Treatment of Glenohumeral Arthrosis

Karen J. Boselli, Christopher S. Ahmad and William N. Levine

Am J Sports Med 2010 38: 2558 originally published online June 3, 2010
DOI: 10.1177/0363546510369250

Treatment of Glenohumeral Arthrosis

CME

Karen J. Boselli,* MD, Christopher S. Ahmad,* MD, and William N. Levine,*† MD
Investigation performed at Center for Shoulder, Elbow and Sports Medicine, Columbia University Medical Center, New York, New York

The successful diagnosis and treatment of glenohumeral arthrosis in the young and active patient can be challenging to even the most experienced of clinicians. A thorough preoperative evaluation, including a detailed understanding of patient expectations, facilitates the selection of a treatment strategy. Arthroscopy is the gold standard for detecting chondral injuries, and it is increasingly used as an effective first line of management. In patients who fail arthroscopic debridement and reparative techniques, further treatment should proceed with an algorithmic decision-making approach encompassing patient-based and disease-based factors. Restorative and reconstructive techniques may provide improvements in pain and functional outcome while delaying the need for total shoulder arthroplasty, although the longevity of these treatments has yet to be established in the literature. Hemiarthroplasty and total shoulder arthroplasty have historically proven to be the most durable and reliable options in properly selected patients. However, concerns about progressive glenoid erosion and glenoid component loosening have led many to pursue alternative nonarthroplasty techniques for the management of arthrosis in active young individuals.

Keywords: glenohumeral arthrosis; treatment; nonarthroplasty

Glenohumeral arthrosis presents a diagnostic and therapeutic challenge to the orthopaedic surgeon, and the treatment of this condition, in both early and late stages, is often controversial. Total shoulder arthroplasty has proven to be a durable option for pain relief and function in most patients,[27] and the incidence of prosthetic shoulder replacement is steadily increasing in the United States.[43] However, in an ever-rising group of individuals—especially, those who are physiologically young and active—results of hemiarthroplasty and total shoulder arthroplasty are not as reproducible,[69,72] which has led to the use of alternative techniques in the management of patients with symptomatic glenohumeral chondral loss.[20,53] Ideally, these alternative management strategies provide the active patient with lasting pain relief and maximal function.[53]

The goal of this review is to present the treatment options for management of glenohumeral arthritis in the young and active patient. A detailed discussion on the use of hemiarthroplasty and total shoulder arthroplasty for the management of end-stage arthrosis is beyond the scope of this review, which instead focuses on alternative arthroplasty and nonarthroplasty management strategies.

†Address correspondence to William N. Levine, MD, 622 West 168th Street, PH-1117, New York, NY 10032 (e-mail: wnl1@columbia.edu).
*Center for Shoulder, Elbow and Sports Medicine, Columbia University Medical Center, New York, New York.
The authors declared that they had no conflicts of interests in their authorship and publication of this contribution.

The American Journal of Sports Medicine, Vol. 38, No. 12
DOI: 10.1177/0363546510369250

BACKGROUND

Arthrosis of the shoulder is common and may result in pain, loss of function, and diminished quality of life.[68] The common thread among all glenohumeral arthritides is that of progressive and irreversible articular destruction,[20] often accompanied by secondary involvement of the surrounding soft tissues. Initially, the soft tissue involvement may include only the synovium but can progress to involve the joint capsule, glenohumeral ligaments, and adjacent rotator cuff tendons. The progression of arthrosis is then influenced by the specific disease process as well as the extent of mechanical joint loading.[44]

The exact incidence and natural history of glenohumeral arthrosis are unknown. During routine arthroscopy, chondral injury may be encountered in 5% to 17% of patients.[32,60] Gartsman and Taverna,[32] in a retrospective review of 200 patients undergoing arthroscopy for full-thickness rotator cuff tears, found that 13% had coexisting chondral injuries, with 5% having major lesions defined as 150 mm^2 in size. Many articular lesions seem to be incidental and well tolerated, and even large chondral injuries may never become symptomatic.[24] However, unlike most major joints in which the pain of arthrosis is secondary to osteoarticular destruction, the shoulder is more often affected by coexisting abnormalities of the periarticular soft tissues. The clinical course of arthrosis is therefore likely to be more dependent on its specific cause and concomitant joint injury or disease.[24]

Although primary osteoarthritis of the shoulder is relatively uncommon, there is a wide spectrum of secondary causes of glenohumeral arthrosis. Chondral damage may be secondary to trauma, instability, postsurgical arthrosis,

avascular necrosis, or inflammatory arthropathy.[7,24,53] Overhead athletes—especially, those with internal impingement—suffer recurrent microtrauma to the shoulder and may have rates of chondral injury as high as 17%.[60] Dislocation, acute and recurrent, has also been associated with chondral shear injury of the glenoid and osteochondral injury of the humeral head in 47% to 100% of patients.[18,40,58] Hovelius and Saeboe[42] recently evaluated the natural history of chondral injury after dislocation, demonstrating moderate or severe arthropathy at 25-year follow-up in 39% of patients with recurrent instability. Risk factors for arthropathy after dislocation include age at primary dislocation, recurrence, participation in high-energy sports, and increased time from initial dislocation until surgery.[17,21,42] Surgical procedures for the correction of instability have been associated with the development of capsulorrhaphy arthropathy as well, most often reported after nonanatomic techniques, including the Bristow and Putti-Platt.[39,41,69]

Other less common secondary sources of chondral damage include osteochondritis dissecans, chondrolysis, and iatrogenic injury.[53] Osteochondritis dissecans of the shoulder is uncommon, most often seen in young to middle-aged males at the anterosuperior humeral head. Although some patients have a history of repetitive microtrauma to the shoulder, in most cases the exact cause is unknown.[38] Iatrogenic damage from anchor placement has been reported, owing to either mechanical destruction[2] or poly(L-lactide) synovitis.[30] Chondrolysis secondary to thermal capsulorrhaphy and bupivacaine pain catheters has also been described.[3,46]

CLINICAL EVALUATION

The shoulder is often affected by the complex interaction of potential pain generators surrounding the glenohumeral joint, which may complicate the diagnosis of a symptomatic chondral lesion.[24] Arthrosis is not a typical cause of shoulder pain, and the diagnosis is often one of exclusion, after other more common pathologic conditions of the shoulder are ruled out.[24] Symptoms may be nonspecific, and pain is often vague, mimicking other shoulder conditions and making it difficult to identify the true source of dysfunction.[7] Pain will often interfere with sleep, and a loss of mobility is a frequent initial complaint. Mechanical symptoms are often present, including catching and clicking.[24,44] Specific inquiries should be made regarding direct traumatic injury to the shoulder, including fracture, dislocation, or previous surgery, given that they suggest the presence of chondral injury.[53]

On physical examination, chondral injuries may closely mimic the symptoms of other intra-articular and extra-articular shoulder conditions, including subacromial impingement, biceps tenosynovitis, and labral tears.[29,59,77] The patient should be visually inspected for any evidence of muscular atrophy, and bony prominences (including the anterior and posterior joint lines) should be assessed for tenderness.[79] Active and passive range of motion should be carefully documented, given that the presence of restricted or painful motion may help to determine diagnosis and treatment.[79] Although pain at the extremes of motion suggests traditional subacromial impingement, exacerbation of pain at the midrange of motion is more suggestive of inflammation or articular damage. Mechanical symptoms during motion may be consistent with the presence of chondral damage. The presence of a chondral injury may yield a positive result to a compression-rotation test in which the humeral head is manually compressed into the glenoid by the examiner while the patient internally and externally rotates the arm.[29] The test can be made more specific with a subacromial lidocaine injection; if pain with forward elevation is eliminated, continued pain with compression-rotation suggests chondral injury rather than impingement.[29]

A careful history and physical examination should be accompanied by appropriate imaging studies. Plain radiographs should always be obtained, including a true anteroposterior in the plane of the scapula (in neutral and external rotation), axillary lateral, and scapular-Y lateral view.[35] Typical radiographic findings of joint space narrowing and subchondral sclerosis or cyst formation may not be present, especially in early stages of the disease.[19] However with the beam orthogonal to the glenohumeral joint surface and the humerus externally rotated, subtle narrowing of the glenohumeral joint and small marginal humeral osteophytes can often be detected, especially on the inferior medial aspect of the humeral head. An axillary lateral or Stryker notch view should be closely examined for evidence of Hill-Sachs lesions at the posterosuperior humeral head.[24,53] A West Point or apical oblique view may allow for visualization of bony lesions at the anterior-inferior glenoid.

In addition to standard radiographs, advanced imaging techniques can often more accurately determine the extent of glenohumeral involvement.[20] Computed tomography is the modality of choice for evaluation of bony anatomy, and it can occasionally aid in characterization of osteochondritis dissecans or traumatic osseous lesions. It can also help to determine glenoid morphologic characteristics and version as well as the pattern of bone loss and quantity of glenoid bone stock.[20] Magnetic resonance imaging (MRI) is the best preoperative tool for evaluating early chondral abnormalities.[7,20] Early in the inflammatory process, MRI may demonstrate synovial proliferation or joint effusion. With more advanced disease, the severity of subchondral changes and osteoarticular destruction can be estimated (Figure 1). Perhaps more important, MRI allows for identification of coexistent intra-articular and extra-articular abnormalities. This information on the surrounding soft tissue structures can be especially valuable for consideration of concomitant diagnoses and for preoperative planning.

