13

Glenohumeral Arthritis in the Young Adult

CDR Matthew T. Provencher, MD, MC, USN
Joseph U. Barker, MD
Eric J. Strauss, MD
Rachel M. Frank, BS
Anthony A. Romeo, MD
Frederick A. Matsen III, MD
Brian J. Cole, MD, MBA

Abstract

Treating glenohumeral arthritis in the young adult remains a significant challenge. There are a variety of etiologies that can lead to this condition, and the diagnosis is often not straightforward. With advances in both surgical techniques and biologic options, the treatment algorithm for patients with glenohumeral arthritis is constantly evolving. When nonsurgical treatment fails, there are a variety of possible surgical options, each with potential benefits. It is helpful to review the diagnostic challenges presented by these patients and understand the palliative, reparative, restorative, and reconstructive surgical options and their associated clinical outcomes, which provide a framework for clinical and surgical decision making.

Instr Course Lect 2011;60:137-153.

Glenohumeral arthritis in young, active patients presents a growing challenge for the orthopaedic surgeon. Diagnosing symptomatic cartilage lesions can be difficult, and a thorough understanding of shoulder anatomy as well as the available surgical techniques is critical for effective treatment. Localized articular cartilage lesions of the glenohumeral joint are rare; however, such lesions can become painful and may limit shoulder function when symptomatic. Often, the diagnosis is initially unclear, and patients continue to present with substantial pain despite previous surgical or nonsurgical treatments. Young adult patients may also present with more global glenohumeral degenerative changes because of a variety of etiologic factors.[1-3] Although total joint arthroplasty offers a definitive solution for resolving symptoms, this remains a less than ideal option in the young, high-demand patient population. Other cartilage treatment options range from palliative arthroscopy to reparative, restorative, and reconstructive surgical techniques. Currently, there are limited

Dr. Provencher or an immediate family member serves as a board member, owner, officer, or committee member of the American Academy of Orthopaedic Surgeons, the American Orthopaedic Society for Sports Medicine, the Arthroscopy Association of North America, and the Society of Military Orthopaedic Surgeons. Dr. Romeo or an immediate family member serves as a board member, owner, officer, or committee member of the American Orthopaedic Society for Sports Medicine, the American Shoulder and Elbow Surgeons, and the Arthroscopy Association of North America; has received royalties from Arthrex and Saunders/Mosby-Elsevier; is a member of a speakers' bureau or has made paid presentations on behalf of Arthrex and DJ Orthopaedics; serves as a paid consultant to or is an employee of Arthrex; has received research or institutional support from Arthrex, Ossur, and Smith & Nephew; and has received nonincome support (such as equipment or services), commercially derived honoraria, or other non–research-related funding (such as paid travel) from Arthrex and DJ Orthopaedics. Dr. Matsen or an immediate family member has received royalties from Kinamed. Dr. Cole or an immediate family member has received royalties from Arthrex, DJ Orthopaedics, Lippincott, and Elsevier; is a member of a speakers' bureau or has made paid presentations on behalf of Genzyme; serves as a paid consultant to or is an employee of Zimmer, Arthrex, Carticept, Biomimetic, and Allosource; and has received research or institutional support from Regentis, Arthrex, Smith & Nephew, and DJ Orthopaedics. None of the following authors or any immediate family member has received anything of value from or owns stock in a commercial company or institution related directly or indirectly to the subject of this chapter: Dr. Barker, Dr. Strauss, and Ms. Frank.

The views expressed in this chapter are those of the authors and do not reflect the official policy or position of the Department of the Navy, the Department of Defense, or the US government.

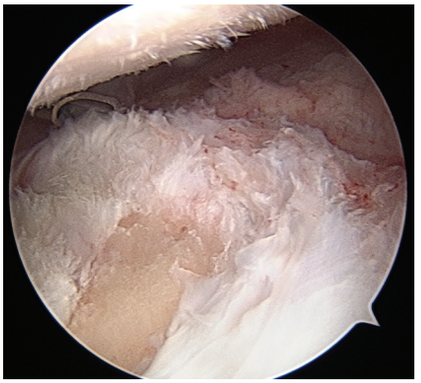

Figure 1 Arthroscopic view of a grade IV lesion of the glenoid in the dominant shoulder in a 27-year-old man.

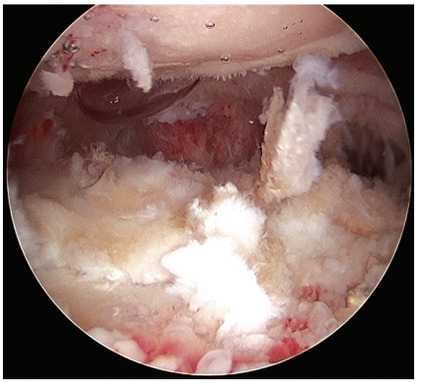

Figure 2 Arthroscopic view of diffuse degenerative disease in the shoulder of a 23-year-old man following the placement of an intra-articular pain pump after labral repair.

data and recommendations to guide treatment decisions for patients with symptomatic chondral lesions of the shoulder. However, with the increasing prevalence of young patients with symptomatic shoulder arthritis, joint-preserving treatments will continue to evolve. This chapter provides an overview of glenohumeral cartilage pathology, discusses patient evaluation and appropriate clinical decision making, and describes the various surgical treatment options for these challenging clinical situations.

Anatomic Considerations

The unique anatomic features of the glenohumeral joint make it challenging to evaluate and treat chondral lesions within this area. There are significant differences in the thickness of the glenohumeral articular cartilage compared with other joints, such as the knee or ankle. Specifically, the mean articular depth of the humerus is 1.24 mm, whereas the mean depth of the glenoid fossa is 1.88 mm.[4] The humeral head cartilage is thickest in the center (1.2 to 1.3 mm thick) but thins to less than 1 mm along the periphery.[5] In the glenoid, the articular cartilage is thickest along the periphery but tapers toward the center with an area that is completely devoid of cartilage (known as the bare area). From a biologic standpoint, the layout of the articular cartilage along both the glenoid surface and the humeral head may make it difficult to diagnose and treat symptomatic chondral lesions. It is important, for example, to avoid inadvertently attributing the bare areas on the glenoid or the humerus to pathologic chondral defects because this may lead to inappropriate treatment recommendations.

The geometry of the glenohumeral joint is also important when considering symptomatic cartilage defects. Specifically, the glenoid radius of curvature is within 2 to 3 mm of the humeral head and is relatively congruent with the humeral head when soft tissues, including the cartilage and labrum, are included.[6] Glenoid version typically varies, with an average of 1.5° of retroversion; notably, retroversion is considerably increased (approximately 11°) with advanced cartilage damage (such as the damage resulting from glenohumeral osteoarthritis). Glenoid inclination also varies, with an average of 4.2° in the superior direction.[6]

Classification of Glenohumeral Chondral Defects

Currently, there is no specific classification scheme for articular cartilage defects of the glenohumeral joint. The Outerbridge classification system,[7] which is commonly used for chondral defects in the knee, can be applied to similar defects in the shoulder. In this system, grade 0 refers to normal articular cartilage, grade I to cartilage softening, grade II to fibrillation involving half the depth of the cartilage, grade III to fissuring involving more than half the depth of the cartilage, and grade IV to full-thickness loss reaching to or through the subchondral bone (**Figure 1**). It is equally important to document the location of the defect, the depth of bony involvement, and the size of the defect relative to the entire dimension of the articular surface. If there are bipolar defects, it should be determined if these defects articulate with one another when bipolar disease exists.

Incidence and Etiology of Glenohumeral Chondral Defects

Injury to the glenohumeral articular cartilage can occur through a variety of mechanisms. Because cartilage lesions are often incidental findings, more common shoulder pathologic entities must be considered and evaluated. Overall, the diagnosis of a symptomatic chondral injury is one of exclusion.[1] Potential etiologies of chondral defects in the shoulder are varied and include genetic and/or degenerative changes to the joint, posttraumatic lesions, postoperative changes, osteonecrosis (commonly from corticosteroid use, alcohol use, or iatrogenic), and defects caused by intra-articular pain pump placement, radiofrequency therapy, and infection[2,3,8-10] (**Figure 2**). Because the etiology of the articular

disease can affect disease progression, it is crucial for the clinician to obtain as much information as possible concerning the patient's symptoms. Specifically, the clinician should note previous surgeries, the nature and onset of symptoms, and the rate of symptom progression. The qualitative nature of symptoms (such as pain and mechanical and neurologic symptoms) should be assessed to help the clinician weigh options relative to the magnitude of the patient's clinical disorders and treatment expectations.

The overall incidence and natural history of glenohumeral chondral defects is unknown. As diagnostic modalities for symptomatic cartilage lesions continue to advance, an improved understanding of glenohumeral articular cartilage pathology can be expected. As previously mentioned, lesions are often found incidentally during imaging and/or the treatment of other shoulder pathologies. In a study of magnetic resonance arthrography (MRA), glenohumeral chondral lesions were found in up to one third of all patients.[11] In a cadaver study analyzing rotator cuff tears, an increase in chondral injury was seen in shoulders with cuff tears compared with those without rotator cuff pathology. Specifically, in shoulders with rotator cuff tears, defects in the glenoid were found in 32% of specimens, and defects in the humeral head were found in 36% compared with 6% and 7%, respectively, in shoulders without cuff tears.[12] Another study found a 4.5% incidence of significant cartilage lesions (Outerbridge type grade IV) in shoulders with rotator cuff tears.[13]

Chondral injuries also have been associated with shoulder instability. In a clinical study of patients with first-time traumatic dislocations, Taylor et al[14] reported that 57 of 63 patients (90%) had Hill-Sachs lesions, with 40% classified as chondral lesions and 60% classified as osteochondral lesions. Hintermann and Gächter[15] prospectively studied the arthroscopic findings of 212 patients with unstable shoulders and reported an increased incidence of chondral damage in patients with multiple dislocation events. Specifically, the authors found a 23% incidence of glenoid defects and an 8% incidence of humeral head degenerative arthritis in patients who sustained only one dislocation, and a 27% incidence of glenoid degenerative arthritis and a 36% incidence of humeral head arthritis in patients who sustained two or more dislocations.[15] Importantly, information related to the prevalence of symptoms associated with these traumatic chondral injuries is largely lacking.

