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TECHNIQUE

Update on Articular Cartilage Restoration

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■ ABSTRACT

Articular cartilage does not heal when injured. There are many procedures that can be used to treat symptomatic articular cartilage defects. This article describes each surgical technique, the rehabilitation necessary after the procedure, and the recent clinical results.

■ INTRODUCTION

Physicians have known for over 250 years that articular cartilage damage is a "troublesome thing and once destroyed, it is not repaired."[1] Chondral lesions, once identified, have been shown to degenerate further within the knee.[2,3] Partial-thickness articular cartilage defects do not heal, but fortunately are only rarely associated with significant clinical problems.[4] Chondral lesions that penetrate to or through the subchondral bone may fill with fibrocartilage, but the biomechanical and biochemical features are inferior to hyaline cartilage.[4–6] On one end of the spectrum, small, full-thickness cartilage lesions can fill in with fibrocartilage and may render a patient asymptomatic. On the other end, large osteochondral lesions are less likely to develop a clinically significant fibrocartilaginous healing response and more frequently result in pain and disability.[4,7]

The incidence of symptomatic high-grade chondral injuries is poorly defined. Curl et al.[8] reviewed 31,516 knee arthroscopies. They reported on the incidence of grade III lesions (41%) and grade IV lesions (19%). In patients younger than 40 years, the incidence of grade IV lesions was only 5%. Hjelle et al.[9] performed a prospective study consisting of 1000 patients and similarly found a 5% incidence of grade III and IV chondral defects. It must be understood that only a small percentage of these lesions were clinically symptomatic, requiring treatment.

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■ HISTORICAL PERSPECTIVE

The first arthroscopic treatment of chondral injuries was arthroscopic debridement. The first cartilage repair techniques involved penetration of the subchondral bone. This led to the formation of a fibrin clot with subsequent migration of pluripotential marrow stem cells into the clot,[10] with resultant formation of fibrocartilage. More recent techniques replace the damaged cartilage with autograft and allograft hyaline cartilage. The newest techniques employ biologic replacement, such as with autologous chondrocyte implantation.

Marrow Stimulation Techniques

In 1946, Magnusson[11] published an article on open debridement that stimulated several approaches for repair. In 1959, Pridie[12] was the first person to describe drilling of denuded areas of articular cartilage to stimulate reparative cartilage formation. Mitchell and Shepard[13] found that in rabbits, a repair tissue resulted from this procedure, but that it began to deteriorate at 1 year. Johnson[14] introduced arthroscopic abrasion arthroplasty in 1981 and was the first to describe using a motorized instrument to perform an abrasion arthroplasty. This was similar to the Pridie procedure, but a superficial layer of subchondral bone was removed ranging from 1 to 3 mm in thickness. Microfracture is another technique that involves penetrating the subchondral bone to expose the defect to pluripotential marrow stem cells. This technique uses arthroscopic picks instead of a drill, minimizing the chance for thermal necrosis.[15]

Marrow stimulation techniques (drilling, abrasion arthroplasty, microfracture) are effective due to the potential for primitive mesenchymal cells to differentiate and

produce fibrocartilage, a type of repair cartilage.[16,17] Fibrocartilage primarily consists of type I collagen with different biomechanical and structural properties than hyaline cartilage, which contains primarily type II collagen.[18,19] The extent and quality of fill are rarely more than 75% of the total volume of the chondral defect.[20]

Cartilage Replacement Techniques

Osteochondral Autograft. Osteochondral autografts survive with intact hyaline cartilage[21] and heal to the surrounding recipient tissue.[22] The key to this procedure is maintenance of chondrocyte viability. Only living chondrocytes can produce and maintain the extracellular matrix of proper load-bearing capacity.[21] In 1985,[23] the results of autogenous osteochondral grafts for osteochondritis dissecans were published. The first arthroscopic treatment using autografts was reported in 1993.[24] Many studies have been published since.[25–29]

Osteochondral Allograft. Fresh osteochondral allografts were first used to restore the articular surface in 1908 by Lexer.[30] He reported good function of the allograft after incorporation, with a 50% success rate.[31] In the 1940s and 1950s, it was thought that allografts could represent a biologic alternative to total joint arthroplasty in young patients with limited articular cartilage damage.[32] In the 1970s, several investigators reported moderate success with massive frozen and cryopreserved osteochondral allografts used for limb salvage after resection of bone tumors.[33,34] Due to increased graft availability, fresh osteochondral allografts are now used more frequently to treat isolated articular cartilage and osteoarticular defects. Fresh grafts are favored over frozen grafts because chondrocyte survival is diminished after freezing.[35] This is one of the few techniques of cartilage restoration that has long-term follow-up greater than 15 years.

Periosteal and Perichondral Grafting. In 1975,[36] an animal study demonstrated that perichondrium implanted into a cartilage defect in the knees of rabbits resulted in a healed cartilage lesion. When rabbit costal perichondrium was transplanted into full-thickness defects of sheep knees, the tissue that resulted was histologically similar to articular cartilage and was 74% type II collagen.[37] This led to subsequent studies evaluating periosteal transplantation in rabbits that resulted in chondroid tissue.[38] Biomechanical and biochemical studies indicate that the repair tissue closely resembles articular cartilage.[19,39] Only performed in a limited number of centers, this procedure works best in younger patients.[40]

Biologic Techniques

Autologous Chondrocyte Implantation. Autogenous chondrocyte implantation (ACI) involves culturing chondrocytes and transplanting them into the cartilage defect beneath a periosteal patch. Animal studies began in the 1980s and led to the clinical application of this procedure.[41,42] One animal study revealed hyaline-like cartilage after ACI.[43] ACI was first reported in humans by Brittberg et al.[44] in 1994 and has grown in popularity since then.

Classification

While many classification systems exist and are gaining popularity, the Outerbridge system[45] is most commonly used. Grade 0 is normal cartilage, grade I has articular cartilage softening, grade II has cartilage fibrillation involving half the depth of the articular surface, grade III has fissuring involving more than half the depth of the articular surface, and grade IV has full-thickness loss reaching to or through the subchondral bone.

■ INDICATIONS/CONTRAINDICATIONS

The patient evaluation is one of the most important factors in decision making. This consists of a history, a physical examination, radiographs, and a review of previous operative notes and arthroscopic pictures. One should begin with the patient history to determine the mechanism of injury. Most commonly, patients recall a macrotraumatic event.

