

CURRENT CONCEPTS REVIEW

SHOULDER ARTHRODESIS

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Current indications for shoulder arthrodesis include posttraumatic brachial plexus injuries, paralysis of the deltoid muscle and rotator cuff, chronic infection, failed revision arthroplasty, severe refractory instability, and bone deficiency following resection of a tumor in the proximal aspect of the humerus.

The trapezius, levator scapulae, serratus anterior, and rhomboid muscles must be functional to optimize the functional result following shoulder arthrodesis.

A consensus has not been reached concerning the ideal position of the shoulder arthrodesis, although excessive abduction or flexion has been associated with chronic postoperative pain.

Decortication of both the acromiohumeral and the glenohumeral surfaces to increase the surface area available for arthrodesis is the most common means for obtaining successful fusion.

Although there are numerous methods for stabilization of a shoulder arthrodesis, the most popular method today is probably the AO technique with either a single plate or double plates.

Humeroscaphular arthrodesis is a well-established operative procedure that involves fusion of the humeral head to the glenoid. In some procedures, the fusion also includes an acromiohumeral arthrodesis. Humeroscaphular arthrodesis is commonly called “shoulder arthrodesis,” and we use that term in this paper for simplicity. Indications for this procedure early in the twentieth century included the treatment of residual glenohumeral destruction resulting from tuberculosis and the treatment of upper-extremity paralysis resulting from poliomyelitis¹⁻⁵. Additional historical indications included osteoarthritis, rheumatoid arthritis, irreparable injury of the rotator cuff, and severely comminuted fracture of the proximal aspect of the humerus. The advent of shoulder arthroplasty has resulted in a marked reduction in the number of shoulder arthrodeses performed, although there are instances when arthrodesis is favored over joint-replacement arthroplasty. This article reviews the indications for shoulder arthrodesis, the pertinent features of the preoperative evaluation, the controversial issue of the desirable position of the arthrodesis, the various techniques for shoulder arthrodesis, and the management of complications.

Indications

The indications for most shoulder arthrodeses today include posttraumatic brachial plexus injury, paralytic disorders in infancy, insufficiency of the deltoid muscle and rotator cuff, chronic infection, failed revision arthroplasty, severe refractory instability, and bone deficiency following resection of a tumor in the proximal aspect of the humerus^{1,4,6-17}. Although

shoulder arthroplasty has become an accepted treatment alternative even in younger patients, there are surgeons who favor arthrodesis over arthroplasty. In a young patient with glenohumeral arthritis who performs heavy manual labor that is likely to place excessive demands on a prosthesis, arthrodesis may be appropriate^{7,18,19}. We¹⁸ reported that the triad of massive rotator-cuff deficiency, deltoid-muscle insufficiency, and excessive excision of the acromion results in pain and a devastating loss of function. Fortunately, this complication can be effectively minimized with arthrodesis of the shoulder^{20,21}.

Glenohumeral arthrodesis may also be indicated following failed total shoulder arthroplasty or hemiarthroplasty. The choice of whether to perform arthrodesis or revision arthroplasty must be individualized for each patient. Factors that require consideration include the presence or absence of infection, the adequacy of available bone stock in both the humerus and the glenoid, and the baseline medical status of the patient. Patients who have undergone several attempts at successful arthroplasty with resultant loosening, infection, deltoid-muscle damage, or instability may benefit from arthrodesis as opposed to an additional attempt at revision^{14,16,22}.

Another indication for glenohumeral arthrodesis in recent times has come with the advent of limb salvage in tumor-resection cases^{23,24}. Resection of the proximal aspect of the humerus and some of the surrounding soft tissue leaves large osseous defects as well as possible functional loss of the musculature that powers the glenohumeral joint. In this situation, implant arthroplasty is not a feasible alternative. Arthrodesis with either vascularized or nonvascularized autograft or prox-

imal humeral allograft will result in a stable, functional extremity^{14,23,24}. The aim of resection arthrodesis in this situation is to place the humerus in a stable position that allows optimal function of the distal part of the extremity. From both functional and cosmetic standpoints, this option is much more acceptable than amputation. Following arthrodesis, these patients are able to use their hand and the distal part of their extremity quite effectively. Gebhardt et al.²⁵ reported on nine patients who were treated with resection arthrodesis after undergoing resection of a malignant tumor. The functional results and the level of patient satisfaction were good or excellent in all cases.

