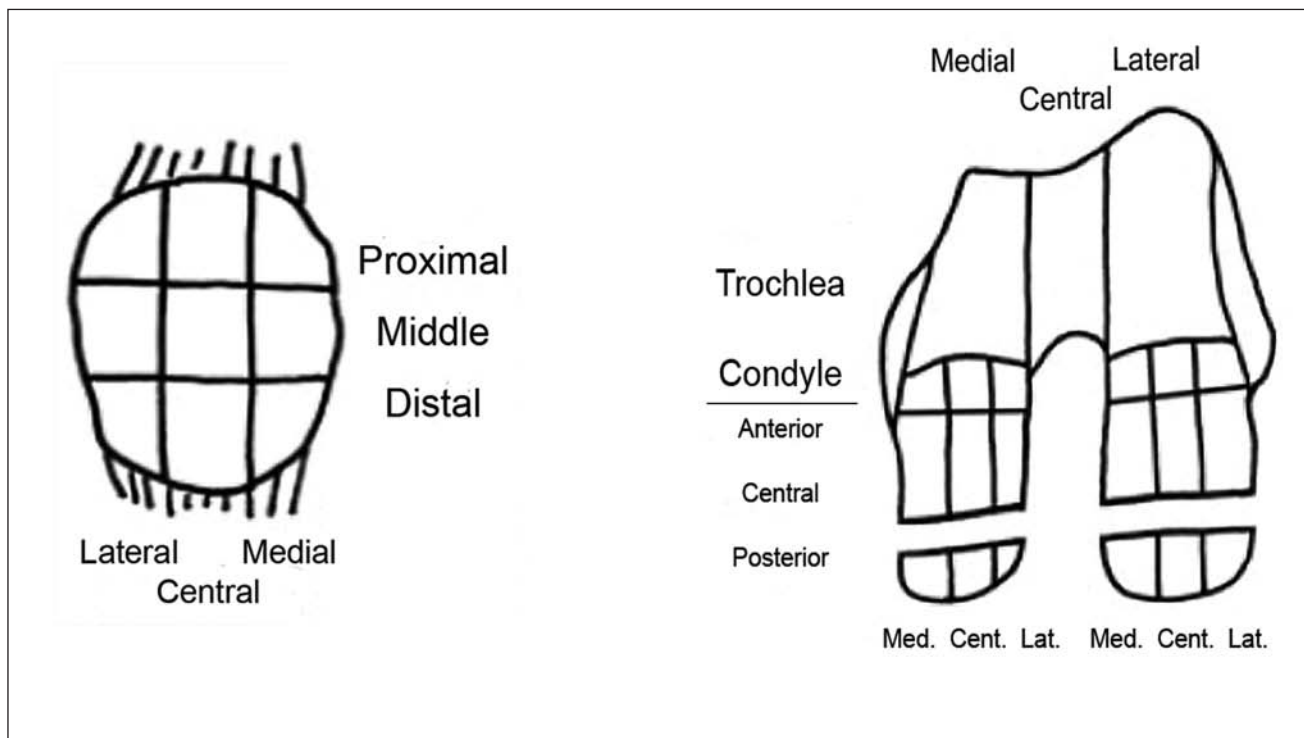


Figure 3. The lesion location diagram from the International Knee Documentation Committee can be used to document the location of articular cartilage lesions on the patella, trochlea, and femoral condyles. (Reprinted with permission from the International Knee Documentation Committee.)

contact area of the patellofemoral moves proximally. At 30° the area of patellofemoral contact (inferior facets) is approximately 2.0 cm².³⁰ The area of contact gradually increases as the knee is flexed. At 60° of knee flexion, the middle facet of the patella articulates with the trochlea. At 90° of knee flexion, the contact area increases up to 6.0 cm², and the superior facets are in contact with the femoral condyles.³⁰

Using this knowledge of joint arthrokinematics, the rate of weightbearing, PROM, and exercise progression may be based on the exact location of the lesion (**Fig. 3**).³¹⁻³⁴ For example, lesions on the posterior condyle may require the avoidance of exercise in deep knee flexion due to the rolling and sliding component of the articulation during deeper knee flexion. Furthermore, the rehabilitation program for lesions on the trochlea may include immediate partial weightbearing with a brace locked in full knee extension because the patella is not in contact with the trochlea in this position.