Although focal chondral defects, whether found as primary lesions or as incidental findings, are challenging to treat, it is perhaps even more difficult to treat patients with progressive and/or diffuse disease. These patients present with varying etiologies, including rheumatoid arthritis, traumatic arthrosis, and osteoarthritis. Patients can also present after one or more failed treatment attempts, especially in the case of postoperative glenohumeral chondrolysis.[2,3,8-10,16] In 1998, Sperling et al[17] described long-term survivorship of total shoulder arthroplasty or hemiarthroplasty in 114 shoulders in patients younger than 50 years with painful glenohumeral arthritis or arthrosis. The authors described long-term improvement in motion as well as substantial pain relief but noted that approximately 50% of the patients were dissatisfied with their treatment, indicating the significant challenge in managing this disease. Although advances in the diagnosis and treatment of isolated chondral defects are certainly areas of focus, increased consideration of more diffuse glenohumeral chondral pathology is also warranted.

Patient Evaluation

Because articular cartilage defects are often incidental findings, it can be difficult to determine which chondral defects are truly symptomatic and which are simply incidental. Especially in patients with multiple shoulder pathologies who had several prior surgical treatments, it is often impossible to ascertain if the articular defects were responsible for their preoperative symptoms. To avoid treating asymptomatic injuries and ignoring truly symptomatic lesions, it is crucial for the surgeon to obtain as much information as possible from the patient during the initial history and physical examination. During the initial clinical visit, the patient should be asked about the original mechanism of injury as well as previous nonsurgical and surgical treatment of the shoulder, including the response to therapy. Specific questions about the activity level of the patient and his or her postoperative treatment goals are important initial considerations to address any potential unrealistic expectations of the patient before discussing potential treatment strategies.

Physical Examination

In addition to a thorough history, a complete physical examination of both shoulders is important for evaluating symptomatic chondral defects and any coexisting pathology, including rotator cuff tears and/or instability. The structure, function, neurologic status, and strength of the injured shoulder should be compared with that of the contralateral shoulder.[16] Loss of motion and stiffness must be noted at the preoperative examination to allow the patient time to restore any deficit before surgically treating the chondral defect. Stability, scapulothoracic dyskinesis, and manual muscle testing should be assessed. If necessary, special shoulder tests should be performed to evaluate any

potential comorbidity or primary etiology for the patient's symptoms. Of note, in patients who have previously been treated with open shoulder surgery, subscapularis dysfunction may be present and should be documented and addressed before any surgical treatment.

Imaging Studies

Imaging studies are a routine component in the evaluation of symptomatic chondral lesions and are especially helpful in analyzing bone loss. Standard views should include AP, scapular-Y, and axillary views; the addition of a Stryker notch view is helpful for evaluating Hill-Sachs lesions, whereas the West Point view is useful in determining glenoid bone loss.[16] CT studies, especially those conducted using three-dimensional reconstruction software, are especially helpful for evaluating glenohumeral joint alignment, glenoid version, and glenoid bone loss. This can be helpful in patients who require more invasive osteochondral reconstruction for full-thickness cartilage defects that include subchondral bone. CT arthrography is quite helpful in evaluating joints and soft tissues without MRI artifact in the setting of prior hardware placement, such as metal glenoid or humeral head anchors.

MRI and MRA are the imaging modalities of choice for evaluating the glenoid and humeral head articular surfaces and are especially helpful in evaluating changes in subchondral bone and associated soft-tissue comorbidities,[18,19] including ligamentous, labrum, and rotator cuff pathologies. Typically, the T2-weighted image, with and without fat suppression, and the T1-weighted fat-suppressed three-dimensional spoiled gradient-echo technique are used. However, the sensitivity and specificity of MRI in evaluating glenohumeral chondral lesions is relatively poor,[11] and up to 45% of grade IV chondral lesions can be missed.[20] Glenohumeral arthroscopy, although clearly more invasive than MRI and MRA, remains the gold standard for diagnosing glenohumeral chondral defects.

Summary of Patient Evaluation

A global evaluation of the patient with symptomatic glenohumeral chondral lesions involves the patient presentation, physical examination, and imaging studies. After considering all the information from the initial patient evaluation, the surgeon must consider several important factors before deciding on an appropriate treatment plan. The patient's age and desired activity level are both crucial factors in the decision process. In addition, the global location of the defect (glenoid surface, humeral head, or bipolar "kissing" lesions); local location of the defect (central, periphery); size, depth, and containment of the defect; and any coexisting shoulder pathologies must be considered in the evaluation of a patient with glenohumeral arthritis. Special attention must be given to any patient presenting with more global or progressive chondral disease because the clinical decision-making process is not as clear in this patient population.

Nonsurgical Treatment

In most patients with symptomatic glenohumeral articular cartilage lesions, nonsurgical treatment should be initially attempted to relieve symptoms. The nonsurgical treatment options for shoulder cartilage defects are similar to those for other joints. A course of oral nonsteroidal anti-inflammatory drugs is often helpful in patients who are able to tolerate the medication and are compliant with the dosing regimen.[21] Physical therapy, with a focus on scapulothoracic and glenohumeral strengthening, is an excellent option for most patients. Stretching the joint and improving range of motion are two important aspects of physical therapy because there is usually some restriction in motion in patients with glenohumeral cartilage damage. Patients usually have relief of symptoms after a course of physical therapy. In instances when future surgery is indicated, preoperative strengthening of the shoulder joint will help to improve postoperative outcomes.

Injecting the glenohumeral joint with corticosteroids or a lidocaine pain challenge may be helpful in some patients; however, this treatment is usually not effective in high-demand, athletic patients because symptoms often return after the patient returns to the sports activity.[22] Often, steroid injections (the efficacy is still unknown) can be more useful as a diagnostic modality rather than as a treatment that provides significant long-term relief of symptoms.[23] Recently, off-label viscosupplementation via hyaluronic acid injections, which has been approved for use in the knee, has been shown to be potentially beneficial in patients with symptomatic glenohumeral arthritis.[24] This type of injection needs further investigation before specific recommendations can be made regarding its efficacy. Explicit informed consent is needed for any patient receiving this type of injection because it is not currently approved by the Food and Drug Administration for use in the shoulder.

Surgical Treatment

Palliative Arthroscopic Débridement

After conservative treatment modalities have been exhausted without success in the active patient with glenohumeral arthritis, arthroscopic débridement is generally considered as the next treatment choice. Arthroscopic débride-

ment is considered a palliative treatment and aims to reduce pain and potentially increase functional range of motion. An arthroscopic débridement may postpone the need for a total joint arthroplasty, which has been shown to have higher incidences of component failure and worse outcomes scores in younger patients.[25,26] Shoulder arthroscopy also can be used as a diagnostic tool to address other pathologies that may coexist with glenohumeral arthritis.

Arthroscopic débridement is generally considered a first-line surgical option in the patient with glenohumeral arthritis if treatment with conservative modalities has failed. In patients older than 65 years or in patients with lower physical demands, an arthroscopic débridement is often used in an attempt to avoid more invasive options. Arthroscopic débridement is especially indicated for patients with significant comorbidities who may not tolerate total shoulder arthroplasty. Younger patients with advanced or diffuse chondral disease are not ideal candidates for arthroplasty because of issues related to glenoid component wear; therefore, débridement may be warranted in an attempt to delay arthroplasty. Patients who have significantly decreased range of motion can potentially benefit from a capsular release to decrease the capsular contracture often associated with glenohumeral arthritis.

Palliative treatment attempts to ameliorate symptoms by decreasing the intra-articular mechanical and biologic milieu.[27] There are a variety of standard techniques used in arthroscopic débridement, including complete synovectomy, the removal of loose bodies, and defect management (**Figure 3**). For cartilage injury, the removal of chondral flaps can be performed with a combination of motorized shavers and arthroscopic curets. In grade IV lesions, a stable, vertical transition zone should be created between the defect and the surrounding cartilage. This was shown to be beneficial in a canine model in which converting cartilage edges with gradual zones to vertical margins led to slower disease progression.[28] With arthroscopic débridement, capsular contractures can be managed with either targeted capsular releases or a complete 360° release. Two studies have reported that complete capsular release is effective for pain relief and patient satisfaction.[29,30] In addition to treating cartilage lesions and capsular contractures, other potential procedures that can be performed based on symptomatic pathology include subacromial decompression, distal clavicle excision, and biceps tenotomy or tenodesis.