The specific assessment of cartilage on MRI is technically challenging, especially in the shoulder, where cartilage of the humeral head and glenoid is relatively thin.[34] Chondral injuries may be difficult to detect unless changes in subchondral bone are present. Consequently, there is a tendency to underestimate the severity of cartilage destruction on MRI as compared with

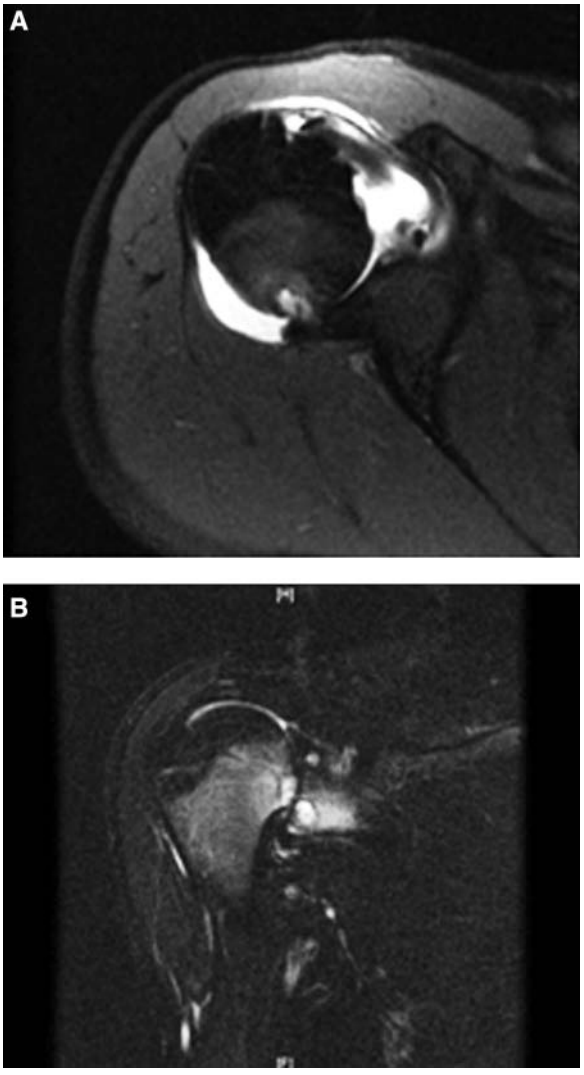

Figure 1. A, axial MRI image of a 22-year-old woman demonstrating full-thickness cartilage loss and a subchondral cyst at the posterior aspect of the humeral head; B, coronal oblique MRI image of the same patient, with cyst formation visible at the glenoid and humeral head. Underlying bony edema is also apparent.

direct observation at arthroscopy.[34] Although magnetic resonance arthrogram may be more effective in the detection of intra-articular abnormalities by increasing the contrast between cartilage and synovial fluid,[36] whether it can increase sensitivity or specificity as compared with other standard pulse sequences is currently unclear.[34]

NONSURGICAL MANAGEMENT

Nonsurgical modalities are a mainstay of treatment for early glenohumeral arthrosis and should focus on reduction of pain and improvement in range of motion. Given that nonsurgical care may be effective in palliating symptoms, it should be considered a first-line treatment, especially in low-demand patients with subacute onset of symptoms. It may also be the treatment of choice for patients who are inappropriate surgical candidates because of medical comorbidities.[68]

Before the initiation of any treatment, patients with chondral injuries must be educated about the implications of their diagnosis. The goals of treatment and anticipated long-term prognosis should be discussed at length to appropriately manage patient expectations. Education may also discourage the patient from participating in activities that are detrimental to the damaged joint and encourage the appropriate adjustment of work and activity level.

Nearly all patients with glenohumeral arthrosis can benefit from physical therapy in regard to pain alleviation and improvement in function. This may be especially true in patients with restricted motion and weakness, in spite of minor radiographic changes. Ideally, therapy should be initiated before the development of atrophy or contracture, and it should be tailored to the specific needs of the patient. Typical programs include gentle range of motion and isometric strengthening of the rotator cuff and scapulothoracic musculature.[11,53] A continuous maintenance program should be emphasized, along with a gradual return to activity. Occupational therapy should also be considered for patients with significant functional limitations at home and in the workplace.

Medical management of arthritis includes salicylates, acetaminophen, and nonsteroidal anti-inflammatory drugs, which can all be effective in relief of pain and inflammation. Unfortunately, nonsteroidal anti-inflammatory medications have drawn negative attention owing to their risk of gastrointestinal, renal, and cardiac toxicity.[8] In spite of these potential side effects, nonsteroidal anti-inflammatory drugs (including selective cyclooxygenase-2 inhibitors) are a mainstay in the treatment for arthritic symptoms in properly selected patients. Narcotics are not typically prescribed, because they are not universally effective and they carry risks, including constipation, dizziness, and addiction. In addition to standard medical management, chondroprotective agents, including chondroitin and glucosamine sulfate, may have a role in the nonoperative management of arthrosis. Although there are no peer-reviewed reports on the use of these agents in the shoulder, a recent meta-analysis suggested probable efficacy, with moderate to large effects in the hip and knee.[52]

Corticosteroid injections, intra-articular and subacromial, have diagnostic and therapeutic use in managing patients with glenohumeral chondral damage.[9] Corticosteroids are especially therapeutic for patients with inflammatory arthropathy but less predictable in patients with osteoarthritis.[53] In addition to relieving symptoms from intra-articular chondral injury, these injections can treat coexisting subacromial lesions or adhesive capsulitis.[9] Unfortunately, pain relief is often temporary in patients with significant chondral involvement.

Viscosupplementation has proved efficacy in treating knee arthritis, but until recently only anecdotal reports existed on use in the shoulder. Hyaluronic acid is

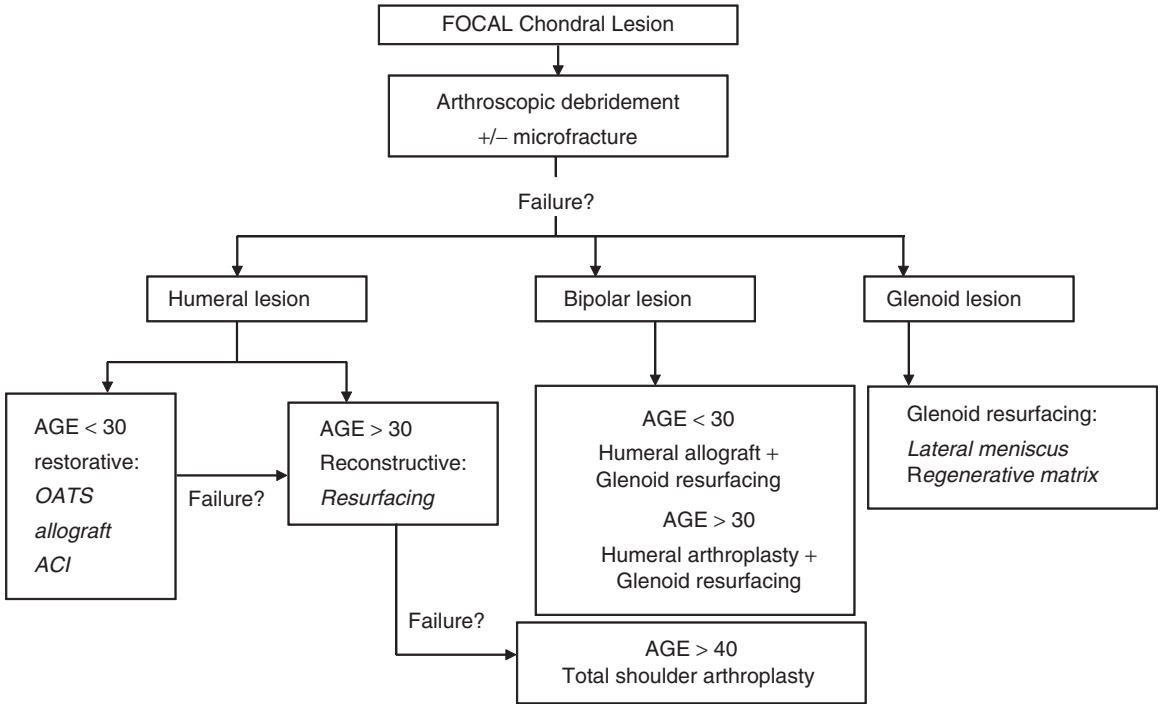

Figure 2. Algorithm for the management of focal chondral lesions. OATS, osteochondral autograft transfer; ACI, autologous chondrocyte implantation.

a naturally occurring polysaccharide that forms the backbone of the proteoglycan aggregates in synovial fluid, and it is integral in the structure and function of articular cartilage. It directly affects the viscoelasticity of synovial fluid by lowering the coefficient of friction, which helps to protect against compressive and shear forces.[68] The concentration and molecular weight of hyaluronic acid are reduced in osteoarthritis, leading to increased shear stress at the articular surface. In the shoulder, recent studies have suggested that these compounds are safe and effective.[8,68] Blaine et al[8] performed a randomized double-blind study of 456 patients treated with sodium hyaluronate in the shoulder, reporting improved pain relief in control patients. A sustained placebo effect was, however, seen in 28% of patients. The authors concluded that the origin of the pain was critical in determining the therapeutic effect of hyaluronic acid, given that patients with a diagnosis of osteoarthritis experienced significantly more pain relief than did individuals with other diagnoses.[8]

SURGICAL MANAGEMENT

The mere presence of a chondral lesion does not necessitate operative treatment; to be considered a surgical candidate, a patient must have symptoms that are consistent with the nature and location of the chondral damage. For those with a confirmed symptomatic chondral injury, based on physical examination and imaging studies, who have already exhausted nonoperative measures, surgical intervention is warranted.[20,24] The choice of treatment then depends on numerous patient-based and disease-based factors. Patient-based considerations include age, occupation, activity level, and (often most important) the expectations for functional recovery.[24] Disease-based considerations include the cause of the chondral damage as well as the lesion size and the extent of chondral involvement.[79]

The treatment of focal chondral lesions can be stratified on the basis of size, depth, and the presence of unipolar versus bipolar involvement (Figure 2). Smaller, superficial unipolar chondral lesions tend to respond to reparative techniques, including abrasion, microfracture, and drilling. Larger and deeper unipolar lesions often require restorative techniques, such as osteochondral allograft.[53] Focal bipolar lesions may necessitate arthroplasty or soft tissue interposition. In the treatment of diffuse or nonfocal lesions, patient age and activity level are important considerations (Figure 3). Chondral damage involving both the humeral head and the glenoid in a young patient may require soft tissue interposition or hybrid arthroplasty-interposition procedures. In the older patient with diffuse involvement, total shoulder arthroplasty remains the standard of treatment for symptomatic glenohumeral arthritis.[7] The surgical options presented in the remainder of this review all serve to delay the need for total shoulder arthroplasty, especially in physiologically young and active individuals.