Rehabilitation exercises are also altered based on the biomechanics of the knee to avoid excessive compressive or shearing forces. Although the exact ROM at which articulation of the lesion occurs is the most important factor to consider when designing the rehabilitation program, the amount

of compressive and shear forces observed at the joint also vary throughout the ROM. Exercises, such as seated knee extension, are commonly performed from 90° to 40° of knee flexion. This ROM provides the lowest amount of patellofemoral joint reaction forces while exhibiting the greatest amount of patellofemoral contact area.^{30,35,36} Weightbearing exercises such as the leg press, vertical squats, lateral step-ups, and wall squats are performed initially from 0° to 30°, where tibiofemoral and patellofemoral joint reaction forces are lower.^{30,35,36} Clinically, we begin these exercises using a leg press machine, rather than the vertical mini-squat, because of the better ability to control the amount of weight applied to the lower extremities. As the repair site heals and patient symptoms subside, the ROMs in which exercises are performed are progressed to allow greater muscle strengthening over a greater ROM. Exercises are progressed based on the patient's subjective reports of symptoms (pain, clicking, etc.) and the clinical assessment of increased swelling and crepitation.

Reduction of Pain and Effusion

Patients often exhibit pain and effusion following the microfracture procedure. Numerous authors have reported



Figure 4. Cryotherapy and intermittent compression applied through a commercial cold device (Gameready; Coolsystems Corporation, Berkeley, CA) with elevation and high-voltage electrical stimulation (300 PV; Empi Corporation, St. Paul, MN) for swelling control.

a progressive decrease in volitional quadriceps activity as the knee exhibits increased pain and distention.³⁷⁻⁴⁰ Therefore, reduction in knee joint pain and swelling is crucial to minimize this reflex inhibition and restore normal quadriceps activity. Furthermore, any increase in intra-articular joint temperature has been shown to stimulate proteolytic enzyme activity, which has a detrimental effect on articular cartilage.^{33,41}

Treatment options for swelling reduction include cryotherapy, elevation, high-voltage stimulation, and joint compression through the use of a knee sleeve or compression wrap (**Fig. 4**). Patients presenting with chronic joint effusion may also benefit from a knee sleeve or compression wrap to apply constant pressure while performing everyday activities.

Pain can be reduced through the use of cryotherapy, transcutaneous electrical nerve stimulation, and analgesic medication. Immediately following injury or surgery, the use of a commercial cold wrap can be extremely beneficial. PROM may also provide neuromodulation of pain during acute or exacerbated conditions.²⁴

Restore Soft-Tissue Balance

One of the most important aspects of articular cartilage rehabilitation involves the avoidance of arthrofibrosis. This is achieved through the restoration of full passive knee extension, patellar mobility, and soft-tissue flexibility of the knee and entire lower extremity. The inability to fully

extend the knee results in abnormal joint arthrokinematics and subsequent increases in patellofemoral and tibiofemoral joint contact pressure, increased strain on the quadriceps muscle, and muscular fatigue.⁴² Therefore, a drop-lock postoperative knee brace locked into 0° of extension is used during ambulation, and PROM out of the brace is performed immediately following surgery.

The goal is to achieve at least 0° of knee extension within the first few days following surgery. Specific exercises to be performed include manual PROM exercises applied by the rehabilitation specialist, supine hamstring stretches with a wedge under the heel, and gastrocnemius stretching with a towel. Overpressure of 2.7 to 5.4 kg (6 to 12 lb) may be used for a low-load, long-duration stretch as needed to achieve full extension (**Fig. 5**). Modalities such as moist heat and ultrasound may also be applied to facilitate greater ROM improvements before and/or during these stretching techniques.^{43,44}

The loss of patellar mobility following surgery may be due to various reasons including excessive scar tissue adhesions from the incision anteriorly, as well as along the medial and lateral aspects of the knee. The loss of patellar mobility may result in ROM complications and difficulty recruiting quadriceps contraction. Patellar mobilizations in the medial-lateral and superior-inferior directions are performed by the rehabilitation specialist and independently by the patient during the home exercise program.

Soft-tissue flexibility and pliability are also important for the entire lower extremity. Soft-tissue mobilization and