A rare indication for shoulder arthrodesis that deserves mention is a paralytic disorder of the shoulder in infancy. Posttraumatic brachial plexus injury results in a flail extremity that is both painful and nonfunctional. Shoulder arthrodesis is indicated in this situation to provide both pain relief and increased functional stability. However, obtaining a solid fusion is more difficult in children because of the excessive amount of cartilage contained in the humeral head. Mah and Hall²⁶ reported on a series of ten children who underwent shoulder arthrodesis for either a birth injury or poliomyelitis. All of these fusions healed, and the patients reported relief of pain and satisfactory functional use of the extremity.

The contraindications to shoulder arthrodesis include paralysis of the trapezius, levator scapulae, serratus anterior, latissimus dorsi, or rhomboid muscles¹³. These scapula-stabilizing muscles are required to provide motor function to the extremity. Richards^{14,27} reported that, if these muscles are nonfunctional, the extremity will be severely impaired despite successful joint fusion. Charcot arthropathy has also been reported as a contraindication to shoulder arthrodesis. The rates of nonunion and infection are stated to be higher in patients with Charcot arthropathy, and thus shoulder arthrodesis is discouraged¹⁷. Another contraindication to shoulder arthrodesis is a contralateral shoulder arthrodesis¹³. Bilateral shoulder arthrodesis severely inhibits the patient's functional abilities, including the ability to perform activities of daily living.

In comparison with shoulder arthroplasty, shoulder arthrodesis is seldom undertaken for the treatment of rheumatoid arthritis or osteoarthritis of the shoulder, even in younger patients who wish to be active. An exception to this was reported by Rybka et al.²⁸. Thirty-seven of forty-one shoulders with rheumatoid arthritis were treated with arthrodesis, with few complications. A brace was used for postoperative support in an attempt to avoid elbow stiffness. This investigation suggested that fusion is easily achieved, inexpensive, and reliable for the treatment of shoulders severely involved with rheumatoid arthritis. In contrast, Jónsson et al.¹⁹ analyzed a series of patients with severe rheumatoid involvement of the shoulder. Five patients underwent shoulder arthrodesis, and five others were treated with cup arthroplasty. Essentially, all ten patients were satisfied with the shoulder postoperatively in terms of pain relief. However, range of motion and rotation were much better in the patients treated with cup arthroplasty. Thus, shoulder function was reported to be superior in the group treated with arthroplasty.

Preoperative Assessment

Candidates for shoulder arthrodesis require extensive preoperative counseling so that they are fully informed about postoperative functional limitations. A thorough history and physical examination are necessary to determine a patient's baseline medical status and the etiology of the shoulder condition. Candidates for shoulder arthrodesis may have variable findings on physical examination, depending on the etiology of their condition. For example, patients who have had multiple failed surgical procedures on the rotator cuff or failed attempts at reconstruction may have severe associated glenohumeral arthritis. These patients are commonly bothered by substantial pain and discomfort, with loss of motion and with functional deficits. Patients with a brachial plexus injury and resultant paralysis of the deltoid and rotator-cuff muscles have symptomatic instability and may also have functional deficits in the distal part of the extremity. The objective of stabilizing a flail extremity is to protect it from further injury, provide pain relief, and optimize function.

The patient requiring glenohumeral arthrodesis generally has weakness or paralysis of the deltoid, supraspinatus, and infraspinatus muscles with associated atrophy. Pain is moderate or severe, and the patient is unable to use the elbow or hand because the shoulder cannot be stabilized. Motor function of the trapezius, levator scapulae, serratus anterior, and rhomboid muscles must be intact to optimize the functional result.

A thorough radiographic examination is also required, primarily to assess the availability of bone stock. Standard anteroposterior and axillary lateral radiographs of the glenohumeral joint provide information about the adequacy of bone stock for internal fixation, the presence or absence of arthritis, and any deficiencies or developmental abnormalities. If assessment of the glenoid is difficult or if the shoulder problem is the result of destruction by a malignant tumor, a computerized tomography scan should be performed²⁷.

