FRANCIS G. O'CONNOR • ROBERT E. SALLIS
ROBERT P. WILDER • PATRICK ST. PIERRE

SPORTS MEDICINE

just the facts

- Learn MORE in LESS time
- Bulleted format for maximum learning
- Ideal for *anyone* who cares for patients with sports-related conditions
- Content reflects topics tested on ABFP Sports Medicine Exams
- Perfect for exam review or clinical practice

9 ARTICULAR CARTILAGE INJURY

Stephen J Lee, BA
Brian J Cole, MD, MBA

INTRODUCTION

- Articular cartilage lines the articulating surfaces of diarthrodial joints and serves several important functions: (1) provision of a smooth, low-friction surface, (2) joint lubrication, and (3) stress distribution with load bearing.
- Articular cartilage injury most commonly occurs in the knee and thus has been most extensively studied in this area. Cartilage injuries of the knee affect approximately 900,000 Americans annually, resulting in more than 200,000 surgical procedures each year to treat high-grade lesions (grade III or IV) (Cole et al, 1999).
- In a restrospective study of 31,516 knee arthroscopies, Curl and associates (1997) identified articular cartilage damage in 63% of the patients. Among those affected, 41% had grade III and 19% grade IV lesions. More recently, Hjelle and colleagues (2002) prospectively evaluated 1000 knee arthroscopies and found chondral or osteochondral defects in 61% of the patients with 55% of the defects classified as grade III and 5% grade IV. The weight-bearing zone of the medial femoral condyle was found to be the most commonly affected area (58% of all articular cartilage lesions). Other commonly affected areas include the weight-bearing zone of the lateral femoral condyle and patellofemoral joint (Hjelle et al, 2002; Brittberg, 2000).

COMPOSITION AND ORGANIZATION

- Articular cartilage consists primarily of a large *extracellular matrix* (ECM) and a sparse population of chondrocytes.

TABLE 9-1 Organization of Articular Cartilage

ZONE	CHONDROCYTE	COLLAGEN	PROTEOGLYCAN	WATER	PROPERTIES
Middle	Random, oblique	Larger diameter, less organized	—	—	Less stiff than superficial zone
Superficial	Flat, parallel to surface	Thin, parallel to surface	Lowest conc.	Highest conc.	Low fluid permeability Resistance to shear forces
Deep	Spherical, in columns	Perpendicular to surface, extending into calcified zone	Highest	Lowest	Anchors cartilage to subchondral bone
Tidemark	Separates deep zone from calcified zone, number increases with age				
Calcified	Small cells in cartilaginous matrix with apatitic salts				

1. Chondrocytes (5% of total wet weight) are derived from mesenchymal stem cells which differentiate during skeletal morphogenesis and are responsible for producing matrix components that regulate cartilage homeostasis. The chondrocytes respond to a variety of factors, including matrix composition, mechanical load, and soluble mediators such as growth factors and cytokines.
2. The primary components of the ECM are water (65–80% of the total wet weight), *proteoglycans* (PG) (aggrecan, 4–7% of the total wet weight), and collagens (primarily type II, 10–20% of the total wet weight), with other proteins and glycoproteins in lesser amounts. The collagens provide form and tensile strength. The proteoglycans bind water and help distribute stresses as water flows through the porous-permeable ECM under compressive loads.

- The ultrastructure of articular cartilage can be divided into four distinct zones: superficial, middle, deep, and calcified. Each has a characteristic composition that imparts unique mechanical properties (Table 9-1).

INJURY AND REPAIR

- Mechanical injuries to articular cartilage occur when abnormal blunt traumatic and shear forces result in high compressive stress throughout the tissue and high shear stress at the cartilage–subchondral bone junction (Finerman and Noyes, 1992). This results in an isolated cartilage injury known as a focal chondral defect, which is different from chondromalacia and osteoarthritis. Chondromalacia describes the macroscopic appearance of a gradation of cartilage damage including softening and fissuring to variable degrees of cartilage depth. Most often it is asymptomatic and does not require treatment. Primary osteoarthritis is a progressive degenerative condition that increases in prevalence nonlinearly after the age of 50 years. Macroscopically, focal chondral lesions appear as an isolated defect whereas osteoarthritis appears as diffuse fraying, fibrillation, and thinning of the articular cartilage.
- The lack of vascular, neural, and lymphatic access to articular cartilage creates a limited environment for spontaneous repair. Injuries that do not penetrate the subchondral bone show little sign of spontaneous repair, whereas those that extend into the depth of subchondral bone initiate a vascular proliferative response that produces a mix of normal hyaline cartilage (primarily type II collagen) and a structurally and biomechanically inferior "scar cartilage," or fibrocartilage (primarily type I collagen).
- Articular cartilage injury can be separated into three distinct types: (1) *cartilage matrix and cell injuries*—microdamage to the cells and matrix without visible disruption of the articular surface, (2) *chondral injuries*—visible mechanical disruption limited to articular cartilage, and (3) *osteochondral injuries*—visible mechanical disruption of articular cartilage and subchondral bone.
  1. Cartilage matrix and cell injuries
     a. Decreased PG concentration, increased hydration, and possibly disorganization of the collagen network. The decreased PG concentration and increased hydration are strongly correlated with a decrease in cartilage stiffness and an increase in its hydraulic permeability. As a result, greater loads are transmitted to the collagen-PG matrix, increasing the vulnerability of the ECM to further damage.
     b. It is not known at what point the accumulated microdamage is irreversible. Presumably, the chondrocytes can restore the matrix as long as the loss of matrix PG does not exceed the rate of

