April D. Armstrong
Anand M. Murthi
Editors

Anatomic Shoulder Arthroplasty

Strategies for Clinical Management

Springer

Anatomic Shoulder Arthroplasty

April D. Armstrong • Anand M. Murthi
Editors

Anatomic Shoulder Arthroplasty

Strategies for Clinical Management

Springer

Editors
April D. Armstrong, MD, FRCSC
Chief, Shoulder and Elbow Surgery
Penn State Hershey Medical Center
Department Orthopaedics and Rehabilitation
Hershey, PA
USA

Anand M. Murthi, MD
Chief, Shoulder and Elbow Surgery
Director, Shoulder and Elbow Fellowship and Research
MedStar Union Memorial Hospital/ MedStar Orthopaedics
Baltimore, Maryland
USA

ISBN 978-3-319-29162-8 ISBN 978-3-319-29164-2 (eBook)
DOI 10.1007/978-3-319-29164-2

Library of Congress Control Number: 2016942273

© Springer International Publishing Switzerland 2016
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG Switzerland

To our trusting patients.

Preface

We owe a great debt to Dr. Neer and his efforts of introducing the first total shoulder replacement concept. Since the 1980s, total shoulder replacement has continued to evolve, and it is now projected as one of the fastest growing joint replacement procedures in North America. Similar to hip and knee replacement, shoulder replacement affords great quality of life to our patients who suffer from debilitating shoulder degenerative joint disease. In this book, we hope that not only you see what great success that we have achieved in developing the standard shoulder joint replacement but that you will also appreciate the challenges that we still face. We are optimistic that with critical minds and careful innovation, we will continue to succeed in solving some of these challenges, to create a long-lasting solution for our patients.

We would like to thank all of the authors involved in making this book a great success. We are very fortunate to have such dedicated colleagues and friends with whom we can honestly discuss and collaborate with to make this procedure such a success. We are indebted to you for your determined efforts.

Last but not least, we must thank our families (Mark, Grace, and Claire; Sarah, Valon, and Nina) for all of their love and support. We as surgeons could not succeed without your support and you inspire us each day.

Hershey, PA, USA — April Armstrong
Baltimore, MD, USA — Anand Murthi

Contents

Contributors

Joseph Abboud, MD Department of Orthopaedic Surgery, Rothman Institute, Thomas Jefferson University, Philadelphia, PA, USA

Wassim A. Aldebeyan, MD, FRCSC Roth|McFarlane Hand and Upper Limb Center, St Joseph's Health Care, London, ON, Canada

Saad Al-Qahtani, MBBS, MSc(c), FRCSC Department of Surgery and Mechanical and Materials Engineering, Queen's University, Kingston, ON, Canada

George S. Athwal, MD, FRCSC Roth|McFarlane Hand and Upper Limb Center, St Joseph's Health Care, London, ON, Canada

John J. Basti, PT Columbia Shoulder and Elbow Society, Center for Shoulder, Elbow & Sports Medicine, Columbia University Medical Center, New York, NY, USA

John-Erik Bell, MD, MS Department of Orthopaedic Surgery, Dartmouth-Hitchcock Medical Center, Lebanon, NH, USA

Ryan T. Bicknell, MD, MSc, FRCS(C) Department of Surgery and Mechanical and Materials Engineering, Queen's University, Kingston, ON, Canada

Aaron J. Bois, MD, MSc, FRCSC Department of Surgery, Section of Orthopaedic Surgery, Cumming School of Medicine, University of Calgary, Calgary, AB, Canada

Peter N. Chalmers, MD Department of Orthopedic Surgery, Washington University School of Medicine, St. Louis, MO, USA

Michael Codsi, MD Department of Evergreen Orthopedic Sports Care, Evergreen Hospital, Kirkland, WA, USA

Louis M. Ferreira, PhD Department of Mechanical and Materials Engineering, University of Western Ontario, London, ON, Canada

Leesa M. Galatz, MD Department of Orthopaedics Surgery, Mount Sinai Health System, New York, NY, USA

Charles L. Getz, MD Department of Orthopedics, Shoulder/Elbow Division, Rothman Institute at Thomas Jefferson University, Philadelphia, PA, USA

Jonah Hebert-Davies, MD, FRCSC Department of Orthopedic Surgery, Hopital du Sacre-Coeur de Montreal, Montreal, QC, Canada

Jay D. Keener, MD Department of Orthopedic Surgery, Washington University School of Medicine, St. Louis, MO, USA

Nikolas K. Knowles, MESc Roth|McFarlane Hand and Upper Limb Centre, Surgical Mechatronics Laboratory, St. Josephs Health Care, London, ON, Canada

Jia-Wei Kevin Ko, MD Department of Orthopedics, Orthopedic Physician Associates at Swedish Orthopedic Institute, Seattle, WA, USA

Tom Lawrence, MD, MSc, FRCS (T&O) Department of Trauma and Orthopaedics, University Hospitals Coventry and Warwickshire NHS Trust, Coventry, UK

Brian Lee, MD Department of Orthopaedic Surgery, Kerlan Jobe Orthopaedic Clinic, Los Angeles, CA, USA

Jonathan Levy, MD Department of Orthopedics, Holy Cross Orthopedic Institute, Fort Lauderdale, FL, USA

Ofer Levy, MD, MCh (Orth), FRCS Reading Shoulder Unit, Royal Berkshire Hospital and Berkshire Independent Hospital, Reading, UK

Ana Mata-Fink, MD, MS Department of Orthopaedic Surgery, Dartmouth-Hitchcock Medical Center, Lebanon, NH, USA

Neil Pennington, MBChB(Hons), MSc, FRCS(Tr&Orth) Department of Trauma and Orthopaedics, Calderdale & Huddersfield NHS Trust, Huddersfield Royal Infirmary, Huddersfield, West Yorkshire, UK

Jeremy S. Somerson, MD Department of Orthopaedics, University of Texas Health Science Center at San Antonio, San Antonio, TX, USA

John Sperling, MD, MBA Department of Orthopedic Surgery, Mayo Clinic, Rochester, MN, USA

Michael A. Wirth, MD Department of Orthopaedics, University of Texas Health Science Center at San Antonio, San Antonio, TX, USA

Michelle Zec, MD, PhD, FRCS(C) Department of Surgery and Mechanical and Materials Engineering, Queen's University, Kingston, ON, Canada

1 Indications and Preoperative Evaluation for Anatomic Shoulder Arthroplasty

Ana Mata-Fink and John-Erik Bell

Introduction

The rate of shoulder arthroplasty has increased over the last decade and is predicted to continue to rise [1]. Anatomic shoulder arthroplasty results improved pain and functional outcomes [2]. Rate of complications is acceptable and decreases with surgeons and hospitals that perform shoulder arthroplasty regularly [3, 4]. Increased risk of short-term complications is associated with fracture as the indication for surgery and greater risk of implant failure are associated with factors related to increased upper extremity activity [5]. Careful preoperative planning is essential to ensure successful shoulder arthroplasty.

Indications

Anatomic shoulder arthroplasty is indicated for patients with an arthritic shoulder experiencing shoulder pain and decreased range of motion that compromises activities of daily living. The most common indication for anatomic shoulder arthroplasty is primary glenohumeral osteoarthritis. Other indications include post-traumatic arthritis, rheumatoid arthritis, osteonecrosis, and arthritis due to shoulder instability or prior shoulder instability surgery.

Contraindications for anatomic shoulder arthroplasty include an irreparable rotator cuff repair or rotator cuff tear arthropathy [6] and insufficient glenoid bone stock to support a glenoid component. In these patients, other options such as hemiarthroplasty or reverse shoulder arthroplasty can be considered.

Osteoarthritis

Osteoarthritis is the most common indication for anatomic shoulder arthroplasty. Osteoarthritis is characterized by inferior humeral head osteophyte of variable size, other marginal osteophytes on the humeral head and glenoid, joint space narrowing, subchondral sclerosis and cyst formation, and often a tight anterior capsule with limited external rotation. In some cases, this can result in posterior subluxation of the humeral head with respect to the glenoid and can lead to posterior glenoid bone loss in particularly advanced cases. While rotator cuff disease and small partial thickness tears are common in patients with osteoarthritis, full-thickness rotator cuff tears are rare and, if present, they are usually repairable [7, 8]. Patients with osteoarthritis have predictably good pain relief and improvement in

A. Mata-Fink, MD, MS (✉) • J.-E. Bell, MD, MS
Department of Orthopaedic Surgery, Dartmouth-Hitchcock Medical Center, 1 Medical Center Drive, Lebanon, NH 03756, USA
e-mail: amatafink@gmail.com; john-erik.bell@hitchcock.org

© Springer International Publishing Switzerland 2016

A.D. Armstrong, A.M. Murthi (eds.), *Anatomic Shoulder Arthroplasty*,
DOI 10.1007/978-3-319-29164-2_1

range of motion after anatomic shoulder arthroplasty [7, 9].

Rheumatoid Arthritis

Rheumatoid arthritis is a common inflammatory arthritis. Common findings include osteopenia, bone erosion, concentric joint space narrowing, and central glenoid wear, which can result in medicalization of the humeral head [10]. Patients with rheumatoid arthritis are also much more likely to have a concomitant full-thickness rotator cuff tear, which is rare in patients with glenohumeral osteoarthritis [7, 10]. Patients with rheumatoid arthritis tend to have good pain relief and improved range of motion after shoulder arthroplasty and are typically satisfied with shoulder arthroplasty results, although the outcomes are not as good as those for patients with osteoarthritis [11–13].

Post-Traumatic Arthritis

Arthritis of the glenohumeral joint may develop following proximal humerus fractures, resulting in shoulder pain with post-traumatic arthritis. Proximal humerus malunions often have angulated or rotated humeral heads with nonanatomic neck-shaft angles and malunited tuberosities. The rotator cuff may also be injured, tight, or athrophied. These anatomic abnormalities make shoulder arthroplasty challenging and outcomes are less predictable than anatomic shoulder arthroplasty for osteoarthritis, although patients usually have acceptable pain relief [14]. Tuberosity osteotomy results in less predictable outcomes and should be avoided if possible [15].

Osteonecrosis

Osteonecrosis may result as a complication of proximal humerus fracture or as a result of chronic steroid use or excessive alcohol use. Anatomic shoulder arthroplasty results in predictable improvement in pain and range of motion if osteonecrosis was not associated with post-traumatic tuberosity malunion or rotator cuff atrophy [16].

Arthritis After Instability

Anterior instability can lead to arthritis either through traumatic cartilage damage resulting from recurrent dislocations, after shoulder stabilization procedures that tighten the anterior capsule (post-capsulorrhaphy arthropathy) [17], or after surgical procedures that result in chondral damage, such as chondrolysis due to thermal capsulorrhaphy [18, 19]. These patients tend to be younger than patients with osteoarthritis and often present with an internal rotation contracture. They are also at increased risk for posterior subluxation and resulting posterior glenoid bone loss. Those with nonanatomic anterior stabilization procedures are at higher risk for neurovascular injury due to distorted anatomy. Anterior capsule release, subscapularis lengthening, and glenoid version correction either through eccentric reaming, bone grafting, or use of an augmented glenoid component are often necessary during anatomic shoulder arthroplasty in these cases. Outcomes after shoulder arthroplasty are not as reliable as outcomes after shoulder arthroplasty for osteoarthritis and may have a higher complication rate [17, 20–22]. Some studies also suggest decreased implant longevity [23].

Locked posterior dislocations have also been treated with shoulder arthroplasty. Shoulder arthroplasty results in improved pain and external rotation, although there is a risk of recurrent instability [24, 25].

Nonoperative Treatment

Nonoperative treatment is the initial standard or care for arthritic conditions of the shoulder and should be exhausted before considering TSA. The American Academy of Orthopaedic Surgeons (AAOS) Clinical Practice Guidelines reviewed operative and nonoperative treatments for glenohumeral arthritis [27]. Nonoperative

strategies include pharmacotherapy, physical therapy, corticosteroid injections, and injectable viscosupplementation.