Bone loss can be an important problem in the face of gunshot injuries, tumor resection, and failed glenohumeral joint-replacement arthroplasty. In the event that substantial osseous defects exist, primary bone-grafting is required with the arthrodesis. In the study by Cofield and Briggs²⁰, eleven of seventy-one patients had autogenous bone-grafting at the time of glenohumeral arthrodesis. When there are massive bone defects, a full-thickness tricortical iliac-crest graft can be used to promote fusion by interposing the graft between the glenoid and the proximal aspect of the humerus. Nonvascularized and vascularized fibular strut grafts can also be used^{14,23}. If there are large defects and structural autogenous bone-graft material is not available, then allograft substitution with autograft supplementation can be used^{14,23}.

Position of Arthrodesis

Numerous investigations have addressed the optimal position of the extremity for shoulder arthrodesis, and there are still numerous opinions on the ideal position. The consensus appears to favor less abduction and forward flexion and more internal rotation. When the position of the arm is being

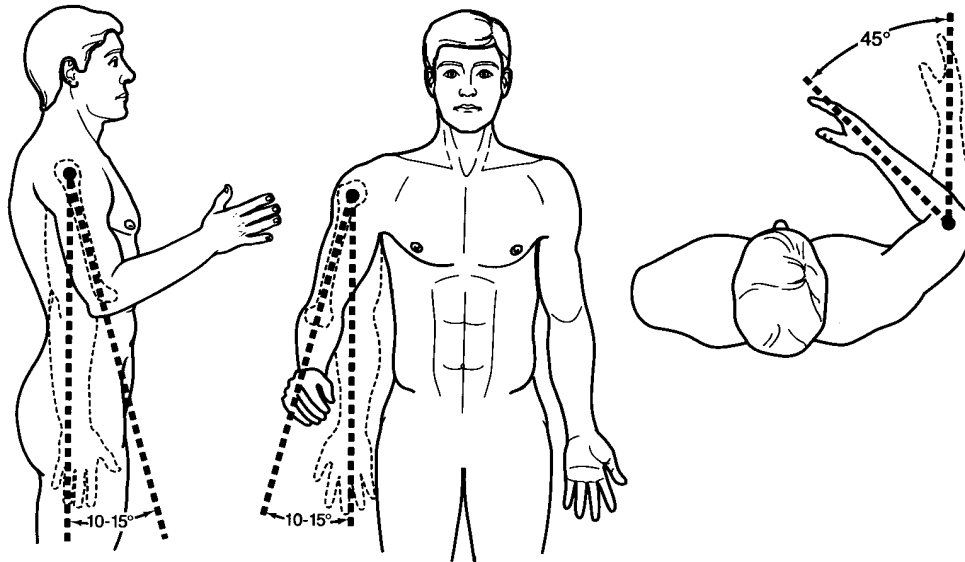


Fig. 1

Line drawings showing the optimal position of arthrodesis in 10° to 15° of both forward flexion and abduction and 45° of internal rotation.

determined, the trunk is commonly used as the point of reference, with the scapula held in the anatomic position. In 1942, a committee of the American Orthopaedic Association proposed placing the extremity in 50° of abduction, 15° to 25° of flexion, and 25° of internal rotation²⁹. Rowe³⁰ subsequently recommended less abduction and flexion, to approximately 20° to 25° each, and more internal rotation, to approximately 40°. It was Rowe's contention that excessive abduction and flexion forced the scapula to rotate and wing when the shoulder was at rest with the arm at the side. This led to fatiguing of the scapulothoracic muscles and ultimately to discomfort. Rowe^{16,30} recommended positioning the extremity to provide enough abduction to clear the axilla, enough forward flexion to reach the face, and sufficient internal rotation to reach the midline of the body. However, Cofield and Briggs²⁰ did not note periscapular pain in patients whose shoulder was fused in excessive flexion and abduction. In their series of seventy-one patients who underwent shoulder arthrodesis, the position of the arthrodesis did not correlate with the amount of residual pain. The authors were unable to demonstrate that shoulders fused in more than 45° of abduction were significantly more painful than those fused in less abduction. The mean position of the arthrodesis was 45° of abduction, 25° of flexion, and 21° of internal rotation. In their series, the amount of rotation was the most important factor determining function of the extremity. Hawkins and Neer^{10,13} recommended 25° to 40° of abduction, 20° to 30° of flexion, and 25° to 30° of internal rotation. Richards et al.^{27,31,32} recommended a position of approximately 30° of abduction, forward flexion, and internal rotation. This position is thought to enable patients to reach their mouth and their front and back pockets. Abduction is referenced from the side of the body and is thought to be accurate to within 10°^{27,31,32}.