Arthroscopy

With few complications and low morbidity, arthroscopy has become increasingly accepted as an option in the

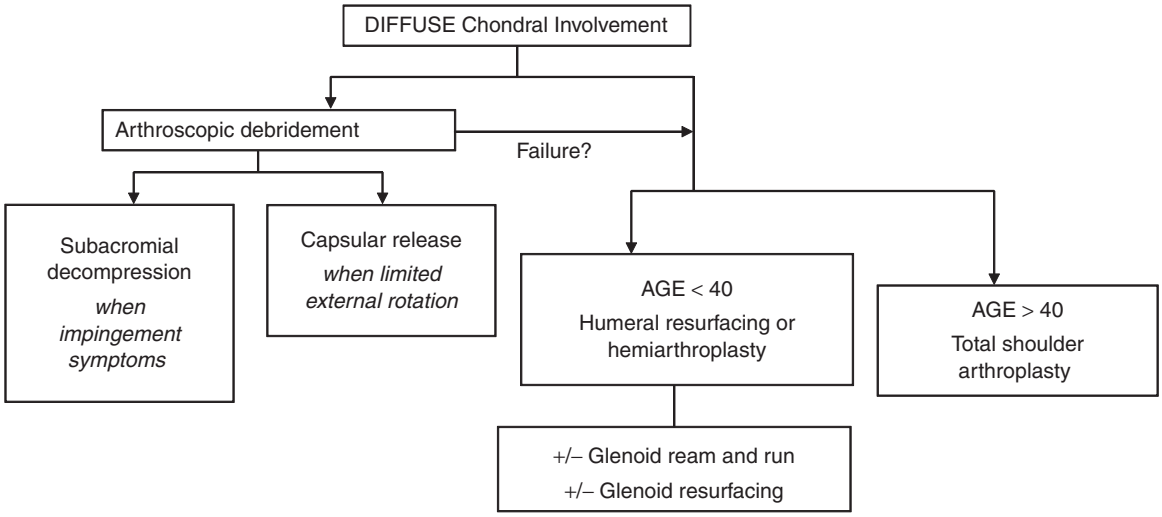

Figure 3. Algorithm for the management of diffuse glenohumeral chondral injury.

management of glenohumeral arthritis of varying origins.[7,20] From a diagnostic standpoint, arthroscopy is the gold standard for the identification and characterization of chondral injury in the shoulder.[20,53] Although the ideal therapeutic indications for arthroscopy in the arthritic patient are difficult to define, it does play an important role in a select group of individuals.[7,59]

Chondral injury is often a secondary finding during surgical arthroscopy for a different primary diagnosis. The presence of incidental early arthritis is not a contraindication to performing procedures for concomitant abnormalities, as long as the surgeon is confident about the primary diagnosis based on thorough preoperative examination and imaging studies.[19,37] Because the clinical significance of early chondral lesions and their likelihood of progression is unknown,[7,20] it is important to identify and treat the primary shoulder condition, including subacromial impingement, acromioclavicular arthropathy, capsular contracture, rotator cuff tear, biceps tendon lesions, or labral injury.[20,24,37]

Debridement. Arthroscopic debridement should be considered a palliative measure for patients with mild or moderate glenohumeral arthrosis.[77] Just as the clinical significance of early chondral lesions is not well understood, it is likewise unknown whether arthroscopy can alter the natural history of degeneration or decrease the probability of disease progression. The goal of debridement should therefore be to improve the intra-articular environment through lavage and removal of loose fragments in the presence of irreparable chondral injury.[24,59,77] Symptomatic relief from arthroscopy is usually transient, however, and patients should be appropriately counseled on the realistic expectations of surgery.[19,29,53,77]

Arthroscopic debridement may have a role in the early management of focal and nonfocal glenohumeral lesions. Although the indications for the procedure are not completely established in the literature, it is thought to be best suited for patients with mild degenerative disease and limited chondral injury.[19,59] The best candidates for arthroscopic debridement have preservation of the joint space, with little to no subchondral sclerosis, cyst, or osteophyte formation. Furthermore, to increase the likelihood of a successful postoperative outcome, patients should ideally have a well-centered and congruent joint. Debridement is relatively contraindicated in patients with biconcave posterior erosion of the glenoid.[19,24] Finally, patients with mechanical symptoms from loose bodies or inflammatory synovitis are also excellent candidates for arthroscopic intervention.[7]

Complete arthroscopic debridement begins with the documentation of all chondral injuries, with the camera positioned in standard posterior and anterior portals[53] (Figure 4). All areas of abnormal cartilage should be probed, including margins of chondral defects and transition zones. The size of any focal chondral lesions should be carefully documented.[53] Cartilaginous flaps should be debrided to a stable rim to prevent mechanical engagement. After the chondral injury is addressed, the joint should be closely inspected for evidence of loose bodies, including the subscapularis recess and axillary pouch. All degenerative labral and rotator cuff tissue should be removed, and reactive synovial or bursal tissue debrided.[20] A thorough synovectomy is especially important in patients with inflammatory arthritis.[7,24] If present, osteophytes at the inferior humeral head or glenoid can be removed with a bur.

Arthroscopic debridement and lavage can provide short-term pain relief in 70% to 88% of patients, although results are inconsistent and, unfortunately, appear to deteriorate with time.[19,37,77] Weinstein et al[77] reported good and excellent results in 78% of individuals at an average of 30 months after arthroscopic debridement and subacromial bursectomy. In the patients with an unsatisfactory outcome, some degree of pain relief was reported for a minimum of 8 months before deterioration. The authors recommended arthroscopy for mild chondral disease, with preservation of joint space and glenohumeral concentricity, while discouraging it in the management of advanced osteoarthritis. Others

have reported similar results directly related to the severity of osteochondral injury, showing inferior outcomes with severe arthrosis and bipolar chondral involvement.[19,59,77] Cameron et al[19] evaluated arthroscopic debridement in patients with grade IV osteochondral lesions, finding an overall 88% rate of postoperative improvement. Of the patients with recurrent pain, 85% had chondral lesions exceeding 2 cm^2 in size and 61% had bipolar articular involvement. Size of the chondral lesion therefore appears to be the best independent predictive variable for patients at risk for clinical failure.[19]

Microfracture. In patients with focal cartilaginous defects and an intact subchondral plate, arthroscopic reparative procedures (in addition to debridement) are a reasonable first-line treatment consideration (Figure 2). These reparative procedures, including abrasion, microfracture, and drilling, are marrow-stimulating techniques designed to produce fibrocartilage at the site of chondral injury. Although smaller lesions can occasionally be addressed with abrasion arthroplasty, the technical difficulty of this procedure should not be underestimated. With limited portals, it is difficult to maintain even distribution of pressure on the concave glenoid or convex humeral head.[24] Therefore, microfracture is more often advised in the early treatment of focal-contained defects (Figure 5). Whether healing of lesions with fibrocartilage is a success or failure, at the least microfracture does not preclude future use of cartilage reconstructive procedures.[24] Microfracture, however, is not an appropriate choice for osteochondral lesions with violation or loss of the subchondral bone.

Although the majority of literature on reparative procedures relates to the knee,[38] similar principles may be extrapolated for use in small isolated defects of the shoulder.[7,73] The lesion should first be debrided to a stable base with vertical walls, and all areas of exposed bone gently scraped with a curette (Figure 6A). Once a stable rim of cartilage has been obtained,[24] awls can be used to penetrate the prepared surface through the subchondral plate with 2 to 3 mm of spacing.[73] Care should be taken to prevent confluence of holes in the softer bone of the humeral head. When pump inflow is stopped, bleeding should be seen from the individual holes (Figure 6B). Blood carries mesenchymal stem cells into the prepared bony bed, forms a fibrin scaffold, and initiates the fibrocartilaginous healing response.[53]

Subacromial Decompression and Capsular Release. In patients with diffuse glenohumeral degeneration, debridement is infrequently performed as an isolated procedure because the chondral injury often coexists with other pathologic conditions of the shoulder.[7,20] Good results have been reported when debridement is combined with bursectomy and subacromial decompression, capsular release, distal clavicle excision, labral debridement, and debridement of partial rotator cuff tears[19,37,59] (Figure 3).

Subacromial decompression is indicated for patients with mild to moderate arthrosis and concomitant impingement symptoms. Interestingly, patients with the signs and symptoms of subacromial impingement may have a higher overall prevalence of chondral lesions at the time of arthroscopy, which are often not apparent on preoperative clinical and radiographic evaluation.[36] To determine the efficacy of arthroscopic decompression in this subgroup of individuals, Guyette et al[37] performed a retrospective review of 36 patients undergoing subacromial decompression with concomitant glenohumeral degenerative changes. Minor glenohumeral changes (grades I to III) were found to be predictive of satisfactory outcomes, whereas severe glenohumeral changes (grade IV) produced uniformly poor results. Although subacromial decompression can consistently improve shoulder function in appropriately selected patients, careful consideration should be exercised in patients with suspected full-thickness cartilage loss.

In those patients with mild degenerative changes and capsular contracture, capsular release is another important surgical consideration; debridement alone will not relieve pain and restore motion in these individuals.[7,19,20,53] It is likely most effective in patients with (1) limited external rotation, compared with that of the contralateral side; (2) mild to moderate arthrosis with no inferior humeral osteophyte formation; and (3) a concentric glenoid.[39] Capsular release is recommended when the patient has lost 15° to 20° of motion in any plane (especially internal and external rotation) as compared with the unaffected side.[19,39] The possibility of capsular release should be discussed with the patient preoperatively; assessment of motion can then be performed under anesthesia at the time of surgery.[20]

If arthrosis has developed as a late complication after capsulorrhaphy for anterior instability, capsular release is also indicated.[7,39] The abnormally tight anterior capsule after instability repair produces abnormal glenohumeral motion, with excess stress on the cartilaginous surfaces. Anterior capsular release may provide moderate pain relief and improvement in motion while slowing the progression of arthrosis and glenoid erosion.[39] In general, if external rotation lacks 20° as compared with that of the contralateral shoulder, arthroscopic capsular release can be performed with symptomatic benefit.[59] Capsular release alone should not be performed for patients with contracture after instability procedures that imbricate the subscapularis and anterior capsule. The preferred management in this situation is that of subscapularis lengthening with concomitant capsular release.[19,56,59]

Restorative Procedures

The common goal of restorative procedures is the reestablishment of hyaline or hyaline-like cartilage at the site of chondral injury.[53] Such procedures include osteochondral allograft, autograft, and autologous chondrocyte implantation. All have limited evidence of success in the shoulder, and all have been more thoroughly studied in the knee. Unlike that of the knee, a restorative procedure in the shoulder often requires an open approach. Compared with arthroscopic techniques, morbidity increases secondary to the open approach, as does the potential for donor site complications and the possible need for 2 staged procedures.[24] Patients must be carefully selected; these procedures are best suited for young, active patients with focal unipolar humeral defects that have failed nonoperative or reparative management strategies[24,53] (Figure 2).

