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Glenohumeral arthrodesis

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A R T I C L E I N F O

Keywords: Shoulder arthrodesis Glenohumeral arthrodesis Shoulder fusion Glenohumeral fusion Glenohumeral salvage Shoulder salvage Glenohumeral arthrodesis is a salvage procedure indicated for brachial plexus palsy, refractory instability, humeral and/or glenoid bone loss, deltoid and rotator cuff insufficiency, and chronic infections. The aim is to provide a painless, stable shoulder that is positioned to maximize function. Scapulothoracic motion as well as motion of the elbow and hand deliver satisfactory function in most patients. Intraarticular, extra-articular, and more commonly, combined techniques involving glenohumeral and humeroacromial fusion, have been described. More recently, authors have reported arthroscopic assisted techniques for shoulder arthrodesis with promising results as well as less complicated conversion from shoulder arthrodesis to reverse total shoulder arthroplasty. Despite advances in materials and techniques, glenohumeral arthrodesis continues to be associated with complication rates as high as 43%. A thorough understanding of the indications, contraindications, outcomes, and complications is paramount to improving patient results. Glenohumeral arthrodesis is a safe and effective procedure for the appropriate indications. The high frequency of complications mandates a frank preoperative discussion to ensure that each patient understands the magnitude of the procedure, its risks, possible complications, and expected outcome.

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Glenohumeral arthrodesis is a salvage procedure indicated for brachial plexus palsy, refractory instability, humeral and/or glenoid bone loss, deltoid and rotator cuff insufficiency, and chronic infections. The aim is to provide a painless, stable shoulder that is positioned to maximize function through the use of scapulothoracic, elbow, and hand motion. Both extra-articular and intra-articular techniques have been described, with most surgeons currently performing intra-articular or combined procedures through open or arthroscopic approaches.^{16,22-25,27} Fixation methods include external fixators, simple screws, and plate-screw constructs.^{2,10,12,14,19,26,28-30,32} Despite improvements in materials and techniques, glenohumeral arthrodesis is associated with complication rates as high as 43%.^{13,23,24,32} A thorough understanding of the indications, contraindications, surgical challenges, outcomes, and complications is paramount to improving patient results.

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Indications

The most common indication for glenohumeral arthrodesis is a brachial plexus injury. Denervation of the shoulder girdle provides a severe functional deficit and eventually glenohumeral subluxation leading to unmanageable pain.^{6,8,24,31} Patients with Erb's palsies have impaired residual shoulder function despite attempted nerve and soft-tissue reconstruction. Additionally, unbalanced motor activity may lead to humeral head subluxation and secondary morphological changes to the glenoid. Glenohumeral arthrodesis has been reported as a reasonable option for these patients.^{2,3,6,27,30}

Refractory glenohumeral instability can be a challenging problem to manage. Often these patients are young and have experienced multiple prior attempts at stabilization. Conditions that increase the likelihood of recurrence, such as seizure disorders or connective tissue disease (eg, Ehlers-Danlos), make glenohumeral arthrodesis the most viable option.^{10,28,29}

Reconstruction procedures are challenging in the setting of massive bone loss of the proximal humerus, which may result from tumor resection, trauma, or multiple failed shoulder arthroplasties. These procedures require the use of supplemental allograft or autograft and commonly require more extensive fixation constructs.^{4,13,20} Additional indications for glenohumeral arthrodesis



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include patients with insufficient function of both the rotator cuff and deltoid musculature or patients with chronic infection of the glenohumeral joint.^{8,33}

Contraindications

There are general contraindications to performing glenohumeral arthrodesis, the most important of which is insufficiency of the periscapular musculature. Functional trapezius, levator scapula, latissimus dorsi, serratus anterior, and rhomboid muscles are necessary to power scapular motion after glenohumeral arthrodesis.^{8,25,33} Relative contraindications include bilateral shoulder arthrodesis and inadequate soft-tissue coverage not amenable to reconstruction, typically associated with massive tumor resection or trauma.²⁵

Surgical factors

Preoperative evaluation

A thorough preoperative evaluation is a prerequisite for a successful glenohumeral arthrodesis. Attention should be directed toward the soft-tissue envelope of the shoulder and the function of the periscapular muscles. In addition, the surgeon should determine the functionality of the contralateral extremity and the ipsilateral elbow, wrist, and digits. A comprehensive neurovascular examination of the operative extremity should also be performed. Preoperative imaging is necessary for assessing humeral and glenoid bone stock. Three-view radiographs are obtained for all patients, and computer tomography can also be helpful.