More recently, we reported our experience with symptomatic malpositioning after arthrodesis in nine of fourteen patients who had complications related to shoulder arthro-

desis. We¹⁸ agreed with Rowe^{16,30} that excessive flexion or abduction produced malrotation or winging of the scapula and a dull, aching pain in the shoulder. We recommended a position of 10° to 15° of abduction, 10° to 15° of flexion, and 45° of internal rotation, which enabled the patient to reach his or her mouth, belt buckle, and contralateral shoulder and axilla comfortably (Fig. 1). We also recommended that, with the patient in the erect position, the fused shoulder should allow the arm to hang like the contralateral arm in a normal, comfortable position without any winging or deformity of the scapula. Matsen et al.¹² favored a position of approximately 15° of abduction and forward flexion and 40° of internal rotation. Jónsson et al.³³ presented a technique for measuring the position for shoulder arthrodesis utilizing moiré photography. This technique is based on grid illumination, giving a topographic image to an object. With this technique, the neutral position of the scapula can be found, enabling a more accurate determination of the position for arthrodesis. They concluded that the optimal position for arthrodesis is 20° to 30° of abduction, forward flexion, and internal rotation. They also suggested that internal rotation should not exceed 40°.

Operative Techniques

The many techniques for glenohumeral arthrodesis are classified as extra-articular (acromioclavicular), intra-articular (glenohumeral), or a combination of extra-articular and intra-articular. The extra-articular methods described by Putti³⁴, Watson Jones³⁵, and Brittain³⁶ were used early in the twentieth century, primarily in treating tuberculosis.

Probably the most successful means of shoulder arthrodesis employs a combination of intra-articular and extra-articular methods and stabilization with internal fixation⁹. Extra-articular bone contact is obtained by bringing the humeral head into contact with the acromion. The articular surfaces of the humeral head, glenoid, and inferior surface of the acromion are decorticated and positioned to maximize contact.

Fixation is then implemented with use of multiple screws^{11,20,37}, plates^{11,13,31,32,37-41}, external fixation^{11,42-45}, or tension-band wiring^{37,46}.

The AO technique with either a single plate or double plates is probably the most popular method today for shoulder arthrodesis, and it has been described by several authors^{11,17,31,38,39}. A long AO broad plate is contoured to lie along the scapular spine, over the acromion, and against the proximal third of the humerus. Initial stabilization is obtained with a screw placed vertically through the acromion and down into the base of the scapular neck. The humeral head is positioned alongside the superior portion of the glenoid and in contact with the undersurface of the acromion. At the level of the humeral head, two cancellous screws pass horizontally through the head and into the glenoid. A second plate is applied posteriorly from the scapular spine to the humeral head if additional stability and rotational control are required³⁸. Bone graft may be supplemented to fill in deficient areas. Postoperatively, the patient wears a Velpeau dressing for several days or a shoulder immobilizer or sling for up to several weeks. Light, active exercises are begun seven to ten days postoperatively to improve scapular motion and muscle strength⁷². An advantage of this method of rigid internal fixation is that it obviates the need for postoperative immobilization with a spica cast.

Cofield and Briggs²⁰ most commonly used three screws for fixation, with two placed laterally across the humeral head into the glenoid and another, vertically oriented screw placed through the acromion into the humeral head. The head is placed superiorly on the glenoid to underlie the acromion. If glenohumeral contact is compromised by the superior placement of the humeral head, a partial osteotomy of the acromion is performed near its junction with the scapular spine, and the acromion is displaced downward, hinging through the acromioclavicular joint^{7,20,37}. After this procedure, the patient wears a shoulder spica cast for three to four months, until there is clinical and radiographic evidence of healing.