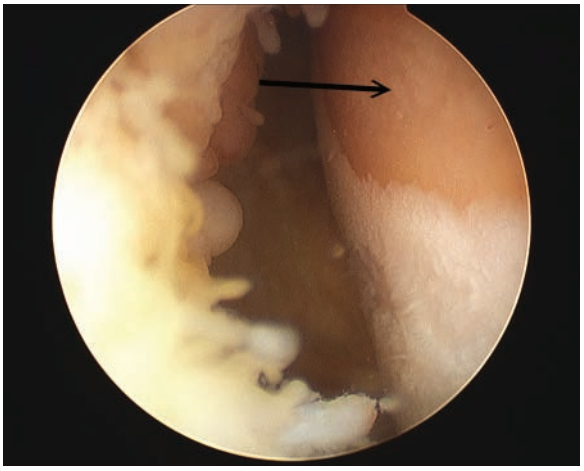

Figure 4. Arthroscopic view of the right shoulder from the posterior viewing portal in the beach chair position. There is complete loss of articular cartilage at the superior half of the humeral head (arrow). The patient wished to avoid arthroplasty and was therefore managed with arthroscopy, chondroplasty, synovectomy, and subacromial decompression.

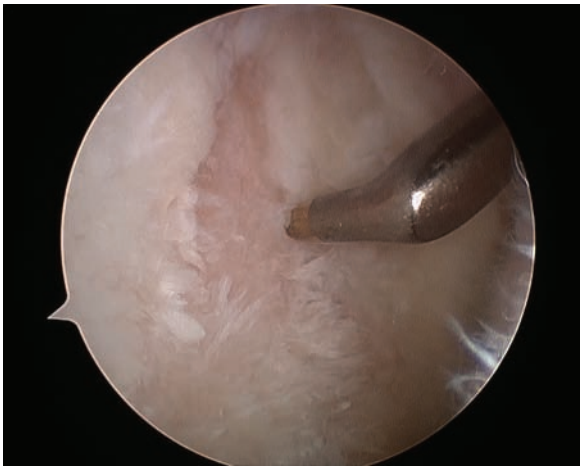

Figure 5. Arthroscopic view of the right shoulder from a posterior viewing portal, in the beach chair position. The patient is a 31-year-old former elite wrestler with grade IV chondral injury at the inferior half of the glenoid. The lesion was managed with chondroplasty, debridement, and microfracture.

Osteochondral Autograft and Allograft. As compared with the reparative treatment strategies that require an intact subchondral plate, osteochondral autograft and allograft procedures are unique in their ability to restore bone and cartilage deficiency. Mosaicplasty has had excellent results in the knee but has been studied on a limited basis in the shoulder. Scheibel et al[67] reported on a small series of osteochondral transplantations from the knee to the shoulder for grade IV traumatic lesions with a mean area of 150 mm^2. At an average follow-up of 32 months, MRI demonstrated incorporation in 7 of 8 grafts, with congruent articular cartilage at the transplantation site. Only 1 patient experienced a donor site complication, which did require reoperation. In spite of postoperative improvement in pain scores, the technique did not seem to alter the development of osteoarthritic changes.[67]

The main limitations of autograft transplantation include donor site morbidity and the limited quantity of osteochondral tissue available for transfer.[53] Allograft procedures are conceptually similar to autografts, using a donor plug and matching recipient site; however, the quantity of tissue available is not limited, and donor site morbidity is eliminated. Furthermore, allograft reconstructions are more suitable for deep and unconstrained defects.[24] Although the technique is still investigational in the shoulder, many of the established principles in knee surgery may be applied. Preoperative radiographs should be measured with a marker to obtain size-matched fresh allograft humeral head tissue,[24] which should ideally be used within 14 to 28 days, after which cell viability and metabolic activity decline.[80] With specialized instrumentation, a press fit of the plug into the donor site can be achieved; however, supplemental fixation can be added if necessary.

Little data have been published on the use of allograft in the management of glenohumeral arthrosis. Small case series have been reported using allograft bone for the treatment of large Hill-Sachs or reverse Hill-Sachs lesions, after failed instability surgery[22,55] (Figure 7). For defects greater than 40% of the humeral head, femoral head allograft has been reported to restore and maintain stability, with satisfactory functional results.[33] Massive allografts with or without biologic glenoid resurfacing have also been described for complex unipolar and bipolar chondral lesions.[54] Although these larger allografts offer a biologic reconstructive option for young patients with large focal humeral lesions, they do risk avascular necrosis of the remaining humeral head. Further long-term studies on allograft transplantation in the shoulder are needed to assess the durability of results.

Autologous Chondrocyte Implantation. Autologous chondrocyte implantation in the treatment of glenohumeral chondral lesions is an investigational technique at this time. Midterm results in the knee have been promising; however, there are little published data on the use of autologous chondrocyte implantation in the shoulder.[65] At minimum, 2 surgeries are required (at least one open) and there is a risk of donor site morbidity of the knee.

Reconstructive Procedures

In patients with more advanced arthrosis that has failed reparative techniques, it becomes increasingly challenging to find treatments that will provide durable pain relief and improve function.[24] Reconstructive procedures such as humeral resurfacing and glenoid interposition arthroplasty are salvage options for active and young patients who wish to avoid the problems associated with total shoulder arthroplasty—specifically, glenoid loosening.[24,72] Humeral resurfacing is indicated in relatively young and high-demand individuals with focal or diffuse lesions of the humeral head that have failed other treatment measures. Biologic glenoid

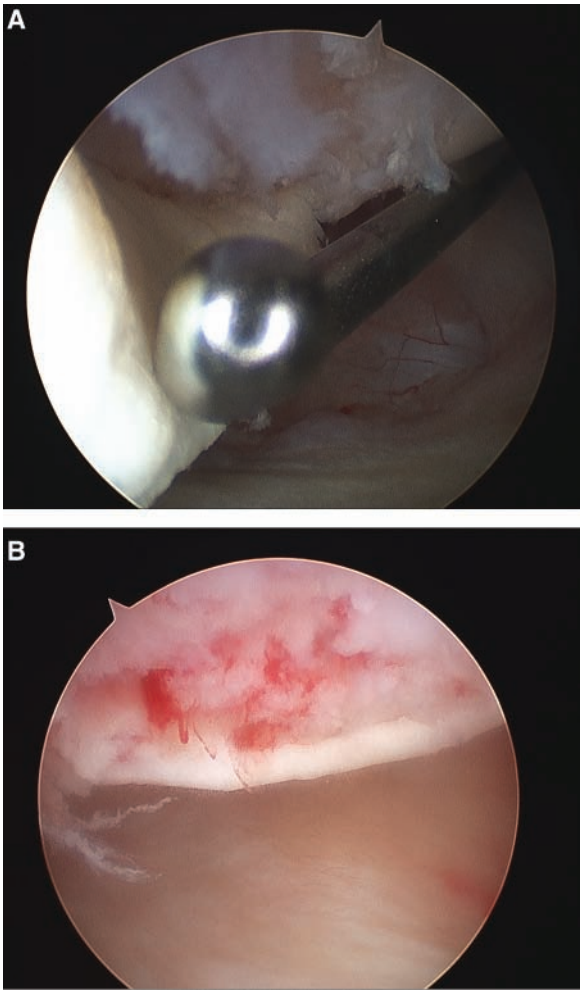

Figure 6. A, arthroscopic image from a posterior viewing portal of the left shoulder in a 39-year-old woman after traumatic injury. The probe is lifting a large chondral flap on the inferior portion of the humeral head. B, view after resection of the devitalized chondral flap to a stable rim, with microfracture of the subchondral bone bed. Note the bleeding from each hole, carrying marrow elements to the site of chondral injury.

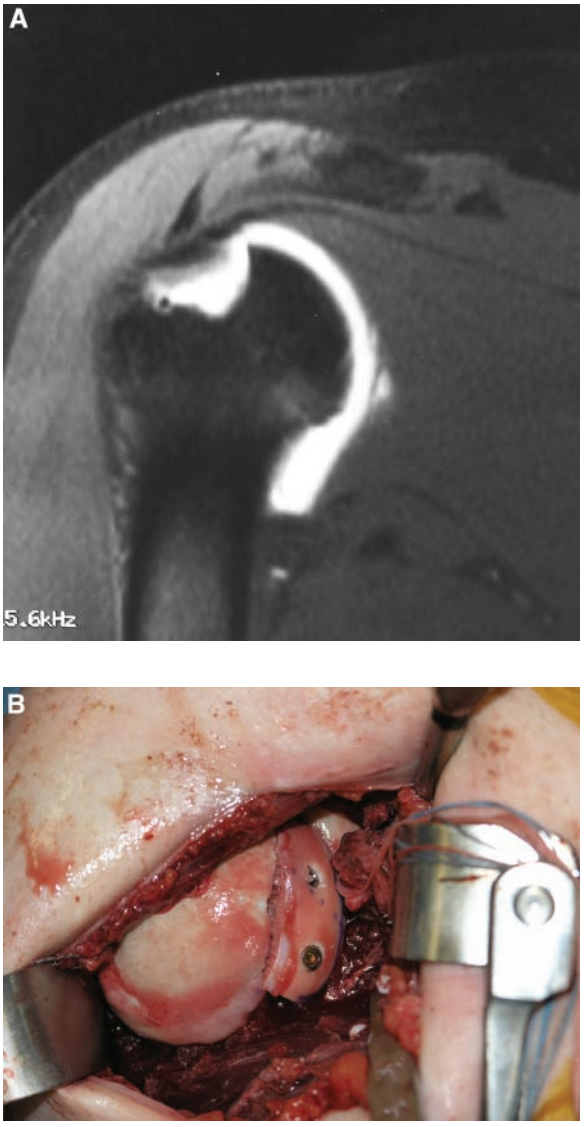

Figure 7. A, coronal MRI demonstrating large Hill-Sachs lesion in a patient with recurrent instability. There is approximately 30% involvement of the humeral head. B, intraoperative view of allograft affixed at the site of chondral injury with 2 countersunk screws.

resurfacing is indicated (1) for the treatment of focal glenoid chondral lesions and (2) for bipolar or diffuse chondral lesions as part of a hybrid arthroplasty-interposition technique (Figures 2 and 3). Preoperatively, patients must understand that these are salvage techniques for pain relief and some restoration of function and that they cannot withstand vigorous activities in the long term. Fortunately, most reconstructive procedures do not preclude later conversion to total shoulder arthroplasty.

Humeral Resurfacing. Cementless humeral resurfacing has recently gained popularity as a bone-preserving alternative to traditional stemmed hemiarthroplasty.[4] The procedure is indicated in relatively young patients with either (1) focal or diffuse lesions of the humeral head that have failed other treatment measures who may benefit from preservation of proximal humeral bone stock or (b) bipolar or diffuse chondral injury as part of a hybrid arthroplasty-interposition procedure. It may also be appropriate for young patients with failure of humeral restorative techniques.