synthesis, the collagen network remains intact, and sufficient chondrocytes remain viable (Martin and Buckwalter, 2000).

2. Chondral injuries
   a. May result in chondral fissures, flaps, fractures, and chondrocyte damage
   b. Lack of vascular access and migration of mesenchymal cells limits the repair response (Buckwalter and Mow, 1992; Buckwalter, Rosenberg, and Hunziker, 1990). The surrounding chondrocytes respond by proliferating and increasing the synthesis of matrix components; however, the proliferating cells and newly synthesized matrix do not fill the tissue defect, and soon after injury the increased proliferative and synthetic activity ceases. The adjacent normal cartilage may then be overloaded and also degenerate over time.
3. Osteochondral injuries
   a. Acute injuries may fracture deep into subchondral bone
   b. Hemorrhage and fibrin clot formation trigger an inflammatory response, altering the synovial fluid and joint environment. The fibrin clot extends into the cartilage defect and releases vasoactive mediators and growth factors, including *transforming growth factor beta* (TGF-β) and *platelet derived growth factor* (PDGF). These factors may stimulate repair of osteochondral defects.
   c. However, the chondral repair tissue is intermediate between normal hyaline cartilage and fibrocartilage, resulting in a structure less stiff and more permeable than normal articular cartilage (Buckwalter et al, 1988; Buckwalter and Mankin, 1997a; 1997b; Buckwalter, Rosenberg, and Hunziker, 1988). The repair tissue rarely persists and most often begins to show evidence of depletion of PGs, increased hydration, fragmentation and fibrillation, increasing collagen content, and loss of chondrocyte-like cells within a year (Buckwalterl, 2002).

PATIENT EVALUATION

- Cartilage injuries can occur in isolation or in association with other intra-articular pathology, thus it is important for the evaluating physician to maintain a high index of suspicion especially in the presence of concomitant pathology such as varus or valgus alignment, patellofemoral malalignment, ligamentous instability, and meniscal deficiency.
- The most common clinical presentation following an acute full-thickness chondral or osteochondral injury is a loose body. When chronic, symptoms may be subtle but often include localized pain, swelling, and mechanical symptoms (locking, catching).
- A thorough history should elicit the onset of symptoms (traumatic or insidious), mechanism of injury, previous injuries, and symptom-provoking activities.
- A thorough physical examination (Table 9-2) is essential to evaluate for concomitant pathology that would alter the treatment plan. Antalgic postures or gaits may be present due to painful weightbearing in the involved knee, or adaptive gait patterns such as in-toeing or out-toeing or a flexed-knee gait may develop as the patient shifts weight away from the affected area. Range of motion testing is usually normal in patients with isolated focal chondral defects. Crepitus, catching, locking, or grinding can occur with focal irregularities in the articular surface.
- Most often, the history, physical examination, and plain radiographs are all that are required to make the appropriate diagnosis. Ideal plain films include 45°

TABLE 9-2 Components of a Comprehensive Musculoskeletal Examination

Habitus
Alignment
Varus
Valgus
Gait
Antalgic
Flexed-knee
Recurvatum (hyperextension)
Compensatory
Thrust
Varus (lateral)/Valgus (medial)
Swelling
Soft tissue
Effusion
Ligamentous laxity
Anteroposterior (ACL/PCL)
Medial-Lateral (MCL/LCL)
Range of motion
Strength, muscle atrophy
Specific compartments
Tibiofemoral
Patellofemoral
Meniscus
Joint line tenderness
Provocative maneuvers
Related joints
Spine
Hips
Feet
Neurovascular

ABBREVIATION: ACL = anterior cruciate ligament; PCL = posterior cruciate ligament; MCL = medial collateral ligament; LCL = lateral collateral ligament.