Hawkins and Neer^{10,13} used three AO cancellous screws, with two placed laterally from the humeral head into the glenoid and the other driven vertically through the acromion into the humeral head. Two major technical points in the performance of shoulder arthrodesis were advocated. First, instead of osteotomizing the acromion, the surgeon displaces the humerus superiorly to contact the acromion in order to preserve the contour and improve the appearance of the shoulder. Second, resecting the distal part of the clavicle was not recommended, as this is not believed to improve shoulder motion after arthrodesis¹³.

Richards et al.^{31,32} advocated using a pelvic reconstruction plate because it is easier to contour and apply than the standard AO broad plate. In addition, pelvic reconstruction plates are not as prominent, and patients are less likely to have soft-tissue complications postoperatively. The incision begins at the spine of the scapula and extends to the anterior aspect of the acromion and down the anterior aspect of the proximal part of the humeral shaft^{27,31}. The deltoid is detached from the anterior aspect of the acromion, and the fibers are split distally. The residual rotator cuff is then excised, the articular

surfaces of the glenoid and humeral head are denuded, and the undersurface of the acromion is decorticated. Richards²⁷ advocated advancing the humerus proximally to improve acromiohumeral and glenohumeral contact areas. A ten-hole, 4.5-mm pelvic reconstruction plate is contoured along the spine of the scapula, over the acromion, and down the shaft of the humerus. Two 6.5-mm cancellous screws are placed across the humeral head and into the glenoid in order to compress the fusion site. A single 6.5-mm cancellous screw is placed across the acromion and into the humeral head. The remainder of the screws are then placed to secure the plate. A thermoplastic orthosis is used for immobilization postoperatively, typically for approximately six weeks following surgery^{14,27,31}.

Rowe and Zarins⁴⁷ used two alternatives for fixation: multiple cancellous screws and compression plates. When using the cancellous screws, they drive them laterally across the humeral head and into the glenoid. Four screws are usually sufficient to gain adequate compression. Screw length is generally 70 to 80 mm, and the use of 16-mm threads is recommended to allow for better compression of the head and glenoid fragments. A washer may also be beneficial to avoid burying the screw head in potentially soft bone. In contrast to Hawkins and Neer¹⁰, Rowe and Zarins⁴⁷ advocated resection of the distal aspect of the clavicle for the purpose of improved elevation of the extremity. Like Cofield and Briggs²⁰, they may also osteotomize the acromion to enable better contact with the humeral head. These patients require a spica cast postoperatively, and they usually wear the cast for up to twelve weeks^{16,47}.

In addition to internal fixation, external fixation may have a role in the stabilization of intra-articular and extra-articular shoulder arthrodeses^{11,42-45}. Charnley and Houston⁴⁸ described a technique of compression arthrodesis of the shoulder with use of external fixation. They reviewed the cases of nineteen patients who underwent shoulder arthrodesis, usually for the treatment of tuberculous arthritis. The patients wore a shoulder spica cast postoperatively. Eighteen of the patients had radiographic evidence of a solid fusion, and the shoulder of the remaining patient was determined to be clinically healed. The position for the arthrodesis was 45° of abduction, flexion, and internal rotation. Johnson et al.⁴³ reported on four patients who underwent shoulder arthrodesis with use of the Hoffmann external fixator. In each patient, osseous union of the fusion site was achieved within six to ten weeks, and the fixator was removed at eight to fifteen weeks. The fixator was loosened when radiographic evidence of healing was observed, and it was removed completely following clinical evaluation of the fusion. The shoulder is approached through the strap-type incision described by Henry⁴⁹, which allows a wide exposure. The glenoid and the humeral head are denuded of their articular cartilage, and the undersurface of the acromion is decorticated. The proximal aspect of the humerus is brought into contact with the glenoid and acromion and held in a position of 20° of abduction, 30° of forward flexion, and 40° of internal rotation. One or two 6.5-mm cancellous screws are placed to provide additional compression as well as to maintain the position for the arthrodesis. The external fixation frame is then applied and is kept in place until

there is radiographic evidence of healing. The patient is able to use the extremity immediately after the operation, and no more immobilization is required. In all cases, healing occurred at six to ten weeks, and the external fixation frame was kept in place for seven to fourteen weeks⁴³. Kocalkowski and Wallace⁴⁴ and Johnson et al.⁴⁵ reported their experience with using an external fixator combined with limited internal fixation for stabilizing shoulder arthrodeses. Several large cancellous screws are used for initial compression and stabilization followed by the placement of the external fixator. The major advantage that external fixation provides is the avoidance of potential wound complications that a prominent plate could cause. As previously mentioned, postoperative immobilization is not necessary.