Limited data in the literature are available on the outcomes of arthroscopic débridement for glenohumeral arthritis. The few available studies show that symptomatic relief can often be achieved but is usually incomplete and of short duration.[31,32] In general, 80% good or excellent results can be achieved at short-term follow-up.[20,32] In 2002, Cameron et al[20] reported on 61 patients with grade IV osteochondral lesions treated with arthroscopic débridement. Thirty-six percent of these patients were treated with capsular release, and 48% were treated with concomitant arthroscopic procedures other than capsular release. At an average follow-up of 28 months, 88% reported significant pain relief (average time to maximal pain relief, 11 weeks), and 87% were satisfied with the procedure. The authors reported worse outcomes with cartilage degeneration greater than 2 × 2 cm^2. Weinstein et al[32] reported on 25 patients, with an average age of 46 years and an average follow-up of 34 months, treated with arthroscopic débridement for early glenohumeral arthritis. In this group, all patients were treated with chondral débridement, synovectomy, and loose body removal as needed. Twenty-three of 25 patients were treated with subacromial bursectomy, and 12 of 25 had capsular release for preoperative stiffness. All the patients had good or excellent results, with 10 of 12 reporting improvement in range of motion after capsular release. In a study of patients treated with arthroscopic débridement, 16 of 71 patients (23%) required arthroplasty at an average of 10.1 months, with 55 of 71 patients (77%) showing significant improvement in American Shoulder and Elbow Surgeons (ASES) scores, simple shoulder test (SST) scores, the visual analog scale (VAS), and range of motion at an average follow-up of 27 months (A Romeo et al, Chicago IL, unpublished data).

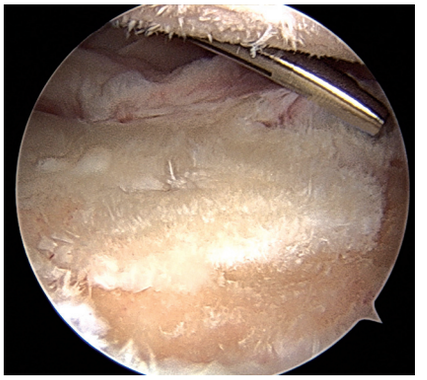

Figure 3 Arthroscopic view of palliative treatment of a grade IV chondral lesion of the glenoid. The motorized shaver is used to create a stable, vertical, transition zone between the defect and the surrounding cartilage.

Reparative: Microfracture

Even in patients with comorbidities, reparative options are used to treat superficial defects believed to be associated with symptoms. The goal of reparative strategies is to resurface a defect with fibrocartilage using a marrow stimulation technique. Steadman et al[33] initially described the technique

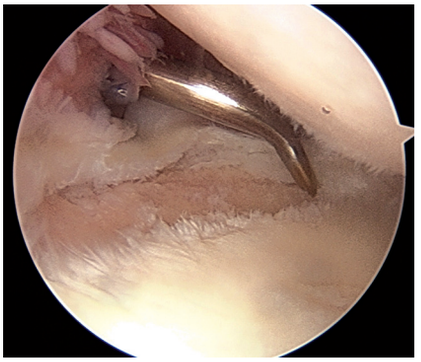

Figure 4 Arthroscopic view of microfracture of a grade IV glenoid lesion using specifically designed awls to penetrate the subchondral bone plate every 2 to 3 mm.

of microfracture to treat cartilage lesions in the knee; this technique has remained the preferred marrow stimulation procedure of this chapter's authors. Other potential reparative strategies include abrasion chondroplasty and drilling. Microfracture has a theoretic advantage over drilling because of the decreased risk of thermal damage to bone and cartilage.[33,34] Reparative techniques do not compromise a surgeon's ability to perform future restorative surgeries and can be performed entirely arthroscopically with little associated morbidity. Rudd et al[28] reported that smaller, well-shouldered lesions should perform better clinically than larger unshouldered lesions with gradual transition zones. Reparative treatment is contraindicated in any osteochondral defects in which the subchondral plate has been violated and in any patient with bone and cartilage loss.[34-36]

The surgical technique for microfracture of glenohumeral cartilage lesions stems from the technique described in the knee.[33,36] The initial step is to débride the lesion to the level of calcified cartilage. This portion of the procedure can be done with a combination of motorized shavers and arthroscopic curets. Next, it is critical to establish vertical walls so that the lesion is contained with normal or near-normal cartilage. Specifically designed awls are then used to penetrate the subchondral plate every 2 to 3 mm (**Figure 4**). This penetration allows mesenchymal marrow elements to form a fibrin scaffold that is gradually replaced by fibrocartilage.

Currently, there are only a limited number of published studies of patients treated with microfracture for glenohumeral cartilage defects. In a recent study by Frank et al,[37] 16 patients (17 shoulders) treated with arthroscopic microfracture of the humeral head and/or glenoid surface were retrospectively reviewed and examined by an independent, blinded examiner. All patients with concomitant labral or rotator cuff repairs were excluded. The mean age of patients was 37 years, and the average follow-up was 27.8 months (minimum follow-up, 12 months). Two shoulders were lost to follow-up, leaving 14 patients (15 shoulders). The average size of humeral and glenoid defects was 5.07 cm^2 and 1.66 cm^2, respectively. Twelve of 14 patients (86%) stated they would have the procedure again, and there was a significant improvement in VAS, ASES, and SST outcomes scores. Based on this small series, the authors concluded that microfracture can provide significant improvement in pain relief and shoulder function in patients with isolated chondral lesions. Yen et al[38] performed a similar study of 31 shoulders in 30 patients treated with microfracture of the glenohumeral joint. Shoulders with rotator cuff tears and patients older than 60 years were excluded. The mean patient age was 43 years, and the average follow-up was 47 months (minimum follow-up, 25 months). In the 6 of 31 shoulders requiring additional surgery, microfracture was considered a failed procedure. Mean ASES scores showed significant postoperative improvement ($P < 0.05$) in ability to work, perform the activities of daily living, and participate in sports activities. The authors concluded that microfracture can be a successful procedure in the glenohumeral joint, with the greatest success achieved in patients with isolated, small, humeral lesions.

Cartilage Restorative Options

Restorative treatment options for glenohumeral defects include osteochondral autografts, osteochondral allografts, and autologous chondrocyte implantation (an off-label indication). These techniques can be used as the primary procedure to treat patients with chondral pathology or as a secondary procedure after failed reparative treatment. These procedures involve significantly greater surgical morbidity than reparative techniques, and all are typically performed through a shoulder arthrotomy. Proper patient selection is critical for success. The ideal candidate is a young, active individual with an isolated focal cartilage defect of the humerus or glenoid in whom nonsurgical treatment options have been exhausted. Although autologous chondrocyte implantation can be used only with isolated cartilage defects, osteochondral autografts and allografts can be used to treat lesions with combined cartilage and bone loss.

Osteochondral Autograft Transfer

Osteochondral autograft transfer traditionally has been used to treat knee and talar lesions with successful results.[39,40] This technique is generally reserved for smaller humeral lesions (1 to 1.5 cm^2) in which first-line treatment has failed. The advantages of this procedure are the ability to restore the glenohumeral architecture with a viable "organ" of bone and cartilage with a single-stage procedure and the ability

to achieve osseous integration and preserve the articular tidemark. A unique disadvantage of this procedure is donor-site morbidity, with the autograft usually harvested from the lateral trochlea of the knee. An arthroscopic procedure is technically challenging, and the current standard procedure is an arthrotomy. The literature has only limited reports of osteochondral autograft transfer to the shoulder. Scheibel et al[41] reported on eight traumatic grade IV chondral lesions of the humeral head treated with osteochondral autograft transfer and followed for a mean of 32.6 months. At this short-term follow-up, six patients were pain free, and two had a reduction in pain compared with the preoperative level. Postoperative MRI showed graft incorporation and congruent articular surfaces in seven of eight patients. One patient required two additional procedures at the donor knee for recurrent effusions. Connor et al[42] described a case report of a patient with bilateral posterior fracture-dislocations of the glenohumeral joint in which one side was treated with hemiarthroplasty and the other side with local autograft taken from the shoulder treated with arthroplasty. This same procedure was used by Ivkovic et al[43] to treat a patient with bilateral locked posterior dislocations, with excellent clinical and radiographic results at 3-year follow-up.

Osteochondral Allograft

The goal of osteochondral allograft implantation is to restore the congruency of an articular surface with an intact osteochondral segment. With increasing availability, improved donor screening and procurement protocols, and rapidly evolving surgical techniques, the use of these grafts in the shoulder is increasing.[44] Fresh osteochondral allografts are composite tissues with viable cartilage layers attached to nonviable subchondral bone.[45] Recent studies have shown that the success of fresh osteochondral allograft implants depends on the number of viable chondrocytes that remain after implantation.[46-48] Currently, osteochondral allografts are being used to treat both humeral and glenoid defects, most commonly associated with postdislocation combined bone and cartilage pathology; however, lesser tuberosity transfer is an available option for reverse Hill-Sachs defects. Fresh osteochondral allografts are the current standard of care because these grafts have higher chondrocyte viability, improved maintenance of the cartilage matrix, and better long-term results compared with cryopreserved grafts.[47,48] Although disease transmission remains a concern, since screening standards were introduced in 1985, there have been no reported cases of human immunodeficiency virus transmission from an allogeneic graft.[49,50]

The surgical technique for osteochondral allograft placement is adapted from clinical experiences with knee procedures. The surgeon's preferred standard exposure method is used to visualize the lesion. For the humerus, commercial allograft transplantation systems are available. The usual goal is to create a socket with a healthy bed of subchondral bone that is typically 7 to 8 mm deep. This can be accomplished using either the dowel technique to create a circular socket, or a wedge-shaped defect can be created in a freehand manner. The graft is usually placed with either a press-fit technique or press-fit with screw fixation for augmentation (**Figure 5**). For the glenoid, a fresh distal tibial osteochondral allograft can be used for glenoid deficiency, and is most commonly indicated for patients with significant bony Bankart lesions after recurrent dislocations. Typically, the graft is fashioned to re-create the normal contour and shape of the glenoid and is fixed with two 3.5-mm fully treated cortical screws in a lag fashion.[51] This technique can be used as a substitute for Latarjet and Bristow procedures and is advantageous because it creates a viable cartilage surface on the glenoid.