The patient's specific symptoms are paramount. Some of the key factors leading to surgical treatment are persistent pain with weightbearing activities, intra-articular swelling, and the presence of mechanical symptoms. These procedures are not for osteoarthritis. The ideal lesion is a symptomatic, full-thickness, weightbearing chondral injury of the femoral articular surface in a physiologically young, active patient. Ideally, the reciprocal joint surface should have no more than grade I or II changes. The knee alignment should be anatomic, there should be no ligamentous laxity or patellofemoral malalignment (if the lesion involves the patella or trochlea), and there should be an intact meniscus. Patients unwilling to adhere to a strict rehabilitation protocol should not be considered candidates for an articular cartilage procedure.

Some generalizations exist regarding the indications for different procedures. Arthroscopic debridement can be used effectively to remove debris, cytokines, and proteases that may contribute to cartilage breakdown. It is a first-line treatment that is frequently employed, or it may be the definitive treatment in the low-demand patient or a patient that does not want to have long rehabilitation with altered weightbearing status. Marrow stimulating techniques are used in low-demand patients with larger lesions or as a first-line treatment in higher-demand patients with smaller lesions. Generally, the marrow-stimulating techniques are recommended for lesions less

than 2 to 3 cm^2.[46] Osteochondral autografts are used as a first-line or second-line treatment for smaller lesions and can be performed arthroscopically or open. Osteochondral allografts are used as a first-line treatment in older patients with large lesions and as a second-line treatment in younger patients. ACI can be used for small and large lesions as a primary or secondary procedure.

■ PREOPERATIVE PLANNING

Preoperative planning is key to the success of cartilage procedures. This includes assessing limb alignment, assessing knee ligament stability, evaluating for degenerative joint disease, and knowing the status of the menisci.

Imaging

Radiographs should include AP, lateral, Merchant, and 45-degree flexion PA weightbearing films.[47,48] Limb alignment is assessed with full leg length films. This series of films will show joint space narrowing, osteophytes, cyst formation, and subchondral sclerosis, which are all consistent with osteoarthritis and, when present, are generally considered contraindications for these procedures. An MRI is valuable to assess the status of the knee ligaments and menisci if it is unknown. The MRI generally tends to underestimate the degree of cartilage abnormalities seen at the time of arthroscopy, and there is no uniform consensus regarding the optimal pulse sequence for cartilage imaging.[49] Fat-suppressed imaging is more sensitive than standard MRI for the detection of abnormalities of the hyaline cartilage in the knee.[50] More recently, specialized fast-spin-echo MRI sequences with a high-resolution matrix allowed for an accurate assessment of articular cartilage in the knee with little interobserver variability.[51]

The role of bone scan is still being defined. Joint overload can initiate the increased osseous metabolic activity of bone that is detectable by scintigraphic methods.[52,53] We occasionally use scintigraphy in difficult cases in which the source and clinical importance of periarticular symptoms remain in doubt. In instances where the pain is out of proportion to the clinical presentation, a bone scan can confirm the existence of increased osseous metabolic activity (which is not shown by other imaging modalities) that could be consistent with subchondral activity in the region of a chondral or osteochondral defect.[54]

■ TECHNIQUE

Marrow-Stimulating Techniques

Pridie/Abrasion Arthroplasty. Abrasion arthroplasty is performed arthroscopically with a shaver or burr and removes 1 to 2 mm of exposed sclerotic bone down to the vasculature of the subchondral plate.[14] This results in a fibrin clot that later develops into fibrocartilage (Fig. 1).

Microfracture. Microfracture involves using a small pick to penetrate the subchondral bone, but still leaves the majority of the subchondral architecture intact. The first step in this procedure involves creating a well shouldered lesion that will allow the formation of fibrocartilage. All unstable cartilage should be removed. Animal studies suggest that removing the calcified cartilage with a curette greatly enhances the percentage of defect fill.[55] A surgical awl is then used to create holes placed 2 to 3 mm apart, beginning at the periphery of the lesion (Fig. 2). The holes should not be confluent. When fat droplets can be seen coming from the marrow cavity, the approximate depth (2–4 mm) has been reached.[56] Once the procedure is completed, the tourniquet (if inflated) should be released and the pump pressure turned down, and one should see blood and marrow fat droplets coming from each hole (Fig. 3). The postoperative rehabilitation program is paramount to the success of this procedure.

Cartilage Replacement Techniques

Osteochondral Autograft Transplantation. Osteochondral autograft transplantation involves transplantation of an osteochondral graft from one region of a joint to another in an effort to restore the damaged articular surface. It is limited by the amount of donor tissue available in the knee. If this technique is considered, it is generally recommended that the lesions are less than 2 cm in diameter.[26] The risk of donor site morbidity increases as more tissue is harvested. The typical sites of

FIG. 1. Femoral condyle lesion after abrasion arthroplasty.

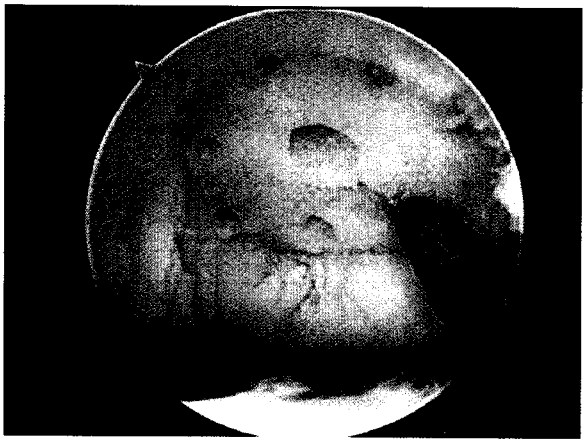

FIG. 2. Arthroscopic pick is used on a focal lesion on the femoral condyle to penetrate the subchondral plate. The holes are 2 to 3 mm apart.

harvest are the femoral intercondylar notch and the periphery of the lateral femur at the patellofemoral joint. Simonian et al.[57] evaluated these two typical sites of harvest and found that they demonstrated significant contact pressure, although the clinical relevance is unknown.

The procedure can be done through a small arthrotomy or arthroscopically. There are several commercial systems available to perform this procedure. We presently use the Osteochondral Autograft Transfer System (OATS; Arthrex, Naples, FL) (Fig. 4). A sizer is used to determine the number and size of grafts that will be needed. The properly sized graft harvester with collared pin is introduced perpendicular to the donor site. It is lightly tapped to a length of approximately 12 to 15 mm. For removal, the harvester is twisted abruptly 90 degrees clockwise, and 90 degrees counterclockwise with an axial load to remove the donor plug. The harvester has a plunger that will push the donor plug into the recipient hole.