Perhaps the most critical component to the preoperative consultation is discussion of postoperative expectations, outcomes, and potential complications. This should be repeated at each clinic visit, and it is often helpful to have the patient meet another individual who has undergone glenohumeral arthrodesis to ensure the patient understands the postoperative limitations. Finally, it is important to have a multidisciplinary team involved that includes occupational and physical therapists.

Operative technique

Glenohumeral arthrodesis is typically performed under general anesthesia with an interscalene nerve block. The surgery can be performed in the beach chair or lateral decubitus position depending on the surgeon's preference. In the beach chair position, the patient is prepped similar to a standard shoulder arthroplasty. This includes placing a foam wedge under the patient's leg and elevating the patient to 30-70° depending on surgeon preference. The operative extremity is placed in an arm holder or a padded Mayo stand. The entire operative extremity, including the scapula, is sterilely prepped and draped into the field. The iliac crest or lower extremity should also be included in the prep if autograft iliac crest or fibula is to be used.

A longitudinal incision is made at the proximal aspect of the glenoid fossa or scapular spine and carried distally over the acromion and down the axis of the humerus. Existing surgical scars from prior shoulder arthroplasties can be incorporated into the distal aspect of the incision. Exposure of the scapula, acromion, and proximal humerus is achieved by reflecting the deltoid and/or the trapezius. If functioning, the axillary nerve is protected, as an innervated deltoid can help preserve deltoid bulk and aid in efforts to preserve remaining soft tissue envelope, thereby helping to prevent symptomatic hardware and improve cosmesis. The rotator cuff is removed and the capsule is opened to expose the glenohumeral joint and visualize both articular surfaces. The articular cartilage is denuded from the glenoid and proximal humerus, and the two surfaces are contoured in preparation for fusion. A combination of glenoid reamers, humeral head reamers, and burrs are used to accomplish this contouring (Fig. 1). Additionally, the inferior aspect of the acromion is decorticated and contoured if it will be included in the arthrodesis.

Positioning of the glenohumeral arthrodesis is the most critical portion of the procedure. Unfortunately, there is no current consensus regarding the optimal position of fusion due in part to the variability in described techniques for measuring the angle of fusion.^{5-7,9,10,12,21,23,24} The trunk, lateral and medial border of the scapula, and scapular spine have all been used as references for measurement. Ruhmann et al advocate measuring against the scapular spine as this is the most reproducible and relatively constant bony reference.²⁴ Most authors advocate for 15-30° of flexion, 15-30° of abduction, and 30-45° of internal rotation.^{2,4,10,12,24-26,33} Precise intraoperative calibration is difficult, in a recent study, Wagner et al found that arthrodesis in abduction and flexion $\geq 25^{\circ}$ was associated with significantly less postoperative pain and improved flexion.³² Sousa et al reported improved ability of the hand to reach the mouth with an abduction of $>35^\circ$, forward flexion of \geq 30°, and internal rotation \leq 45°.²⁷ In contrast, Cofield et al found that the position of fusion did not influence postoperative pain or the patient's assessment of the procedure.⁹ Other authors argue that providing a functional, stable extremity is more important than any specific fusion position.^{9,19,30} The ideal fusion position should allow the patient's hand to reach the mouth and perineal area for feeding and hygiene care. Once in the desired position, the glenohumeral joint is pinned with Steinmann pins or Kirschner wires. The extremity is then taken through a range of motion to ensure that functional use is attainable.