TABLE 9-3 Modified International Cartilage Repair Society Classification System for Chondral Injury

GRADE OF INJURY	MODIFIED ICRS
Grade 0	Normal cartilage
Grade I	Superficial fissuring
Grade II	<1/2 cartilage depth
Grade III	>1/2 cartilage depth up to subchondral plate
Grade IV	Through subchondral plate, exposing subchondral bone

flexion weight bearing *posteroanterior* (PA), patellofemoral, and non-weight-bearing lateral projections (Mandelbaum, Romanelli, and Knapp, 2000). These views allow assessment of joint space narrowing, subchondral sclerosis, osteophytes, and cysts. Special studies such as long-cassette mechanical axis view may be necessary to evaluate overall alignment. If significant joint space narrowing is present on the 45° flexion PA radiograph, MRI is not indicated. An MRI is valuable in assessing the status of the knee ligaments and menisci, but generally tends to underestimate the degree of cartilage abnormalities seen at the time of arthroscopy (Khanna et al, 2001). The role of the bone scan remains controversial: isolated articular surface defects that do not penetrate subchondral bone may not be identified by bone scan. Arthroscopy continues to remain the gold standard for the diagnosis of articular cartilage injuries.

- The Outerbridge classification system (Outerbridge, 1961) was initially developed for macroscopic grading of chondromalacia patellae and has since been modified on numerous occasions. A recent modification by the International Cartilage Repair Society (ICRS) (Brittberg, 2000; Brittberg and Peterson, 1998) classifies chondral injuries into five distinct grades (Table 9-3).

NONSURGICAL MANAGEMENT

- Nonsurgical management (Table 9-4) is largely ineffective in symptomatic patients and should be reserved for relatively low-demand patients, patients wishing to avoid or delay surgery, and patients with advanced degenerative osteoarthritis which is a contraindication for articular cartilage restoration procedures.
- Traditional methods for treatment of chondral lesions include the judicious use of nonsteroidal anti-inflammatory drugs combined with activity modification. Oral chondroprotective agents such as glucosamine and chondroitin sulfate potentially offer some relief in subjective symptoms. Glucosamine is thought to stimulate chondrocyte and synoviocyte activity, and chondroitin is thought to inhibit degradative enzymes and prevent fibrin thrombi formation in periarticular tissues (Gosh, 1992; Bucci, 1994; Muller-Fassbender et al, 1994). Recent studies indicate that pain, joint line tenderness, range of motion, and walking speed may be improved with these medications (Barclay, Tsourounis, and McGart, 1998; DaCamara and Dowless, 1998). However, there are no clinical data showing that these oral agents affect the formation of cartilage (Tomford, 2000). Viscosupplementation with high-molecular weight hyaluronans remains an option despite the lack of well-controlled studies demonstrating efficacy.

TABLE 9-4 Nonsurgical Management of Chondral Lesions

Oral medications	Non-steroidal anti-inflammatory drugs (NSAIDS) Acetaminophen Glucosamine-sulfate—believed to stimulate chondrocyte and synoviocyte metabolism Chondroitin-sulfate—believed to inhibit degradative enzymes and prevent fibrin thrombi formation in periarticular tissues
Physical modalities	Activity modification—avoidance of high-impact exercises Physical therapy—quadriceps strengthening hamstring flexibility
Bracing	Knee sleeve for improved proprioception Unloader brace to protect damaged knee compartment
Injections	Corticosteroids High-molecular weight hyaluronans

- Prolonged nonsurgical management of symptomatic chondral lesions may lead to additional joint deterioration, making surgical intervention more difficult or less successful. Suggested indications for referral to an orthopedic surgeon with expertise in cartilage restoration techniques are presented in Table 9-5.

TABLE 9-5 Indications for Referral to an Orthopedic Surgeon

High-energy injury with direct trauma to the knee
Acute motion loss
Gross deformity
Acute neurovascular deficit
Mechanical symptoms (catching, locking, sensation of a loose body)
Failed nonsurgical management greater than 3 months in duration
Repeated giving way or complaints of instability

SURGICAL MANAGEMENT

- Various surgical modalities exist for the treatment of chondral lesions and can be grouped into three categories: (1) palliative, (2) reparative, and (3) restorative (Table 9-6). The goals are to reduce symptoms, improve joint congruence by restoring the articular surface with the most normal tissue (i.e., hyaline cartilage) possible, and to prevent further cartilage degeneration. Concomitant management of associated pathology such as malalignment, ligament insufficiency, and/or meniscal injury is essential for a successful outcome.