The published data on treating glenohumeral defects with osteochondral allografts are limited to case reports and a single case series. Yagishita and Thomas[52] recently described a patient with a chronic anterior shoulder dislocation secondary to a large Hill-Sachs lesion that was treated with a femoral head allograft. At 2-year follow-up, the patient was symptom free with no episodes of recurrent instability. Chapovsky and Kelly[18] used three osteochondral allograft plugs placed arthroscopically to treat a 16-year-old boy with recurrent instability secondary to an engaging Hill-Sachs lesion. One year after surgery, the patient had returned to athletic activity and was symptom free. Gerber and Lambert[53] treated four patients with chronic, locked posterior shoulder dislocations using osteochondral allografts to fill the reverse Hill-Sachs lesion. In all four patients the humeral head defect was at least 40% of the articular surface. At a mean follow-up of 68 months, good to excellent results were reported in three patients; osteonecrosis in the remainder of the humeral head developed postoperatively in the fourth patient. Osteochondral allograft humeral head resurfacing in combination with a lateral meniscal allograft glenoid resurfacing was described by McCarty and Cole[54] in a case report involving a 16-year-old girl with symptomatic bipolar glenohumeral chondrolysis subsequent to arthroscopic thermal capsulorrhaphy. At 2-year follow-up, the patient reported complete resolution of her shoulder pain, and radiographs showed maintenance of the glenohumeral joint space

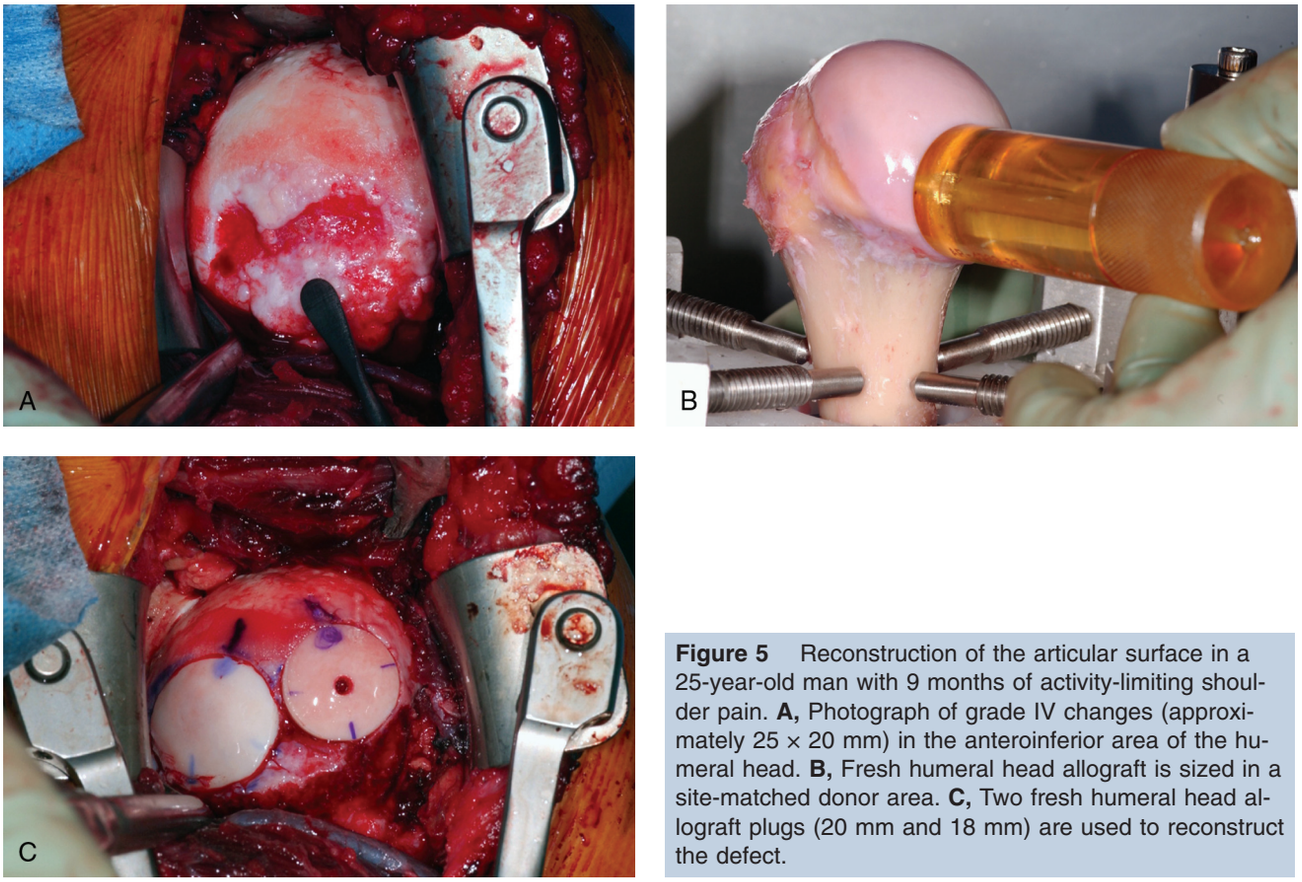

Figure 5 Reconstruction of the articular surface in a 25-year-old man with 9 months of activity-limiting shoulder pain. **A,** Photograph of grade IV changes (approximately 25 × 20 mm) in the anteroinferior area of the humeral head. **B,** Fresh humeral head allograft is sized in a site-matched donor area. **C,** Two fresh humeral head allograft plugs (20 mm and 18 mm) are used to reconstruct the defect.

with no evidence of allograft collapse or hardware migration. The patient's postoperative ASES score was 83 (preoperative = 50), and her SST score was 8 (preoperative = 1). Glenohumeral forward flexion and external rotation improved from 90° and 40° to 160° and 50°, respectively. Kropf and Sekiya[55] used arthroscopic management of the anterior capsulolabral pathology combined with a limited, open, posterior approach to place an osteochondral allograft to fill a large Hill-Sachs lesion. At 1-year follow-up, the patient was on active military duty without restrictions. In a study of 20 young patients (mean age, 19.7 years) with extensive postoperative surgical glenohumeral arthritis, McNickle et al[2] described the use of biologic resurfacing with osteochondral allografts for the humeral head and lateral meniscal allografts for the glenoid in seven patients; one patient was treated with osteochondral allograft resurfacing of the humeral head alone. At a mean follow-up of 3.1 years (range, 1.9 to 6.5 years), improvements were reported with respect to SST, ASES and VAS scores.

Three case series report on the treatment of anterior glenoid defects with osteochondral allografts. Weng et al[56] describes a study of nine consecutive patients with anterior instability associated with glenoid bone loss. Patients were treated with an anteroinferior capsular shift combined with a bone buttress femoral head osteochondral allograft. One patient had a repeat dislocation, and one had subluxation (both events occurred following a seizure). At mean follow-up of 4.5 years, all grafts had radiographic evidence of bony union with the native glenoid. Hutchinson et al[57] performed a similar procedure with a femoral head osteochondral allograft bone buttress to treat nine epileptic patients with recurrent instability. In this study, there were no recurrences. Provencher et al[51] reported using a distal tibial allograft for anterior glenoid reconstruction with a mean glenoid bone loss of 30%. The advantages of this graft include a viable cartilage surface, a dense weight-bearing corticocancellous bone, a radius of curvature that nearly matches the normal glenoid contour, and increased availability compared with glenoid allografts (**Figure 6**). Further research, including clinical studies, of this promising treatment option for anterior glenoid bone loss is currently being performed.