Arthrodesis techniques include extra-articular and intraarticular methods. Extra-articular fusion, historically used for tuberculosis infections, involves fusion of the humerus to nonarticular regions of the scapula. Intra-articular fusion involves fusion of the humerus to the glenoid. Combined intra-articular and extra-articular fusion, with the humerus in contact with the superior glenoid and inferior acromion as shown in Figure 2, is the mainstay of surgical treatment.^{23-25,27}

Various fixation techniques have been described for glenohumeral arthrodesis, including plates, screws alone, combined plate and screw fixation, and external fixation.^{5,6,33} Plate options include reconstruction plates or dynamic or locked compression plates.^{2,10,12,14,19,23,24,26-30} The plate is contoured to fit the underlying bone and then temporarily affixed to the scapula, acromion, and humerus. Compression through the glenohumeral joint and acromiohumeral interval is achieved with screws through the plate. The remaining plate holes are filled with a combination of locking or compression screws. A cranially inserted screw docking into the scapular neck or a secondary plate can improve stability.¹⁷ Alternatively, the plate may be placed under the acromion to avoid hardware irritation.⁵ Glenohumeral arthrodesis can be performed with isolated screw fixation. With this method, screws are inserted from the humerus into the glenoid under fluoroscopic control. Additional screws can be placed from the acromion into the humerus.^{19,24,32} External fixation has also been proposed as a method of glenohumeral arthrodesis and has the reported benefit of not requiring postoperative immobilization.⁶

Proponents of isolated screw fixation note that this procedure mitigates the concerns for skin irritation caused by symptomatic plates. Ruhmann et al found that shoulder arthrodesis using plates led to a higher rate of hardware removal.²⁴ Additionally, plating had a higher incidence of infection and postoperative fractures. However, the same study found a higher rate of pseudoarthrosis with screw fixation.²⁴ Irlenbusch et al noted 100% fusion rate and a low



Figure 1 Intraoperative photos depicting a lateral approach to the glenohumeral joint for shoulder arthrodesis. (A) The deltoid is released off the acromion and rotator cuff tendons released off of the greater and lesser tuberosities of the proximal humerus, giving access to the glenoid and proximal humerus. (B and C) With the humeral head retracted posteriorly, the glenoid is reamed down to subchondral bone in preparation for fusion. The incision is extended along the spine of the scapula and down the axis of the humerus to accommodate plate fixation.



Figure 2 (**A**) Preoperative and (**B**) 6-week postoperative radiographs of a 64-year-old female with a history of terrible chronic shoulder pain after an arthroscopic procedure several years prior. The patient was found to have chronic infection and significant bone loss of the glenoid and acromion on CT scan, precluding any viable reconstructive arthroplasty options. Radiograph B shows a combined intra- and extra-articular fusion with contoured plate fixation between the acromion and humerus, supplemented by 6.5-mm cancellous screws across the glenohumeral joint and cables encircling the humeral shaft and spine of the scapula. *CT*, computed tomography.

complication rate in 11 patients undergoing glenohumeral arthrodesis with plate fixation at a mean of three to four months.¹⁴ Miller et al performed a biomechanical analysis comparing different fixation techniques and found that screw fixation alone had the weakest bending and torsional stiffness compared with other techniques, including plate fixation.¹⁸ Given the data demonstrating increased stiffness of plate-screw constructs, most surgeons today perform glenohumeral arthrodesis using a combination of plates and screws.

A range of grafts have been used to supplement fixation in glenohumeral arthrodesis, including fibular autograft,^{20,26} iliac crest autograft,^{21,0,28,33} local morselized acromion,²⁵ humeral autograft,²⁹ and allograft.²⁶ Atlan et al compared outcomes of cancellous and corticocancellous autografting and reported a 10-fold higher rate of pseudoarthrosis in the cancellous group.² Graft choice is particularly important in the setting of significant bone

loss or tumor resection. Fibular grafts can assist in filling the void in larger defects. Bilgin et al showed favorable results with free vascularized fibular grafts in patients who underwent glenohumeral arthrodesis, with 7 of 9 patients achieving union in their series.⁴ Mimata et al treated 2 patients for tumor resection with doublebarrel vascularized fibular graft and compared outcomes with those of 3 patients treated with a single vascularized fibular graft. The authors noted better functional results and a lower rate of fracture in patients who underwent dual bone fusion.²⁰

Once fixation and grafting of the glenohumeral arthrodesis is completed, care should be taken to reattach reflected muscles to their origins to provide soft-tissue coverage for the plate. This can be accomplished with heavy nonabsorbable suture or suture anchors docked into the muscle's respective osseous origin.