PALLIATIVE

- Arthroscopic debridement and lavage is used to remove degenerative debris, cytokines, and proteases that may contribute to cartilage breakdown. It is ideally indicated in the patient with defect area less than 2 cm^2 and who has exhausted all nonoperative treatments. Postoperative rehabilitation involves weight-bearing as tolerated and early strengthening exercises. In the absence of meniscal pathology, the results following arthroscopic debridement are at best guarded.
- Thermal chondroplasty (laser, radiofrequency energy) of superficial chondral defects allows more precise contouring of the articular surface when used in conjunction with debridement. However, there is concern regarding the depth of chondrocyte death and cellular necrosis in the treated area and thus remains investigational.

REPARATIVE

- *Marrow stimulating techniques* (MST—microfracture, abrasion arthroplasty, and subchondral drilling) involve surgical penetration of subchondral bone to allow the migration of mesenchymal cells and fibrin clot formation in the area of the chondral defect. The resulting quality and volume of repair tissue (fibrocartilage) is variable. These procedures are used in low demand patients with larger lesions (>2 cm^2) or in higher demand patients with smaller lesions (<2 cm^2). Microfracture is preferred over subchondral drilling and abrasion arthroplasty for several reasons: (1) it is less destructive to the subchondral bone because it creates less thermal injury than drilling, (2) it allows better access to difficult areas of the articular surface, (3) it provides a controlled method of depth penetration, and (4) selection of the correctly angled awl permits the microfracture holes to be made perpendicular to the subchondral plate (Steadman, Rodkey, and Rodrigo, 2001; Steadman, 1997). Postoperative rehabilitation consists of nonweight bearing for 6 to 8 weeks and may include *continuous passive motion* (CPM) to improve the extent and quality of the repair tissue. As MSTs are low-cost and relatively low-morbidity procedures, they remain the mainstay for the initial management of small chondral lesions.

RESTORATIVE

- *Autologous chondrocyte implantation* (ACI) is a two-stage procedure involving biopsy of normal articular cartilage, culture of chondrocytes in vitro, and transplantation into the chondral defect beneath a periosteal patch. This restorative procedure results in hyaline-like cartilage which is believed to be superior to fibrocartilage (Grande, 1997). Postoperative rehabilitation entails aggressive CPM and nonweight bearing for 6 weeks with a gradual increase to full-weight bearing from 6 to 12 weeks. ACI is a costly procedure with a relatively lengthy recovery period and is most often used as a secondary procedure for the treatment of medium to larger focal chondral defects (>2 cm^2).
- Osteochondral grafts restore articular congruity by transplanting a cylindrical plug of subchondral bone and articular cartilage which can be obtained from the

TABLE 9-6 Surgical Management of Chondral Lesions

PROCEDURE	INDICATIONS	OUTCOME
Arthroscopic debridement and lavage	Minimal symptoms, short-term relief	Palliative
Thermal chondroplasty (laser, radiofrequency energy)	Partial thickness defects, investigational	Palliative
Marrow stimulating techniques	Smaller lesions, persistent pain	Reparative
Autologous chondrocyte implantation	Small and large lesions with or without subchondral bone loss	Restorative
Osteochondral autograft	Smaller lesions, persistent pain	Restorative
Osteochondral allograft	Larger lesions with subchondral bone loss	Restorative

TABLE 9-7 Results of Arthroscopic Debridement and Lavage

AUTHOR	N	MEAN FOLLOW-UP	RESULTS
Owens et al, 2002	19 patients	24 months	Fulkerson score 12 mos – 80.9, 24 mos – 77.5
Hubbard, 1996	76 knees	4.5 years	>50% improved
Timoney et al, 1990	109 patients	48 months	63% good 37% fair/poor
Baumgartner et al, 1990	49 patients	33 months	52% good 48% fair/poor
Jackson, 1989	137 patients	3.5 years (2 to 9)	68% remained improved
Sprague, 1981	78 patients	14 months	74% good 26% fair/poor

patient (i.e., autograft) or from a cadaveric source (i.e., allograft). The two-dimensional surface area can be covered, but the challenge lies in accurately restoring the three-dimensional surface contour.

a. Osteochondral autografts offer the advantage of using the patient's own tissue; however, the limited amount of donor tissue confines this technique to smaller lesions (<2 cm^2). The risk of donor-site morbidity increases as more tissue is harvested. Postoperative rehabilitation includes early range of motion and nonweight bearing for 2 weeks with an increase to full-weight bearing from 2 to 6 weeks. It is most commonly indicated for the primary treatment of smaller lesions considered symptomatic and for similarly sized lesions for which an MST or ACI procedure has failed.
b. Osteochondral allograft can be used to treat larger lesions (>2 cm^2) that are difficult to treat with other methods. Tissue matching and immunologic suppression are unnecessary as the allograft tissue is avascular and alymphatic. Postoperative rehabilitation consists of immediate CPM and nonweight bearing for 6 to 12 weeks. This procedure is most often used as a secondary treatment option for failed ACI in larger defects.