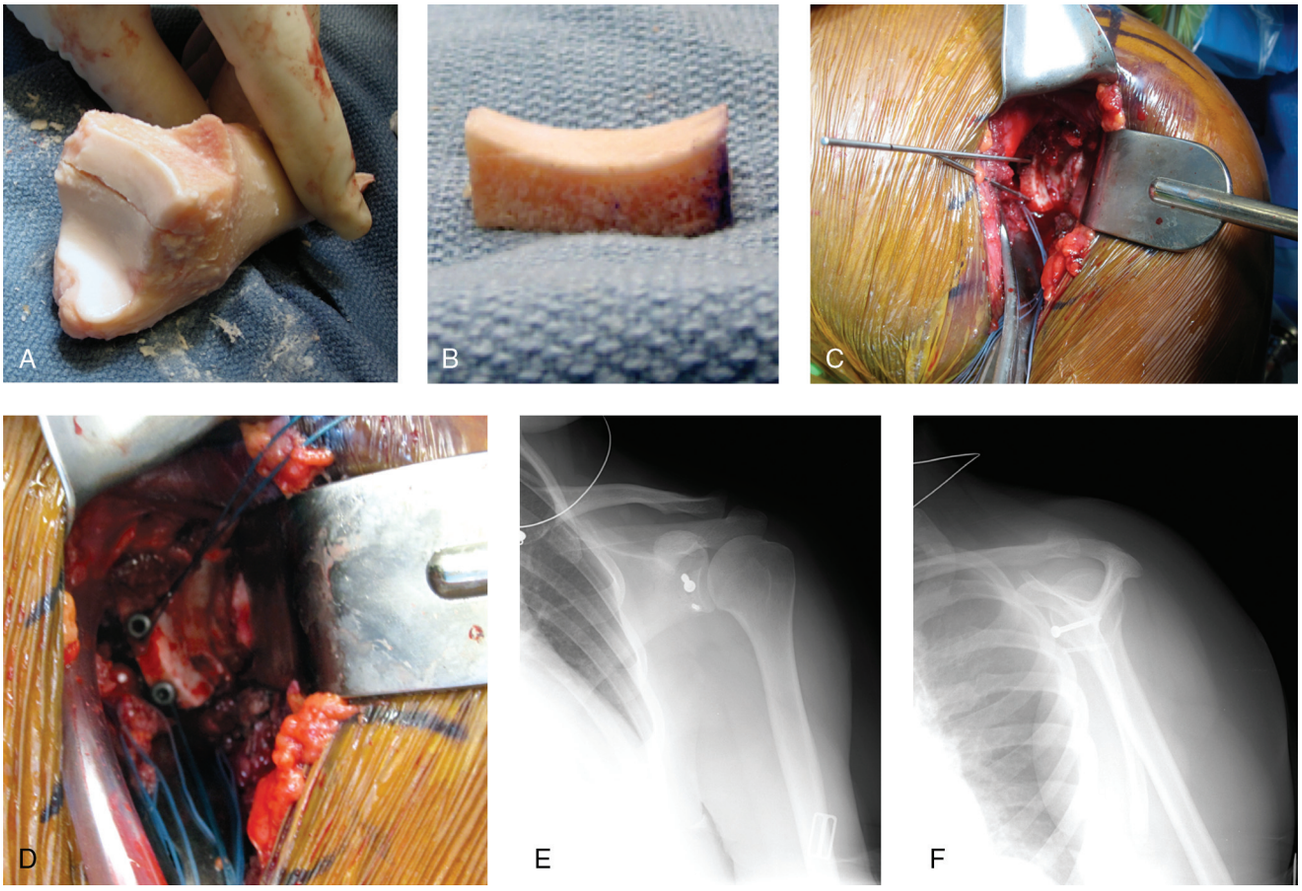

Figure 6 A distal tibial allograft is used to reconstruct the anterior glenoid with significant bone loss. **A,** The lateral aspect of the distal tibia provides a good fitting allograft for the anterior or posterior glenoid. **B,** The donor fresh distal tibial graft is harvested. It is approximately 30 mm superior to inferior, 10 mm anterior to posterior, and 10 mm deep. **C,** Intraoperative photograph of the fresh distal tibial graft in place and temporarily fixed with Kirschner wires. The native anterior glenoid was prepared with a high-speed burr to remove the defect (8 mm anterior to posterior). **D,** The fresh distal tibial allograft is affixed with two 3.5-mm cortical screws and small washers. **E,** AP radiograph shows the allograft in place. **F,** Postoperative supraspinatus outlet radiographic view of the allograft in place.

Autologous Chondrocyte Implantation

Autologous chondrocyte implantation remains investigational and is an off-label use of this technique in the glenohumeral joint. The basic principle of autologous chondrocyte implantation stems from its use in the knee and includes harvesting of healthy articular cartilage, subsequent culturing and expansion of cells over a 3- to 4-week period, and implantation. This technique may have potential use in a contained unipolar superficial defect greater than 2 cm^2 of the humerus in a young patient in whom first-line treatment has failed (**Figure 7**). The current literature is limited to a case report of a 16-year-old baseball player with a focal defect of the humeral head, which developed following arthroscopic capsulorrhaphy using a radiofrequency device.[58] The standard autologous chondrocyte implantation technique was performed, including harvesting cartilage from the intercondylar notch, growing the cells for 1 month, and using a periosteal graft from the proximal tibia. At 1-year follow-up, the patient had full range of painless motion.

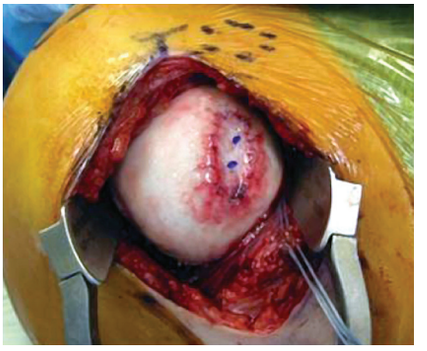

Figure 7 Intraoperative view of a focal humeral head chondral defect treated with autologous chondrocyte implantation.

Glenohumeral Reconstructive Options

In an effort to decrease pain and restore long-lasting shoulder function, biologic reconstructive techniques have been developed for young patients with glenohumeral degenerative arthritis. These techniques are indicated for patients with advanced unipolar or bipolar disease because biologic reconstructive surgery is a last resort before considering total shoulder arthroplasty. Reconstructive surgical options typically include biologic resurfacing of the glenoid coupled with either biologic or nonbiologic resurfacing of the humeral head.

Biologic resurfacing of the humeral head may be performed using an osteochondral allograft or autologous chondrocyte implantation.[1] As stated previously, at the present time, these treatment options remain investigational with limited clinical evidence available in the orthopaedic literature. More commonly, humeral head implant resurfacing or hemiarthroplasty is used in combination with biologic resurfacing of the glenoid. First proposed by Burkhead and Hutton[59] in 1988, biologic resurfacing of the glenoid combined with hemiarthroplasty has been used with variable results in treating young patients with glenohumeral arthritis. In their initial clinical series, interposition of soft tissue (local articular capsule or autogenous fascia lata) between the humeral head implant and the native glenoid provided consistent pain relief and improvement in shoulder range of motion at 2-year follow-up. As experience with biologic glenoid resurfacing has increased, other interposition options have been used, including Achilles tendon allografts; lateral meniscal allografts; and processed tissue grafts; such as the dermal patch regenerative tissue matrix (dermis) and porcine small intestine submucosa.[59-66]

The use of lateral meniscal allografts for soft-tissue glenoid resurfacing has been described using both open and arthroscopic techniques.[60,67] As an interposition material, the lateral meniscus has been shown to provide more complete coverage of the glenoid compared with the medial meniscus; this coverage significantly reduces the peak force and contact area across the glenohumeral joint during physiologic loading.[1,68] For lateral meniscal allograft resurfacing, the allograft tissue should be requested from a male donor younger than 30 years to maximize the size and quality of the material for glenoid coverage. Dermal patch regenerative tissue matrix resurfacing of the glenoid has similarly been described using both open and arthroscopic methods.[69] This processed human skin retains the native collagen structure, bioactive components, and vascular channels of the dermis, providing a framework to support cellular repopulation and vascularization after implantation.[1] Available in 4 × 4 cm^2 sheets, 1 to 2 mm thick, the dermal patch matrix can be fashioned to the size and shape of each patient's glenoid.

Open Lateral Meniscal Allograft or Dermal Patch Resurfacing

With the patient in the beach chair position under a combination of regional interscalene anesthesia and general anesthesia, a deltopectoral surgical approach is used. Preparation of the humeral head along with the necessary soft-tissue and/or capsular releases is routinely first performed to provide adequate access to the glenoid. The glenoid labrum is left in situ to serve as an anchor for fixation of either the interposition lateral meniscal allograft or the dermal patch matrix. Any remaining articular cartilage on the glenoid surface is removed with a curet, and concentric reaming is performed starting with a small reamer to avoid damage to the native labral tissue. Reaming creates a concentric surface with punctate bleeding to allow adhesion and healing of the interposed lateral meniscal allograft or the dermal patch matrix and provides the opportunity to correct glenoid version if any orientation abnormalities have developed during the disease course. When reaming is completed, nonabsorbable sutures are placed through the labrum, allowing 6 to 8 points of circumferential fixation to the glenoid (**Figure 8**). When necessary for supplemental graft fixation, suture anchors are inserted into the glenoid rim, and/or transosseous sutures are placed.

In patients treated with lateral meniscal allograft resurfacing, sutures from the labrum are passed through the lateral meniscal allograft, orienting the graft so that the anterior and posterior horns face anteriorly and the thickest portion of the graft covers the posterior portion of the glenoid. The horns are sutured together to provide stability during peripheral fixation. Each circumferential suture is then tied, leaving the fixation of the horns to the anterior aspect of the glenoid as the last step. Final suturing of the two horns of the meniscal allograft is then performed allowing for adjustment (as needed) for stability and sizing. Once the lateral meniscal allograft is placed, the humerus is carefully dislocated forward, which allows the hemiarthroplasty prosthesis to be implanted. The shoulder is then reduced to allow assessment of the conformity of the humeral head component, the implanted lateral meniscal allograft, and glenohumeral range of motion and stability. The subscapularis is then anatomically repaired, and the surgical incision is closed in layers.

In contrast to the lateral meniscal allograft resurfacing procedure, in dermal patch resurfacing, preparation and

implantation of the humeral head hemiarthroplasty is completed before approaching the glenoid. After the hemiarthroplasty is implanted, the shoulder is reduced, and the conformity of the implant with the patient's native articular surface is evaluated. Retractors are then inserted, which allows the humeral head implant to be displaced posteriorly, providing a straight-on approach to the glenoid. After the glenoid is prepared, its size and shape are noted; this allows the thawed, hydrated, dermal patch matrix to be fashioned accordingly. After cutting to the proper size and shape, the thickest available dermal patch matrix (2 mm in thickness) is secured to the glenoid by individually passing the sutures from the labrum through the edges of the material. This sequential suture passage and tying allows the dermal patch to be tensioned over the glenoid surface. The shoulder is then reduced, allowing glenohumeral range of motion and stability to be assessed. The subscapularis is then anatomically repaired, and the surgical incision is closed in layers.