Medications

Multiple types of medications have been used to delay shoulder arthroplasty. These include anti-inflammatories, acetaminophen, and opioids. A Cochrane Review found both acetaminophen and nonsteroidal anti-inflammatories to be useful for pain control in people with hip and knee osteoarthritis [28]. However, the AAOS Clinical Practice Guidelines were unable to find supporting evidence for glenohumeral osteoarthritis [27]. Similarly, the use of glucosamine and chondroitin sulfate for osteoarthritis of the shoulder is not supported in the orthopedic literature [27, 29, 30]. While there has been an increasing trend of prescribing opioids for osteoarthritis pain in the United States over the past 10 years, there is no clear evidence supporting the use of narcotics in the initial treatment of osteoarthritis [27, 31].

Physical Therapy

Physical therapy treatments for glenohumeral arthritis have included joint mobilization and manipulation, exercise, massage, phonophoresis, iontophoresis, ultrasound, and electrical stimulation among others. Given the wide range of physical therapy treatments, the current literature is insufficient to show a clear benefit from physical therapy for patients with osteoarthritis.

Injection

Both corticosteroid and viscosupplementation injections are used to treat glenohumeral osteoarthritis. Studies have shown a short-term improvement in pain with corticosteroid injections for knee osteoarthritis but this effect has not yet been shown in the glenohumeral joint [27, 32, 33]. Viscosupplementation injection, such as hyaluronic acid, appears more promising [32, 34]. The AAOS Clinical Practice Guidelines note that while it is a treatment option, the primary study showing its effectiveness in glenohumeral arthritis is industry supported [27]. Furthermore, there is no viscosupplementation currently available that is FDA approved for the shoulder.

Non-arthroplasty Surgery

Other treatment options that are considered less invasive than shoulder arthroplasty were also reviewed. These include arthroscopic debridement, capsular release, chondroplasty, microfracture, removal of loose bodies, subacromial decompression, distal clavicle excision, and labral repair among others. The AAOS Clinical Practice Guidelines neither support nor oppose the use of these procedures in the treatment of glenohumeral arthritis [27]. There is some data to suggest that arthroscopic debridement is a short-term option for young patients with glenohumeral arthritis as a temporizing measure prior to shoulder arthroplasty [35–37].

Preoperative Evaluation

History

A thorough history is important in identifying patients with pathology that can be treated with anatomic shoulder arthroplasty. There are many etiologies of shoulder pain including arthritis, rotator cuff tear, and cervical spine pathology. A good history and physical exam can help determine the cause of the shoulder pain and the most appropriate treatment.

Most patients with arthritis report pain and decreased range of motion. Decreased range of motion is noted as difficulty with activities of daily living, particularly activities that require external rotation such as putting on a coat. The distribution of pain is important, as radicular distribution with or without numbness may be indicative of cervical spine pathology [38]. Typically arthritic pain is characterized as deep and difficult to localize. Often there is tenderness to

palpation along the anterior and posterior glenohumeral joint lines.

Duration of pain and nonsurgical treatment history are important to elucidate. Arthritic pain is insidious in onset and worsens over time, with occasional acute flairs. The onset of pain can help differentiate acute and chronic disease processes. Arthritis pain usually has an insidious onset [39, 40]. Acute onset associated with trauma is more suggestive of injury, such as acute rotator cuff tear or fracture or an acute arthritic flair that may subside with time and medical management. Aggravating factors can also help identify shoulder pathology. Pain with most shoulder movements and gelling with periods of inactivity are characteristics of arthritis, while patients with rotator cuff tears usually report more specific activity-related pain with overhead activity [40].

Patients should be asked about prior conservative treatments for pain management and if these have been effective. Those who have not tried conservative therapy or who are experiencing acute pain may benefit from a trial of nonsteroidal anti-inflammatory medications or an intra-articular injection. While not supported by the AAOS Clinical Practice Guidelines, these conservative measures often help relieve pain in patients experiencing acute flairs. Conservative management may also be reasonable management for patients who are not medically stable for surgery or those who would prefer to delay arthroplasty.

Patient age, lifestyle, and expectations are an important factor when planning shoulder arthroplasty. The ideal candidate for shoulder arthroplasty is older, but in recent years younger patients are increasingly requesting this procedure as well due to its success and possibly due to perceived improved implant longevity and better revision options. There is no consensus on the results of shoulder arthroplasty in younger patients with some studies showing good implant survival rates at 10 years and others showing decreased long-term function and survival [26, 41]. Younger patients tend to be more active and have increased expectations about what activities they will be able to do after shoulder arthroplasty. While there are no clear guidelines, most surgeons discourage shoulder arthroplasty patients from activities that transmit high loads across the shoulder, such as contact sports and heavy lifting [42, 43]. Therefore, patient expectations should be discussed preoperatively. Heavy laborers and weightlifters may need to consider a new occupation or finding lower-impact activities postoperatively. If such patients are not willing to do this, it may be reasonable to postpone arthroplasty.

An understanding of the patient's social situation is also recommended. Most patients will be in a sling for at least 2 weeks postoperatively and limited activity for 6 weeks or longer to protect their subscapularis repair. This may necessitate visiting nurses or other help at home postoperatively, especially if the affected arm is their dominant arm. Ensuring adequate support postoperatively can help to increase patient compliance and, in turn, minimize complications.

Past Medical and Surgical History

While preoperative clearance by the patient's primary care physician is often required, the surgeon should also be familiar with the patient's medical and surgical history. Significant cardiac or pulmonary problems that may impact anesthesia choice should be discussed. Diabetes should be well controlled and patients should be counseled that it is a risk factor for postoperative infection. Patients with inflammatory arthritis, such as rheumatoid arthritis, may be on corticosteroids or immunomodulators, which can increase the risk of wound breakdown and postoperative infection. A history of venothromboembolism may require more aggressive postoperative anticoagulation. Smoking cessation is recommended to improve the probability of subscapularis healing. Systemic symptoms suggestive of infection at another site should be screened for, including foot ulcerations, open wounds on the ipsilateral extremity and poor dentition.

Shoulder arthroplasty is typically done in the beach chair position, which has been associated with decreased cerebral oxygenation and increased risk of neurologic events [44]. Patients should be screened for medical issues, such as

hypertension, prior stroke, or carotid disease, which may make them more susceptible to adverse effect from positioning.

History of prior shoulder injury, instability, or surgery is crucial. Previous surgery may suggest an etiology of the shoulder pain and may alert the surgeon to possible anatomic abnormalities. Prior stabilization procedures affect soft tissue tensioning, alter surgical landmarks, and can increase the risk to neurovascular structures during surgery. Bony stabilization procedures, such as a Bristow or Latarjet coracoid transfer, posterior bone grafting, or glenoid osteotomy, alter the bony anatomy and also introduce hardware into the glenoid which may require removal. Soft tissue stabilization procedures such as the Putti-Platt and Magnuson-Stack procedures can result in subscapularis shortening, severely limited external rotation, and fixed posterior subluxation of the glenohumeral joint with eccentric glenoid wear.

Patient medications and allergies should be reviewed. Special attention should be paid to immunomodulators, steroids, and anticoagulants. These medications may need to be held in the perioperative period. Current opioid use should be noted as it may make postoperative pain control more difficult. Specific attention should be paid to metal allergies and, if present, implants should be chosen that are free of those specific metals.

Physical Exam

The physical exam should start with inspection of the entire upper extremity. The shoulder should be examined for prior incisions or scars. Previous incisions suggest prior surgical procedures and potentially distorted anatomy. Use of the prior incisions should be considered in surgical planning. Erythema or swelling over the shoulder is worrisome for infection. Visible atrophy of the deltoid or rotator cuff muscles can be indicative of neurologic injury or chronic rotator cuff tear. Examination of the hands also may suggest the underlying diagnosis. Ulnar deviation of the fingers is indicative of rheumatoid arthritis while Heberden's nodes are characteristic of osteoarthritis.

The exam continues with palpation. Palpation should focus on areas of tenderness and any masses around the shoulder. Deep pain that is not localized is typical of arthritis. Point tenderness to palpation over the acromioclavicular joint may suggest other etiologies such as symptomatic acromioclavicular arthritis.

Shoulder range of motion is assessed. The shoulder should be fully exposed so that scapulothoracic motion can be appreciated. Patients with arthritis typically have decreased active and passive range of motion due to osteophytes and capsular contractures. Range of motion is often painful [40]. Loss of external rotation is characteristic of arthritis. Patients may partially compensate for loss of glenohumeral motion with scapulothoracic motion. Decreased glenohumeral range of motion does not appear to significantly impact postoperative outcomes [45]. There has not been any association between preoperative and postoperative forward elevation. However, preoperative internal rotation contracture has been associated with decreased postoperative external rotation [45]. Severe preoperative internal rotation contractures may require subscapularis lengthening in addition to the standard anterior capsulectomy at the time of surgery.

Assessment of the rotator cuff is a crucial part of the physical exam when considering anatomic shoulder arthroplasty. Rotator cuff assessment should consist of individual rotator cuff muscle evaluation [46]. The lift-off test, belly press, and internal rotation strength assess the subscapularis. External rotation lag sign and external rotation strength assess the supraspinatus and infraspinatus. The empty can test evaluates the supraspinatus. Hornblower's sign assesses teres minor. Large, irreparable rotator cuff tear is a contraindication for an anatomic shoulder arthroplasty [6]. Patients with minimally retracted supraspinatus tears and rotator cuff atrophy are still candidates for anatomic shoulder [8, 47]. Rotator cuff assessment can be difficult in patients with arthritis due to range of motion limitations. If there are concerns for rotator cuff integrity, advanced imaging should be considered.

Anatomic shoulder replacement is still a reasonable option in conjunction with solid repair of small full-thickness rotator cuff tears.

Neurovascular testing is an essential part of the physical exam prior to proceeding with shoulder arthroplasty. Atrophy of the infraspinatus or deltoid can be appreciated on inspection of the shoulder and is suggestive of neurologic compromise around the shoulder. Neurovascular testing should include strength testing of shoulder abduction, elbow flexion and extension, wrist flexion and extension, and finger function. It should also include sensory testing in the axillary, lateral antebrachial cutaneous, radial, median, and ulnar nerve distribution. Brachial plexopathy and axillary nerve palsy may be contraindications to anatomic shoulder arthroplasty or may require tendon transfer prior to shoulder arthroplasty or shoulder arthrodesis [48, 49]. Radial pulse should be palpable.

Imaging

Appropriate imaging is essential in preoperative planning for shoulder arthroplasty.

Radiographs

Radiographic evaluation of the affected shoulder should begin with standard radiographs. Important views include Grashey or glenoid oblique, scapular Y, and axillary views. The Grashey or glenoid oblique view shows joint space narrowing more accurately than the AP shoulder and inferior osteophytes are best visualized (Fig. 1.1a, b). Humeral head height can also be evaluated. A high riding humeral head, defined as an acromiohumeral distance less than 7 mm, is suggestive of a rotator cuff tear. The scapular Y view can show humeral head subluxation and loose bodies in the subscapular recess or long head biceps sheath. The axillary view is crucial to ensure the glenohumeral joint is concentrically reduced and identifies anterior or posterior humeral head subluxation. The joint space, osteophytes, glenoid wear pattern, and glenoid bone stock can also be studied from an axillary view (Fig. 1.1c, d).

Shoulder radiographs should be inspected for any hardware that may need to be removed prior to shoulder arthroplasty and for any evidence of prior surgery. After evaluating the shoulder, the humerus should be examined. The humeral canal can be measured in the AP and lateral views to estimate stem size. Decreased cortical thickness or proximal tapering should also be evaluated and, if very thin, cementation of the humeral component may be optimal to minimize risk of intraoperative humerus fracture with press-fit technique. With appropriate software and magnification markers, it is possible to electronically template an anatomic shoulder arthroplasty from the radiographs preoperatively.

The proximal humerus and humeral shaft should be closely examined in patients with a history of prior fracture. Prior proximal humerus fractures may have varus or valgus angulated and/or malrotated humeral head. Prior fractures involving the greater tuberosity often result in superiorly and posteriorly displaced tuberosity malunion. Full-length humerus images should be obtained if the patient has a history of humeral shaft fracture to ensure that a standard stemmed implant can be placed.