- Tables 9-7 through 9-12 provide a summary of outcomes studies for arthroscopic debridement and lavage, microfracture, ACI, and osteochondral autografts and allografts.

TABLE 9-8 Results of Microfracture

AUTHOR	N	MEAN FOLLOW-UP	RESULTS
Steadman et al, 2003	71 knees Age ≤ 45 years	11 years (7 to 17 years)	80% improved Lysholm 59 → 89 Tegner 6 → 9 Majority of improvement 1st year Maximal improvement 2 to 3 years Younger patients did better
Steadman, Rodkey, and Rodrigo, 2001	75 patients	11.3 years	Lysholm 58.8 → 88.9 Tegner 3.1 → 5.8 Work 4.9 → 7.6 Sports 4.2 → 7.1
Blevins et al, 1998	140 recreational athletes Mean age 38 years Mean defect size 2.8 cm^2	4 years	54 2nd look arthroscopy: 35% with surface unchanged Older, less active did worse
	38 high-level athletes Mean age 26 years Mean defect size 2.2 cm^2	3.7 years	77% returned to sports @ 9.3 months
Gill et al, 1998; Gill and MacGillivray, 2001	103 patients	6 years (2 to 12 years)	86% rated knee as normal/nearly normal Acute (treated within 12 weeks) did better
Steadman et al, 1997	203 patients	3 years (2 to 12 years)	75% improved, 19% unchanged, 6% worse 60% improved sports Poor prognosis—joint space narrowing, age >30 years, no postoperative CPM

TABLE 9-9 Results of Autologous Chondrocyte Implantation

AUTHOR	N	LOCATION	MEAN FOLLOW-UP	RESULTS
Peterson et al, 2002	18	F	>5 years	89% good/excellent
	14	OCD	>5 years	86% good/excellent
	17	P	>5 years	65% good/excellent
	11	F/ACL	>5 years	91% good/excellent
Minas, 2001	169	F, Tr, P, T	>1 year	85% significant improvement 13% failure
Micheli et al, 2001	50	F, Tr, P	>3 years	84% significant improvement 2% unchanged 13% declined
Peterson et al, 2000	25	F	>2 years	92% good/excellent
	19	P	>2 years	62% good/excellent Improved to 85% with distal realignment
	16	F/ACL	>2 years	75% good/excellent
	16	Multiple	>2 years	67% good/excellent
Gillogly, Voight, and Blackburn, 1998	25	F, P, T	>1 year	88% good/excellent
Brittberg et al, 1994	16	F	39 months	88% good/excellent 12% poor
	7	P without distal realignment	36 months	29% good/excellent 42% fair 29% poor

ABBREVIATIONS: F = femur; Tr = trochlea; P = patella; T = tibia; ACL = anterior cruciate ligament; OCD = osteochondritis dissecans.

TABLE 9-10 Results of Osteochondral Autografts

AUTHOR	N	LOCATION	MEAN FOLLOW-UP	RESULTS
Hangody et al, 2001	461	F	>1 year	92% good/excellent
	93	P/Tr	>1 year	81% good/excellent
	24	T	>1 year	80% good/excellent
Kish, Modis, and Hangody, 1999	52	F in competitive athletes	>1 year	100% good/excellent 63% returned to full sports 31% returned to sports at lower level 90% <30 years returned to full sports 23% >30 years returned to full sports
Bradley, 1999	145		18 months	43% good/excellent 43% fair 12% poor
Hangody et al, 1998	57	F, P	48 months	91% good/excellent

ABBREVIATIONS: F = femur; Tr = trochlea; P = patella; T = tibia.

TABLE 9-11 Results of Osteochondral Allografts

AUTHOR	N	LOCATION	MEAN FOLLOW-UP	RESULTS
Aubin et al, 2001	60 Mean age 27 years	F	10 years	84% good/excellent 20% failure
Bugbee, 2000	122 Mean age 34 years	F	5 years	91% success rate at 5 years 75% success rate at 10 years 5% failure
Chu et al, 1999	55 Mean age 35 years	F, T, P	75 months	76% good/excellent 16% failure
Gross, 1997	123 Mean age 35 years	F, T, P	7.5 years	85% success rate
Garrett, 1994	17 Mean age 20 years	F	3.5 years	94% success rate
Meyers, Akeson, and Convery F, 1989	39 Mean age 38 years	F, T, P	3.6 years	78% success rate 22% failures

ABBREVIATIONS: F = femur; P = patella; T = tibia.