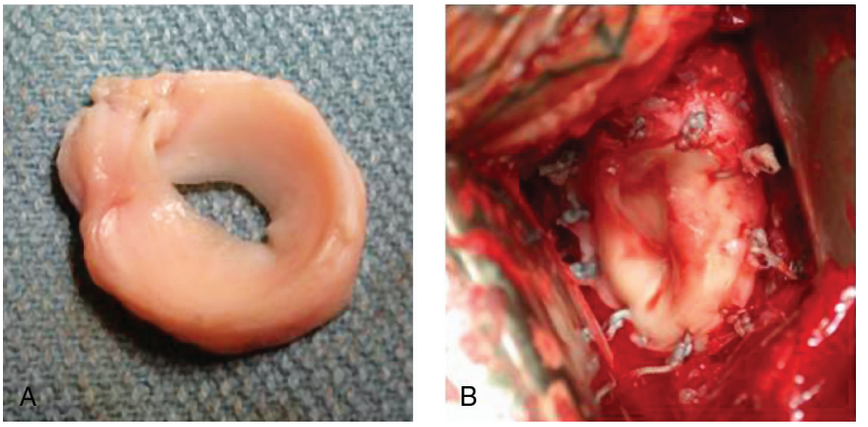

Figure 8 Biologic resurfacing of the glenoid using a lateral meniscal allograft (**A**) in combination with hemiarthroplasty in a 44-year-old patient with symptomatic glenohumeral arthrosis. **B,** View of the lateral meniscal allograft in place. It is affixed with suture to the remaining glenoid labral rim.

Outcomes

In the initial clinical series of Burkhead and Hutton,[59] 14 patients were treated with humeral head hemiarthroplasty and biologic resurfacing of the glenoid using either autogenous fascia lata or anterior shoulder capsule. Six patients with a mean age of 48 years (range, 33 to 54 years) were available for evaluation at a minimum 2-year follow-up. At a mean of 28 months postoperatively, the authors reported a reduction in pain in all patients and improvements in glenohumeral forward elevation, external rotation, and internal rotation of 57°, 45°, and six spinal segments, respectively. According to Neer's criteria, five of the six patients had excellent outcomes, with the remaining results classified as satisfactory. Lee et al[70] retrospectively evaluated 18 shoulders (mean patient age, 54.8 years) treated with soft-tissue resurfacing of the glenoid (anterior capsule) coupled with humeral head surface replacement. At a mean follow-up of 4.8 years, the authors reported a mean ASES score of 74.4; a mean Constant score of 71.4; and glenohumeral forward flexion, abduction, and external rotation of 130°, 122°, and 39°, respectively. Although 83% of the patients were satisfied with their postoperative clinical outcome, radiographic analysis showed moderate to severe glenoid erosion in 56% of the shoulders.

Long-term follow-up was reported by Krishnan et al[71] in their retrospective evaluation of 36 shoulders in 34 patients treated over a 15-year period. Biologic glenoid resurfacing was performed using autologous fascia lata (11 shoulders), anterior articular capsule (7 shoulders), and Achilles tendon allograft (18 shoulders). At a mean follow-up of 7 years, the authors reported an improvement in ASES scores from 39 preoperatively to 91 at the most recent evaluations. According to Neer's criteria, good to excellent results were seen in 86% of the shoulders. Radiographic evaluation of this cohort showed a mean 7.2 mm of glenoid erosion over the observation period, which appeared to stabilize at 5 years postoperatively.

Significantly worse outcomes following biologic resurfacing were reported by Elhassan et al[63] in a retrospective review of 13 patients younger than 50 years treated with hemiarthroplasty combined with soft-tissue interposition (Achilles tendon allograft, autogenous fascia lata, or anterior shoulder capsule). Ten of the 13 patients required conversion to total shoulder arthroplasty at a mean of 14 months postoperatively (range, 6 to 34 months). Combined with postoperative infection that developed in two patients, the authors found a 92.3% failure rate. Based on their findings, the authors concluded that soft-tissue resurfacing of the glenoid combined with humeral head arthroplasty is unreliable as a treatment in young, active patients with glenohumeral arthritis.

Lateral meniscal allograft interposition performed in conjunction with humeral head implant resurfacing was reviewed by Nicholson et al[64] in a study of 30 patients with a mean age of 42 years (range, 18 to 52 years). At a

mean follow-up of 18 months, the authors reported significant improvements in ASES scores (38 preoperatively to 69 postoperatively), SST scores (3.3 to 7.8), VAS pain scores (6.4 to 2.3), and shoulder range-of-motion parameters (forward elevation, 96° to 139°; external rotation, 26° to 53°). Complications requiring revision surgery occurred in five patients (17%) within the first postoperative year; however, despite this incidence, 94% of study patients reported satisfaction with their clinical outcome and would have the procedure again if needed.

Wirth[72] recently reported the outcomes for 30 patients treated with humeral head arthroplasty and lateral meniscus allograft interposition of the glenoid. Ninety percent of the patients were available for follow-up at a mean of 35 months. Overall, there was a 16% reoperation rate, with 50% of those procedures performed secondary to failure of the meniscal portion of the construct. The author did not report significant improvement in ASES, SST, and VAS scores for the patients in the study.

The use of dermal patch regenerative matrix in interposition resurfacing of the glenoid was reported by Huijsmans et al[73] in a clinical study of six patients with a mean age of 47 years. At 6-month follow-up, the authors reported preliminary improvement with overall good results. Savoie et al[74] recently reported outcomes following arthroscopic glenoid resurfacing using a biologic patch (Restore; DePuy Orthopaedics, Warsaw, IN) in 23 consecutive patients with a mean age of 32 years (range, 15 to 58 years) treated for severe glenohumeral arthritis. At 3- to 6-year follow-ups, 75% of patients in the cohort remained satisfied with their surgical results. Significant improvements were reported with respect to ASES scores (22 preoperatively to 78 postoperatively), University of California at Los Angeles scores (15 to 29), Rowe scores (55 to 81), and Constant-Murley scores (26 to 79). Five patients required conversion to arthroplasty during the follow-up period; however, four of the five reported that they would undergo the arthroscopic resurfacing again if necessary.

Glenoid Ream and Run Procedure

The ream and run procedure involves humeral head implant resurfacing coupled with concentric reaming of the glenoid to a radius of curvature 1 to 2 mm greater than that of the humeral head prosthesis.[75] The ream and run procedure attempts to achieve glenohumeral stability by spherical reaming about the centerline of the glenoid to correct eccentric wear and minimize the potential progressive erosion and instability that has been reported with humeral hemiarthroplasty alone.[76]

In a cadaver model, Weldon et al[77] showed that denuding the glenoid of its cartilaginous surface reduced its contribution to glenohumeral stability, and spherical reaming restored stability to values seen in both the native glenoid and those reconstructed with a polyethylene implant. The potential for a healing response or remodeling at the reamed glenoid surface was reported by Matsen et al[78] in a canine model using the ream and run technique. The authors reported that at 24 weeks following the procedure, a thick, firmly attached fibrocartilaginous tissue layer completely covered the glenoid surface and articulated with the prosthetic humeral head.

In a recent case-controlled study comparing the ream and run procedure with standard total shoulder arthroplasty, Clinton et al[75] reported significant and comparable functional improvement in both patient groups. At 12-month follow-up, patients in the total shoulder arthroplasty cohort had significantly higher SST scores; however, at both 2 and 3 years after surgery, the SST scores were similar between the two treatment groups. Based on these results, the authors concluded that although a longer recovery time was required, the ream and run procedure provided the opportunity for a comparable functional outcome without the potential risk of glenoid component failure.

Arthroplasty in the Young, Active Patient

For appropriately selected patients, total shoulder arthroplasty has been shown to reliably decrease pain and improve shoulder function.[79,80] Other options include osteotomies of the glenoid, humerus, or both; a double osteotomy of the neck of the glenoid and humerus (without displacement has been described in 13 patients with good results at approximately 3 years after surgery.[81]

In a recent meta-analysis of 23 clinical studies comparing total shoulder arthroplasty with humeral head replacement for the treatment of primary glenohumeral osteoarthritis, Radnay et al[82] reported that total shoulder arthroplasty resulted in significantly better pain relief, postoperative range of motion, and patient satisfaction, along with a lower revision rate. However, in younger active patients, the longevity of a total shoulder arthroplasty has been questioned, secondary to increased rates of glenoid component failure reported in several clinical studies.[83-85] In the younger patient population, the results of total shoulder arthroplasty have been shown to be variable, with recent studies reporting outcomes inferior to those seen in the typical patient older than 60 years.[17,86-88]

Humeral head hemiarthroplasty alone has been reported to provide

pain relief and improved short-term function, but studies with longer follow-up have shown progressive joint-space narrowing, glenoid erosion, and diminishing outcomes.[89-92] In a retrospective review of 78 hemiarthroplasties performed in patients younger than 50 years, Sperling et al[17] reported that at 15-year follow-up, the procedure had unsatisfactory results in 45% of their patients. Radiographic analysis demonstrated significant glenoid erosions in 68% of hemiarthroplasties. Radiolucent lines around the humeral component were reported in 24% of patients, perhaps indicating some degree of loosening. Survival estimates performed on data from this cohort found that 92% of the hemiarthroplasties survived to 5 years, 83% to 10 years, and 73% to 15 years. Based on their findings, the authors concluded that care should be exercised when hemiarthroplasty is offered to patients who are 50 years or younger. The outcomes after the conversion of a hemiarthroplasty to a total shoulder replacement with a polyethylene resurfaced glenoid are much less predictable than outcomes after a primary total shoulder arthroplasty. Patients treated in this fashion have increased residual pain, a higher risk for subsequent surgeries, and less predictable postoperative range of motion.[93,94]