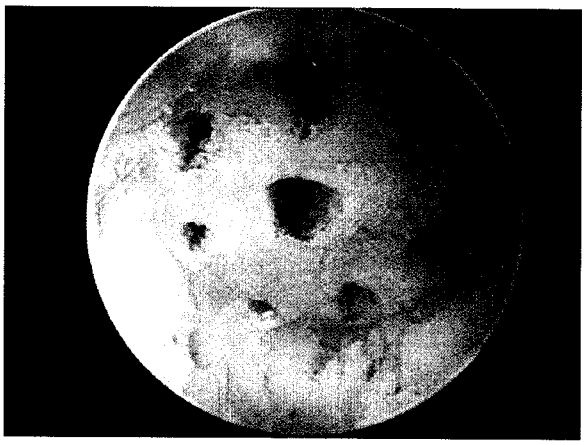

FIG. 3. Microfracture of a femoral condyle after the tourniquet has been released, with blood flowing from the penetration of the subchondral bone.

The recipient tube harvester is then driven into the defect to a depth of 2 mm less than the donor graft just harvested and extracted in the same manner as the donor core. Maintaining a perpendicular relationship with the articular surface ensures a flush transfer. A calibrated alignment stick of the diameter of the harvest is used to measure the depth of the recipient socket. The donor tube harvester is then placed over the recipient site (there is a beveled edge to help seat it) perpendicular and in the exact same orientation it was harvested and advanced atraumatically into the defect. The final seating of the plug can be done with an oversized tamp. The plug should be just flush with the surrounding articular cartilage (Fig. 5). It is important during each stage of harvest and implantation to maintain a constant knee flexion angle. If performing several core transfers, each should be completed prior to proceeding with further recipient socket creation. This prevents potential recipient tunnel wall fracture and allows subsequent cores to be placed directly adjacent to previously inserted bone cores.

Osteochondral Allograft Transplantation. In many cases, a medial or lateral peripatellar miniarthrotomy can be used to expose the lesion. The lesion is assessed to determine the graft shape that would best fit the defect (Fig. 6). When possible, an instrumentation system (Arthrex) is used to create and harvest a circular graft. Because of the close tolerance between the donor plug and recipient socket that results from this technique, one can press-fit the graft, eliminating the need for supplemental internal fixation. If the lesion is not amenable to a circular graft, a shell graft can be fashioned freehand, typically in a trapezoidal configuration that matches a hand-prepared defect bed using a motorized burr and oscillating saw with cold irrigation. Freehand sizing of a graft is more time-consuming and often requires fixation, as the fit is less precise.

The diameter of the defect is matched to the sizing cylinder (range, 12–35 mm) that best incorporates the majority of the defect. With the sizing cylinder held centered and perpendicular to the defect, a guide pin is drilled in the center of the lesion to a depth of 2 to 3 cm. While irrigating with normal saline, the cannulated counter bore is drilled over the pin to create a cylindrical defect to a depth of 8 to 10 mm (Fig. 7). Bone depth is intentionally minimized, as the subchondral bone is known to be the most immunologic component of the composite graft. A sterile marking pen is used to mark the 12 o'clock position of the lesion to orient the donor plug appropriately, and the depth of the recipient lesion

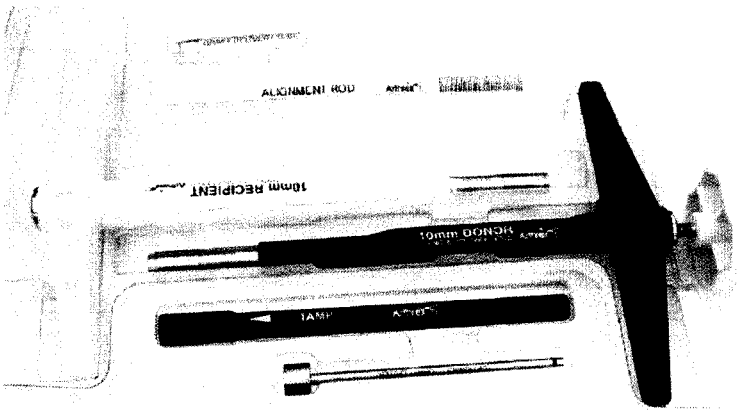

FIG. 4. Instrument set used to perform an osteochondral autograft.

is measured in four quadrants to determine the exact depth of the final cut of the donor plug (Fig. 8).

If an entire hemicondyle is made available, it is first sectioned to create a flat surface perpendicular to the proposed harvest site. The allograft is secured in the allograft workstation. The bushing is secured such that the donor site matches the location and angle of the recipient site as viewed from the side of the workstation, using the sizing cylinder for orientation. While matching the location of the defect on the donor condyle is preferred, defects smaller than 2 cm^2 are easily matched from most regions of the hemicondyle. The 12 o'clock position of the donor graft is marked. While irrigating with normal saline, the donor graft is then drilled through its entire depth with a harvester, and the graft is extracted (Fig. 9). A ruler is used to measure and mark the graft to match the graft depth to the four quadrants measured previously at the recipient site. Holding forceps are used to secure the allograft while it is irrigated and cut using an oscillating saw. To facilitate insertion, the edge of the allograft is slightly beveled with a rongeur (Fig. 10). Prior to insertion, the graft is pulsatile lavaged to remove blood and bone marrow elements to reduce the chance of disease transmission and graft immunogenicity.[58]

A calibrated dilator is inserted in the recipient socket to dilate the socket an additional 0.5 mm. The graft is press-fit into the socket by hand after carefully aligning the four quadrants to the recipient site (Figs. 11, 12). Further impaction is achieved by gently tapping the graft with an oversized tamp and mallet. If the graft is particularly large, fixation can be achieved with bioabsorbable pins or metal screws. When necessary, we prefer a headless screw (Acumed, Beaverton, OR), which provides excellent compression but may need to be removed at a later date if not properly recessed.

Perichondral/Periosteal Grafting. Perichondral grafting involves suturing rib perichondrium over the full-thickness chondral defect. Chondroprogenitor cells from the perichondrial germinative layer in the periosteum are introduced to the defect to provide a repair of the lesion.[59–61] Clinically, this technique is rarely used today.