TABLE 9-12 Survivorship Analysis of Osteochondral Allografts

AUTHOR	N	LOCATION	5/7.5 YEARS	10 YEARS	14/15 YEARS	20 YEARS
Gross et al, 2002	60 Mean age 27 years	F	85%	85%	74%	
Ghazavi et al, 1997	123 Mean age 35 years	F, T, P	95%	71%		66%
Beaver et al, 1992	92 Mean age 50 years	F, T	75%	64%	63%	

ABBREVIATIONS: F = femur; P = patella; T = tibia.

DECISION MAKING

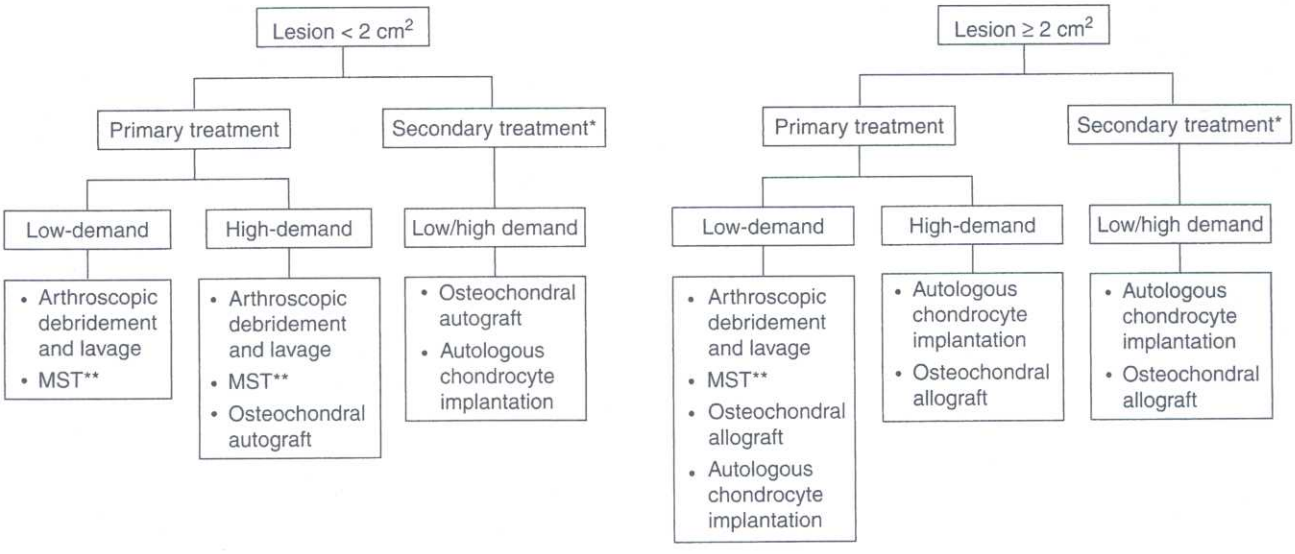
- The choice of surgical intervention is complex and involves the consideration of many factors, including defect size, depth, location, chronicity, response to previous treatments, concomitant pathology, patient age, physical demand level, and expectations. Multiple options often exist for similar lesions and there is not necessarily a consensus regarding the optimal treatment. Thus, the treatment algorithm presented in Fig. 9-1 should be regarded as an overview of the surgical-decision tree currently available to treat symptomatic chondral lesions. It is important to note that even though treatment options are not currently amenable to a menu-driven decision making process, there are several lesion- and patient-specific factors that are critical to the decision making process. These include: location and size of the injury or extent of disease progression, primary versus secondary treatment and patient activity demand. This algorithm is currently evolving and will undoubtedly change as we acquire new information from animal studies and clinical trials.

REFERENCES

Aubin PP, Cheah HK, Davis AM, et al: Long-term follow-up of fresh femoral osteochondral allografts for posttraumatic knee defects. *Clin Orthop* 391:S318–S327, 2001.

Barclay TS, Tsourounis C, McGart GM: Glucosamine. *Ann Pharmacother* 32:574–579, 1998.

Baumgaertner MR, Cannon WDJ, Vittori JM, et al: Arthroscopic debridement of the arthritic knee. *Clin Orthop* 253:197–202, 1990.



*In patients who have failed primary treatment (arthroscopic debridement, MST)
**Marrow stimulating techniques (i.e., microfracture, abrasion, drilling)

FIG. 9-1 Surgical management algorithm for the treatment of symptomatic focal chondral lesions.

Beaver RJ, Mahomed M, Backstein D, et al: Fresh osteochondral allografts for post-traumatic defects in the knee. A survivorship analysis. *J Bone Joint Surg* 74B:105–110, 1992.

Blevins FT, Steadman JR, Rodrigo JJ, et al: Treatment of articular cartilage defects in athletes: An analysis of functional outcome and lesion appearance. *Orthopedics* 21:761–7, 1998.