CT Scan

While plain radiographs are generally sufficient for standard shoulder arthroplasty, complex shoulders may require advanced imaging. CT scan is the most accurate imaging modality for characterizing glenoid wear, bone loss, and version [50–54]. It is important for the surgeon to be aware of the glenoid morphology preoperatively in order to properly position the glenoid component (Fig. 1.2). Improperly placed components can lead to early arthroplasty failure.

Walch et al. characterized glenoid morphology into five categories (Fig. 1.3a, b). Type A1 is a centered humeral head with minimal glenoid erosion. Type A2 is a centered humeral head with major glenoid erosion. Type B1 is a posteriorly subluxed humeral head with minimal erosion.

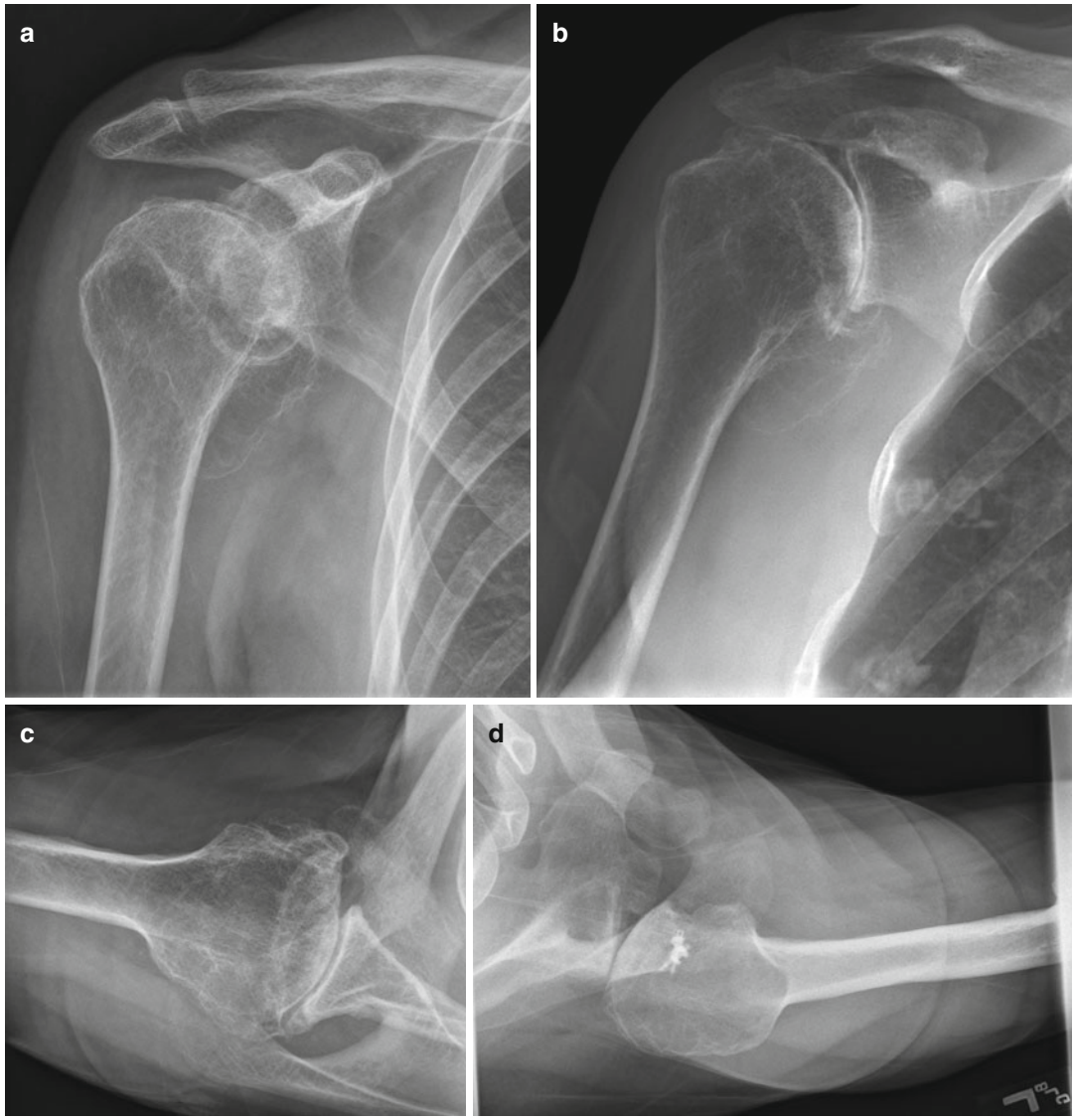


Fig. 1.1 (**a**) Standard AP of the shoulder with osteoarthritis. Note the large inferior humeral neck osteophyte and preserved acromiohumeral interval. (**b**) Grashey or glenoid oblique view of the same shoulder. Note how this view demonstrates the loss of glenohumeral joint space. (**c**) Axillary view of the same shoulder. Note osteophytes anteriorly and posteriorly that may contribute to loss of motion. Also note concentricity of the joint and loss of joint space. (**d**) Axillary view of a patient with prior anterior instability surgery. Note the posterior subluxation of the humerus with respect to the glenoid and posterior glenoid wear

Type B2 is a posteriorly subluxed humeral head with posterior erosion and a biconcave glenoid. Type C is a dysplastic glenoid that is retroverted more than 25° [55, 56]. Glenoid retroversion can be calculated by comparing the glenoid surface to a line perpendicular to the long axis of the scapula [57]. Glenoid version can be calculated on an axillary view but is more accurately calculated on CT scan [51]. A retroverted glenoid may require eccentric reaming, posterior bone grafting, or an augmented glenoid component to appropriately position the implant.

Glenoid bone deficiencies should be inspected. Surgeons should be prepared for posterior bone

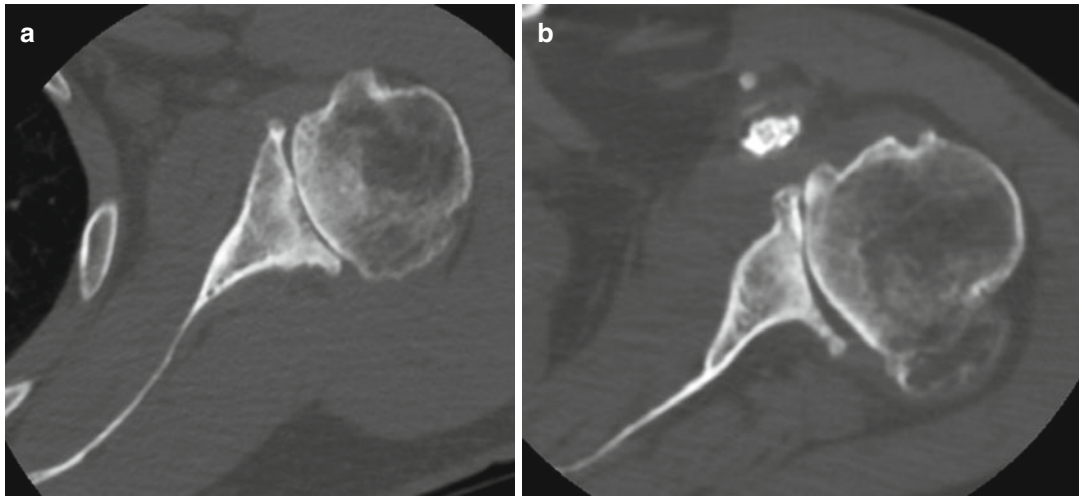


Fig. 1.2 (**a**) Axial cut of CT scan demonstrating mild posterior glenoid erosion. This can likely be treated with eccentric reaming of the anterior glenoid to restore glenoid version without significant medialization of the joint. (**b**) Axial cut of CT scan demonstrating more severe posterior glenoid bone loss. Anterior reaming alone may result in medialization with more retroversion than is desirable. Alternative options include bone grafting or augmented glenoid component implantation

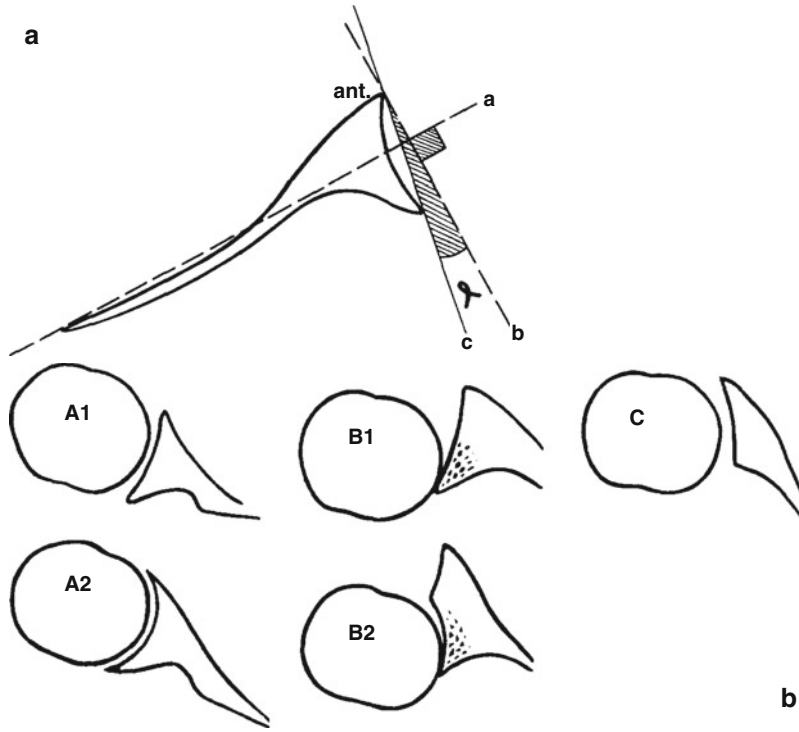


Fig. 1.3 (**a**) Method for calculation of glenoid version. *A* is the axis of the blade of the scapula. *B* is a line perpendicular to the axis of the blade of the scapula. *C* is a line tangent to the anterior and posterior edges of the glenoid fossa. γ is the angle of glenoid retroversion. (**b**) Types of glenoid morphology in primary osteoarthritis (see text) (Figs. 1 and 3 from Ref. [55])

grafting if there is more than 15° of retroversion on the glenoid or if there does not appear to be enough bone to seat the glenoid component [57]. Alternatively, there are now posteriorly augment glenoid component options available in several shoulder replacement systems for management server posterior wear without the need for bone grafting.

Recent studies have looked at using 3D CT scans for preoperative planning. 3D reconstructions with the humeral head subtracted allow for better visualization of the glenoid and understanding of its morphology, version, and bone deficiencies. Current studies suggest more accurate glenoid component placement with the use of preoperative 3D CT scans [58, 59].

MRI

MRI is the best imaging modality for evaluating soft tissues around the shoulder. It should be obtained when there is concern based on the patient's history, physical, or plain radiographs for a rotator cuff tear (Fig. 1.4a, b). An identified rotator cuff tear should be evaluated on whether or not it can be repaired. A repairable rotator cuff tear is not a contraindication for anatomic shoulder arthroplasty, but irreparable or questionably repairable rotator cuff tears are more appropriately treated with hemiarthroplasty or reverse shoulder arthroplasty depending on functional status, activity level, and patient age.

Rotator cuff atrophy can also be identified on MRI. Rotator cuff atrophy is not a contraindication to anatomic shoulder arthroplasty if the rotator cuff is intact. Long-standing arthritis limits shoulder range of motion resulting in rotator cuff atrophy in older patients. Deltoid atrophy may raise concern for axillary nerve injury or brachial plexopathy.

Other Imaging Modalities

Ultrasonography has been shown to be equivalent to MRI in identifying rotator cuff tears, measuring retraction of torn rotator cuff muscles, and characterizing fatty infiltration [60, 61]. Ultrasonography is highly operator dependent. It may replace MRI for preoperative rotator cuff assessment in hospitals that use ultrasonography for rotator cuff evaluation on a regular basis.