For the periosteal technique, the chondral lesion is excised, sclerotic subchondral bone is removed, and multiple drillings through the remaining subchondral bone in the cancellous bone are performed. The periosteum is taken from the proximal tibia with a thin layer of bone and is anchored to the underlying bed with the cambium layer facing the bone. Sutures are placed in the patch;

FIG. 5. Osteochondral autograft with two plugs in place flush with the femoral condyle.

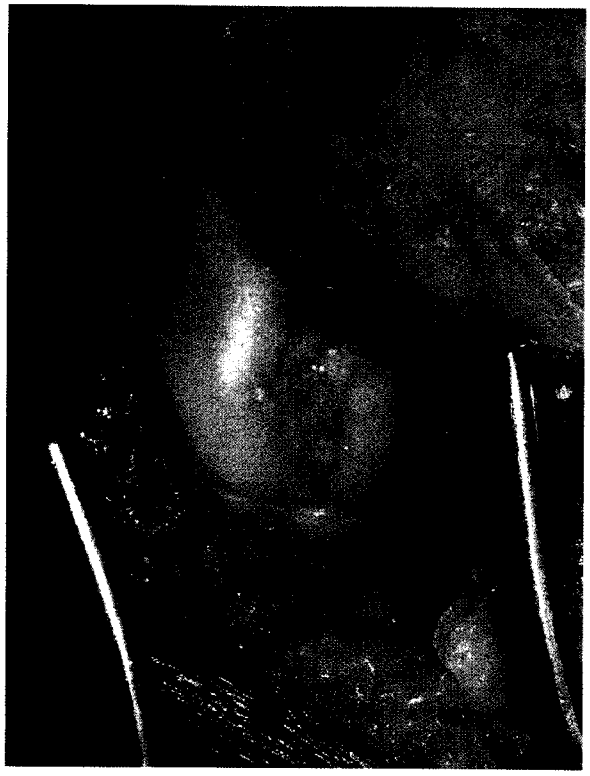

FIG. 6. Femoral condyle lesion.

prior to securing them, fibrin glue is placed between the graft and the subchondral bone.[62]

Biologic Techniques

Autologous Chondrocyte Implantation. Autologous chondrocyte implantation can be used for lesions measuring roughly 2 to 10 cm^2. This is a two-stage procedure. A biopsy must be taken first from either the superomedial edge of the trochlea[63] or the authors' preferred site, the lateral side of the intercondylar notch (the same location where an ACL notchplasty is performed). The biopsy is sent to Genzyme Biosurgery Corp. (Cambridge, MA) for processing. The biopsy can be maintained for 18 months until it is processed. It undergoes cellular expansion, and after 3 to 5 weeks, it is ready for implantation. The exposure is dependent on defect location. Patellofemoral lesions are approached through a midline incision, allowing concomitant distal realignment procedures to be performed routinely. Femoral condyle lesions are addressed through limited ipsilateral parapatellar arthrotomies (Fig. 13).

Defect preparation involves removing the remnant cartilage and leaving the healthy hyaline cartilage to form vertical walls shouldering the lesion. A #15 scalpel and sharp ring curettes are used to incise the defect border to the subchondral bone (Fig. 13). Penetration through the subchondral bone results in bleeding, which

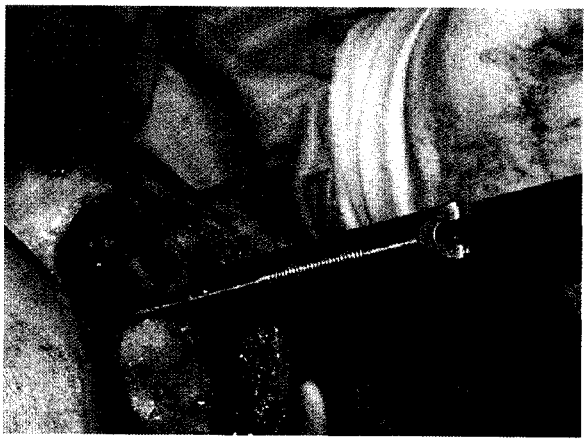

FIG. 8. Measuring the depth of the recipient lesion.

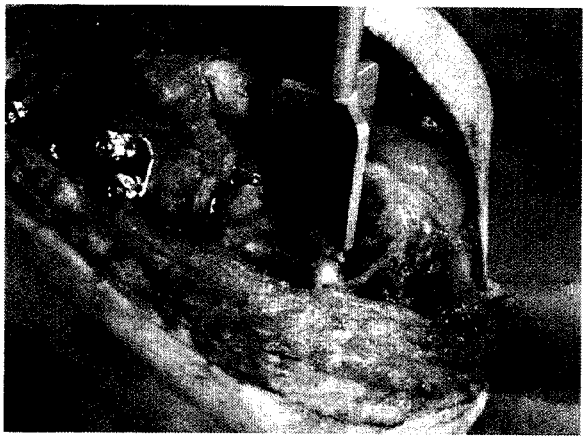

FIG. 7. A counter bore is used to prepare the base of the recipient socket.

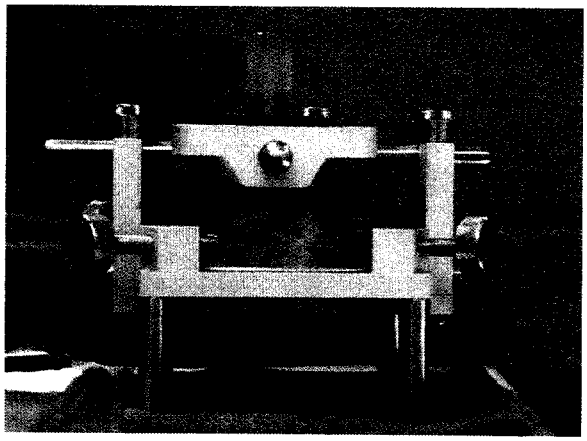

FIG. 9. Femoral hemicondyle is in the work station with the graft harvester about to ream donor condyle.