Resurfacing was initially proposed as treatment for arthrosis that would preserve native anatomy and avoid humeral head resection.[14] As opposed to a standard humeral osteotomy, it requires reaming of the humeral head and replacement with a metal cap (Figure 8). The majority of current resurfacing designs are cobalt-chrome alloy with a variably sized central peg. Most have hydroxyapatite or ceramic porous coating for press-fit insertion and

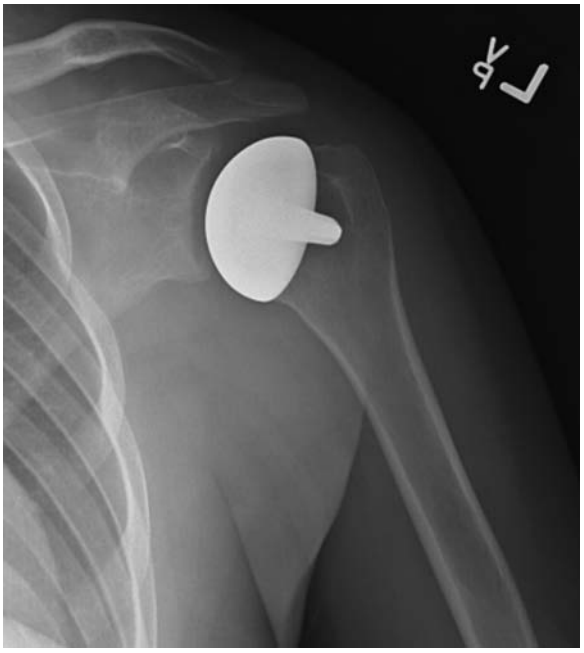

Figure 8. Nineteen-year-old man after humeral resurfacing with lateral meniscus allograft interposition. A true anteroposterior radiograph 3 years postoperatively demonstrates maintenance of the glenohumeral joint space.

later bony ingrowth.[15] When indicated, soft tissue interposition or placement of a conventional polyethylene glenoid can be performed in conjunction with the procedure.[14]

There are numerous potential advantages of humeral resurfacing as compared with conventional stemmed hemiarthroplasty. Because no osteotomy is performed, the humeral inclination, neck-shaft angle, and offset remain nearly anatomic.[4,48,74] There is minimal bone resection involved; operative times are short; and the incidence of periprosthetic fractures is low.[14,74] Cementless resurfacing implants can be easily revised owing to preservation of bone stock and the native humeral canal.[75] In patients with limited preoperative proximal bone stock, surface replacement is contraindicated, given that at minimum, 60% of normal humeral head bone is reportedly necessary to place a stemless implant.[25,75] If there is any question about bone stock adequacy on imaging before surgery, a stemmed implant should be available at the time of the procedure.

Recent studies have indicated favorable results after humeral resurfacing in younger individuals with glenohumeral arthrosis. Bailie et al[4] evaluated functional improvement in patients under the age of 55 years treated with humeral resurfacing. If indicated at the time of surgery, the glenoid was managed with biologic resurfacing or microfracture. At a mean of 2 years postoperatively, all had improved significantly with respect to pain and functional outcomes. Of the 36 patients studied, 35 were satisfied with their outcomes and had returned to their desired levels of activity. Despite the high activity levels of the patients studied, no loosening was demonstrated at the most recent radiographic follow-up.[4]

At midterm follow-up, outcomes of humeral resurfacing appear to be comparable with those of traditional stemmed hemiarthroplasty.[48] Thomas et al[75] reported a 5-year survival of 98.2% in 56 patients with hydroxyapatite-coated surface replacement implants. Osteolysis and subsequent loosening were seen in 3 patients (6.2%), although only 1 was symptomatic and required revision. There was 1 periprosthetic fracture requiring conversion to stemmed hemiarthroplasty. More recently, Buchner et al[13] directly compared the outcomes of 22 patients with surface replacement to a group of matched controls undergoing stemmed hemiarthroplasty. Although mean operative time, estimated blood loss, and length of stay were decreased in the resurfacing group, early outcomes (including the 1-year Constant score) were slightly superior in patients with stemmed arthroplasty. In spite of the inferior early outcomes in the cementless resurfacing patients, the authors suggested that the preservation of bone stock makes cementless surface replacement a viable option for young patients with glenohumeral arthrosis. A prospective study comparing humeral resurfacing with standard hemiarthroplasty or total shoulder arthroplasty has yet to be performed.[13]

Focal humeral resurfacing is an even newer technique designed for the treatment of small or asymmetric unipolar chondral defects. The humeral implant can address lesions of various sizes by matching its shape and size to the articular surface. These partial resurfacing devices have 2 parts that mate: a tapered headless screw and a cobalt-chrome articular component[14] (Figure 9). There are currently few published studies on the outcomes of this technique.[66,76] Uribe and Bemden[76] recently conducted a prospective study of 12 patients treated with HemiCAP (Arthrosurface, Franklin, Massachusetts) for advanced avascular necrosis of the humeral head. At a mean follow-up of 30 months, all patients had significant pain relief, with average visual analog score decreasing from 75 to 16. Significant improvements in range of motion were also reported—specifically, forward elevation, which increased from 94° to 142°. Although early studies present encouraging results, continued evaluation of implant survivorship is needed. The effect of focal resurfacing implants on the glenoid will also need to be addressed.[14]

Glenoid Soft Tissue Resurfacing. Interposition arthroplasty has been reported in the knee and elbow literature as an effective technique resulting in pain relief and improved range of motion.[5,15,16,20] In the glenohumeral joint, a hybrid technique combining hemiarthroplasty with biologic glenoid resurfacing was initially proposed as a means to improve on the results of hemiarthroplasty in young and active patients.[15,72] Adjunctive biologic resurfacing was considered to slow the process of progressive glenoid erosion, which is a major factor in the poor outcomes after hemiarthroplasty in young patients.[47,72,71,82] The goal of resurfacing is therefore to provide pain relief and function equivalent to that of total shoulder arthroplasty while avoiding the potential complications of polyethylene wear and glenoid loosening.[5,15,16,45]

Selection of candidates for glenoid resurfacing is difficult and should be based on the individual patient as

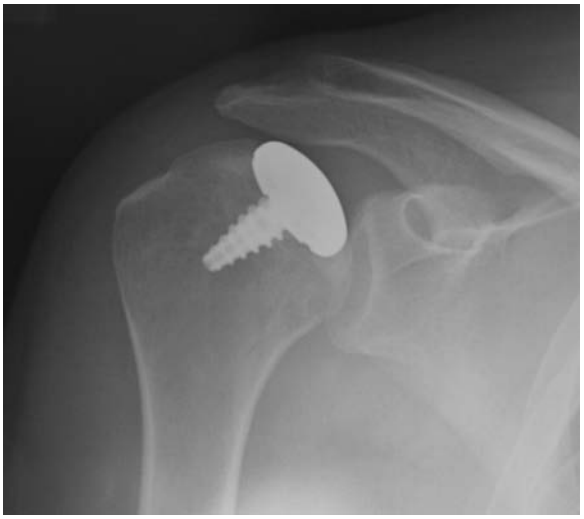

Figure 9. Anteroposterior radiograph demonstrating focal humeral resurfacing implant. The device consists of a tapered headless screw and a cobalt-chrome articular component.

well as the specific disease process. Ideal patients have failed a trial of nonoperative and operative treatments, including arthroscopic palliative or restorative surgery.[53] In young and active patients, the procedure may be indicated for the treatment of focal unipolar glenoid lesions as a means of decreasing contact stresses at the articular surface. Glenoid resurfacing can also be used as a hybrid allograft-interposition or arthroplasty-interposition technique in the management of bipolar or diffuse chondral injury (Figures 2 and 3). The technique is a useful substitute in young patients who might otherwise require a conventional polyethylene glenoid component but in whom age and functional demands raise concern about early glenoid loosening and failure.[26,45] The biologic resurfacing material may provide an improved glenoid-bearing surface for articulation with a humeral component. Theoretically, interposition may preserve bone stock by reducing the risk of progressive glenoid erosion.[5]

Although a detailed description of glenoid-resurfacing technique is beyond the scope of this review, several surgical considerations are important to highlight. When interposition is performed in conjunction with humeral resurfacing, exposure of the glenoid may be difficult because the majority of the humeral head is retained; a more aggressive capsular release is often necessary.[16] When performed as a hybrid technique with stemmed hemiarthroplasty, the humeral osteotomy should allow for full glenoid exposure with standard releases of the anterior and inferior capsule. Once visualized, all remaining glenoid cartilage should be removed with a bur or curette. If biconcave, the glenoid should be recontoured to create a concentric surface[20] and reamed into neutral version. The soft tissue chosen for interposition may then be attached with anchors or by suturing to remaining labral and capsular tissue.[16] Finally, if neutral glenoid version cannot be achieved with reaming, consideration is given to placing the humeral component in slightly less retroversion to avoid posterior subluxation.[20]

Although a variety of biologic surfaces have been proposed for resurfacing, the basic principles are the same. The material must be durable, providing an immediate, smooth, biologically active bearing surface with a low coefficient of friction.[16] Additionally, the blood clot that forms between the soft tissue surface and underlying cancellous bone should ultimately form fibrocartilage, hyaline cartilage, fibrous tissue, or some combination thereof.[16,45] Despite promising early results, there are few long-term data on the durability of biologic tissues in glenoid resurfacing.[5,11] Current concerns include the unknown durability of biologic interposition tissues, along with questions of whether tissue material ultimately becomes fixed to the cancellous bone of the glenoid.[50] Although many tissues have been described for resurfacing of the glenoid, the ideal material has yet to be determined.