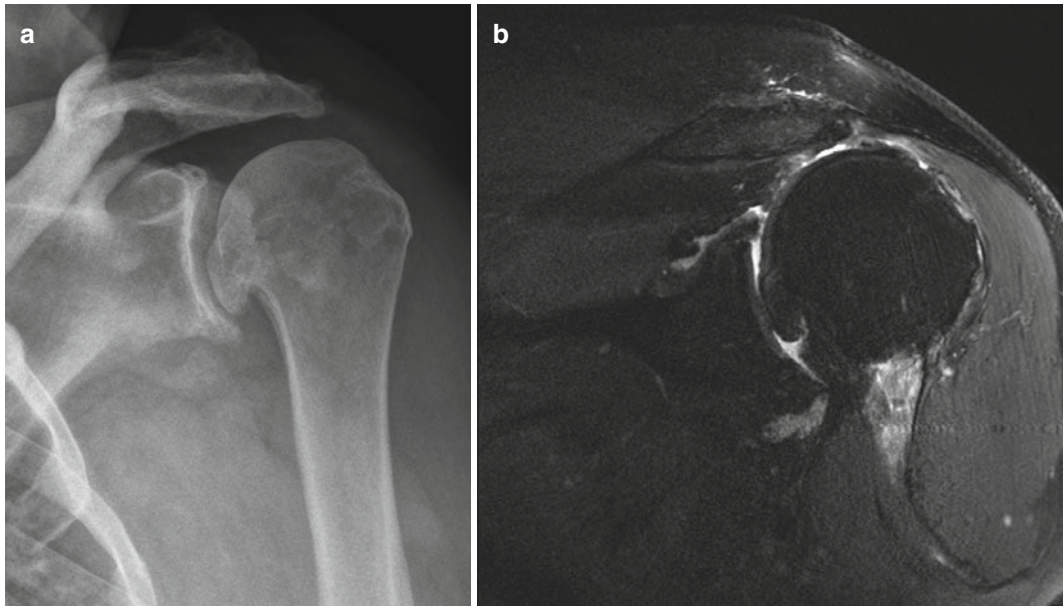


Fig. 1.4 (**a**) Grashey view of shoulder with osteoarthritis and significant rotator cuff weakness. (**b**) Coronal MRI cut showing massive retracted supraspinatus tear with cartilage loss

For patients who cannot undergo MRI, CT arthrogram is a reasonable alternative. While rotator cuff atrophy may be more difficult to characterize, full-thickness rotator cuff tears should be identifiable.

Laboratory Studies

Preoperative laboratory studies can help to ensure that the patient is medically ready for surgery. Complete blood count will identify patients with preoperative anemia or thrombocytopenia. Both of these factors will increase the patient's risk for requiring a blood transfusion postoperatively. Type and screen should be obtained on all patients preoperatively in the event a blood transfusion is required intraoperatively or postoperatively.

Coagulation markers (INR, PT, PTT) are important if the patient is on warfarin. Warfarin is generally stopped 5–7 days prior to surgery with an INR checked on the day of surgery to ensure that it has normalized. Elevated INR in patients not on warfarin may be suggestive of liver disease.

A basic metabolic panel may be obtained. Creatinine clearance can be calculated which may be necessary when dosing perioperative antibiotics. For patients with renal disease, it will establish a baseline creatinine that can be compared to postoperatively. High glucose may be suggestive of undiagnosed or poorly controlled diabetes.

Hemoglobin A1C is crucial for diabetic patients. Poorly controlled diabetics are at increased risk of wound healing complications and postoperative infections [62]. In well-controlled diabetics, hemoglobin A1C is usually below 7–7.5 %.

In elderly patients in whom there is a concern for malnutrition, pre-albumin, albumin, and transferrin should be obtained. Malnourished patients are at increased risk for wound healing complications and infection [63]. Since anatomic shoulder arthroplasty is an elective procedure, improving the patient's nutritional status is essential.

Other Considerations

Surgical Timing

Surgical timing is an important consideration for patients with osteoarthritis and inflammatory arthritis. Many of these patients have more than one joint affected. Lower extremity arthroplasty often requires the use of ambulatory aides that can compromise the shoulder arthroplasty. If possible, hip or knee arthroplasty should be done before shoulder arthroplasty [64].

Tranexamic Acid

Tranexamic acid has been used in total hip and total knee arthroplasty to decrease intraoperative and postoperative blood loss. Multiple studies have shown decrease in blood transfusions with the use of intravenous or topical tranexamic acid [65, 66]. A recent study has shown similar results with topical tranexamic acid after total shoulder arthroplasty [67]. While further study is needed, the current shoulder arthroplasty results and extrapolation from the hip and knee arthroplasty data suggests that the use of tranexamic acid might be considered during shoulder arthroplasty.

Postoperative Pain Control

Pain control is a concern after every surgery. In older patients, large doses of opioids can cause confusion and delirium. Minimizing opioids decreases many of these side effects. Multiple studies have shown that multimodal pain control results in better pain control and higher satisfaction with lower amounts of opioids. There has been no evidence of increased adverse events with the addition of an interscalene or other peripheral nerve blocks or nerve catheters to a multimodal pain control regimen [68, 69]. Regional anesthesia should be considered for pain control during and immediately after shoulder arthroplasty.

Postoperative Anticoagulation

The use of postoperative anticoagulation after orthopedic surgery is often discussed with regard to hip and knee arthroplasty patients. Shoulder arthroplasty patients tend to have better mobility postoperatively than knee and hip arthroplasty patients, and recent data suggests that deep vein thrombosis after shoulder surgery is lower than after knee arthroplasty [70]. The AAOS clinical practice guidelines recommend either mechanical or chemical venothromboembolism prophylaxis based on patient risk factors. Shoulder arthroplasty patients on anticoagulation preoperatively should have their anticoagulation restarted.

Summary

This chapter outlines the indications for anatomic shoulder arthroplasty and details the preoperative workup that should be completed prior to proceeding with surgery. Subsequent chapters will outline the technical aspects, rehabilitation, and outcomes of the procedure in great detail.

References

1. Day JS, Lau E, Ong KL, Williams GR, Ramsey ML, Kurtz SM, et al. Prevalence and projections of total shoulder and elbow arthroplasty in the United States to 2015. J Should Elb Surg/Am Should Elb Surg. 2010;19(8):1115–20. Epub 2010/06/18.
2. Lo IK, Litchfield RB, Griffin S, Faber K, Patterson SD, Kirkley A. Quality-of-life outcome following hemiarthroplasty or total shoulder arthroplasty in patients with osteoarthritis. A prospective, randomized trial. J Bone Joint Surg Am. 2005;87(10):2178–85. Epub 2005/10/06.
3. van de Sande MA, Brand R, Rozing PM. Indications, complications, and results of shoulder arthroplasty. Scand J Rheumatol. 2006;35(6):426–34. Epub 2007/03/09.
4. Jain N, Pietrobon R, Hocker S, Guller U, Shankar A, Higgins LD. The relationship between surgeon and hospital volume and outcomes for shoulder arthroplasty. J Bone Joint Surg Am. 2004;86(3):496–505. Epub 2004/03/05.
5. Farng E, Zingmond D, Krenek L, Soohoo NF. Factors predicting complication rates after primary shoulder arthroplasty. J Should Elbow Surg/Am Should Elb Surg [et al]. 2011;20(4):557–63. Epub 2011/02/18.
6. Franklin JL, Barrett WP, Jackins SE, Matsen 3rd FA. Glenoid loosening in total shoulder arthroplasty. Association with rotator cuff deficiency. J Arthroplasty. 1988;3(1):39–46. Epub 1988/01/01.
7. Norris TR, Iannotti JP. Functional outcome after shoulder arthroplasty for primary osteoarthritis: a multicenter study. J Should Elb Surg/Am Should Elb Surg [et al]. 2002;11(2):130–5. Epub 2002/05/04.
8. Edwards TB, Boulahia A, Kempf JF, Boileau P, Nemoz C, Walch G. The influence of rotator cuff disease on the results of shoulder arthroplasty for primary osteoarthritis: results of a multicenter study. J Bone Joint Surg Am. 2002;84-A(12):2240–8. Epub 2002/12/11.
9. Bryant D, Litchfield R, Sandow M, Gartsman GM, Guyatt G, Kirkley A. A comparison of pain, strength, range of motion, and functional outcomes after hemiarthroplasty and total shoulder arthroplasty in patients with osteoarthritis of the shoulder. A systematic review and meta-analysis. J Bone Joint Surg Am. 2005;87(9):1947–56. Epub 2005/09/06.
10. Chen AL, Joseph TN, Zuckerman JD. Rheumatoid arthritis of the shoulder. J Am Acad Orthop Surg. 2003;11(1):12–24. Epub 2003/04/18.
11. McCoy SR, Warren RF, Bade 3rd HA, Ranawat CS, Inglis AE. Total shoulder arthroplasty in rheumatoid arthritis. J Arthroplasty. 1989;4(2):105–13. Epub 1989/01/01.
12. Sojbjerg JO, Frich LH, Johannsen HV, Sneppen O. Late results of total shoulder replacement in patients with rheumatoid arthritis. Clin Orthop Relat Res. 1999;366:39–45. Epub 2000/01/11.
13. Stewart MP, Kelly IG. Total shoulder replacement in rheumatoid disease: 7- to 13-year follow-up of 37 joints. J Bone Joint Surg. 1997;79(1):68–72. Epub 1997/01/01.
14. Jacobson JA, Duquin TR, Sanchez-Sotelo J, Schleck CD, Sperling JW, Cofield RH. Anatomic shoulder arthroplasty for treatment of proximal humerus malunions. J Should Elb Surg/Am Should Elb Surg [et al]. 2014;23(8):1232–9. Epub 2014/01/21.
15. Boileau P, Trojani C, Walch G, Krishnan SG, Romeo A, Sinnerton R. Shoulder arthroplasty for the treatment of the sequelae of fractures of the proximal humerus. J Should Elb Surg/Am Should Elb Surg [et al]. 2001;10(4):299–308. Epub 2001/08/23.
16. Moineau G, McClelland Jr WB, Trojani C, Rumian A, Walch G, Boileau P. Prognostic factors and limitations of anatomic shoulder arthroplasty for the treatment of posttraumatic cephalic collapse or necrosis (type-1 proximal humeral fracture sequelae). J Bone Joint Surg Am. 2012;94(23):2186–94. Epub 2012/12/12.
17. Green A, Norris TR. Shoulder arthroplasty for advanced glenohumeral arthritis after anterior