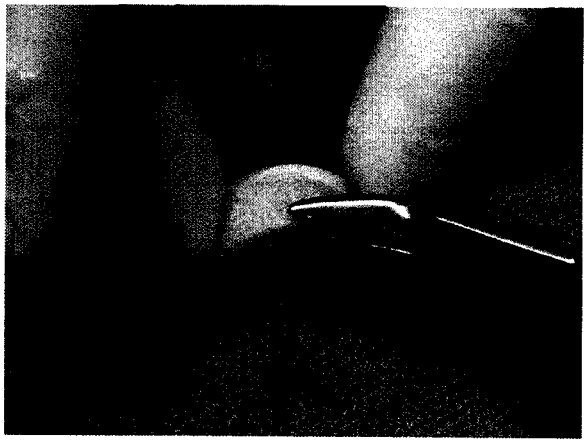

FIG. 10. Rongeur used to round the edges of the donor graft slightly.

is toxic to the implanted chondrocytes. When the defect is peripheral, it may be better to leave a thin wall of mildly injured cartilage at the edge of the lesion to maintain a contained lesion. Hemostasis is controlled with the use of neuro-patties soaked with a dilute 1:1000 epinephrine and sterile saline solution.

The periosteal patch is harvested through a 3-cm incision on the subcutaneous border of the proximal tibia, two fingerbreadths distal to the pes anserine tendon attachments. The outer surface is marked to distinguish it from the inner cambium layer. A patch is then harvested that should be 2 mm larger than the size of the defect, as

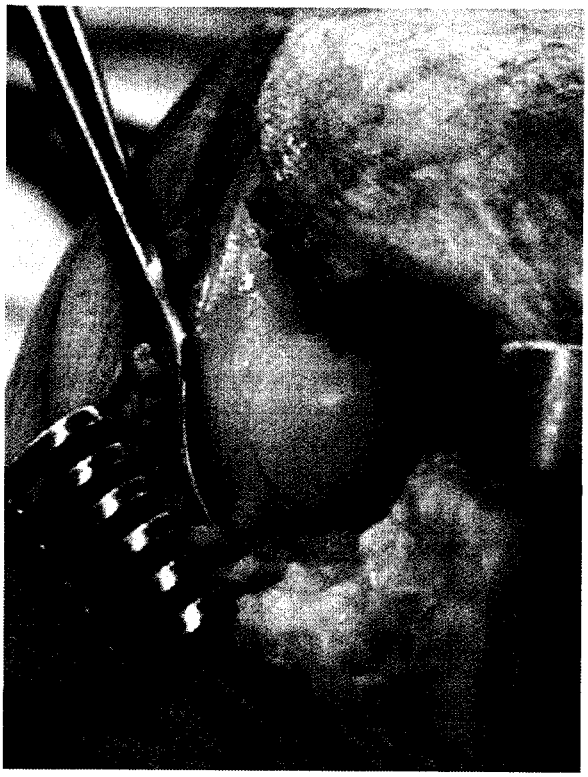

FIG. 12. Implanting the allograft and lining up the marks at the 12 o'clock position.

FIG. 11. Placing the allograft by hand. Reproduced with permission of Arthrex.

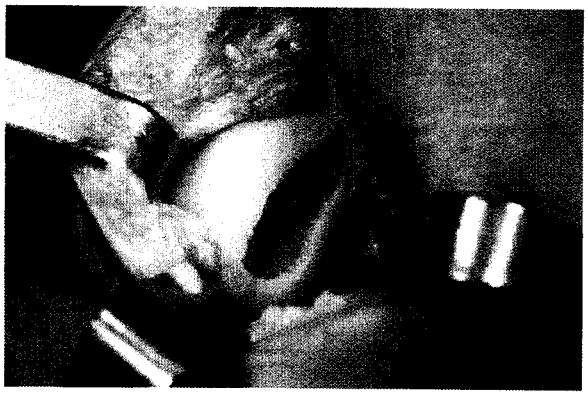

FIG. 13. Prepared medial femoral condyle lesion (patient is concurrently receiving a medial meniscus transplant).

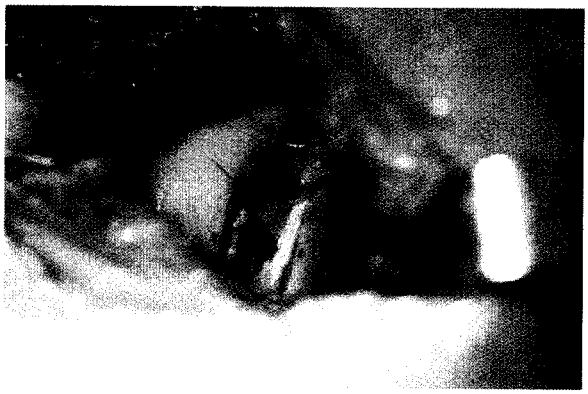

FIG. 15. Sewing the periosteal patch in place.

the patch will shrink some after harvest. The patch's edges are scored to bone with a #15 scalpel and elevated with a sharp periosteal elevator beginning distally (Fig. 14).

Hemostasis is obtained within the defect following tourniquet deflation. The patch is now sewn onto the cartilage with the cambium layer facing the defect. The periosteum is secured with a 6-0 absorbable Vicryl suture (Ethicon, Sommerville, NJ) on a P-1 cutting needle (Fig. 15). The suture should be coated in sterile glycerin or mineral oil to facilitate smooth passage through the periosteum and cartilage to prevent tearing of either tissue. The suture is passed through the patch first and then through the cartilage. The needle should enter the cartilage perpendicular to the inside wall of the defect at a depth of 2 mm below the articular surface and exit the articular surface 3 to 4 mm from the edge of the defect. First, secure the four corners of the defect, and then fill in the gaps with sutures every 3 mm, leaving one 4-mm to 6-mm area free to insert the cells. The patch should be tight over the defect, with a space below to insert the cells.

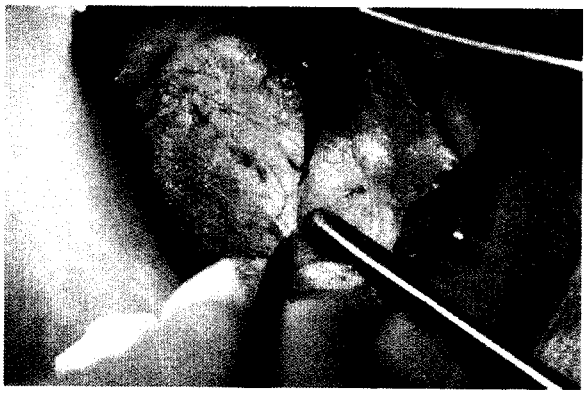

FIG. 14. Harvesting the periosteum with two fine forceps and an elevator.