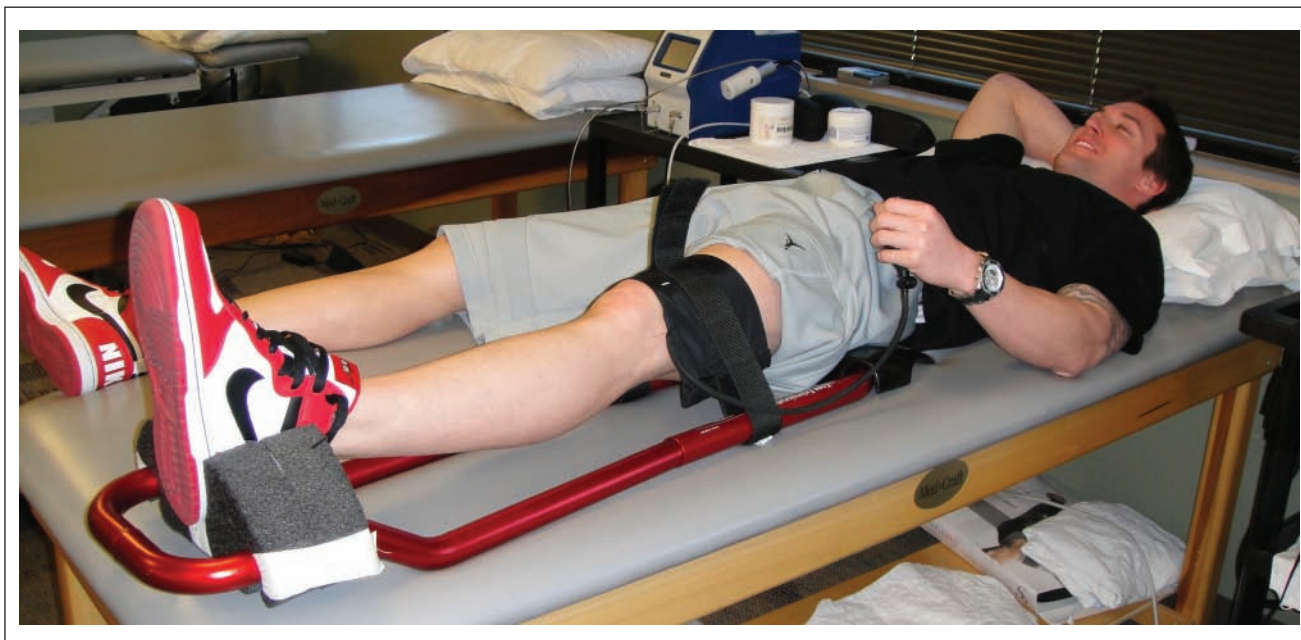


Figure 5. A low-load, long-duration stretch used to restore the patient's full passive knee extension. A 10-lb weight is used for 10 to 12 min, while a bolster is placed under the ankle to create a stretch. This commercial device (Extensionator; End Range of Motion Improvement [ERMI], Atlanta, GA) is used to improve extension range of motion and prevent compensatory hip external rotation.

scar management are performed to prevent the development of adhesions around the anterior, medial, and lateral aspects of the knee. In addition, flexibility exercises are performed for the entire lower extremity, including the hamstrings, hip, and calf musculature. As ROM improves and the lesion begins to heal, quadriceps stretching may also be performed as tolerated by the patient.

Restoring Muscle Function

Because of the inhibition of the quadriceps muscle secondary to pain and effusion, electrical muscle stimulation and biofeedback are often incorporated with therapeutic exercises to facilitate the active contraction of the quadriceps musculature in the acute stage of rehabilitation. The use of electrical stimulation and biofeedback appears to facilitate the return of muscle activation.^{45,46} Clinically, we use electrical stimulation immediately following surgery while performing isometric and isotonic exercises such as quadriceps sets, straight leg raises, hip adduction and abduction, and knee extensions (**Fig. 6**). Electrical stimulation is used when the patient presents acutely with the inability to activate the quadriceps in an attempt to recruit a maximum amount of muscle fibers during active contraction and may also be used throughout the rehabilitation process. Once independent muscle activation is present, biofeedback may be used to facilitate further neuromuscular activation of the quadriceps.

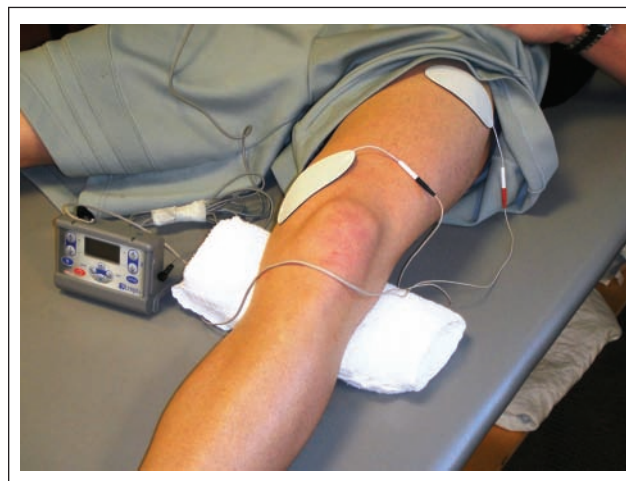


Figure 6. Neuromuscular electrical stimulation (300 PV; Empi Corporation, St. Paul, MN) applied to the quadriceps muscle during exercises such as knee extension.