instability repair. J Should Elb Surg/Am Should Elb Surg [et al]. 2001;10(6):539–45. Epub 2001/12/18.
18. Levine WN, Clark Jr AM, D'Alessandro DF, Yamaguchi K. Chondrolysis following arthroscopic thermal capsulorrhaphy to treat shoulder instability. A report of two cases. J Bone Joint Surg Am. 2005;87(3):616–21. Epub 2005/03/03.
19. Levy JC, Virani NA, Frankle MA, Cuff D, Pupello DR, Hamelin JA. Young patients with shoulder chondrolysis following arthroscopic shoulder surgery treated with total shoulder arthroplasty. J Should Elb Surg/Am Should Elb Surg [et al]. 2008;17(3):380–8. Epub 2008/03/11.
20. Bigliani LU, Weinstein DM, Glasgow MT, Pollock RG, Flatow EL. Glenohumeral arthroplasty for arthritis after instability surgery. J Should Elb Surg/Am Should Elb Surg [et al]. 1995;4(2):87–94. Epub 1995/03/01.
21. Lehmann L, Magosch P, Mauermann E, Lichtenberg S, Habermeyer P. Total shoulder arthroplasty in dislocation arthropathy. Int Orthop. 2010;34(8):1219–25. Epub 2009/12/31.
22. Matsoukis J, Tabib W, Guiffault P, Mandelbaum A, Walch G, Nemoz C, 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):1417–24. Epub 2003/08/20.
23. 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):1775–81. Epub 2002/10/16.
24. Wooten C, Klika B, Schleck CD, Harmsen WS, Sperling JW, Cofield RH. Anatomic shoulder arthroplasty as treatment for locked posterior dislocation of the shoulder. J Bone Joint Surg Am. 2014;96(3):e19. Epub 2014/02/07.
25. Gavriilidis I, Magosch P, Lichtenberg S, Habermeyer P, Kircher J. Chronic locked posterior shoulder dislocation with severe head involvement. Int Orthop. 2010;34(1):79–84. Epub 2009/03/21.
26. Denard PJ, Raiss P, Sowa B, Walch G. Mid– to long-term follow-up of total shoulder arthroplasty using a keeled glenoid in young adults with primary glenohumeral arthritis. J Should Elbow Surg/Am Should Elb Surg [et al]. 2013;22(7):894–900. Epub 2013/01/15.
27. Izquierdo R, Voloshin I, Edwards S, Freehill MQ, Stanwood W, Wiater JM, et al. Treatment of glenohumeral osteoarthritis. J Am Acad Orthop Surg. 2010;18(6):375–82. Epub 2010/06/01.
28. Towheed TE, Maxwell L, Judd MG, Catton M, Hochberg MC, Wells G. Acetaminophen for osteoarthritis. Cochrane Database Syst Rev. 2006(1):CD004257. Epub 2006/01/27.
29. Reichenbach S, Sterchi R, Scherer M, Trelle S, Burgi E, Burgi U, et al. Meta-analysis: chondroitin for osteoarthritis of the knee or hip. Ann Intern Med. 2007;146(8):580–90. Epub 2007/04/18.
30. Singh JA, Noorbaloochi S, MacDonald R, Maxwell LJ. Chondroitin for osteoarthritis. Cochrane Database Syst Rev. 2015;1:CD005614. Epub 2015/01/30.
31. Wright EA, Katz JN, Abrams S, Solomon DH, Losina E. Trends in prescription of opioids from 2003–2009 in persons with knee osteoarthritis. Arthritis Care Res. 2014;66(10):1489–95. Epub 2014/05/02.
32. Colen S, Geervliet P, Haverkamp D, Van Den Bekerom MP. Intra-articular infiltration therapy for patients with glenohumeral osteoarthritis: a systematic review of the literature. Int J Should Surg. 2014;8(4):114–21. Epub 2014/12/30.
33. Hepper CT, Halvorson JJ, Duncan ST, Gregory AJ, Dunn WR, Spindler KP. The efficacy and duration of intra-articular corticosteroid injection for knee osteoarthritis: a systematic review of level I studies. J Am Acad Orthop Surg. 2009;17(10):638–46. Epub 2009/10/02.
34. 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):979–85. Epub 2007/03/31.
35. Sayegh ET, Mascarenhas R, Chalmers PN, Cole BJ, Romeo AA, Verma NN. Surgical treatment options for glenohumeral arthritis in young patients: a systematic review and meta-analysis. Arthrosc : J Arthrosc Relat Surg : Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc. 2014. Epub 2014/12/30.
36. Bishop JY, Flatow EL. Management of glenohumeral arthritis: a role for arthroscopy? Orthop Clin North Am. 2003;34(4):559–66. Epub 2004/02/27.
37. Denard PJ, Wirth MA, Orfaly RM. Management of glenohumeral arthritis in the young adult. J Bone Joint Surg Am. 2011;93(9):885–92. Epub 2011/05/06.
38. Burbank KM, Stevenson JH, Czarnecki GR, Dorfman J. Chronic shoulder pain: part I. Evaluation and diagnosis. Am Fam Physician. 2008;77(4):453–60. Epub 2008/03/11.
39. Mitchell C, Adebajo A, Hay E, Carr A. Shoulder pain: diagnosis and management in primary care. BMJ. 2005;331(7525):1124–8. Epub 2005/11/12.
40. Armstrong A. Evaluation and management of adult shoulder pain: a focus on rotator cuff disorders, acromioclavicular joint arthritis, and glenohumeral arthritis. Med Clin North Am. 2014;98(4):755–75. xii. Epub 2014/07/06.
41. Bartelt R, Sperling JW, Schleck CD, Cofield RH. Shoulder arthroplasty in patients aged fifty-five years or younger with osteoarthritis. J Should Elb Surg/Am Should Elb Surg [et al]. 2011;20(1):123–30. Epub 2010/08/28.
42. Golant A, Christoforou D, Zuckerman JD, Kwon YW. Return to sports after shoulder arthroplasty: a survey of surgeons' preferences. J Should Elb Surg/Am Should Elb Surg [et al]. 2012;21(4):554–60. Epub 2011/03/12.
43. Magnussen RA, Mallon WJ, Willems WJ, Moorman 3rd CT. Long-term activity restrictions after shoulder arthroplasty: an international survey of experienced shoulder surgeons. J Should Elb Surg/Am Should Elb Surg [et al]. 2011;20(2)):281–9. Epub 2010/11/06.
44. Murphy GS, Szokol JW, Marymont JH, Greenberg SB, Avram MJ, Vender JS, et al. Cerebral oxygen desaturation events assessed by near-infrared spectroscopy during shoulder arthroscopy in the beach chair and lateral decubitus positions. Anesth Analg. 2010;111(2):496–505. Epub 2010/05/29.

45. 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):251–8. Epub 2003/02/07.
46. Tennent TD, Beach WR, Meyers JF. A review of the special tests associated with shoulder examination. Part I: the rotator cuff tests. Am J Sports Med. 2003;31(1):154–60. Epub 2003/01/18.
47. Lapner PL, Jiang L, Zhang T, Athwal GS. Rotator cuff fatty infiltration and atrophy are associated with functional outcomes in anatomic shoulder arthroplasty. Clin Orthop Relat Res. 2015;473(2):674–82. Epub 2014/10/01.
48. Richards RR. Glenohumeral arthrodesis. In: Iannotti JP, Williams Jr GR, editors. Disorders of the shoulder, Diagnosis and management: shoulder reconstruction. Third editionth ed. Philadelphia: Wilkins; 2014. p. 523–5.
49. Goldner JL. Muscle-tendon trasfers for partial paralysis of the shoulder girdle. In: EvartsCMCC, editor. Surgery of the musculoskeletal system. New York: Churchill Livingstone; 1983. p. 167.
50. Friedman RJ, Hawthorne KB, Genez BM. The use of computerized tomography in the measurement of glenoid version. J Bone Joint Surg Am. 1992;74(7):1032–7. Epub 1992/08/01.
51. Nyffeler RW, Jost B, Pfirrmann CW, Gerber C. Measurement of glenoid version: conventional radiographs versus computed tomography scans. J Should Elb Surg/Am Should Elb Surg [et al]. 2003;12(5):493–6. Epub 2003/10/18.
52. Scalise JJ, Bryan J, Polster J, Brems JJ, Iannotti JP. Quantitative analysis of glenoid bone loss in osteoarthritis using three-dimensional computed tomography scans. J Should Elb Surg/Am Should Elb Surg [et al]. 2008;17(2):328–35. Epub 2008/01/26.
53. Scalise JJ, Codsi MJ, Bryan J, Brems JJ, Iannotti JP. The influence of three-dimensional computed tomography images of the shoulder in preoperative planning for total shoulder arthroplasty. J Bone Joint Surg Am. 2008;90(11):2438–45. Epub 2008/11/04.
54. Scalise JJ, Codsi MJ, Bryan J, Iannotti JP. The three-dimensional glenoid vault model can estimate normal glenoid version in osteoarthritis. J Should Elb Surg/Am Should Elb Surg [et al]. 2008;17(3):487–91. Epub 2008/02/20.
55. Walch G, Badet R, Boulahia A, Khoury A. Morphologic study of the glenoid in primary glenohumeral osteoarthritis. J Arthroplasty. 1999; 14(6):756–60. Epub 1999/10/08.
56. Walch G, Boulahia A, Boileau P, Kempf JF. Primary glenohumeral osteoarthritis: clinical and radiographic classification. The Aequalis Group. Acta Orthop Belg. 1998;64 Suppl(2):46–52. Epub 1999/01/29.
57. Sears BW, Johnston PS, Ramsey ML, Williams GR. Glenoid bone loss in primary total shoulder arthroplasty: evaluation and management. J Am Acad Orthop Surg. 2012;20(9):604–13. Epub 2012/09/04.
58. Iannotti JP, Weiner S, Rodriguez E, Subhas N, Patterson TE, Jun BJ, et al. Three-dimensional imaging and templating improve glenoid implant positioning. J Bone Joint Surg Am. 2015;97(8):651–8. Epub 2015/04/17.
59. Walch G, Mesiha M, Boileau P, Edwards TB, Levigne C, Moineau G, et al. Three-dimensional assessment of the dimensions of the osteoarthritic glenoid. Bone Joint J. 2013;95-B(10):1377–82. Epub 2013/10/01.
60. Roy JS, Braen C, Leblond J, Desmeules F, Dionne CE, MacDermid JC, et al. Diagnostic accuracy of ultrasonography, MRI and MR arthrography in the characterisation of rotator cuff disorders: a meta-analysis. Br J Sports Med. 2015. Epub 2015/02/14.
61. Wall LB, Teefey SA, Middleton WD, Dahiya N, Steger-May K, Kim HM, et al. Diagnostic performance and reliability of ultrasonography for fatty degeneration of the rotator cuff muscles. J Bone Joint Surg Am. 2012;94(12):e83. Epub 2012/06/22.
62. Wirth MA, Rockwood Jr CA. Complications of total shoulder-replacement arthroplasty. J Bone Joint Surg Am. 1996;78(4):603–16. Epub 1996/04/01.
63. Cross MB, Yi PH, Thomas CF, Garcia J, Della Valle CJ. Evaluation of malnutrition in orthopaedic surgery. J Am Acad Orthop Surg. 2014;22(3):193–9. Epub 2014/03/08.
64. Shapiro J, Zuckerman JD. Glenohumeral arthroplasty: indications and preoperative considerations. Instr Course Lect. 2002;51:3–10. Epub 2002/06/18.
65. Sukeik M, Alshryda S, Haddad FS, Mason JM. Systematic review and meta-analysis of the use of tranexamic acid in total hip replacement. J Bone Joint Surg. 2011;93(1):39–46. Epub 2011/01/05.
66. Alshryda S, Sarda P, Sukeik M, Nargol A, Blenkinsopp J, Mason JM. Tranexamic acid in total knee replacement: a systematic review and meta-analysis. J Bone Joint Surg. 2011;93(12):1577–85. Epub 2011/12/14.
67. Gillespie RJ, Shishani Y, Hanzlick S, Streit J, Gobezie R. A Randomized, prospective evaluation on the effectiveness of tranexamic acid in reducing blood loss after total shoulder arthroplasty. ASES Specialty Day; Las Vegas, NV2015.
68. Goon AK, Dines DM, Craig EV, Gordon MA, Goytizolo EA, Lin Y, et al. A clinical pathway for total shoulder arthroplasty-a pilot study. HSS J musculoskelet J Hosp Spec Surg. 2014;10(2):100–6. Epub 2014/07/23.
69. Stundner O, Rasul R, Chiu YL, Sun X, Mazumdar M, Brummett CM, et al. Peripheral nerve blocks in shoulder arthroplasty: how do they influence complications and length of stay? Clin Orthop Relat Res. 2014;472(5):1482–8. Epub 2013/10/30.
70. Willis AA, Warren RF, Craig EV, Adler RS, Cordasco FA, Lyman S, et al. Deep vein thrombosis after reconstructive shoulder arthroplasty: a prospective observational study. J Shoulder Elb Surg/Am Should Elb Surg [et al]. 2009;18(1):100–6. Epub 2008/12/20.

Humeral Head Replacement: Anatomy and Biomechanics

2

Michelle Zec, Saad Al-Qahtani, and Ryan T. Bicknell

Introduction

The evolution of proximal humeral arthroplasty began when a French surgeon, Pean, performed the first shoulder arthroplasty in 1893 for destructive tuberculosis osteomyelitis [1]. Gluck, a German surgeon, also made a great contribution and designed several shoulder implants [1]. Krueger in the 1950s performed the first modern shoulder anatomic arthroplasty. The pioneering work by Neer, in the 1950s, established the foundations for the current state of modern shoulder arthroplasty. Proximal humeral replacement has continued to evolve with significant changes in design over the last few decades. Shoulder implants that offer modularity, coupled with an increasing understanding of proximal humerus anatomy and biomechanics, have enabled current surgeons to accurately and repeatedly recreate the native humeral anatomy and restore shoulder biomechanics and function.