Watertightness testing is performed with a saline-filled tuberculin syringe and 18-gauge catheter to ensure cell containment and to prevent defect contamination with postoperative hemarthrosis. After injection, all of the saline should be removed. Any site of leakage should be sutured tight. After the cartilage surrounding the patch is gently dried, the edges of the patch should be sealed with fibrin glue (Tisseel; Baxter Health Care Corp., Glendale, CA), and a second watertightness test should be performed as previously described (Fig. 16).

The chondrocytes come in vials that should remain upright at all times. Meticulous attention to sterility is paramount during this step, as the vial's exterior is not sterile. The vials are held vertical, the lid is removed, and the top is wiped with alcohol. An 18-gauge catheter is inserted into the vial. The needle is withdrawn, leaving the catheter; a 3-mL syringe is attached to the catheter; the fluid is aspirated into the syringe, leaving the cells behind; and the fluid is gently injected back into the vial, suspending the cells within the fluid. This process is repeated until a uniform suspension is achieved whereby the entire contents of the vial are aspirated into the syringe and the syringe and catheter are carefully withdrawn from the vial.

To insert the cells into the defect, the catheter is placed through the opening at the top of the defect and advanced to the distal end. The cells are slowly injected into the bed of the defect with a side to side motion while the catheter is slowly withdrawn. The opening is then closed with additional sutures and sealed with fibrin glue (Fig. 16).

■ RESULTS

To date, it is difficult to derive an evidence-based approach to the decision making for articular cartilage res-

FIG. 16. Periosteal patch sewn in place, with fibrin glue around the periphery.

toration. The initial studies evaluating abrasion arthroplasty and Pridie drilling had an average patient age of 50 years and knees that were arthritic. This is not comparable to younger patients with symptomatic focal chondral defects treated with osteochondral allografts or ACI, for example. In addition, concomitantly performed procedures often generate nonhomogeneous patient populations.

Marrow Stimulation Techniques

The results of abrasion arthroplasty are unpredictable and generally deteriorate with time (Table 1).[64–66] In an animal study, burr arthroplasty resulted in decreased fibrocartilage formation compared to subchondral drilling.[67] Abrasion arthroplasty results by Johnson[14,68] found that 75% of patients with exposed subchondral bone had satisfactory results. However, only 12% of the patients had no symptoms 2 years following the treatment. Baumgaertner et al.[69] found a 39% early failure rate in a series of 49 knees, and 47% failure at final follow-up examination. Bert and Maschka[70] and Bert[71] found radiographic evidence of increased joint space after abrasion arthroplasty in 51% of patients, but 31% of these individuals either had no symptomatic improvement or more severe symptoms. Friedman et al.[72] reported on 73 patients treated with abrasion arthroplasty. Follow-up at 6 to 18 months found that 83% of patients still had "pain present." In a 1991 study, Rand[65] found the results of abrasion arthroplasty to be highly unpredictable.

There have been few published clinical studies on microfracture. A recent review of microfracture cases for medial femoral condyle lesions averaging 3.2 cm^2 found that 63% of patients rated their overall condition "good" or "excellent" on the modified Cincinnati Knee Rating System. This study consisted of 19 patients that did not consistently use a CPM or alter their weight bearing.[73] Gobbi et al.[74] reported on 53 patients and found that their subjective knee rating after 2 years was 70 (a normal knee would be 100). Steadman et al.[15] reported 3-year to 5-year results of 75% improved and 20% unchanged with regard to pain. Sixty-five percent improved, 20% were unchanged, and 13% were worse with regard to activities of daily living and labor.

Cartilage Replacement Techniques

Osteochondral Autograft Transplantation. The results of osteochondral autograft transplantation are summarized in Table 2.[21,25,26,75] Kish et al.[21] looked a subset of 52 osteochondral autografts performed on competitive athletes with follow-up greater than 1 year. All patients had HSS scores of good to excellent. However, only 63% returned to full participation. Thirty-one percent did return at a lower level. Ninety percent of patients younger than 30 years returned to full participation, while only 23% of patients older than 30 years returned to full competition.

A multicenter prospective study was performed com-

TABLE 1. *Abrasion arthroplasty results*

Author	*N*	*Indication*	*Mean f/u*	*Improved good/excellent*	*Unchanged/ fair*	*Worse/ poor*
Rand (1991)	28	DJD	45 m	39%	29%	32%
Bert (1989)	59	DJD	60 m	51%	16%	33%
Friedman (1984)	73		>6 m	60%	34%	6%

M, months; DJD, Degenerative Joint Disease.

TABLE 2. *Osteochondral autograft transplantation results*

Author	Type/location	N	Mean f/u	Good excellent	Satisfactory	Poor
Hangody (2001)	Femur	461	>12 m	92%		
	Patella/trochlea	93		81%		
	Tibia	24		88%		
Kish (1999)	Femur	52	>12 m	100%		
Bradley (1999)	—	145	18 m	43%	43%	12%
Hangody (1998)	Femur/patella	57	48 m	91%		

m, months.

paring marrow stimulating techniques to osteochondral allografts in 413 patients.[76] Osteochondral autograft resulted in significantly better outcomes at 3, 4, and 5 years.

Osteochondral Allograft Transplantation. Osteochondral allografts have the more long-term follow-up than any other cartilage procedure (Tables 3, 4). Gross[77] reported an 85% success rate in 126 knees followed for a mean of 7.5 years. In 122 patients treated for femoral condyle lesions, Bugbee[78] reported a success rate of 91%. At 10-year follow-up, the clinical success was 75%. Several studies have looked at long-term survivorship to determine the durability of osteochondral allografts.[79–83] The treatment of bipolar disease is considerably less successful than that of unipolar disease.[84] Garrett[85] reviewed a group treated for osteochondritis dissecans lesions in adults and found excellent results.