Exercises that strengthen the entire lower extremity, such as machine weights and weightbearing exercises, may be included as the patient progresses to more advanced phases of rehabilitation. It is important not to concentrate solely on the quadriceps. Furthermore, the importance of incorporating core stability exercises cannot be overlooked. Training of the trunk, hip, and ankle musculature is

emphasized to assist in controlling the production and dissipation of forces in the knee.

Enhance Proprioception and Neuromuscular Control

Proprioceptive and neuromuscular control drills of the lower extremities should be included to restore dynamic stabilization of the knee joint postoperatively. Proprioceptive deficits have been noted in the injured and postoperative knee.^{47,48} Specific drills initially include weight shifting side to side, weight shifting diagonally, mini-squats, and mini-squats on an unstable surface such as a tilt or balance board (Fig. 7). Perturbations can be added to challenge the neuromuscular system, as can additional exercises including lunges, step-ups, and balance onto unstable surfaces (Figs. 8 and 9).

Controlling the Application of Loads

The next principle of rehabilitation involves gradually increasing the amount of stress applied to the injured knee as the patient returns to functional activities. This progression is used to provide a healthy stimulus for healing cartilage tissues while ensuring that forces are gradually applied without causing damage. Common clinical signs that a patient may be progressing too quickly and overloading the healing tissue are joint line pain and effusion. This should be monitored throughout the rehabilitation process.

In addition, patients may benefit from the use of orthotics, insoles, and bracing to alter the applied loads on the articular cartilage during functional activities. These devices are used to avoid excessive forces by unloading the area of the knee where the lesion is located. Unloading braces are often used for patients with subtle uncorrected abnormal alignments (such as genu varum), patients with large or uncontained lesions, as well as in the presence of concomitant osteotomies and meniscal allografts (Fig. 10).

Team Communication

Communication between the surgeon and therapist is essential to determine the accurate rate of progression based on the location of the lesion, size of the lesion, tissue quality of the patient, and the addition of concomitant surgical procedures. Also, communication between the medical team and patient is essential to provide the patient with education regarding the avoidance of deleterious forces as well as improving the patient's compliance with precautions. Oftentimes, a preoperative physical therapy evaluation may be useful to mentally and physically prepare the patient for the articular cartilage procedure and postoperative rehabilitation.



Figure 7. Mini-squats on an unstable surface such as a tilt board. The patient is instructed to squat while preventing movement of the board.

Rehabilitation following Microfracture Procedure

Microfracture

The microfracture procedure is a form of marrow stimulation, similar in concept to the chondroplasty procedure.⁴⁹⁻⁵¹ A sharp awl is used arthroscopically through one of the portals, and a mallet is used to impact the awl into the subchondral bone and thus generate bleeding from the bone. This procedure is also referred to as “picking” because of its nature. Holes are created at regular intervals



Figure 8. Lateral step-up exercises performed while standing on an unstable surface such as a piece of foam. This exercise requires eccentric control of the lower extremity to perform the step-up exercise as well as to balance throughout the movement.

until the entire defect has been addressed. The penetration of the subchondral bone eventually creates fibrocartilagenous tissue that covers the cartilage lesion.⁴⁹⁻⁵¹

The rehabilitation progression is designed based on the 4 biological phases of cartilage maturation: proliferation, transitional, remodeling, and maturation.^{7,8,10-12,41,52-54} The duration of each phase will vary depending on the lesion, patient, and the specifics of the surgery discussed previously; however, the concepts of each phase are consistent. The following is an overview of the general rehabilitation process during each of the 4 phases.



Figure 9. Single-leg balance on an unstable surface such as foam. The patient may use a weighted ball while performing reciprocal movement patterns with the uninvolved upper and lower extremities to alter the patient's center of gravity throughout the exercise.

Phase 1: Proliferation Phase

The 1st phase of cartilage healing requires protection of the repair and typically involves the first 4 to 6 wk following surgery.^{7,8,10-12,41,52-54} During this phase, the initial healing process begins, and it is imperative to decrease swelling, gradually restore PROM and weightbearing, and enhance volitional control of the quadriceps.

Gradual PROM and controlled partial weightbearing will help to nurture the cartilage through diffusion of synovial fluid as well as provide the proper stimulus for the cells



Figure 10. An osteoarthritis unloading brace (OA Defiance, Don Joy Corporation, Vista, CA) using a 4-point leverage system to unload the medial compartment of the knee by providing a mild valgus stress to the knee.

to produce specific matrix markers.^{1,5,13,14,16,17} Individuals begin with partial weightbearing activities using crutches, and progressive loading exercises are used to gradually increase the amount of load applied to the weightbearing surfaces of the joint. The use of a pool or aquatic therapy may be beneficial for gait training and lower extremity exercises once the incisions are well healed.