Fascia Lata Autograft and Achilles Allograft. Autogenous fascia lata is one of the most common materials used for interposition outside the shoulder, and it was described, along with the use of anterior capsule, in the early reports of biologic glenoid resurfacing. Although it is readily available, is easy to harvest, and conforms well to articular surfaces, it does unfortunately carry the risk of donor site complications.[5] Because of concerns about durability, unpredictable outcomes in the literature, and the potential for donor site morbidity, current techniques tend to favor allograft tissue for glenoid resurfacing. Achilles allograft has often been used because of its durability, thickness, ready availability, and low cost. Studies have demonstrated favorable intermediate and long-term wear characteristics, with these results attributed to its collagen structure.[45]

Several recent studies have addressed clinical outcomes after glenoid resurfacing with various biologic interposition materials. Krishnan et al[45] expanded on their previous results of biologic interposition,[15] reporting 2- to 15-year follow-up of hybrid glenoid resurfacing with porous-coated humeral hemiarthroplasty. In total, 34 patients (36 shoulders) were treated, with an average age of 52 years. Resurfacing materials included anterior capsule (19%), autogenous fascia lata (31%), and Achilles allograft (50%). Good or excellent results were obtained in 86% of the patients in this series. Unsatisfactory results were often associated with the use of anterior capsule, with postoperative pain and instability frequently necessitating conversion to total shoulder arthroplasty. None of the patients with Achilles allograft had an unsatisfactory result. The authors concluded that, given its durability and reproducible outcomes, Achilles allograft is the material of choice for glenoid resurfacing.[45]

More recently, however, Elhassan et al[28] reported significantly less favorable results with the use of Achilles allograft. Thirteen patients, with an average age of 34, were evaluated after biologic glenoid interposition with humeral hemiarthroplasty or resurfacing. Postoperatively, there was no significant improvement in Constant-Murley or subjective shoulder scores. An overall failure rate of 92% was reported, with 10 of 13 patients undergoing revision to total shoulder arthroplasty at a mean of 14 months after

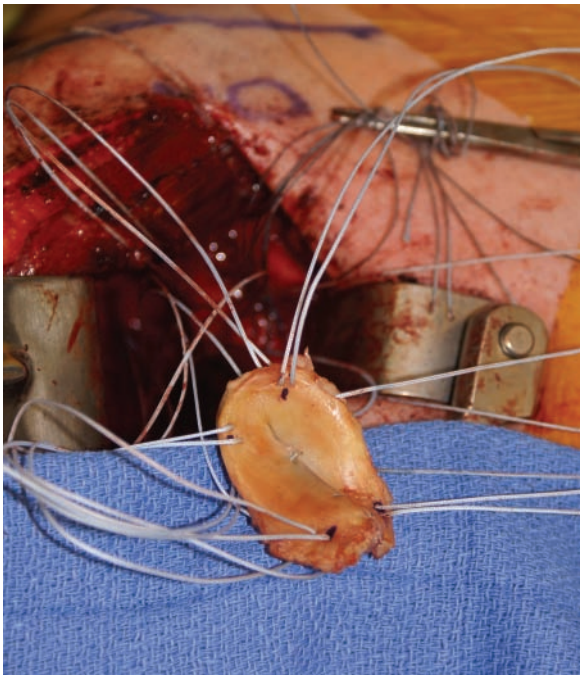

Figure 10. Lateral meniscus allograft prepared for insertion in a 32-year-old man with advanced glenohumeral arthritis after instability surgery.

the initial procedure. At the time of revision, the allograft was found to be absent in all cases. The authors cautioned against use of this technique because their results did not support previous studies demonstrating durability of the graft material and reliable improvements in pain and function.[28] Given these conflicting results, future studies are clearly needed to delineate the role of Achilles allograft in glenoid resurfacing.

Lateral Meniscus Allograft. Although more expensive and less available than other allograft materials, lateral meniscus has been an attractive option for glenoid resurfacing because of its natural durability and documented ability to heal to surrounding synovial tissue in the knee.[5,20,26] Because of its circular shape and its compliance, it easily conforms to the glenoid and can cover a significant portion of the articular surface.[24] The wedge-shaped concavity of the meniscus can also partially restore the contour of a posteriorly eroded glenoid, theoretically creating a concentric articulation with the convex humeral head[5,20,81] (Figure 10).

Lateral meniscus allograft interposition should not be considered a labral replacement but, rather, a soft tissue implant designed to reduce contact forces of the glenohumeral joint. In a recent cadaveric study, Creighton et al[26] demonstrated a substantial decrease in total force and glenoid contact area after placement of the lateral meniscus allograft. Additionally, a central sparing effect was seen with preferentially more contact at the periphery of the meniscal tissue. This central sparing effect may be particularly important in patients with unipolar central glenoid chondral injury.[26]

Early reports of lateral meniscus allograft have shown promising clinical results in small series of patients, albeit with relatively high complication rates and concerns about durability of the interposition material. Ball et al[5] were the first to describe an open technique of lateral meniscus interposition in 6 patients, reporting "good" satisfaction and a significant improvement in range of motion at 2-year follow-up. The authors cited a need for future studies to determine optimal fixation techniques to maximize the likelihood of graft incorporation.[5,57] More recently, Nicholson et al[57] reported short-term results in 30 high-demand patients undergoing uncemented humeral hemiarthroplasty and lateral meniscus allograft interposition. At an average follow-up of 18 months, American Shoulder and Elbow Surgeons scores improved from 38 to 62, and significant improvements were observed in forward elevation and external rotation. However, 5 patients (17%) experienced a complication necessitating reoperation within the first year, with 2 patients requiring conversion to a polyethylene glenoid secondary to persistent pain. The authors raised concern about the longevity and durability of lateral meniscus tissue.[57]

Wirth[81] most recently evaluated the results of 30 young patients after hemiarthroplasty and lateral meniscus interposition. At a mean follow-up of 3 years, patients experienced significant improvement in pain scores and range of motion. Although no additional glenoid bone loss or erosion was seen on postoperative radiographs, the immediate postoperative joint space of 3.5 mm had decreased to 1.7 mm (51%) at final follow-up. The results suggest that meniscal allograft interposition may maintain glenohumeral joint space and prevent glenoid erosion in the short term. However, based on these and other data, the long-term ability of lateral meniscus allograft to maintain the joint space is unknown. Additional peer-reviewed studies are needed to determine the long-term durability of the material, as well as its ability to prevent progressive glenoid erosion.[81]

Regenerative Tissue Matrix. Xenografts and human dermal collagen allografts have recently been investigated as alternatives to traditional autograft and allograft tissue. Although more expensive, these grafts carry less antigenicity than Achilles allograft and may be equally durable.[16] The Restore Orthobiologic Implant (DePuy Orthopaedics, Warsaw, Indiana), a xenograft of porcine small intestine submucosa, and GRAFTJACKET (Wright Medical Technology Inc, Arlington, Tennessee), a human acellular dermal matrix, have both been used off-label for glenoid soft tissue resurfacing. The acellular material in GRAFTJACKET is thought to retain its extracellular matrix, which is then rapidly infiltrated by host cellular material, including fibroblasts and vascular tissue.[1] The tissue therefore has the potential for regenerative healing,[16] and histological analysis after second-look arthroscopy has demonstrated fibrocartilage at the glenoid articular surface after GRAFTJACKET interposition.[6]

Regenerative tissue matrix interposition is indicated for use as a primary resurfacing material in patients with focal or diffuse chondral injury and preserved sphericity of the humeral head.[11] It can also be applied as a hybrid arthroplasty-resurfacing technique in patients whose age

precludes use of a traditional polyethylene glenoid component, owing to concerns of early loosening.[45] Although biologic resurfacing procedures are still considered investigational, the technique shows promise as a temporizing measure in high-demand individuals. Brislin et al[11] performed arthroscopic glenoid resurfacing using the Restore Orthobiologic Implant in 10 patients, showing radiographic preservation of the joint space in all patients at short-term follow-up. Improvements in pain and function were also noted, with an average increase in active forward elevation from 90° to 150° and in abduction from 70° to 120°. Additional studies with longer follow-up and larger numbers of patients are needed to determine the durability of these graft materials and the longevity of results.[1,6]

Arthroplasty

The treatment of glenohumeral arthrosis in active young patients has become an increasingly difficult problem with no ideal solution. These high-demand individuals expect relief of pain and the ability to return to their usual level of function. Although hemiarthroplasty and total shoulder arthroplasty have historically offered excellent pain relief and durable functional outcomes,[31,71] in this subgroup of patients it is unknown which activities will affect the longevity of an implant.[4] With hemiarthroplasty, concerns relate to the deterioration of results over time, especially in those patients with an asymmetric glenoid wear pattern.[47] In total shoulder arthroplasty, concerns center on glenoid failure secondary to mechanical loosening.[10,72] Despite these concerns, humeral head or total shoulder replacement may be necessary in patients with chondral injuries who have failed all palliative, restorative, or reconstructive treatment options[57] (Figures 2 and 3). Arthroplasty must also be considered as a primary treatment strategy in those with advanced arthrosis, who are not appropriate candidates for restorative or reconstructive techniques.

Hemiarthroplasty. Numerous clinical outcome studies have demonstrated that total shoulder arthroplasty provides improved results over humeral head replacement alone in regard to pain relief, range of motion, and activity level.[12,31,71,81] The most significant benefit of hemiarthroplasty, however, is avoidance of potential glenoid loosening and the subsequent need for revision surgery. This is important to consider in physiologically young and active individuals, who are at higher risk for complications related to a cemented polyethylene glenoid. In carefully selected patients with a congruent and minimally arthritic glenoid, primary hemiarthroplasty can provide substantial clinical improvement at early and midterm follow-up.[47,63,82]

Unfortunately the results of hemiarthroplasty in young individuals appear to deteriorate with time, and there remains a high rate of patient dissatisfaction and revision surgery.[63,72,71] Sperling et al[71] found that in spite of long-term improvements in pain relief and function after hemiarthroplasty in patients under 50 years, there was a 60% rate of unsatisfactory results. Overall 10- and 20-year survival of hemiarthroplasty were 82% and 75%, respectively, with revision most often required because of painful glenoid arthritis. Several other studies have confirmed that long-term functional results appear to be compromised by progressive glenoid wear, especially in those individuals with preexisting asymmetric glenoid erosion.[31,47,63,64,72]

Hemiarthroplasty With Glenoid Reaming. The concept of hemiarthroplasty with concentric glenoid reaming was developed on the basis of concerns about the inadequate long-term results of hemiarthroplasty for pain relief.[71] The "ream and run" technique involves concentric reaming of the glenoid to a spherical concave shape, with a diameter of curvature approximately 2 mm greater than that of the prosthetic humeral head.[23] This reaming process is thought to restore stability in patients with asymmetric posterior glenoid wear, who might otherwise be at risk for progressive posterior subluxation of a humeral head replacement.[78]

The concentrically reamed glenoid has been shown to heal and regenerate into a biologic joint surface. In a living canine model, Matsen et al[51] found that at 6 months after hemiarthroplasty and glenoid reaming, the reamed glenoid bone was completely covered with a smooth, thick layer of fibrocartilaginous tissue that was securely attached to the underlying bone. Beneath this surface, bone was uniform in density and structure, suggesting that humeral loads were evenly distributed to the glenoid.[51] Recent clinical trials have suggested the importance of this fibrocartilaginous tissue at the glenoid surface. Lynch et al[49] performed a prospective clinical analysis reporting the outcomes of hemiarthroplasty with glenoid reaming in 38 patients. At a mean follow-up of 2.7 years, 32 experienced improved comfort and functional outcome on self-assessment questionnaires. Patients with preservation of joint space at final follow-up had significantly better function than did those without, suggesting that presence of fibrocartilaginous regeneration at the joint surface may be the predictor of successful results after this procedure.[49]