The ultimate goal of an anatomic shoulder arthroplasty is to improve pain and, consequently, restore shoulder function. The surgical goal is to reproduce the patient's normal anatomy and biomechanics through a combination of bony reconstruction and soft tissue balancing. Accurate recreation of the patient-specific proximal humeral anatomy, along with appropriate balancing of the soft tissue (primarily muscle) forces, is essential for a good outcome. The two are interrelated, as the bony anatomy affects the soft tissue muscle balancing (primarily deltoid and rotator cuff lever arms) in both the vertical and horizontal planes [2, 3]. Any change in this normal anatomy may lead to abnormal biomechanics of the shoulder, through malpositioning of the joint line and center of rotation, which subsequently alters soft tissue balance/function [4].

Anatomy

In order to perform shoulder arthroplasty, the surgeon requires detailed knowledge of the normal bony and soft tissue anatomy. It is important that the surgeon understands the proximal humeral bony anatomy and appreciates the relationship between multiple variables to be able to perform a patient-specific anatomic recreation of the proximal humerus.

M. Zec, MD, PhD, FRCS(C) • S. Al-Qahtani, MBBS, MSc(c), FRCSC • R.T. Bicknell, MD, MSc, FRCS(C) (✉)
Department of Surgery and Mechanical and Materials Engineering, Queen's University, Kingston, ON, Canada
e-mail: zec.michelle@gmail.com; dr.saaad01@gmail.com; rtbickne@yahoo.ca

© Springer International Publishing Switzerland 2016

A.D. Armstrong, A.M. Murthi (eds.), *Anatomic Shoulder Arthroplasty*,
DOI 10.1007/978-3-319-29164-2_2

Humeral Head Size and Shape

The humeral head is often described as a sphere, but may be more accurately represented as a partial ellipsoid with the articular surface constituting only one third of this sphere. In several studies, the difference in the radii of curvature between the transverse and coronal planes was less than 1 mm, confirming that the humeral head is comparable to a sphere. However, other studies have found that the central portion of the articular surface is spherical but the periphery is elliptical, with the transverse plane smaller than the coronal plane by 2 mm [5–7, 11]. Men have a greater head diameter by 2 mm in both dimensions compared to women [7, 12, 13]. Studies have reported an average humeral head diameter of 46.2 mm [4–6]. The average humeral head radius of curvature is 24 mm in men and 19 mm in women. However, the average humeral head height is 15.2 mm [5]. These studies also support the finding that there is a constant relationship between the diameter of the humeral head and the thickness of the humeral head, with a consistent ratio of 70–80% ratio of humeral head radius of curvature to height [4–9, 12] (Fig. 2.1).

Humeral Head Offset

The humeral head offset refers to the position of the center of rotation of the humeral head from the axis of the humeral shaft in both the transverse and coronal planes. Several studies have shown that the humeral head center of rotation is offset from the humeral shaft axis, in both the transverse and coronal planes. In the transverse plane, the center of rotation is offset an average of 2.6 mm (range 2–4 mm) posteriorly. In the coronal plane, the center of rotation is offset an average of 6.6 mm (range 6–9 mm) medially. Therefore, these offsets both combine creating a center of rotation that is posteromedially offset [5, 8, 12, 15–17] (Fig. 2.2).

Humeral Head Retroversion

Humeral head retroversion is generally defined as the angle between the central axis of the humeral head and the epicondylar axis of the distal humerus. However, there are several other common methods described, leading to some confusion in the literature. One study reported an average of 28.8° of retroversion when measured from the forearm axis [18]. Another study measured retroversion from the lateral margin of the lesser tuberosity as an average of 48° [19]. The bicipital groove has been used and shown to lie an average of 8–9 mm from the equator of the humeral head [8, 20, 21]. Using the epicondylar axis, different values have been reported in the literature, ranging from 17.9° (±13.7°) to 21.4°

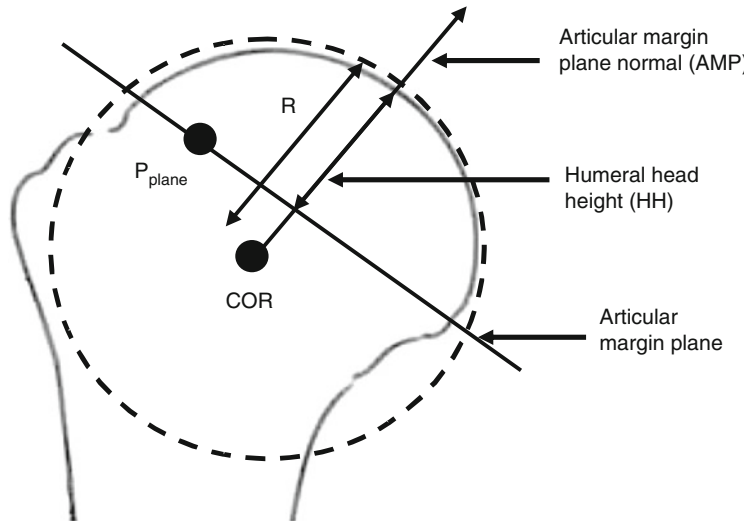


Fig. 2.1 Humeral head size and shape. Shown in a coronal plane view, the humeral head height (*HH*) is the distance along a vector passing through the humeral head center of rotation (*COR*) in the direction of the articular margin plane (*AMP*) normal, between a point on the articular margin plane (P_{plane}) and the humeral head articular surface (Adapted with permission from DeLude et al. [24])

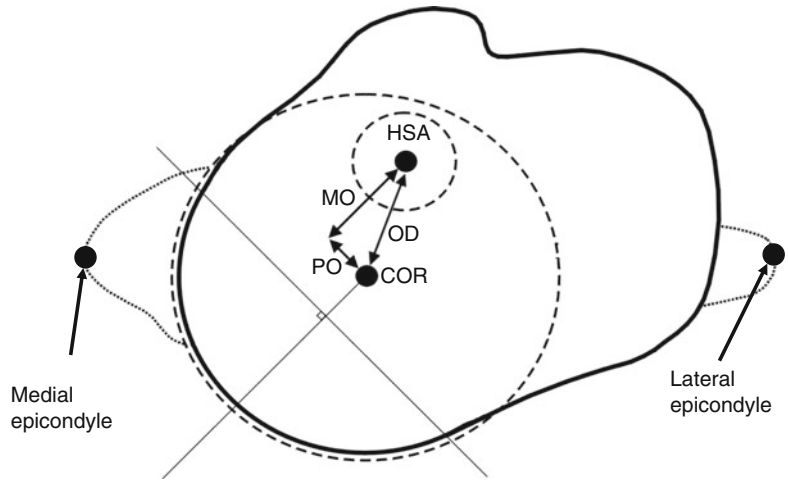


Fig. 2.2 Humeral head offset. The humeral shaft axis (*HSA*) is out of the page and the humeral head center of rotation (*COR*) is shown. The distance between the humeral shaft axis and the humeral head center of rotation (*COR*) is characterized by the humeral head offset distance (*OD*), humeral head posterior offset (*PO*), and humeral head medial offset (*MO*) (Reproduced with permission from DeLude et al. [24])

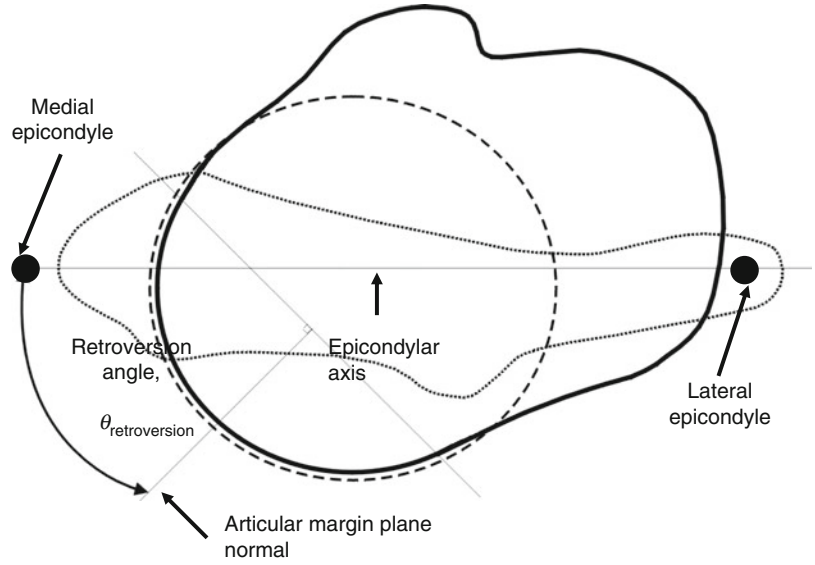


Fig. 2.3 Humeral head retroversion. The humeral axis is out of the page. Humeral head retroversion ($\theta_{retroversion}$) is defined by the angle between the epicondylar axis and the articular margin plane (AMP) normal after both vectors have been projected onto a plane perpendicular to the humeral shaft axis (Reproduced with permission from DeLude et al. [24])

(±3.3°) [5, 22]. As well, retroversion shows quite a large variability associated with age, sex, race, and between sides [5, 20, 23, 24] (Fig. 2.3).

Humeral Head Inclination

Humeral head inclination, also referred to as neck-shaft angle, is defined as the angle between the humeral shaft axis and a line perpendicular to the articular margin plane (i.e., central line of the humeral head). In the literature, values range from 129.6 to 137° with an average of 134.4° [5, 8, 15]. In a large cadaveric study, Iannotti found that 135° was the most common value and that 78 % of humeri fell between 130 and 140° [25] (Fig. 2.4).

Proximal Humerus Morphology

Not only is the morphology of the humeral head variable but there is also considerable variability in the upper proximal humeral morphology itself. Hertel [8] described three distinct types of metaphyseal morphology that considered the offset of the greater tuberosity from the long axis of the humerus, described as standard, high offset,

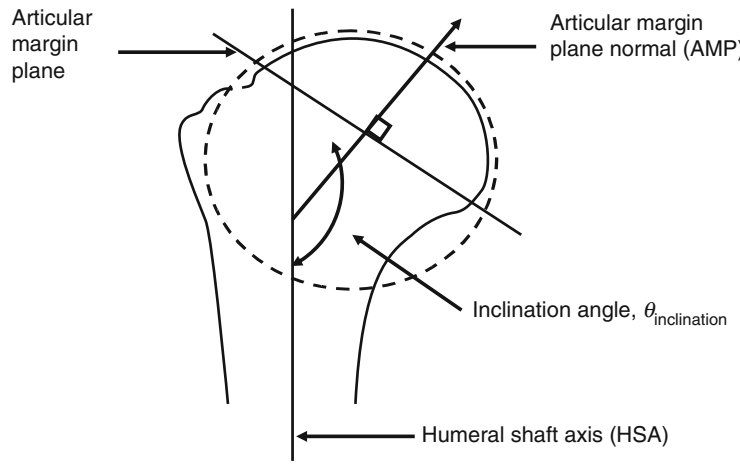


Fig. 2.4 Humeral head inclination. As shown in a coronal plane view, the humeral head inclination angle ($\theta_{inclination}$) is defined by the angle between the humeral shaft axis (HSA) and the articular margin plane (AMP) normal (Reproduced with permission from DeLude et al. [24])

and low offset (Fig. 2.5). With respect to the humeral shaft morphology, the size and shape can vary, with the intramedullary canal described as either cylindrical or funnel shaped [60] (Fig. 2.6).

Proximal Humeral Bone Quality

Patients who present for treatment of osteoarthritis of the shoulder are often elderly and often suffer from concurrent osteoporosis [26–29]. Therefore, the proximal humeral bone quality is an important factor to consider when performing a shoulder arthroplasty. Several methods are available to identify patients with osteoporosis and poor bone quality, including patient history and risk factors [30–33], bone mineral density, proximal humeral diaphyseal cortical thickness [34, 35], and proximal humerus computed tomography (CT)-derived Hounsfield unit (HU) measurements [36]. Patient age and gender also have a major impact on the proximal humerus bone quality [37].