Bradley JP (ed.): Osteochondral autograft transplantation clinical outcome study, in *Metcalf Memorial Meeting*. Sun Valley, ID, 1999.

Brittberg M: Evaluation of cartilage injuries and cartilage repair. *Osteologie* 9:17–25, 2000.

Brittberg M, Peterson L: Introduction to an articular cartilage classification. *CRS Newsl* 1:8, 1998.

Brittberg M, Lindahl A, Nilsson A, et al: Treatment of deep cartilage defects in the knee with autologous chondrocyte transplantation. *N Engl J Med* 331:889–895, 1994.

Bucci L. Chondroprotective agents: Glucosamine salts and chondroitin sulfates. *Townsend Lett Doct* 1:52–54, 1994.

Buckwalter, JA: Articular cartilage injuries. *Clin Orthop* 402:21–37, 2002.

Buckwalter JA, Mankin HJ: Articular cartilage I: Tissue design and chondrocyte-matrix interactions. *J Bone Joint Surg* 79A:600–611, 1997*a*.

Buckwalter JA, Mankin HJ: Articular cartilage II: Degeneration and osteoarthrosis, repair, regeneration, and transplantation. *J Bone Joint Surg* 79A:612–632, 1997*b*.

Buckwalter JA, Mow VC: Cartilage repair in osteoarthritis, in Moskowitz RW, Howell DS, Goldberg VM, Mankin HJ (eds.): *Osteoarthritis: Diagnosis and Management,* 2nd ed. Philadelphia, Saunders 1992, pp 71–107.

Buckwalter JA, Rosenberg LA, Hunziker EB: Articular cartilage: Injury and repair, in Woo SL, Buckwalter JA (eds.): *Injury and Repair of the Musculoskeletal Soft Tissues*. Park Ridge, IL, American Academy of Orthopaedic Surgeons 1988, pp 465–482.

Buckwalter JA, Rosenberg LA, Hunziker EB: Articular cartilage: Composition, structure, response to injury, and methods of facilitation repair, in Ewing JW (ed.): *Articular Cartilage and Knee Joint Function: Basic Science and Arthroscopy*. New York, NY, Raven Press 1990, pp 19–56.

Buckwalter JA, Hunziker EB, Rosenberg LC, et al: Articular cartilage: Composition and structure, in Woo SL, Buckwalter JA (eds.): *Injury and Repair of the Musculoskeletal Soft Tissues*. Park Ridge, IL, American Academy of Orthopaedic Surgeons 1988, pp 405–425.

Bugbee WD: Fresh osteochondral allografting. *Oper Tech Sports Med* 8:158–162, 2000.

Chu CR, Convery FR, Akeson WH, et al: Articular cartilage transplantation. Clinical results in the knee. *Clin Orthop* 360:159–368, 1999.

Cole BJ, Frederick R, Levy A, et al: Management of a 37 year old man with recurrent knee pain. *J Clin Outcomes Manag* 6:46–57, 1999.

Curl W, Krome J, Gordon E, et al: Cartilage injuries: A review of 31,516 knee arthroscopies. Arthroscopy 13:456–460, 1997.

DaCamara CC, Dowless GV: Glucosamine sulfate for osteoarthritis. *Ann Pharmacother* 32:580–587, 1998.

Finerman GAM, Noyes FR (eds.): *Biology and Biomechanics of the Traumatized Synovial Joint: The Knee as a Model*. Rosemont, IL, American Academy of Orthopaedic Surgeons 597, 1992.

Garrett JC: Fresh osteochondral allografts for treatment of articular defects in osteochondritis dissecans of the lateral femoral condyle in adults. *Clin Orthop* 303:33–37, 1994.

Ghazavi MT, Pritzker KP, Davis AM, et al: Fresh osteochondral allografts for post-traumatic osteochondral defects of the knee. *J Bone Joint Surg* 79B:1008–1013, 1997.

Gill TJ, MacGillivray JD: The technique of microfracture for the treatment of articular cartilage defects in the knee. *Oper Tech Sports Med* 11:105–107, 2001.

Gill TJ, Steadman JR, Rodrigo JJ, et al: Indications and long-term clinical results of microfracture. *2nd Symp Int Cartilage Repair Soc*, Boston, MA, November, 1998.

Gillogly SD, Voight M, Blackburn T: Treatment of articular cartilage defects of the knee with autologous chondrocyte implantation. *J Orthop Sports Phys Ther* 28:241–251, 1998.

Gosh P: Second-line agents in osteoarthritis, in Dixon JS and Furst DE (eds.). Second Line Agents in the Treatment of Rheumatic Diseases. New York, NY, Marcel Dekker 1992, pp 363–427.