Autologous Chondrocyte Implantation. The published results of ACI now have follow-up extending to 9 years (Table 5).[44,63,86–88] Micheli et al.[86] published a multicenter study of the first 50 patients treated outside of Sweden. The patients were prospectively followed for a minimum of 36 months. Seventy-eight percent of the patients had a previous cartilage procedure. The patients' Modified Cincinnati Score revealed a significant improvement of 5 points (10-point scale). Eighty-four percent of patients had an improvement in their condition, 2% were unchanged, and 13% declined. One third of these patients had failed a previous marrow stimulating procedure. Peterson et al.[87] published their results on 94 patients with 2-year to 9-year follow-up. They found that the results varied considerably based on location. The results of ACI when treating the patella initially were 62% good to excellent. However, later in the series, they began performing a distal realignment, and the results improved to 85%. The majority of biopsies revealed hyaline-like tissue, and immunohistochemical staining for type II cartilage was positive in all biopsy specimens with hyaline-like cartilage. Hypertrophic periosteal healing response with resulting pain and catching occurs in 10 to 15% of the cases between 3 and 9 months and may require arthroscopic evaluation.[63,87] Graft failure is documented in up to 7%.[86,87]

Periosteal and Perichondrial Grafting. The initial results of periosteal/perichondrial grafting were encouraging (Table 6).[89,90] Follow-up of perichondrial grafting at 1 year has shown mineralization radiographically in the repaired defects in 20 of 25 patients.[60] This later led to failure of the procedure in most cases.[91] Other studies have found type X collagen deposition,[92,93] presence of enchondral ossification, and subsequent bone formation within the graft.[91,94] Amiel et al.[59] reported on perichondral grafting in a rabbit model and found only 50% biologically acceptable results. Beckers et al.[95] reported their results with perichondrial transplantation, and at mean follow-up of 32 months found that 42 of 80 patients were failures and lost grafts. In general, these procedures are not performed, given the viability of the other alternatives.

■ COMPLICATIONS

While the same complications may occur virtually any procedure (i.e., arthrofibrosis, effusion, and hemarthro-

TABLE 3. *Osteochondral allografts transplantation results*

Author	N	Location	Diagnosis	Mean f/u	Mean age	Success rate	Excellent/ good	Failures
Aubin (2001)	60	Femur	Middle	10 yr	27 yr		66%	20%
Bugbee (2000)	122	Femur	Multiple	5.0 yr	34 yr	91%		5%
Chu (1999)	55	F,T,P	Multiple	6.3 yr	35 yr		76%	16%
Gross (1997)	123	F,T,P	Trauma/OCD	7.5 yr	35 yr	85%		
Garrett (1994)	17	Femur	OCD	3.5 yr	20 yr	94%		
Meyers (1989)	39	F,T,P	Multiple	3.6 yr	38 yr	78%		22%

F, femur; P, Patella; T, tibia; OCD, osteochondritis dissecans; yr, year.

TABLE 4. *Survivorship analysis of osteochondral allografts*

Author	N	Location	Average age	5/7.5 yr	10 yr	14/15 yr	20 yr
Gross (2002)	60	Femur	27 yr	85%	85%	74%	
Ghavazi (1997)	123	F,T,P	35 yr	95%	71%		66%
Beaver (1992)	91	F,T	50 yr	75%	64%	63%	

F, Femur; P, Patella; T, tibia; yr, year.

sis), there are those considered relatively unique to each specific treatment option. Osteochondral autograft complications include the potential for condylar fracture and avascular necrosis if multiple small plugs are taken from the same region. Complications unique to osteochondral allograft include infection secondary to disease transmission from the donor tissue. Failure of the graft to incorporate leads to mechanical fatigue, which will result in failure. ACI may result in a hypertrophic overgrowth of the periosteum that usually is evident within 6 months. This requires arthroscopic assessment and possible debridement.

■ POSTOPERATIVE MANAGEMENT

Postoperative management is crucial to the success of these procedures. Noncompliance may lead to procedure failure. We use cryotherapy to reduce pain and inflammation. All patients begin isometric quadriceps and hamstring strengthening the day after surgery.

The *microfracture technique* requires a modification of weight bearing and use of continuous passive motion (CPM) after the surgery. Rodrigo et al.[96] recommend 6 hours of CPM each day for 8 weeks and found better gross healing at second-look arthroscopy in those that used CPM when compared to those who did not. Patients unable to use a CPM machine should do 500 repetitions of knee flexion and extension three times every day. Patients must be nonweightbearing for 6 to 8 weeks. Patients who have treatment of a trochlear/patellar lesion may bear weight in extension, but also may have their flexion limited to about 45 to 60 degrees, depending on the flexion angle of defect contact.

Similarly, the rehabilitation following *osteochondral autograft transplantation* relies on early motion and gradual load bearing to ensure chondrocyte survival and continued production of matrix constituents.[21] Patients should be kept nonweightbearing for the first 2 weeks and progressed to full over the ensuing 6 weeks, depending on the stability of the implanted grafts. Ergometer exercises begin at 6 to 8 weeks, and at 3 months, normal daily activities are generally possible. Some running can begin at 6 months. Sporting activities that involve shear forces can begin at 9 months.[21] Some have advocated immediate weight bearing after autografting.[97]

For *osteochondral allograft transplantation*, restricted weight bearing is recommended for at least 8 weeks to protect the cartilage surface and to minimize the chance for subchondral collapse during the creeping substitution phase of graft healing. CPM is used for 6 to 8 hours per day at one cycle per minute starting as tolerated for the first 4 to 6 weeks. Return to normal activities of daily living and light sporting activity are considered at 4 to 6 months. In general, high-impact sports are not recommended after osteochondral allografting for large articular cartilage lesions due to the theoretical risk

TABLE 5. *Autologous chondrocyte implantation results*

Author	Location	N	Mean f/u	Significant improvement	Good to excellent	Fair	Poor
Peterson (2002)	Femur	18	>5 yr		89%		
	OCD	14	>5 yr		86%		
	Patella	17	>5 yr		65%		
	Femur/ACL	11	>5 yr		91%		
Minas (2001)	F,Tr,P,T	169	>1 yr	85%			
Micheli (2001)	F,Tr,P	50	>3 yr	84%			
Peterson (2000)	Femur	25	>2 yr		92%		
	Patella	19	>2 yr		65%		
	Femur/ACL	16	>2 yr		75%		
	Multiple	16	>2 yr		67%		
Gillogly (1998)	Femur/Patella/tibia	25	>1 yr	88%	88%		
Brittberg (1994)	Femur/Patella	16	39 m		88%	—	13%
	Patella	7	36 m		29%	43%	29%

F, Femur; Tr, Trochlea; P, Patella; ACL, Anterior Cruciate Ligament; OCD, osteochondritis dissecans; yr, year.