The Rotator Cuff

The authors of several anatomical studies have delineated the footprints of the supraspinatus, infraspinatus, and subscapularis and reported values for their maximum length and width [38–41]. Surgeons must be aware of this anatomy when performing humeral head resection and/or rotator cuff (usually subscapularis) reattachment associated with humeral head replacement. The subscapularis inserts along the medial aspect of the biceps groove, and its distance from the articular surface tapered from 0 mm superiorly to 18 mm inferiorly. The average maximum length was 40 mm (range, 35–55 mm), and the average maximum width was 20 mm (range, 15–25 mm). It is important to understand that the most superior intra-articular margin is purely tendinous, and as the subscapularis insertion progresses inferiorly, it tapered to end as a purely musculocapsular attachment [38]. Mochizuki et al. have shown that the supraspinatus tendon was composed of two portions: the anterior half, which was long and thick, and the posterior half, which was short and thin [42]. Similarly, the superior half of the infraspinatus tendon was long and thick, while the inferior half was short and thin. He also reported that the footprint of the supraspinatus had a triangular shape, which tapered away from the joint capsule. The average maximum length of the footprint was 6.9 ± 1.4 mm. The average width was 12.6 ± 2.0 mm on the medial margin and 1.3 ± 1.4 mm on the lateral margin. The footprint of the infraspinatus was shaped like a trapezoid, which was wider laterally compared with the more medial insertion along the joint capsule. The average maximum length of the infraspinatus footprint was 10.2 ± 1.6 mm. The average width was 20.2 ± 6.2 mm on the medial margin and 32.7 ± 3.4 mm on the lateral margin [42] (Fig. 2.7).

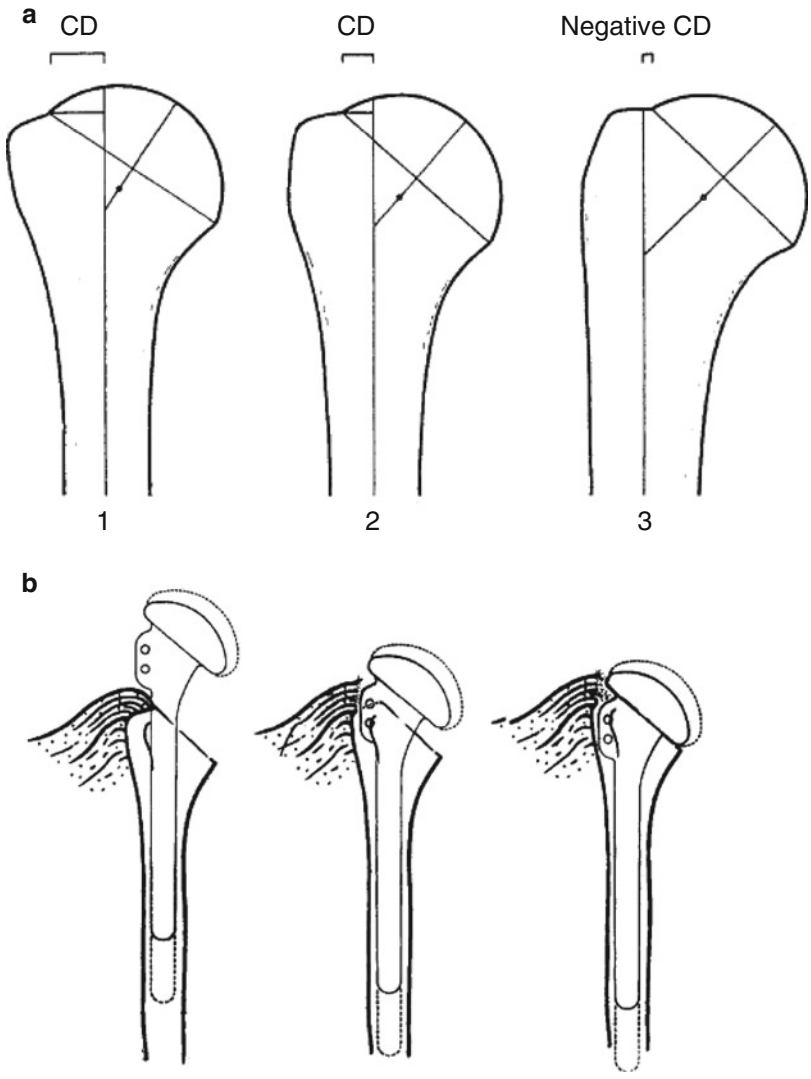


Fig. 2.5 Proximal humerus morphology – metaphyseal. (**a**) *1* High offset, *2* standard offset, and *3* low offset. With decreasing critical distance (CD), the introduction of a straight-stemmed prosthesis becomes increasingly difficult. (**b**) The introduction of a straight-stemmed canal fitting implant may damage the supraspinatus tendon insertion in a humerus with a low-offset metaphyseal morphology (Reproduced with permission from Hertel et al. [8])

Biomechanics

The complex biomechanics of the shoulder girdle encompasses the motion of three bones, four joints, and sixteen muscles. The glenohumeral joint has the greatest range of motion of any diarthrodial joint in the body, and as a result, perhaps more so than any other joint, there is a delicate balance between mobility and stability. A thorough understanding of the biomechanics of the shoulder girdle complex in both the native shoulder and the prosthetic shoulder is essential for achieving a well-functioning, mobile, and stable anatomic shoulder arthroplasty. For the surgeon aiming to restore joint motion, it is imperative to understand the key movements of the shoulder joint (i.e., kinematics) and the forces and moments behind these motions (i.e., kinetics).

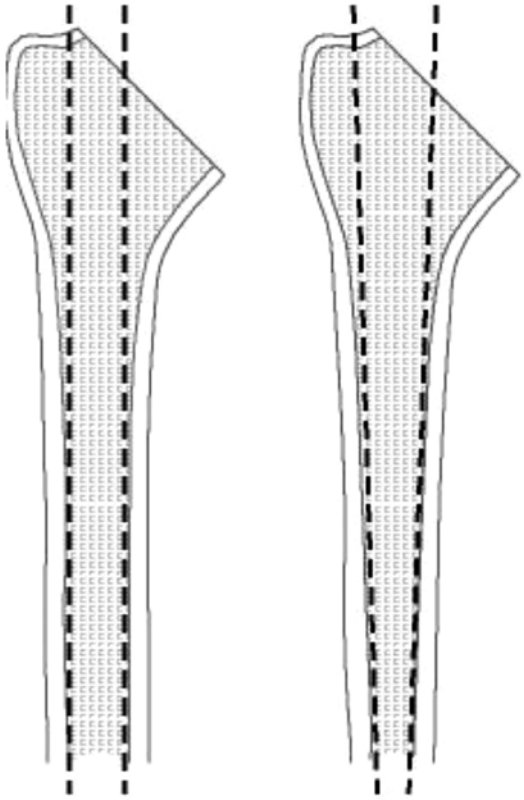


Fig. 2.6 Proximal humerus morphology – shaft. There is a wide variety among the shape of humeral medullary canals. Some are more cylindrical (*left*) and some are more funnel shaped (*right*) (Reproduced with permission from Matsen and Lippitt [61])

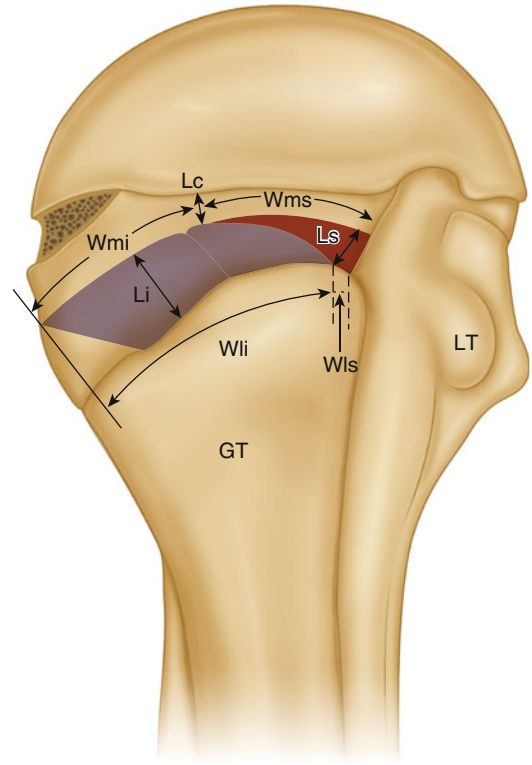


Fig. 2.7 Rotator cuff footprint. *GT* greater tuberosity, *LT* lesser tuberosity, *Wli* width of the lateral margin of the footprint of the infraspinatus, *Wls* width of the lateral margin of the footprint of the supraspinatus, *Wmi* width of the medial margin of the infraspinatus, *Wms* width of the medial margin of the supraspinatus, *Lc* length of the attachment of the articular capsule at the posterior edge of the footprint of the supraspinatus, *Li* maximum length of the footprint of the infraspinatus, and *Ls* maximum length of the footprint of the supraspinatus (Reproduced with permission from Mochizuki et al. [42]

Glenohumeral Stability

Glenohumeral joint stability is provided by an intricate system of static and dynamic restraints. Static stability is provided by (1) the bony congruity of the articular surfaces, (2) the restraining function of ligaments and capsulolabral tissues, as well as (3) negative intra-articular pressure. There is a mismatch between the radius of curvature of the humeral head and the corresponding curvature of the glenoid and the glenoid labrum helps to increase congruency of these two surfaces [43]. However, given the small surface area of the glenoid in relation to the humeral head, only 20–30 % of its articular surface is in contact with the glenoid at any given time [59]. Dynamic stability is provided muscles, particularly those of the rotator cuff. The relative contribution of these two types of stabilizers varies with joint position and loading conditions, with the static stabilizers typically playing a greater role at end range of motion, while the dynamic stabilizers play a greater role in mid-range, when static soft tissue restraints are slack.

Glenohumeral Mobility

Shoulder motion is a combination of movement in four joints: glenohumeral, scapulothoracic, acromioclavicular, and sternoclavicular. In terms of magnitude, the glenohumeral and scapulothoracic joints make the greatest contributions. The relative contribution of these two joints is referred

to as the scapulohumeral rhythm. In a native shoulder, the relative contribution of the glenohumeral vs. the scapulothoracic joint to shoulder motion for elevation in the plane of the scapula, is described as a 2:1 ratio. This ratio represents an average over the entire arc of motion. Poppen and Walker reported a 4:1 glenohumeral-to-scapulothoracic motion ratio during the first 25° of arm elevation with an almost equal 5:4 rotation ratio occurring during subsequent elevation [44].

Motion at the glenohumeral joint is a complex function of both rotations and translations. Rotation is the predominant motion, generally of a larger magnitude. In contrast, translations at the glenohumeral joint are much smaller in magnitude. Translations occur in both the superior-inferior direction and the anterior-posterior direction [60] (ref).

A Balance of Mobility and Stability

Translation and rotation can also be used to assess joint stability in the glenohumeral joint. *Translational laxity* is described as the distance the humeral head can be translated in a specific direction from its centered position in the glenoid [61]. In a normal shoulder, the translational laxity is generally greater than 1 cm in all directions when the joint is in a position within the midrange of motion. *Rotational laxity* of the glenohumeral joint is the angle through which the humeral head can be rotated in a specific direction from its centered position within the glenoid [61] (ref). Finally, *obligate translation* occurs at terminal rotation when capsuloligamentous structures become taut, and further rotation produces increased compressive load at the joint as well as a displacing force [61] (ref). Therefore, this obligate translation occurs when the displacing force overcomes the intrinsic stability of the joint.

In addition to mobility, the forces produced by muscles of the shoulder girdle play an important role in joint stability. The rotator cuff muscles in particular, by virtue of their location and insertion points, are ideally suited to the role of compressors of the humeral head [62]. Perhaps most importantly, glenohumeral joint stability is also influenced by the integrity of the *transverse force couple*. This force couple is formed anteriorly by subscapularis and posteriorly by the infraspinatus [45]. According to this theory, the glenohumeral joint is able to maintain normal joint mechanics when this force couple is intact (Fig. 2.8). Therefore, even with a full-thickness tear of supraspinatus, the infraspinatus-subscapularis force couple can still maintain adequate compression to suppress superior migration of the humeral head. In a cadaver study, Mura et al. [46] showed that isolated transection of the supraspinatus did not lead to superior migration of the humeral head, but extension of the "tear" into infraspinatus did cause superior migration.