Total Shoulder Arthroplasty. Progression of glenoid arthrosis remains the most common reason for reoperation after humeral hemiarthroplasty.[47,61,70,72] In spite of early data on the ream-and-run procedure suggesting comparable functional outcomes to those of standard total shoulder arthroplasty,[23] long-term durability of the technique has yet to be determined. Total shoulder arthroplasty remains the most reliable and consistent treatment strategy for advanced bipolar chondral involvement of the glenohumeral joint. Pain relief and functional outcome have proven superior to hemiarthroplasty in numerous studies.[12,31,62,81] Even in patients under the age of 50 years, survival rates of 97% and 84% at 10 and 20 years have been reported.[71] The procedure should be considered with caution in younger individuals, however, because there does remain a significant risk of complications related to polyethylene glenoid insertion. In a recent review of 33 previously published studies, Bohsali et al[10] found that glenoid component loosening accounted for 39% of all complications after total shoulder arthroplasty. Sperling et al[71] similarly reported high rates of loosening and declining prosthesis survival after 5 to 8 years, specifically in younger individuals. Given the risk of glenoid loosening, careful patient selection for total shoulder arthroplasty is paramount. It

is a durable and effective option in appropriately selected and counseled individuals who have had failure with all palliative and reconstructive treatment modalities.

CONCLUSION

The successful diagnosis of glenohumeral arthrosis can be challenging to even the most experienced clinician, and the treatment remains controversial. A thorough history and physical examination, with appropriately selected diagnostic imaging, are essential to ensure that chondral injury is indeed the source of shoulder complaints. Arthroscopy remains the gold standard for diagnosis of chondral damage, and it may have a therapeutic value for palliative debridement. The selection of additional treatment strategies depends on both patient-based and disease-based factors. Reparative, restorative, and reconstructive techniques may provide improvements in pain and functional outcome, although their longevity has not yet been well established. Alternatively, hemiarthroplasty and total shoulder arthroplasty have historically proven to be successful and durable options in properly selected patients. However, concerns about progressive glenoid erosion and glenoid component loosening with these 2 procedures have led many to seek alternative nonarthroplasty techniques for the management of arthrosis in active young individuals. Although the ideal solution to this challenging problem of glenohumeral arthrosis has yet to be found, the answer may lie in future research on improved bearing surfaces and cartilage restoration techniques.

ACKNOWLEDGMENT

We thank Michele Roberts for her administrative assistance in the preparation and management of this article.

REFERENCES

1. Adams JE, Steinmann SP. Soft tissue interposition arthroplasty of the shoulder. *J Shoulder Elbow Surg*. 2007;16(5)(suppl):S254-S260.
2. Athwal GS, Shridharani SM, O'Driscoll SW. Osteolysis and arthropathy of the shoulder after use of bioabsorbable knotless suture anchors: a report of four cases. *J Bone Joint Surg Am*. 2006;88(8):1840-1845.
3. Bailie DS, Ellenbecker T. Severe chondrolysis after shoulder arthroscopy: a case series. *J Shoulder Elbow Surg*. 2009;18:742-747.
4. Bailie DS, Llinas PJ, Ellenbecker TS. Cementless humeral resurfacing arthroplasty in active patients less than fifty-five years of age. *J Bone Joint Surg Am*. 2008;90(1):110-117.
5. Ball CM, Galatz LM, Yamaguchi K. Meniscal allograft interposition arthroplasty for the arthritic shoulder: description of a new surgical technique. *Tech Shoulder Elbow Surg*. 2001;2:247-254.
6. Bhatia DN, van Rooyen KS, du Toit DF, de Beer JF. Arthroscopic technique of interposition arthroplasty of the glenohumeral joint. *Arthroscopy*. 2006;22(5):570, e571-e575.
7. Bishop JY, Flatow EL. Management of glenohumeral arthritis: a role for arthroscopy? *Orthop Clin North Am*. 2003;34(4):559-566.
8. Blaine T, Moskowitz R, Udell J, et al. Treatment of persistent shoulder pain with sodium hyaluronate: a randomized, controlled trial. A multicenter study. *J Bone Joint Surg Am*. 2008;90(5):970-979.
9. Blair B, Rokito AS, Cuomo F, Jarolem K, Zuckerman JD. Efficacy of injections of corticosteroids for subacromial impingement syndrome. *J Bone Joint Surg Am*. 1996;78(11):1685-1689.
10. Bohsali KI, Wirth MA, Rockwood CA Jr. Complications of total shoulder arthroplasty. *J Bone Joint Surg Am*. 2006;88(10):2279-2292.
11. Brislin KJ, Savoie FH, Field LD, Ramsey JR. Surgical treatment for glenohumeral arthritis in the young patient. *Tech Shoulder Elbow Surg*. 2004;5:165-169.
12. Bryant D, Litchfield R, Sandow M, Gartsman GM, Guyatt G, Kirkley A. A comparison of pain, strength, range of motion, and functional outcomes after hemiarthroplasty and total shoulder arthroplasty in patients with osteoarthritis of the shoulder: a systematic review and meta-analysis. *J Bone Joint Surg Am*. 2005;87(9):1947-1956.
13. Buchner M, Eschbach N, Loew M. Comparison of the short-term functional results after surface replacement and total shoulder arthroplasty for osteoarthritis of the shoulder: a matched-pair analysis. *Arch Orthop Trauma Surg*. 2008;128(4):347-354.
14. Burgess DL, McGrath MS, Bonutti PM, Marker DR, Delanois RE, Mont MA. Shoulder resurfacing. *J Bone Joint Surg Am*. 2009;91(5):1228-1238.
15. Burkhead WZ Jr, Hutton KS. Biologic resurfacing of the glenoid with hemiarthroplasty of the shoulder. *J Shoulder Elbow Surg*. 1995;4(4):263-270.
16. Burkhead WZ Jr, Krishnan SG, Lin KC. Biologic resurfacing of the arthritic glenohumeral joint: historical review and current applications. *J Shoulder Elbow Surg*. 2007;16(5)(suppl):S248-S253.
17. Buscayret F, Edwards TB, Szabo I, Adeleine P, Coudane H, Walch G. Glenohumeral arthrosis in anterior instability before and after surgical treatment: incidence and contributing factors. *Am J Sports Med*. 2004;32(5):1165-1172.
18. Calandra JJ, Baker CL, Uribe J. The incidence of Hill-Sachs lesions in initial anterior shoulder dislocations. *Arthroscopy*. 1989;5(4):254-257.
19. Cameron BD, Galatz LM, Ramsey ML, Williams GR, Iannotti JP. Nonprosthetic management of grade IV osteochondral lesions of the glenohumeral joint. *J Shoulder Elbow Surg*. 2002;11(1):25-32.
20. Cameron BD, Iannotti JP. Alternatives to total shoulder arthroplasty in the young patient. *Tech Shoulder Elbow Surg*. 2004;5(3):135-145.
21. Cameron ML, Kocher MS, Briggs KK, Horan MP, Hawkins RJ. The prevalence of glenohumeral osteoarthrosis in unstable shoulders. *Am J Sports Med*. 2003;31(1):53-55.
22. Chapovsky F, Kelly JD IV. Osteochondral allograft transplantation for treatment of glenohumeral instability. *Arthroscopy*. 2005;21(8):1007.
23. Clinton J, Franta AK, Lenters TR, Mounce D, Matsen FA 3rd. Nonprosthetic glenoid arthroplasty with humeral hemiarthroplasty and total shoulder arthroplasty yield similar self-assessed outcomes in