PROM exercises, performed by a rehabilitation specialist or CPM machines, are also performed immediately after surgery to nourish the healing articular cartilage and prevent the formation of adhesions.^{19,20,24-27} The use of CPM typically begins 6 to 8 h following surgery and is performed for at least 2 to 3 wk, with recommended use up to 6 to 8 wk.^{27,55} A CPM should be used throughout the day for a total of 6 to 8 h.^{27,55} The patient is also instructed to perform active-assisted ROM frequently throughout the

day. Patellar mobilization, soft-tissue mobilization, and soft-tissue flexibility exercises are also performed to minimize scar tissue formation and avoid loss of motion.

Early strengthening exercises are performed to restore volitional quadriceps control and neuromuscular control, through the use of concomitant electrical stimulation.^{45,46} Exercises performed during this phase are limited based on the specific weightbearing status of each patient. These typically include quadriceps sets, straight leg raises, and basic proprioception exercises such as weight shifting.

Phase 2: Transition Phase

This phase typically consists of weeks 4 through 12 post-surgery.^{7,8,10-12,41,52-54} The repair tissue at this point is gaining strength, which will allow for the progression of rehabilitation exercises. During this phase, the patient progresses from partial to full weightbearing while full ROM and soft-tissue flexibility is achieved. Continued maturation of the repair tissue is fostered through higher level functional and motion exercises. It is during this phase that patients typically resume most normal activities of daily living. The rehabilitation program will gradually progress strengthening activities to include machine weights and weightbearing exercises, such as leg press, front lunges, wall slides, and lateral step-ups, as the patient's weightbearing status returns to normal.

The progression of weightbearing activities and ROM restoration involves the gradual advancement of activities to facilitate healing and avoid postsurgical complications. Common complications include motion restrictions and scar tissue formation. Furthermore, an overaggressive approach early within the rehabilitation program may result in increased pain, inflammation, or effusion, as well as graft damage. Progression is controlled for strengthening exercises, proprioception training, neuromuscular control drills, and functional drills. For example, exercises such as weight shifts and lunges are progressed from straight plane anterior-posterior or medial-lateral directions to involve multiplane and rotational movements. Exercises using 2 lower extremities, such as leg press and balance activities, are progressed to single lower extremity exercises. Thus, the progression through the postoperative rehabilitation program involves a gradual progression of applied and functional stresses to provide a healthy stimulus for healing tissues without causing damage.

Phase 3: Remodeling Phase

This phase generally takes place from 3 mo to 6 mo post-operatively.^{7,8,10-12,41,52-54} During this phase, there is a continuous remodeling of tissue into a more organized structure that is increasing in strength and durability.^{7,8,10-12,41,52-54} As



Figure 11. Progressive loading treadmill (Alter G Anti-Gravity Treadmill, Fremont, CA) in which the patient can progressively increase the body-weight percentage during walking and running activities.

the tissue becomes firmer and integrated, it allows for more functional training activities to be performed. At this point, the patient typically notes improvement of symptoms and has normal ROM. The patient is encouraged to continue with his or her rehabilitation program independently to maximize strength and flexibility. Low- to moderate-impact activities such as bicycle riding, golfing, and recreational walking may often be gradually incorporated (**Figure 11**).

Phase 4: Maturation Phase

The final phase begins in the range of 4 mo to 6 mo and can last up to 15 to 18 mo postsurgery.^{7,8,10-12,41,52-54} It is during this phase that the repair tissue reaches its full maturation. The duration of this phase varies based on several factors, such as lesion size and location and the specific surgical procedure performed. The patient will gradually return to full pre-morbid activities as tolerated. Impact loading activities are gradually introduced. A return to athletic activities is determined based on the unique presentation of each patient. A return to competitive athletics has been documented for microfracture, with good outcomes often expected.^{49-51,56-61}

Conclusion

The rehabilitation process following articular cartilage repair procedures is vital to the long-term success and functional

outcome of these patients. The rehabilitation programs discussed are based on our current understanding of articular cartilage and the natural healing response observed following articular cartilage repair procedures. Rehabilitation is based on several key principles used to facilitate the repair process by creating a healing environment while avoiding deleterious forces that may overload the healing tissue. It must also consider any concomitant surgery performed. The basic principles outlined in this article may be applied and integrated as our understanding and clinical use of this procedure improve.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interests with respect to the authorship and/or publication of this article.

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