Authors' Preferred Method

We recommend use of 4.5-mm pelvic reconstruction plates for internal fixation of shoulder arthrodesis^{12,18}. If patients weigh in excess of 100 kg, we favor using the 4.5-mm dynamic compression plate. The exposure is created with an incision along the spine of the scapula, over the acromion, and down the proximal aspect of the shaft to the level of the deltoid insertion. The articular surfaces are denuded of cartilage, and the undersurface of the acromion is decorticated. The head of the humerus is placed in contact

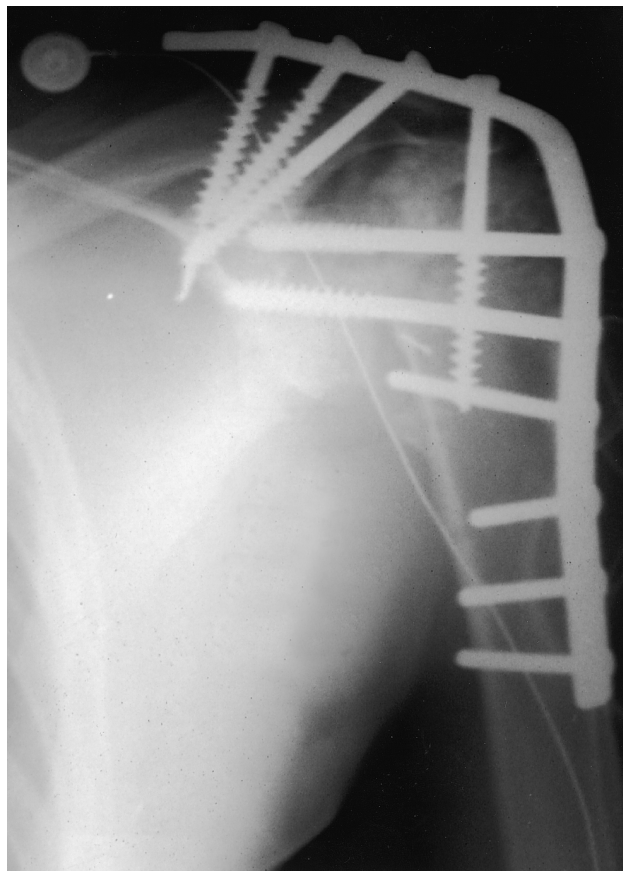


Fig. 2
Postoperative radiograph following shoulder arthrodesis with multiple screws and a 4.5-mm AO plate.

with the undersurface of the acromion and the superior portion of the glenoid fossa. The shoulder is then placed in our preferred position of 10° to 15° of abduction, 10° to 15° of forward flexion, and 45° of internal rotation. This position enables the patient to reach the mouth, belt buckle, and contralateral shoulder and axilla comfortably (Fig. 1). Placement is temporarily stabilized with two threaded Steinmann pins. The position is checked to ensure that the patient's hand can reach the mouth, the front of the abdomen, and the anterior perineal area. A thin aluminum template is used to precisely determine the contour of the fusion mass, and the final selected plate is bent to the same contour as the template. In stabilizing the arthrodesis and placing the plate, we adhere to two important AO principles. First, one or two 6.5-mm cancellous screws are placed across the plate, through the acromion, and down into the neck of the scapula, approximately 1 cm medial to the surface of the glenoid. These screws are believed to provide the critical fixation of the plate to the scapula. Second, two or three more cancellous screws are placed horizontally through the plate, compressing the humeral head into the glenoid fossa. The remainder of the screws placed are cortical screws. The plate should be of sufficient length to allow placement of four or five screws in the scapula, two horizontal screws across the humeral head into the glenoid fossa, and at least four screws into the humeral shaft (Fig. 2). Postoperatively, the patient wears a sling for three weeks. Range-of-motion exercises of the elbow, wrist, and hand are begun the morning after the surgery, and the patient begins to use the extremity for daily activities as soon as tolerated.