the management of comparable patients with glenohumeral arthritis. *J Shoulder Elbow Surg*. 2007;16(5):534-538.
24. Cole BJ, Yanke A, Provencher MT. Nonarthroplasty alternatives for the treatment of glenohumeral arthritis. *J Shoulder Elbow Surg*. 2007;16(5)(suppl):S231-S240.
25. Copeland S. The continuing development of shoulder replacement: ''reaching the surface.'' *J Bone Joint Surg Am*. 2006;88(4):900-905.
26. Creighton RA, Cole BJ, Nicholson GP, Romeo AA, Lorenz EP. Effect of lateral meniscus allograft on shoulder articular contact areas and pressures. *J Shoulder Elbow Surg*. 2007;16(3):367-372.
27. Edwards TB, Kadakia NR, Boulahia A, et al. A comparison of hemiarthroplasty and total shoulder arthroplasty in the treatment of primary glenohumeral osteoarthritis: results of a multicenter study. *J Shoulder Elbow Surg*. 2003;12(3):207-213.
28. Elhassan B, Ozbaydar M, Diller D, Higgins LD, Warner JJ. Soft-tissue resurfacing of the glenoid in the treatment of glenohumeral arthritis in active patients less than fifty years old. *J Bone Joint Surg Am*. 2009;91(2):419-424.
29. Ellman H, Harris E, Kay SP. Early degenerative joint disease simulating impingement syndrome: arthroscopic findings. *Arthroscopy*. 1992;8(4):482-487.
30. Freehill MQ, Harms DJ, Huber SM, Atlihan D, Buss DD. Poly-L-lactic acid tack synovitis after arthroscopic stabilization of the shoulder. *Am J Sports Med*. 2003;31(5):643-647.
31. Gartsman GM, Roddey TS, Hammerman SM. Shoulder arthroplasty with or without resurfacing of the glenoid in patients who have osteoarthritis. *J Bone Joint Surg Am*. 2000;82(1):26-34.
32. Gartsman GM, Taverna E. The incidence of glenohumeral joint abnormalities associated with full-thickness, reparable rotator cuff tears. *Arthroscopy*. 1997;13(4):450-455.
33. Gerber C, Lambert SM. Allograft reconstruction of segmental defects of the humeral head for the treatment of chronic locked posterior dislocation of the shoulder. *J Bone Joint Surg Am*. 1996;78(3):376-382.
34. Gold GE, Reeder SB, Beaulieu CF. Advanced MR imaging of the shoulder: dedicated cartilage techniques. *Magn Reson Imaging Clin N Am*. 2004;12(1):143-159.
35. Green A, Norris TR. Imaging techniques for glenohumeral arthritis and glenohumeral arthroplasty. *Clin Orthop Relat Res*. 1994;307: 7-17.
36. Guntern DV, Pfirrmann CW, Schmid MR, et al. Articular cartilage lesions of the glenohumeral joint: diagnostic effectiveness of MR arthrography and prevalence in patients with subacromial impingement syndrome. *Radiology*. 2003;226(1):165-170.
37. Guyette TM, Bae H, Warren RF, Craig E, Wickiewicz TL. Results of arthroscopic subacromial decompression in patients with subacromial impingement and glenohumeral degenerative joint disease. *J Shoulder Elbow Surg*. 2002;11(4):299-304.
38. Hamada S, Hamada M, Nishiue S, Doi T. Osteochondritis dissecans of the humeral head. *Arthroscopy*. 1992;8(1):132-137.
39. Hawkins RJ, Angelo RL. Glenohumeral osteoarthrosis: a late complication of the Putti-Platt repair. *J Bone Joint Surg Am*. 1990;72(8): 1193-1197.
40. Hintermann B, Gachter A. Arthroscopic findings after shoulder dislocation. *Am J Sports Med*. 1995;23(5):545-551.
41. Hovelius L. Glenohumeral osteoarthrosis after Putti-Platt repair. *J Shoulder Elbow Surg*. 2000;9(3):257.
42. Hovelius L, Saeboe M. Neer Award 2008: Arthropathy after primary anterior shoulder dislocation—223 shoulders prospectively followed up for twenty-five years. *J Shoulder Elbow Surg*. 2009;18(3):339-347.
43. Jain N, Pietrobon R, Hocker S, Guller U, Shankar A, Higgins LD. The relationship between surgeon and hospital volume and outcomes for shoulder arthroplasty. *J Bone Joint Surg Am*. 2004;86(3):496-505.
44. Krishnan SG, Harkins DC, Burkhead WZ. Alternatives to replacement arthroplasty for glenohumeral arthritis. In: Iannotti JP, Williams GR, eds. *Disorders of the Shoulder: Diagnosis and Management*. 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2006:655.
45. Krishnan SG, Nowinski RJ, Harrison D, Burkhead WZ. Humeral hemiarthroplasty with biologic resurfacing of the glenoid for glenohumeral arthritis: two to fifteen-year outcomes. *J Bone Joint Surg Am*. 2007;89(4):727-734.
46. Levine WN, Clark AM Jr, D'Alessandro DF, Yamaguchi K. Chondrolysis following arthroscopic thermal capsulorrhaphy to treat shoulder instability: a report of two cases. *J Bone Joint Surg Am*. 2005;87(3):616-621.
47. Levine WN, Djurasovic M, Glasson JM, Pollock RG, Flatow EL, Bigliani LU. Hemiarthroplasty for glenohumeral osteoarthritis: results correlated to degree of glenoid wear. *J Shoulder Elbow Surg*. 1997;6(5):449-454.
48. Levy O, Copeland SA. Cementless surface replacement arthroplasty of the shoulder: 5- to 10-year results with the Copeland mark-2 prosthesis. *J Bone Joint Surg Br*. 2001;83(2):213-221.
49. Lynch JR, Franta AK, Montgomery WH Jr, Lenters TR, Mounce D, Matsen FA 3rd. Self-assessed outcome at two to four years after shoulder hemiarthroplasty with concentric glenoid reaming. *J Bone Joint Surg Am*. 2007;89(6):1284-1292.
50. Matsen FA 3rd, Bicknell RT, Lippitt SB. Shoulder arthroplasty: the socket perspective. *J Shoulder Elbow Surg*. 2007;16(5)(suppl): S241-S247.
51. Matsen FA 3rd, Clark JM, Titelman RM, et al. Healing of reamed glenoid bone articulating with a metal humeral hemiarthroplasty: a canine model. *J Orthop Res*. 2005;23(1):18-26.
52. McAlindon TE, LaValley MP, Gulin JP, Felson DT. Glucosamine and chondroitin for treatment of osteoarthritis: a systematic quality assessment and meta-analysis. *JAMA*. 2000;283(11):1469-1475.
53. McCarty LP 3rd, Cole BJ. Nonarthroplasty treatment of glenohumeral cartilage lesions. *Arthroscopy*. 2005;21(9):1131-1142.
54. McCarty LP 3rd, Cole BJ. Reconstruction of the glenohumeral joint using a lateral meniscal allograft to the glenoid and osteoarticular humeral head allograft after bipolar chondrolysis. *J Shoulder Elbow Surg*. 2007;16(6):e20-e24.
55. Miniaci A, Gish GM. Management of anterior glenohumeral instability associated with large Hill-Sachs defects. *Tech Shoulder Elbow Surg*. 2004;5(3):170-175.
56. Nicholson GP. Arthroscopic capsular release for stiff shoulders: effect of etiology on outcomes. *Arthroscopy*. 2003;19(1):40-49.
57. Nicholson GP, Goldstein JL, Romeo AA, et al. Lateral meniscus allograft biologic glenoid arthroplasty in total shoulder arthroplasty for young shoulders with degenerative joint disease. *J Shoulder Elbow Surg*. 2007;16(5)(suppl):S261-S266.
58. Norlin R. Intraarticular pathology in acute, first-time anterior shoulder dislocation: an arthroscopic study. *Arthroscopy*. 1993;9(5):546-549.
59. Ogilvie-Harris DJ, Wiley AM. Arthroscopic surgery of the shoulder: a general appraisal. *J Bone Joint Surg Br*. 1986;68(2):201-207.
60. Paley KJ, Jobe FW, Pink MM, Kvitne RS, ElAttrache NS. Arthroscopic findings in the overhand throwing athlete: evidence for posterior internal impingement of the rotator cuff. *Arthroscopy*. 2000;16(1): 35-40.
61. Parsons IM 4th, Millett PJ, Warner JJ. Glenoid wear after shoulder hemiarthroplasty: quantitative radiographic analysis. *Clin Orthop Relat Res*. 2004;421:120-125.
62. Radnay CS, Setter KJ, Chambers L, Levine WN, Bigliani LU, Ahmad CS. Total shoulder replacement compared with humeral head replacement for the treatment of primary glenohumeral osteoarthritis: a systematic review. *J Shoulder Elbow Surg*. 2007;16(4): 396-402.
63. Rispoli DM, Sperling JW, Athwal GS, Schleck CD, Cofield RH. Humeral head replacement for the treatment of osteoarthritis. *J Bone Joint Surg Am*. 2006;88(12):2637-2644.
64. Rodosky MW, Bigliani LU. Indications for glenoid resurfacing in shoulder arthroplasty. *J Shoulder Elbow Surg*. 1996;5(3):231-248.
65. Romeo AA, Cole BJ, Mazzocca AD, Fox JA, Freeman KB, Joy E. Autologous chondrocyte repair of an articular defect in the humeral head. *Arthroscopy*. 2002;18(8):925-929.
66. Scalise JJ, Miniaci A, Iannotti JP. Resurfacing arthroplasty of the humerus: indications, surgical technique, and clinical results. *Tech Shoulder Elbow Surg*. 2007;8(3):152-160.

67. Scheibel M, Bartl C, Magosch P, Lichtenberg S, Habermeyer P. Osteochondral autologous transplantation for the treatment of full-thickness articular cartilage defects of the shoulder. *J Bone Joint Surg Br*. 2004;86(7):991-997.
68. Silverstein E, Leger R, Shea KP. The use of intra-articular hylan G-F 20 in the treatment of symptomatic osteoarthritis of the shoulder: a preliminary study. *Am J Sports Med*. 2007;35(6):979-985.
69. Sperling JW, Antuna SA, Sanchez-Sotelo J, Schleck C, Cofield RH. Shoulder arthroplasty for arthritis after instability surgery. *J Bone Joint Surg Am*. 2002;84(10):1775-1781.
70. Sperling JW, Cofield RH. Revision total shoulder arthroplasty for the treatment of glenoid arthrosis. *J Bone Joint Surg Am*. 1998;80(6):860-867.
71. Sperling JW, Cofield RH, Rowland CM. Minimum fifteen-year follow-up of Neer hemiarthroplasty and total shoulder arthroplasty in patients aged fifty years or younger. *J Shoulder Elbow Surg*. 2004;13(6):604-613.
72. Sperling JW, Cofield RH, Rowland CM. Neer hemiarthroplasty and Neer total shoulder arthroplasty in patients fifty years old or less: long-term results. *J Bone Joint Surg Am*. 1998;80(4):464-473.
73. Steadman JR, Rodkey WG, Rodrigo JJ. Microfracture: surgical technique and rehabilitation to treat chondral defects. *Clin Orthop Relat Res*. 2001;391(suppl):S362-S369.
74. Thomas SR, Sforza G, Levy O, Copeland SA. Geometrical analysis of Copeland surface replacement shoulder arthroplasty in relation to normal anatomy. *J Shoulder Elbow Surg*. 2005;14(2):186-192.
75. Thomas SR, Wilson AJ, Chambler A, Harding I, Thomas M. Outcome of Copeland surface replacement shoulder arthroplasty. *J Shoulder Elbow Surg*. 2005;14(5):485-491.
76. Uribe JW, Bemden AB. Partial humeral head resurfacing for osteonecrosis. *J Shoulder Elbow Surg*. 2009;18:711-716.
77. Weinstein DM, Bucchieri JS, Pollock RG, Flatow EL, Bigliani LU. Arthroscopic debridement of the shoulder for osteoarthritis. *Arthroscopy*. 2000;16(5):471-476.
78. Weldon EJ 3rd, Boorman RS, Smith KL, Matsen FA 3rd. Optimizing the glenoid contribution to the stability of a humeral hemiarthroplasty without a prosthetic glenoid. *J Bone Joint Surg Am*. 2004;86(9):2022-2029.
79. Williams MD, Edwards TB. Glenohumeral arthrosis in the athlete: evaluation and algorithm for management. *Oper Tech Sports Med*. 2008;16(1):2-8.
80. Williams SK, Amiel D, Ball ST, et al. Prolonged storage effects on the articular cartilage of fresh human osteochondral allografts. *J Bone Joint Surg Am*. 2003;85(11):2111-2120.
81. Wirth MA. Humeral head arthroplasty and meniscal allograft resurfacing of the glenoid. *J Bone Joint Surg Am*. 2009;91(5):1109-1119.
82. Wirth MA, Tapscott RS, Southworth C, Rockwood CA Jr. Treatment of glenohumeral arthritis with a hemiarthroplasty: a minimum five-year follow-up outcome study. *J Bone Joint Surg Am*. 2006;88(5):964-973.