Recently, arthroscopic and arthroscopic assisted mini-open glenohumeral arthrodesis techniques have been reported.^{15,16,22}

Lenoir et al treated 8 patients with arthroscopic arthrodesis and reported 100% fusion at a mean follow-up of 28 months.¹⁶ Porcellini et al compared 12 patients undergoing arthroscopic assisted glenohumeral arthrodesis with a cohort of patients undergoing traditional open fusion. At two-year follow-up, there was no difference in patient satisfaction or complication rates, and there was a 100% fusion rate among arthroscopic assisted cases.²²

Postoperative care

Options for postoperative immobilization include spica casting,^{9,25,26,28,30} abduction splinting,^{2,9,24} bracing,¹⁰ or a sling.⁸ Some authors have reported no postoperative immobilization.³³ Regardless of the postoperative immobilization, weight-bearing should be restricted until there is radiographic evidence of successful fusion. Therapy should begin immediately and focus on active elbow, wrist, and digit range of motion and on maintaining the function of the nonoperative extremity. Serial radiographs should be taken until fusion is obtained.

Outcomes

Outcomes following glenohumeral arthrodesis are difficult to assess given the range of indications, variations in techniques and outcome instruments used, and a lack of long-term follow-up. A few studies exist studying glenohumeral arthrodesis in a larger cohort of mixed indications. Wagner et al reviewed 29 patients undergoing glenohumeral arthrodesis with a mean follow-up of 12 vears. The authors found that patients with neurological injuries had worse functional outcomes than those with nonneurological injuries and that 87% of patients had postoperative limitations. Only 43% of patients were able to return to full-time work.³² Dimmens et al reported the results of 18 patients undergoing glenohumeral arthrodesis with plate fixation with an average followup of 7.5 years. They noted that 15 of the patients were satisfied postoperatively compared with their preoperative status.¹¹ Ruhmann et al studied 43 patients undergoing glenohumeral arthrodesis and reported that 91% of their cohort rated their outcome as excellent, good, or satisfactory. They noted an increase in Constant scores across the entire cohort, with the greatest increase seen in the group indicated for paralysis.²⁴ In 1993, Richards et al reviewed 57 patients undergoing shoulder arthrodesis with plate fixation. They noted that patients indicated for brachial plexus injury, osteoarthritis, and failed shoulder arthroplasty reported the highest satisfaction.²³ Lastly, Cofield et al in 1979 studied 71 patients undergoing arthrodesis for various etiologies with an average of 9.5-year follow-up. They found that 82% of their patients felt they benefited from the operation.⁹

Focusing on specific indications for glenohumeral arthrodesis, van der Lingen et al reviewed 12 patients undergoing glenohumeral arthrodesis for brachial plexus palsy at a mean of nearly 20-year follow-up. Fifty percent of their patients were highly satisfied, and 50% reported they were moderate or only slightly improved. All patients however stated they would undergo the arthrodesis procedure again.³¹ Sousa et al reported that 12 of their 13 patients treated for brachial plexus palsy were satisfied or very satisfied with the procedure at an average follow-up of 8.5 years.²⁷ Chammas et al compared 11 patients with upper plexus palsy (functional hand) with 16 patients with total plexus palsy (flail hand). They noted an increase in functional capacity of both groups.⁶

Thangarajah et al studied outcomes in 8 patients with glenohumeral arthrodesis for refractory shoulder instability, showing increased function at 57 months postoperatively.²⁹ Diaz et al reported on 8 patients undergoing glenohumeral arthrodesis for refractory instability and noted significant subjective improvement and no postoperative instability events at a mean follow-up of 35 months. $^{\rm 10}$