Saltzman et al[86] recently evaluated 1,045 consecutive total shoulder arthroplasties and compared the surgical diagnoses between patients younger than 50 years and those older than 50 years. The authors found that the younger patients in their study had more complex pathologic conditions leading to shoulder arthroplasty compared with the older patients, adding a level of difficulty to the surgical procedure and potentially contributing to the poorer outcomes seen in the younger patient population. In a 1998 study, Sperling et al[17] reviewed the long-term results of Neer hemiarthroplasty (78 cases) and Neer total shoulder replacement (36 cases) performed in patients 50 years or younger who were followed for a mean of 12.3 years. Both total shoulder replacement and hemiarthroplasty in this series resulted in significant long-term pain relief and active shoulder abduction and external rotation. Based on their data, estimated implant survivorship for total shoulder replacement in this patient population was 97% at 10 years and 84% at 15 years. However, despite the high percentage of implant survivorship, unsatisfactory outcomes were reported in 17 of the total shoulder patients (47.2%). In a 2002 study by Sperling et al,[87] the authors retrospectively reviewed 33 patients with a mean age of 46 years managed with shoulder arthroplasty (10 hemiarthroplasties and 21 total shoulder replacements) for symptomatic glenohumeral arthritis after instability surgery. They found that while the procedures were associated with significant pain relief and improvement in active range of motion, high rates of revision surgery and unsatisfactory results occurred. According to the Neer criteria, at a mean follow-up of 7 years, patients treated with total shoulder arthroplasty had 3 excellent, 5 satisfactory, and 13 unsatisfactory outcomes. Eight total shoulder arthroplasty patients (38%) required revision surgery secondary to component failure and instability during the follow-up period. Better outcomes were reported by Raiss et al[95] in their prospective study of 21 patients with a mean age of 55 years (range, 37 to 60 years) with glenohumeral arthritis treated with total shoulder arthroplasty. At a mean follow-up of 7 years, 20 patients (95%) were either very satisfied (18 patients) or satisfied (2 patients) with their postoperative results. Significant improvement in the Constant-Murley score was reported (24.1 to 64.5). No patients had clinical or radiographic evidence of implant loosening, and at most recent follow-up, no revision surgeries had been necessary.

An alternative to arthroplasty, the Arthrosurface HemiCap (Arthrosurface, Franklin, MA) can also be used as a treatment option for pain relief and restoration of function in the shoulder with both focal and diffuse chondral damage. Using the Arthrosurface HemiCap on the diseased humeral head is similar in theory to hemiarthroplasty; however, instead of an entire stem positioned into the humeral shaft, the cap is attached to the humeral head with a smaller, central post. Only a single case report describing the use of the Arthrosurface HemiCap on the humerus is available in the literature, which was performed in conjunction with a Latarjet coracoid transfer procedure with successful results in a patient with recurrent shoulder dislocation.[96]

Based on the available data in the orthopaedic surgery literature, hemiarthroplasty and total shoulder arthroplasty in young, active patients represent viable treatment options. However, the potential for variable postoperative outcomes and concerns for glenoid erosion with hemiarthroplasty as well as glenoid component loosening with total shoulder arthroplasty must be acknowledged. Although a few recent follow-up studies have legitimized some of these concerns, these potential postoperative complications seem to occur over the long term, providing the patient with years of symptom-free, improved function. With improved implant designs, more durable biomaterials, and innovations in surgical technique, shoulder arthroplasty may become the procedure of choice for the young, active patient with glenohumeral degenerative disease.

Summary

Young patients with symptomatic degenerative disease of the glenohumeral joint represent a challenge for the treating orthopaedic surgeon. Secondary to the variety of etiologies that can lead to glenohumeral arthritis in the young adult, a thorough understanding of the appropriate workup and initial management of the disease is vital. Palliative, reparative, restorative, and reconstructive surgical options are available, with variable indications and outcomes. The development of a workable treatment algorithm based on the individual patient's pathology and physical demands will help guide the surgeon in the decision-making process. Continued research with an emphasis on correlating new surgical techniques with clinical outcomes is ongoing in an effort to optimize the treatment of patients with symptomatic degenerative disease of the glenohumeral joint.

References

1. Cole BJ, Yanke A, Provencher MT: Nonarthroplasty alternatives for the treatment of glenohumeral arthritis. *J Shoulder Elbow Surg* 2007;16(5, Suppl): S231-S240.
2. McNickle AG, L'Heureux DR, Provencher MT, Romeo AA, Cole BJ: Postsurgical glenohumeral arthritis in young adults. *Am J Sports Med* 2009;37(9): 1784-1791.
3. Solomon DJ, Navaie M, Stedje-Larsen ET, Smith JC, Provencher MT: Glenohumeral chondrolysis after arthroscopy: A systematic review of potential contributors and causal pathways. *Arthroscopy* 2009;25(11):1329-1342.
4. Yeh LR, Kwak S, Kim YS, et al: Evaluation of articular cartilage thickness of the humeral head and the glenoid fossa by MR arthrography: Anatomic correlation in cadavers. *Skeletal Radiol* 1998; 27(9):500-504.
5. Fox JA, Cole BJ, Romeo AA, et al: Articular cartilage thickness of the humeral head: An anatomic study. *Orthopedics* 2008;31(3):216.
6. Bicos J, Mazzocca A, Romeo AA: The glenoid center line. *Orthopedics* 2005;28(6):581-585.
7. Outerbridge RE: The etiology of chondromalacia patellae. *J Bone Joint Surg Br* 1961;43-B:752-757.
8. Busfield BT, Romero DM: Pain pump use after shoulder arthroscopy as a cause of glenohumeral chondrolysis. *Arthroscopy* 2009; 25(6):647-652.
9. Saltzman M, Mercer D, Bertelsen A, Warme W, Matsen F: Postsurgical chondrolysis of the shoulder. *Orthopedics* 2009;32(3):215.
10. Bailie DS, Ellenbecker TS: Severe chondrolysis after shoulder arthroscopy: A case series. *J Shoulder Elbow Surg* 2009;18(5):742-747.
11. 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.
12. Hsu HC, Luo ZP, Stone JJ, Huang TH, An KN: Correlation between rotator cuff tear and glenohumeral degeneration. *Acta Orthop Scand* 2003;74(1):89-94.
13. Gartsman GM, Taverna E: The incidence of glenohumeral joint abnormalities associated with full-thickness, reparable rotator cuff tears. *Arthroscopy* 1997;13(4): 450-455.
14. Taylor DC, Arciero RA: Pathologic changes associated with shoulder dislocations. Arthroscopic and physical examination findings in first-time, traumatic anterior dislocations. *Am J Sports Med* 1997;25(3):306-311.
15. Hintermann B, Gächter A: Arthroscopic findings after shoulder dislocation. *Am J Sports Med* 1995;23(5):545-551.
16. Kang RW, Frank RM, Nho SJ, et al: Complications associated with anterior shoulder instability repair. *Arthroscopy* 2009;25(8): 909-920.
17. 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.
18. Chapovsky F, Kelly JD IV: Osteochondral allograft transplantation for treatment of glenohumeral instability. *Arthroscopy* 2005; 21(8):1007.
19. 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, vii.
20. Cameron BD, Galatz LM, Ramsey ML, Williams GR, Iannotti JP: Non-prosthetic management of grade IV osteochondral lesions of the glenohumeral joint. *J Shoulder Elbow Surg* 2002;11(1): 25-32.
21. Millett PJ, Gobezie R, Boykin RE: Shoulder osteoarthritis: Diagnosis and management. *Am Fam Physician* 2008;78(5):605-611.
22. Buchbinder R, Green S, Youd JM: Corticosteroid injections for shoulder pain. *Cochrane Database Syst Rev* 2003;1:CD004016.
23. Bell AD, Conaway D: Corticosteroid injections for painful shoulders. *Int J Clin Pract* 2005; 59(10):1178-1186.
24. 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.