TABLE 6. *Perichondrial graft results*

Author	*Type/location*	*N*	*Mean f/u*	*Excellent*	*Good*	*Poor*
Lorentzon 91998)	Periosteal/patella	26	42 m	65%	31%	4%
Homminga (1990)	Perichondral/femur patella	25	12 m	85%	12%	4%

of graft collapse and potential deterioration in the long-term survival of the graft.[98]

ACI rehabilitation for the first 6 weeks also consists of CPM for 6 to 8 hours per day. CPM has a beneficial effect on the quality of the repair tissue and on the degree of defect fill.[39,99] Weight bearing is not allowed except for trochlear/patellar lesions, where patients bear weight in extension. Strengthening exercises focus on quadriceps. From 6 to 12 weeks, the goal is full knee motion, and weight bearing is progressed 20% per week until full. Short arc closed chain strengthening exercises are initiated. From 3 to 5 months, strengthening continues, with wider arcs of motion with increasing resistance. Trochlear repairs are still restricted from deep flexion exercises. The final phase of recovery lasts until there is a full return to activities. This may be as soon as 12 months for small and moderate sized lesions to as long as 18 months for larger lesions or patellofemoral repairs.

The postoperative regimen for *periosteal grafting* consists of CPM and partial weight bearing.[62]

■ CONCERNS/FUTURE OF TECHNIQUE

Beyond primary repair, nonprosthetic arthroplasty treatment options for focal chondral defects can be described as palliative, reparative, or restorative (Table 7, Fig. 17). Arthroscopic debridement and lavage are palliative as they provide only temporary relief. Reparative treatment includes marrow-stimulating techniques that result in fibrocartilage formation within the defect. Restorative techniques are those that result in cartilage that is articular in nature. These include osteochondral autograft/allograft transplantation, periosteal/perichondrial transplantation, and ACI.

Several factors must be considered when indicating a patient for a particular procedure. Defect size, depth, location, chronicity, response to previous treatments, concomitant pathology, patient age, physical demand level, and expectations are important to consider when attempting to match the most appropriate treatment option to the existing pathology. It is notable that at this particular time, evidence-based decision making remains an ideal that is yet to be realized given the complexity of this problem.

Chondral Lesion Size

Some generalizations can be made with regard to size, although there are no absolutes. Each technique is surgeon-specific and situation-specific and varies accordingly. Smaller lesions (< 2–3 cm^2) may be amenable to several treatment options, including arthroscopic debridement and lavage, marrow stimulating techniques, osteochondral autograft, and autologous chondrocyte implantation (ACI). As the size of the lesion increases (> 2–3 cm^2), the limits of osteochondral autograft are approached. Osteochondral allografts may become a more viable option, especially if the defect is associated with subchondral bone loss. Marrow stimulation techniques have poorer results for lesions greater than 3 cm^2.[100] ACI is also a viable option for larger lesions.

Primary *versus* Secondary Treatment

There is increasing acceptance that some treatment methods, while notably effective, may offer only short-term or medium-term symptomatic relief. Thus, not uncommonly, patients with symptomatic chondral lesions may require revision or salvage surgery in an effort to control symptoms further. Although the results of some techniques used as a primary treatment option are considered limited, there is an even greater paucity of literature supporting the use of the same procedure twice (i.e., as a secondary treatment) in a scenario in which it had already failed as a primary procedure. If a marrow stimu-

TABLE 7. *Surgical treatment options for chondral defects*

Procedure	*Indications*	*Outcome*
Arthroscopic lavage and debridement	Minimal symptoms	Palliative
Marrow stimulating procedures	Smaller lesions, lower demand patients	Reparative
Osteochondral autograft	Smaller lesions, low or high demand patient	Restorative
Osteochondral allograft	Larger lesions with bone loss, low or high demand patient	Restorative
Autologous chondrocyte implantation	Small and large lesions with and without bone loss, high demand patients	Restorative
Genetic engineering	Investigational	Restorative

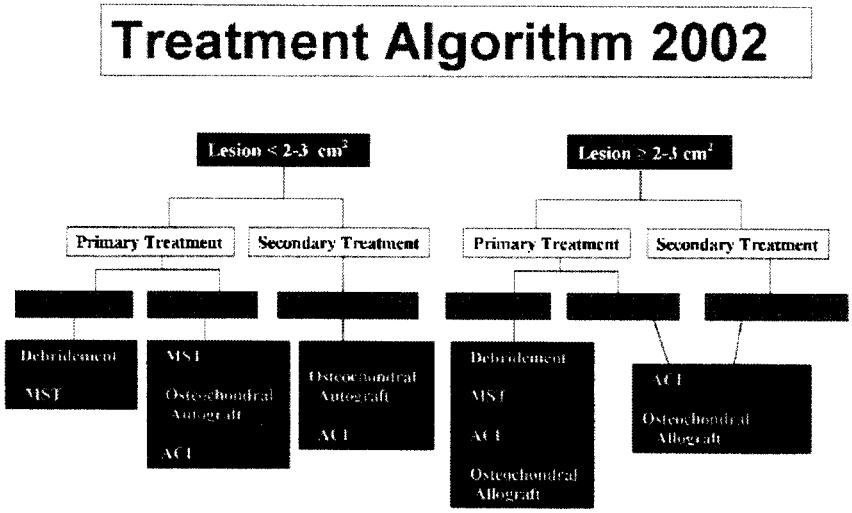

FIG. 17. Treatment algorithm for articular cartilage procedures based on size, primary or secondary treatment, and patient demands.

lation technique has failed once, it probably should not be attempted a second time. Especially for larger lesions, ACI or osteochondral allografting may be a better choice.

Demand Matching

One would like to match the expected outcome of a given technique not only to the specific pathology but also to the aggregate biomechanical and physiologic demand that the patient imposes on the knee. All patients may not require state-of-the-art techniques for cartilage restoration. In certain patients of lower aggregate demand, fibrocartilage repair tissue formed from marrow stimulation may be an acceptable solution to reduce symptoms. On the other hand, patients of greater aggregate demand may require higher-grade tissue formed from alternative options such as ACI or osteochondral grafting to reduce symptoms.

Future Considerations

Genetic engineering is a new strategy for treating chondral injuries. This involves a combination of gene transfer techniques and tissue engineering.[101] In gene therapy, specific genes for growth factors are transferred into the chondrocyte or progenitor cells. Once treated, these cells have the potential to produce the growth factors that are conducive to chondrocyte proliferation. Tissue engineering is based on the creation of biologic substitutes for the repair or regeneration of damaged tissue. The application of this process for chondral defects involves the transplantation of viable cells into an appropriate supportive vehicle. Autologous chondrocyte implantation is an example of this technique, although the ideal scaffold for cartilage engineering has not yet been identified.[101] It is likely that future considerations will focus on these scaffolds, reductions in the expenses associated with the production of these technologies, and less invasive means to implement cartilage restoration procedures.

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