There is a paucity of literature reporting on glenohumeral arthrodesis for patients with bone loss, deltoid and rotator cuff insufficiency, or infection. In a series of 21 patients undergoing glenohumeral arthrodesis in the setting of bone loss after tumor resection, Fuchs et al reported good postoperative function at a mean follow-up of 11 years.¹³ Wick et al followed up 15 patients treated for septic arthritis for a mean of 8.3 years and reported a 90% satisfaction rate. Additionally, the authors found better outcomes in younger patients (<50 years old) and in those with fewer prior operations (<4).³³

Reduction of pain is one of the primary goals of glenohumeral arthrodesis. Wagner et al reported that 10 of 29 patients (34%) had moderate to severe pain postoperatively compared with 93% preoperatively.³² Similarly, in 1979, Cofield et al reported that 17 of 66 (26%) patients had moderate to severe pain at the final follow-up.⁹ Irlenbusch et al reported a decrease in the visual analog scale (VAS) from 8.3 preoperatively to 2.4 at follow-up in 11 patients undergoing glenohumeral arthrodesis with plate fixation.¹⁴ Dimmens et al reported that 9 of 18 patients had pain at a mean follow-up of 8 years; among those reporting pain, the VAS score was 3.¹¹ Finally, Wick et al noted an improved in the VAS from 7.9 to 3.3 in 15 patients undergoing glenohumeral arthrodesis for infection.³³

Functional outcomes after glenohumeral arthrodesis have been difficult to determine given the variety of functional outcomes tools used including the Subjective Shoulder Value (SSV) score,^{28-30,32} Oxford Shoulder Score (OSS),^{11,14,30} Disabilities of the Arm, Shoulder, and Hand,^{16,31,32} American Shoulder and Elbow Surgeons Score,^{11,16} and the Musculoskeletal Tumor Society score among others.¹³ The most frequently reported scores are the SSV and the OSS.

Wagner reported a mean SSV score of 35 in 23 respondents' status after glenohumeral arthrodesis.³² Thangarajah et al measured postoperative SSV in a series of manuscripts on glenohumeral arthrodesis. There was a mean SSV score of 45 among patients with brachial plexus injuries, 73 in patients indicated for recurrent instability, and 42 in patients with epilepsy-related instability.²⁸⁻³⁰ OSS scores range from 11 to 32 in the literature.^{11,14,30}

Postoperatively, patients maintain motion through the scapulothoracic joint. Wagner et al reported a mean postoperative flexion of 60° and 13° of external rotation, noting that less motion was seen in patients with neurological injuries.³² At nearly 20-year follow-up, van der Lingen et al reported a median flexion of 60°, abduction of 48°, and internal rotation of 32°.³¹ Ruhmann et al reported postoperative improvement of abduction from 25° to 56°, forward flexion from 27° to 60°, and internal rotation from 42° to 59°.²⁴

Complications

Complication rates are high after glenohumeral arthrodesis. Component malpositioning, nonunion, fracture, and infection account for many of these complications.^{13,23,24,32} In a series of 29 patients, Wagner et al reported an overall complication rate of 41%.³² Fuchs et al reported a 43% complication rate in 21 patients undergoing arthrodesis after tumor resection.¹³ Ruhmann et al noted a 28% complication rate in their series of 43 patients,²⁴ and Richards et al reported a complication rate of 14% in 57 patients.²³

Perhaps the most problematic complication after glenohumeral arthrodesis is produced by malpositioning. Malpositioning of the arthrodesis in excessive flexion, rotation, or abduction is theorized to lead to scapular winging and pain.^{5,8,12,27} Treatment of glenohumeral malpositioning typically requires corrective osteotomies.