Results of Clinical Series

As previously discussed, shoulder arthrodesis is a viable treatment option for the salvage of shoulders with a variety of conditions. The advent of shoulder arthroplasty has resulted in a reduction in the number of arthrodeses performed. Compared with shoulder arthroplasty, shoulder arthrodesis results in definitive functional limitations. By and large, clinical results have varied. Some authors report satisfactory clinical and functional results, while others have reported less-than-satisfactory results. This section reviews a number of clinical results following use of the previously mentioned techniques.

Kostuik and Schatzker³⁸ reported on a series of eighteen patients who underwent shoulder arthrodesis with the double-plate technique. Fifteen of the patients were relieved of pain following the arthrodesis and were able to return to their preoperative employment status. The three patients who still had pain were receiving Workers' Compensation. Solid fusion occurred in all of the patients, while overall subjective satisfaction was reported by 87% of the patients.

In a series of seventy-one fused shoulders reviewed by Cofield and Briggs²⁰ at a mean of nine years, sixty-eight were solidly fused and three had required repeat arthrodesis. Pain relief was adequate in approximately 75% of the patients. Functionally, approximately 70% of the patients were able to lift a moderate weight with the extremity at the side, dress themselves, perform adequate personal hygiene, and feed themselves.

Nearly half of the patients were able to comb their hair, and only 21% were able to perform tasks with the arm at shoulder level. In their series, 82% of the patients benefited from the surgery, while the condition of the other 18% had not improved or was worse²⁰. Other authors have also described less rigid fixation techniques and postoperative immobilization of the shoulder with a spica cast, with good results^{6,50}.

Hawkins and Neer¹⁰ reviewed the cases of seventeen patients at a mean of three years and four months after they underwent shoulder arthrodesis. Eight of the patients were satisfied with the result of the surgery because of relief of pain. Of these eight patients, five expressed dissatisfaction with their functional abilities. The other nine patients were not satisfied at all secondary to persistent pain and functional loss. Only four of the seventeen patients were completely free of pain. Fourteen of the seventeen patients were able to work satisfactorily with their arm at the waist level, while the other three could not work at that level because of the pain. The results in this series demonstrate that shoulder arthrodesis must be reserved as the final salvage option considered.

Richards et al.^{14,31} assessed the functional outcomes in a series of thirty-three patients who underwent shoulder arthrodesis. Nearly all of these patients were able to perform work with their arm at waist level, while twenty-one of the patients were able to work at shoulder level. Only roughly half of the patients had no problems with eating or performing adequate toilet function^{14,31,32}. The authors noted a correlation between the ability to perform activities of daily living after glenohumeral arthrodesis and the adequacy of hand function of patients with brachial plexus injury. Regression analysis revealed the underlying indication for shoulder arthrodesis to be the single best predictor of the ability of patients to perform activities of daily living after glenohumeral arthrodesis. Another predictor of outcome was whether the patient was receiving Workers' Compensation. Patient satisfaction was highest when the patient had undergone the procedure for a brachial plexus injury, osteoarthritis, or a failed total shoulder arthroplasty^{14,31}.

Good results have been reported with techniques utilizing external fixation along with internal fixation for additional stabilization. In Charnley's series⁴², all patients reported adequate ability to perform daily activities but did have limitations with regard to performing tasks above eye level. Most importantly, all patients reported marked pain relief. Schröder and Frandsen⁴⁵ reported on a series of twelve patients who underwent external compression arthrodesis. Two half-pins are used in this construct. The first is driven from the posterosuperior aspect of the acromial base through the main mass of the scapula into the glenoid. The second pin enters posterolaterally on the humerus to enter the surgical neck. Two compression clamps are added to the pins, and compression is applied. Eleven of the twelve patients had healing of the fusion site, with the last patient requiring bone-grafting to obtain union. Ten patients had no pain and subjectively rated their result as good. Functionally, the status of nearly all of these patients improved compared with their preoperative status⁴⁵.

Complications of Shoulder Arthrodesis

Many authors have stressed the value of internal fixation for maintenance of the position of the humeral and scapular surfaces, especially when the arthrodesis combines both intra-articular (glenohumeral) and extra-articular (acromioclavicular) techniques^{22,27,31,32,38,39}. This combination has resulted in a high rate of successful fusion, although complications continue to be reported^{18,20}.