25. Green A, Norris TR: Shoulder arthroplasty for advanced glenohumeral arthritis after anterior instability repair. *J Shoulder Elbow Surg* 2001;10(6):539-545.
26. Matsoukis J, Tabib W, Guiffault P, et al: Shoulder arthroplasty in patients with a prior anterior shoulder dislocation: Results of a multicenter study. *J Bone Joint Surg Am* 2003;85-A(8):1417-1424.
27. Hsieh YS, Yang SF, Chu SC, et al: Expression changes of gelatinases in human osteoarthritic knees and arthroscopic debridement. *Arthroscopy* 2004;20(5):482-488.
28. Rudd RG, Visco DM, Kincaid SA, Cantwell HD: The effects of beveling the margins of articular cartilage defects in immature dogs. *Vet Surg* 1987;16(5): 378-383.
29. Nicholson GP: Arthroscopic capsular release for stiff shoulders: Effect of etiology on outcomes. *Arthroscopy* 2003;19(1):40-49.
30. Warner JJ, Allen A, Marks PH, Wong P: Arthroscopic release for chronic, refractory adhesive capsulitis of the shoulder. *J Bone Joint Surg Am* 1996;78(12):1808-1816.
31. Ellman H, Harris E, Kay SP: Early degenerative joint disease simulating impingement syndrome: Arthroscopic findings. *Arthroscopy* 1992;8(4):482-487.
32. Weinstein DM, Bucchieri JS, Pollock RG, Flatow EL, Bigliani LU: Arthroscopic debridement of the shoulder for osteoarthritis. *Arthroscopy* 2000;16(5):471-476.
33. Steadman JR, Rodkey WG, Rodrigo JJ: Microfracture: surgical technique and rehabilitation to treat chondral defects. *Clin Orthop Relat Res* 2001;(391, Suppl): S362-S369.
34. Salata MJ, Bajaj S, Verma NN, Cole BJ: Glenohumeral microfracture. *Cartilage* 2010;1(2): 121-126.
35. McCarty LP III, Cole BJ: Nonarthroplasty treatment of glenohumeral cartilage lesions. *Arthroscopy* 2005;21(9):1131-1142.
36. Frank RM, Romeo AA, Verma NN, Cole BJ: Resurfacing of isolated articular cartilage defects in the glenohumeral joint with microfracture: Surgical technique and case report. *Am J Orthop* 2010;39(7):326-332.
37. Frank RM, Van Thiel GS, Slabaugh MA, Romeo AA, Cole BJ, Verma NN: Clinical outcomes after microfracture of the glenohumeral joint. *Am J Sports Med* 2010;38(4):772-781.
38. Yen YM, Cascio B, O'Brien L, Stalzer S, Millett PJ, Steadman JR: Treatment of osteoarthritis of the knee with microfracture and rehabilitation. *Med Sci Sports Exerc* 2008;40(2):200-205.
39. Hangody L, Feczkó P, Bartha L, Bodó G, Kish G: Mosaicplasty for the treatment of articular defects of the knee and ankle. *Clin Orthop Relat Res* 2001;391(Suppl): S328-S336.
40. Hangody L, Kish G, Módis L, et al: Mosaicplasty for the treatment of osteochondritis dissecans of the talus: Two to seven year results in 36 patients. *Foot Ankle Int* 2001;22(7):552-558.
41. 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.
42. Connor PM, Boatright JR, D'Alessandro DF: Posterior fracture-dislocation of the shoulder: Treatment with acute osteochondral grafting. *J Shoulder Elbow Surg* 1997;6(5):480-485.
43. Ivkovic A, Boric I, Cicak N: One-stage operation for locked bilateral posterior dislocation of the shoulder. *J Bone Joint Surg Br* 2007; 89(6):825-828.
44. Ho JY, Miller SL: Allografts in the treatment of athletic injuries of the shoulder. *Sports Med Arthrosc* 2007;15(3):149-157.
45. Görtz S, Bugbee WD: Fresh osteochondral allografts: Graft processing and clinical applications. *J Knee Surg* 2006;19(3):231-240.
46. Williams RJ III, Dreese JC, Chen CT: Chondrocyte survival and material properties of hypothermically stored cartilage: An evaluation of tissue used for osteochondral allograft transplantation. *Am J Sports Med* 2004;32(1):132-139.
47. Wingenfeld C, Egli RJ, Hempfing A, Ganz R, Leunig M: Cryopreservation of osteochondral allografts: Dimethyl sulfoxide promotes angiogenesis and immune tolerance in mice. *J Bone Joint Surg Am* 2002;84-A(8): 1420-1429.
48. Czitrom AA, Keating S, Gross AE: The viability of articular cartilage in fresh osteochondral allografts after clinical transplantation. *J Bone Joint Surg Am* 1990;72(4): 574-581.
49. Simonds RJ, Holmberg SD, Hurwitz RL, et al: Transmission of human immunodeficiency virus type 1 from a seronegative organ and tissue donor. *N Engl J Med* 1992;326(11):726-732.
50. Buck BE, Malinin TI, Brown MD: Bone transplantation and human immunodeficiency virus: An estimate of risk of acquired immunodeficiency syndrome (AIDS). *Clin Orthop Relat Res* 1989;240:129-136.
51. Provencher MT, Ghodadra N, LeClere L, Solomon DJ, Romeo AA: Anatomic osteochondral glenoid reconstruction for recurrent glenohumeral instability with glenoid deficiency using a distal tibia allograft. *Arthroscopy* 2009; 25(4):446-452.
52. Yagishita K, Thomas BJ: Use of allograft for large Hill-Sachs lesion

associated with anterior glenohumeral dislocation: A case report. *Injury* 2002;33(9):791-794.

53. 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.
54. McCarty LP III, 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. Kropf EJ, Sekiya JK: Osteoarticular allograft transplantation for large humeral head defects in glenohumeral instability. *Arthroscopy* 2007;23(3):322, e1-e5.
56. Weng PW, Shen HC, Lee HH, Wu SS, Lee CH: Open reconstruction of large bony glenoid erosion with allogeneic bone graft for recurrent anterior shoulder dislocation. *Am J Sports Med* 2009;37(9):1792-1797.
57. Hutchinson JW, Neumann L, Wallace WA: Bone buttress operation for recurrent anterior shoulder dislocation in epilepsy. *J Bone Joint Surg Br* 1995;77(6): 928-932.
58. 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.
59. Burkhead WZ Jr, Hutton KS: Biologic resurfacing of the glenoid with hemiarthroplasty of the shoulder. *J Shoulder Elbow Surg* 1995;4(4):263-270.
60. Ball CG, Yamaguchi K: Meniscal allograft interposition arthroplasty for the arthritic shoulder: Description of a new surgical technique. *Tech Shoulder Elbow Surg* 2001;2: 247-254.
61. Baumgarten KM, Lashgari CJ, Yamaguchi K: Glenoid resurfacing in shoulder arthroplasty: Indications and contraindications. *Instr Course Lect* 2004;53:3-11.
62. 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.
63. 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.
64. 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.
65. Pearl ML, Romeo AA, Wirth MA, Yamaguchi K, Nicholson GP, Creighton RA: Decision making in contemporary shoulder arthroplasty. *Instr Course Lect* 2005;54: 69-85.
66. Brislin KJ, Field LD, Ramsey JR: Surgical treatment for glenohumeral arthritis in the young patient. *Tech Shoulder Elbow Surg* 2004;5:165-169.
67. Pennington WT, Bartz BA: Arthroscopic glenoid resurfacing with meniscal allograft: A minimally invasive alternative for treating glenohumeral arthritis. *Arthroscopy* 2005;21(12):1517-1520.
68. 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.
69. 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, e1-e5.
70. Lee KT, Bell S, Salmon J: Cementless surface replacement arthroplasty of the shoulder with biologic resurfacing of the glenoid. *J Shoulder Elbow Surg* 2009; 18(6):915-919.
71. Krishnan SG, Reineck JR, Nowinski RJ, Harrison D, Burkhead WZ: Humeral hemiarthroplasty with biologic resurfacing of the glenoid for glenohumeral arthritis: Surgical technique. *J Bone Joint Surg Am* 2008;90(Suppl 2, Pt 1):9-19.
72. Wirth MA: Humeral head arthroplasty and meniscal allograft resurfacing of the glenoid. *J Bone Joint Surg Am* 2009;91(5):1109-1119.
73. Huijsmans PR, van Rooyen K, du Toit DF, de Beer JF: The treatment of glenohumeral OA in the young and active patient with the graft jacket: Preliminary results. *J Bone Joint Surg Br* 2004; 87(suppl III):275.
74. Savoie FH III, Brislin KJ, Argo D: Arthroscopic glenoid resurfacing as a surgical treatment for glenohumeral arthritis in the young patient: Midterm results. *Arthroscopy* 2009;25(8):864-871.
75. Clinton J, Franta AK, Lenters TR, Mounce D, Matsen FA III: 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.
76. Hasan SS, Leith JM, Campbell B, Kapil R, Smith KL, Matsen FA III: Characteristics of unsatisfactory shoulder arthroplasties. *J Shoulder Elbow Surg* 2002;11(5): 431-441.
77. Weldon EJ III, Boorman RS, Smith KL, Matsen FA III: Opti-

mizing the glenoid contribution to the stability of a humeral hemiarthroplasty without a prosthetic glenoid. *J Bone Joint Surg Am* 2004;86-A(9):2022-2029.

78. Matsen FA III, 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.
79. Iannotti JP, Norris TR: Influence of preoperative factors on outcome of shoulder arthroplasty for glenohumeral osteoarthritis. *J Bone Joint Surg Am* 2003; 85-A(2):251-258.
80. Norris TR, Iannotti JP: Functional outcome after shoulder arthroplasty for primary osteoarthritis: A multicenter study. *J Shoulder Elbow Surg* 2002;11(2): 130-135.
81. Benjamin A, Hirschowitz D, Arden GP: The treatment of arthritis of the shoulder joint by double osteotomy. *Int Orthop* 1979;3(3): 211-216.
82. 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.
83. Torchia ME, Cofield RH, Settergren CR: Total shoulder arthroplasty with the Neer prosthesis: Long-term results. *J Shoulder Elbow Surg* 1997;6(6):495-505.
84. Wirth MA, Rockwood CA Jr: Complications of shoulder arthroplasty. *Clin Orthop Relat Res* 1994; 307:47-69.
85. Wirth MA, Rockwood CA Jr: Complications of total shoulder-replacement arthroplasty. *J Bone Joint Surg Am* 1996;78(4): 603-616.
86. Saltzman MD, Mercer DM, Warme WJ, Bertelsen AL, Matsen FA III: Comparison of patients undergoing primary shoulder arthroplasty before and after the age of fifty. *J Bone Joint Surg Am* 2010;92(1):42-47.
87. 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-A(10):1775-1781.
88. 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.
89. 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.
90. Parsons IM IV, Millett PJ, Warner JJ: Glenoid wear after shoulder hemiarthroplasty: Quantitative radiographic analysis. *Clin Orthop Relat Res* 2004;421:120-125.
91. Pfahler M, Jena F, Neyton L, Sirveaux F, Molé D: Hemiarthroplasty versus total shoulder prosthesis: Results of cemented glenoid components. *J Shoulder Elbow Surg* 2006;15(2):154-163.
92. 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.
93. Sperling JW, Cofield RH: Revision total shoulder arthroplasty for the treatment of glenoid arthrosis. *J Bone Joint Surg Am* 1998;80(6):860-867.
94. Carroll RM, Izquierdo R, Vazquez M, Blaine TA, Levine WN, Bigliani LU: Conversion of painful hemiarthroplasty to total shoulder arthroplasty: Long-term results. *J Shoulder Elbow Surg* 2004;13(6):599-603.
95. Raiss P, Aldinger PR, Kasten P, Rickert M, Loew M: Total shoulder replacement in young and middle-aged patients with glenohumeral osteoarthritis. *J Bone Joint Surg Br* 2008;90(6): 764-769.
96. Moros C, Ahmad CS: Partial humeral head resurfacing and Latarjet coracoid transfer for treatment of recurrent anterior glenohumeral instability. *Orthopedics* 2009;32(8):602.