Grande D, Pitman M, Peterson L, et al: The repair of experimentally produced defects in rabbit articular cartilage by autologous chondrocyte implantation. *J Orthop Res* 7:208–218, 1997.

Gross AE: Fresh osteochondral allgorafts for post-traumatic knee defects: Surgical technique. *Oper Tech Orthop* 7:334, 1997.

Gross AE, Aubin P, Cheah HK, et al: A fresh osteochondral allograft alternative. *J Arthroplasty 17, Suppl* 1:50–53, 2002.

Hangody L, Feczki P, Bartha L, et al: Mosaicplasty for the treatment of articular defects of the knee and ankle. *Clin Orthop 391 Suppl* S328–S336, 2001.

Hangody L, Kish G, Karpati Z, et al: Mosaicplasty for the treatment of articular cartilage defects: application in clinical practice. *Orthopedics* 21:751–756, 1998.

Hjelle K, Solheim E, Strand T, et al: Articular cartilage defects in 1,000 knee arthroscopies. *Arthroscopy* 18:730–734, 2002.

Hubbard MJ: Articular debridement versus washout for degeneration of the medial femoral condyle. A five-year study. *J Bone Joint Surg* 78B:217–219, 1996.

Jackson RW: Meniscal and articular cartilage injury in sport. *J R Coll Surg Edinb* 34:S15–S17, 1989.

Khanna BAJ, Cosgarea AJ, Mont MA, et al: Magnetic resonance imaging of the knee. Current techniques and spectrum of disease. *J Bone Joint Surg 83A, Suppl 2 Pt* 2:128–141, 2001.

Kish G, Modis L, Hangody L: Osteochondral mosaicplasty for the treatment of focal chondral and osteochondral lesions of the knee and talus in the athlete. Rationale, indications, techniques, and results. *Clin Sports Med* 18:45–66, 1999.

Mandelbaum BR, Romanelli DA, Knapp TP: Articular cartilage repair: Assessment and classification. *Op Tech Sports Med* 8:90–97, 2000.

Martin JA, Buckwalter JA: The role of chondrocyte-matrix interactions in maintaining and repairing articular cartilage. *Biorheology* 37:129–140, 2000.

Meyers MH, Akeson W, Convery F. Resurfacing of the knee with fresh osteochondral allograft. *J Bone Joint Surg* 71A:704–713, 1989.

Micheli LJ, Browne JE, Erggelet C, et al: Autologous chondrocyte implantation of the knee: Multicenter experience and minimum 3-year follow-up. *Clin J Sports Med* 11:223–228, 2001.

Minas T: Autologous chondrocyte implantation for focal chondral defects of the knee. *Clin Orthop* 391:S349–S361, 2001.

Muller-Fassbender H, Bach GL, Haase W, et al: Glucosamine sulfate compared to ibuprofen in osteoarthritis of the knee. *Osteoarthritis Cartilage* 2:61–69, 1994.

Outerbridge RE: The etiology of chondromalacia patellae. *J Bone Joint Surg* 43B:752–757, 1961.

Owens BD, Stickles BJ, Balikian P, et al. Prospective analysis of radiofrequency versus mechanical debridement of isolated patellar chondral lesions. *Arthroscopy* 18:151–155, 2002.

Peterson L, Brittberg M, Kiviranta I, et al: Autologous chondrocyte transplantation. Biomechanics and long-term durability. *Am J Sports Med* 30:2–12, 2002.

Peterson L, Minas T, Brittberg M, et al: Two- to 9-year outcome after autologous chondrocyte transplantation of the knee. *Clin Orthop* 374:212–234, 2000.

Sprague NF, 3rd: Arthroscopic debridement for degenerative knee joint disease. *Clin Orthop* 160:118–123, 1981.

Steadman JR, Briggs KK, Rodrigo JJ, et al: Outcomes of microfracture for traumatic chondral defects of the knee: Average 11-year follow-up. *Arthroscopy* 19:477–484, 2003.

Steadman JR, Rodkey WG, Rodrigo JJ. Microfracture: Surgical technique and rehabilitation to treat chondral defects. *Clin Orthop* 391:S362–S369, 2001.

Steadman JR, Rodkey WG, Singleton SB, et al: Microfracture technique for full-thickness chondral defects: technique and clinical results. *Operative Tech Orthop* 7:300–304, 1997.

Timoney JM, Kneisl JS, Barrack RL, et al: Arthroscopy update #6. Arthroscopy in the osteoarthritic knee. Long-term follow-up. *Orthop Rev* 4:371–3, 376–9, 1990.

Tomford WW: Chondroprotective agents in the treatment of articular cartilage degeneration. *Oper Tech Sports Med* 8:120–121, 2000.