Difficulties that may arise with shoulder arthrodesis are not unique to this operative procedure. Wound infection at the operative site is managed with standard techniques, which include irrigation and drainage along with culture of specimens from the wound. Appropriate antibiotics (an intravenous course followed by an oral course) have been successful in the treatment of this wound problem^{15,18}. Similarly, a wound hematoma may develop, particularly in association with harvest of iliac-crest bone graft. Evacuation of the hematoma is often indicated. Also related to the harvest of iliac-crest bone graft is the risk of injury to the lateral femoral cutaneous nerve and the potential development of meralgia paresthetica.

Fracture about the shoulder may occur in a patient treated with a shoulder arthrodesis. The fracture may occur in association with the fixation device or distal to the site of the arthrodesis. Distal fractures have responded to nonoperative treatment with simple use of a sling. Union has been observed to occur without substantial change in the position of the shoulder^{15,18}. Fractures that occur more proximally in association with internal fixation devices have been successfully treated with removal of the devices and repeat plate application and bone-grafting^{15,18}.

Failure of union may occur after either primary or revision shoulder arthrodesis, but this is rare when current fixation techniques are used^{18,32}. To further minimize chances of failure, patients should be counseled preoperatively to abstain from tobacco use because of the association of smoking with an increased risk for nonunion in general. Optimal operative technique includes careful attention to elimination of all cartilage, maximum bone coaptation, and solid positioning of all implants.

By far the most critical complication that may accompany shoulder arthrodesis is malpositioning of the extremity, which is primarily the result of excessive abduction and flexion. As previously discussed, excessive abduction and flexion produce malrotation or winging of the scapula, which results in a dull, painful ache in the shoulder¹⁶. In addition, excessive abduction can cause a traction neuritis on the brachial plexus and, specifically, on the suprascapular nerve⁹. The operative technique for correcting a malpositioned arthrodesis has been described by us¹⁸. In our series of fourteen patients treated for complications related to shoulder arthrodesis, the complications were the result of a malpositioned arthrodesis in nine cases. These patients underwent a reconstructive osteotomy of the fusion mass for correction of the malpositioned extremity, and their cases were reviewed at a mean of six years following the surgery. Preoperatively, the mean position of fusion was 47° of forward flexion, 37° of abduction, and 37° of internal rotation. All patients had chronic, long-standing pain and

difficulty with daily activities. Postoperatively, the mean position of the shoulder was 13° of forward flexion, 16° of abduction, and 48° of internal rotation. All patients had substantial relief of pain and were able to perform their daily activities much more effectively¹⁸.

Overview

Humeroscapular (shoulder) arthrodesis is a well-established procedure in orthopaedic surgery, but over the years the indications for this operation have narrowed. This narrowing is primarily attributable to the advent of shoulder arthroplasty. Better options now exist for the treatment of conditions traditionally treated by arthrodesis. Patient satisfaction after shoulder arthrodesis has been nearly 80%. Current indications for shoulder arthrodesis include a complete brachial plexus lesion, deltoid paralysis, massive rotator-cuff deficiency following multiple attempts at repair, multiple failed arthroplasties, chronic infection, bone deficiency following tumor resection, and chronic dislocation. Shoulder arthrodesis should be considered an end-stage salvage procedure. If other reconstructive options exist, they should be considered prior to proceeding with arthrodesis^{8,51}. As previously mentioned, any procedure that restores some of the glenohumeral motion and rotation has advantages over arthrodesis. Patients who are candidates for shoulder arthrodesis require preoperative counseling for a full understanding of their postoperative limitations and functional capacities. Great controversy exists concerning the ideal position for arthrodesis. The current consensus for the ideal position among most authors favors less abduction and forward

flexion and more internal rotation than are recommended in the older literature. There are multiple operative techniques for glenohumeral arthrodesis, with various surgical approaches, fixation alternatives, and immobilization options. When all other options in the treatment of a shoulder condition have been attempted and no other alternatives exist, shoulder arthrodesis has proved to provide satisfactory pain relief, a stable shoulder, and improved function. ■

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The authors did not receive grants or outside funding in support of their research or preparation of this manuscript. They did not receive payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity. No commercial entity paid or directed, or agreed to pay or direct, any benefits to any research fund, foundation, educational institution, or other charitable or nonprofit organization with which the authors are affiliated or associated.

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