Sousa et al reported malpositioning in 1 of 13 of their patients. The patient underwent a humeral derotational osteotomy that then developed into a pseudarthrosis.²⁷ This emphasizes the serious nature of malpositioning. Irlenbusch et al reported that 1 of 11 patients required a subcapital corrective osteotomy for gleno-humeral malpositioning.¹⁴ Lastly, Miller et al reported 2 of 13 shoulder arthrodesis required humeral osteotomies for malrotation.¹⁸

Another common complication after glenohumeral arthrodesis is nonunion. Surgeons should begin to suspect nonunion if there is lack of radiographic evidence of fusion and continued pain around two to three months postoperatively. Nonunions frequently require revision of fixation and grafting. Cofield et al reported solid fusion in 68 of 71 patients after the initial glenohumeral arthrodesis at an average of 16 weeks.⁹ In contrast, other large series have reported much lower rates of union. Wagner et al reported a 24% nonunion rate, Atlan et al reported a 24% nonunion rate after the primary surgery, and Ruhmann et al reported a 12% pseudoarthrosis rate. Surgical factors may predispose patients to nonunion. Wagner et al found an increased risk of nonunion in patients who did not have the acromion incorporated into the fusion. There were no other risk factors associated with nonunion, including bone graft, fixation technique, or surgical indication.³² In contrast, as mentioned earlier, Atlan et al reported a 10-fold increase in the rate of pseudoarthrosis among patients with brachial plexus palsy supplemented with cancellous graft as compared with corticocancellous graft.²

Fracture around the arthrodesis, most commonly seen just distal to the humeral plate, is another possible complication. This is treated with immobilization in braces or splints, or the patient can be treated with plate fixation. Wagner et al reported a 21% fracture rate with the fractures occurring at a mean 15 months postoperatively. Four of the fractures were treated nonoperatively, and all fractures had healed at the latest follow-up. Interestingly, the authors noted an arthrodesis position of $\geq 25^{\circ}$ abduction or flexion trended toward a significant risk of periprosthetic fracture.³² A review by Ruhmann et al in 2005 showed that postoperative fracture was more common after plate fixation (5 of 189) than after screw fixation (1 of 88).²⁴ Cofield et al reported an 11% postoperative humeral fracture rate in 71 patients. The authors emphasized the importance of recognizing the plate as a stress riser on the humerus.⁹

Other reported complications include infection, painful hardware, and chronic regional pain syndrome (CRPS). Reports of infection after glenohumeral arthrodesis typically range from 4% to 12% in larger series.^{2,6,24,32} Infections usually require irrigation and débridement and a course of organism-specific antibiotics. Some authors have reported using muscle flaps to provide coverage and minimize wound issues.¹³ In a review of published literature, Ruhmann et al reported a 17% rate of pain from device in 317 patients.²⁴ This high rate of pain could be secondary to the subcutaneous position of the plate and the poor soft-tissue envelope in patients undergoing arthrodesis. Taking care to preserve the axillary nerve, when it is functional, can help maintain deltoid bulk and hopefully prevent symptomatic hardware. Some authors perform a partial acromial osteotomy to bend the acromion and help minimize symptomatic hardware.¹¹ One of the most serious potential complications is the development of CRPS. Dimmen et al noted one of their patients developed CRPS with severe pain requiring highdose opioids daily.¹¹ There is a high reoperation rate after glenohumeral arthrodesis, up to 40% in some series. Patients should be made aware of the potential for additional surgery.^{9,13,32}

It is of interest to note that successful conversion of a stable glenohumeral arthrodesis to reverse total shoulder arthroplasty has been reported. Alta et al described this procedure in four patients presenting with pain and seeking increased mobility. The authors reported a considerable decrease in pain and improved Constant scores. They emphasized the importance of obtaining preoperative electromyography or magnetic resonance imaging to ensure there is a functional deltoid before conversion to reverse total shoulder arthroplasty.¹

Summary

Glenohumeral arthrodesis is a safe and effective procedure for the appropriate indications. When properly performed, reduced pain and improved overall function in the involved extremity can be expected. However, residual scapulothoracic discomfort is a not infrequent occurrence which may potentially lead to revision surgery. The high frequency of complications mandates a frank preoperative discussion to ensure that each patient understands the magnitude of the procedure, its attendant risks, possible complications, and expected outcome.

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