Muscle Function

There are many muscles that contribute to the complex motion of the shoulder. However, the primary muscles of concern for shoulder arthroplasty are the rotator cuff and deltoid.

The Rotator Cuff

The rotator cuff muscles are important stabilizers of the glenohumeral joint in multiple shoulder positions [47]. During shoulder motion, these muscles work in concert to elevate and rotate the arm, compress and center the humeral head within the glenoid fossa, and resist humeral head superior translation due to deltoid activity

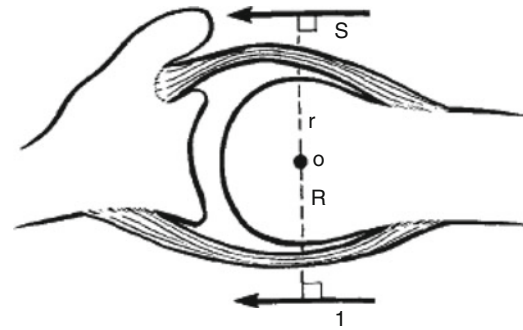


Fig. 2.8 Transverse force couple. The infraspinatus must be intact to adequately oppose the moment created by the subscapularis (Reproduced with permission from Burkhart [45])

[48]. This latter function is important in early humeral elevation when the resultant force vector from the deltoid is directed in a primarily superior direction.

Supraspinatus: The supraspinatus acts to compress and abduct and may provide a small external rotation (ER) torque to the GH joint. Due to a decreasing moment arm with abduction, the supraspinatus is more effective during elevation in the scapular plane at smaller abduction angles, but it still generates abductor torque throughout its arc of motion.

Infraspinatus and teres minor: The infraspinatus and teres minor muscles provide glenohumeral compression, external rotation, and abduction. They also resist superior and anterior humeral head translation by exerting a posteroinferior force to the humeral head [47]. With the arm in abduction, external rotation by these muscles facilitates the greater tuberosity clearing the coracoacromial arch during overhead movements, thereby minimizing subacromial impingement. The ability for infraspinatus to generate external rotation torque is dependent upon the position of the arm, being most effective at lower abduction angles [49]. In contrast, teres minor generates a relatively constant external rotation torque throughout arm abduction movement.

Subscapularis: The subscapularis acts to produce glenohumeral compression, internal rotation (IR), and abduction. Similar to infraspinatus, its muscle bellies generate their peak torque with the arm at 0° of abduction.

Deltoid

The deltoid is the most important muscle providing movement of the shoulder joint, primarily abduction but also contributing to rotation. At low abduction angles (less than 40°), the abduction moment arms generated by the deltoid are less than those produced by supraspinatus, infraspinatus, and subscapularis [50]. The moment arm produced by the anterior muscle belly varies with humeral rotation, increasing with external rotation and decreasing with internal rotation. This effect is much less pronounced in the middle and posterior heads of the deltoid with the magnitude of change being less likely to be clinically relevant.

Joint Reaction Forces

As mentioned in the previous section, the muscles of the shoulder girdle produce joint compressive forces as well as displacement (i.e., translation). Depending on the particular loading conditions, these forces and moments can cause shear stresses at the articular surface. Although not a weight-bearing joint, significant joint forces are still generated across the shoulder joint [61]. However, the joint reaction forces generated depend upon the arm position and the magnitude of force produced by the muscles. Poppen and Walker reported loads in the range of 0.9–1.4× BW for abduction [44]. Runciman noted forces of 4–7× BW for activities such as push-ups, chin-ups, and press-ups [51]. In vivo studies with instrumented shoulder prostheses have estimated that in the setting of patients undergoing post-op rehabilitation, joint reaction forces can be as high as 2.4× BW [52].

Implant Selection/Implantation

Anatomic shoulder arthroplasty aims to alleviate pain and restore function primarily by recreating the native glenohumeral joint anatomy. Implant design has evolved with the aim of achieving a durable reconstruction that improves pain and mobility. Innovation has led to modular implants with an impressive array of implant choices for the surgeon to choose from. With modular implants the surgeon can adjust for a variety of variables that enable anatomic recreation. Understanding the mechanical role of each implant variable will guide the surgeon toward the best implant choice for each patient. Finally, innovation in implant design necessitates constant evaluation of new designs as well as the introduction of novel means of assessment. Evaluating the biomechanics of the prosthetic shoulder joint may lead to ongoing refinement of implant design aimed at enhancing function and longevity.

For proper restoration of shoulder function, it is essential that the reconstruction restores the patient's bony anatomy and that the soft tissue (primarily muscle) forces are appropriately

balanced. Bony reconstruction refers to patient-specific bony anatomic recreation. This is facilitated by a detailed knowledge of anatomy and biomechanics and the availability of modern adaptable implants. Soft tissue balancing refers to appropriate balancing of capsuloligamentous and musculotendinous structures to enable a proper combination of both stability and mobility. This usually is considered after an accurate bony reconstruction has occurred. Most commonly, this involves the release of tight tissues from the anterior aspect of the shoulder joint. Less commonly, this involves tightening of redundant tissues in the posterior aspect of the shoulder joint. Even less commonly, adjusting the bony reconstruction may be necessary. This could include up- or downsizing the humeral head and/or shifting its center of rotation. After appropriate bony and soft tissue reconstruction, the arm should attain 40° of external rotation at the side, 50 % translation of the humeral head on the glenoid width with a posterior directed force, and 60° of internal rotation with the arm in abduction. This is often referred to as the 40-50-60 rule [61].

Humeral Head Size and Shape

Inaccurate anatomic recreation of the size of the humeral head may cause biomechanical consequences through malpositioning of the joint line or displacing the center of rotation. Fischer has shown that displacing the center of rotation by 20 % of its radius (5 mm for an average radius of curvature of 25 mm) changes the lever arm of the rotator cuff by 20 %. In a cadaveric biomechanical study, Vaesel et al. investigated the influence of head size on shoulder kinematics [53]. They observed that a large head size was associated with decreased mobility (abduction and external rotation) and superior translation, and a small head size translated inferiorly. The observed reduction in mobility secondary to oversizing the head is often referred to as "overstuffing" and may also lead to an increased risk of secondary rotator cuff tears, due to increased tension on the tendons. In a similar fashion, increasing humeral head height can also limit motion. Harryman et al. [54] reported that increasing humeral head thickness by 5 mm reduced range of motion and caused earlier translation of the humeral head on the prosthetic glenoid, while Pearl and Volk observed that increasing head height also altered the position of the center of rotation and the articular surface arc [14].

As mentioned earlier, the humeral head is not spherical in shape. Recent biomechanical studies [55] have demonstrated that custom, nonspherical humeral heads more accurately replicate head shape, rotational range of motion, and glenohumeral joint kinematics than a spherical prosthetic head when compared with the native humeral head. However, a recent retrospective clinical study was not able to detect a significant difference in clinical outcomes, radiographic performance, or survivorship when attempts were made to match patient geometry [56].

Humeral Head Offset

A small variation in the humeral head offset can cause a large change in the glenohumeral kinematics [5, 8, 12, 15–17]. Boileau and Walch reported that there was significant variation in proximal humeral anatomy and, in particular, that variations in inclination, retroversion, medial offset, and posterior offset were not well accommodated by available implants at that time [5]. Most contemporary implant systems now come with centered and eccentric heads, of variable thickness to allow the surgeon to dial in the appropriate amount of offset (Fig. 2.9).

Humeral Head Retroversion

Intraoperatively, assessing the epicondylar axis is often difficult, so generally either the forearm axis or the bicipital groove is used as a landmark for humeral head retroversion. If using the forearm axis as a reference, the surgeon must consider the 10–15° carrying angle at the elbow. Implantation of the proximal humeral prosthesis in 30–40° of retroversion based on the forearm

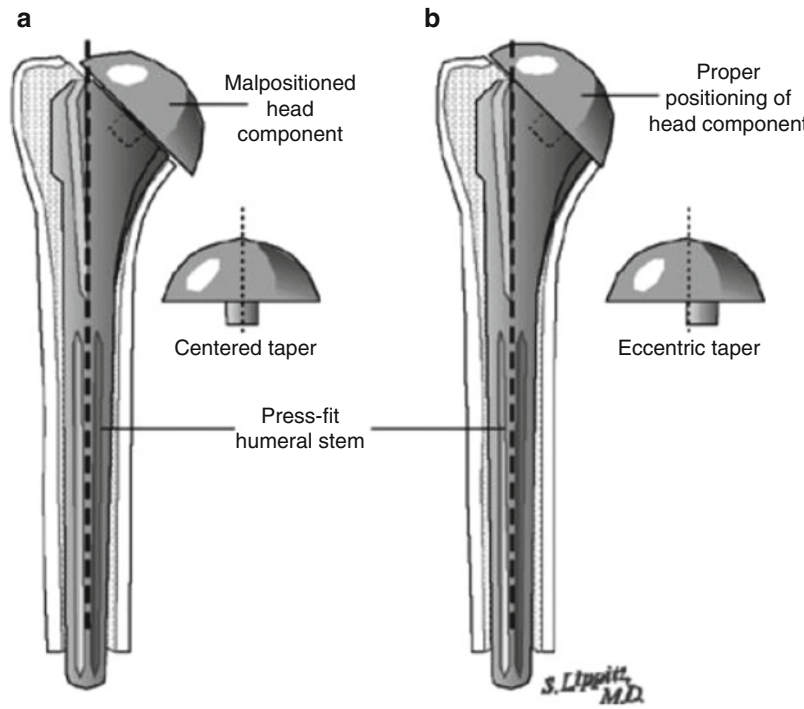


Fig. 2.9 Humeral head offset. (**a**) The mismatch in the humeral head offset with a press fit stem and centered head taper results in malpositioning of the humeral head component inferiorly. (**b**) In this case, an eccentric taper humeral head orients the humeral head superiorly and provides proper humeral head positioning (Reproduced with permission from Iannotti et al. [17])

axis results in a true anatomical version of 20° with respect to the epicondylar axis [10, 57]. Surgeon preference guides the extent to which the patient's natural version is reproduced. Retroversion can be achieved by the use of modular implants that allow this to be "dialed in" to the implant vs. strategic implantation of the stem in the appropriate amount of retroversion.

Humeral Head Inclination

It is important to note that alterations in neck-shaft angle may alter the tension on the rotator cuff and deltoid tendons potentially leading to rotator cuff and/or deltoid dysfunction. Therefore, the surgeon must ensure the implant aligns appropriately with the humeral head resection to achieve optimal soft tissue tension and the largest articular surface arc [16, 35, 58]. Recognizing that variability in humeral head inclination exists, the surgeon may approach recreating this angle in one of two ways: (1) utilize an adaptable implant with a variable neck-shaft angle or; (2) if using an implant with a fixed neck-shaft angle, plan the osteotomy and insertion depth to achieve an appropriate articular surface arc for the humerus (Fig. 2.10). Essentially, these two options can be summarized as adapting the prosthesis to the patient's anatomy or adapting the patient's anatomy to the prosthesis.

Proximal Humerus Morphology

In addition to the variability in the morphology of the humeral head, consideration must also be given to the variability in proximal humerus morphology. Hertel described three distinct metaphyseal morphotypes, described as standard, high offset, and low offset [8] (Fig. 2.5). The use of an adaptable implant is often essential in these situations to enable an anatomic recreation and avoid damage to the rotator cuff insertion. For example, the authors noted that insertion of a straight-stemmed prosthesis in a low-offset humerus risks damage to the insertion of the supraspinatus tendon. With respect to shaft morphology, assessment of shaft size and shape is essential when reaming the canal. Over-reaming a narrow shaft or cylindrical reaming of a funnel shaped canal can both create a stress riser at the tip of the prosthesis (ref) [61]. When inserting the definitive implant, the surgeon should be mindful of the position of

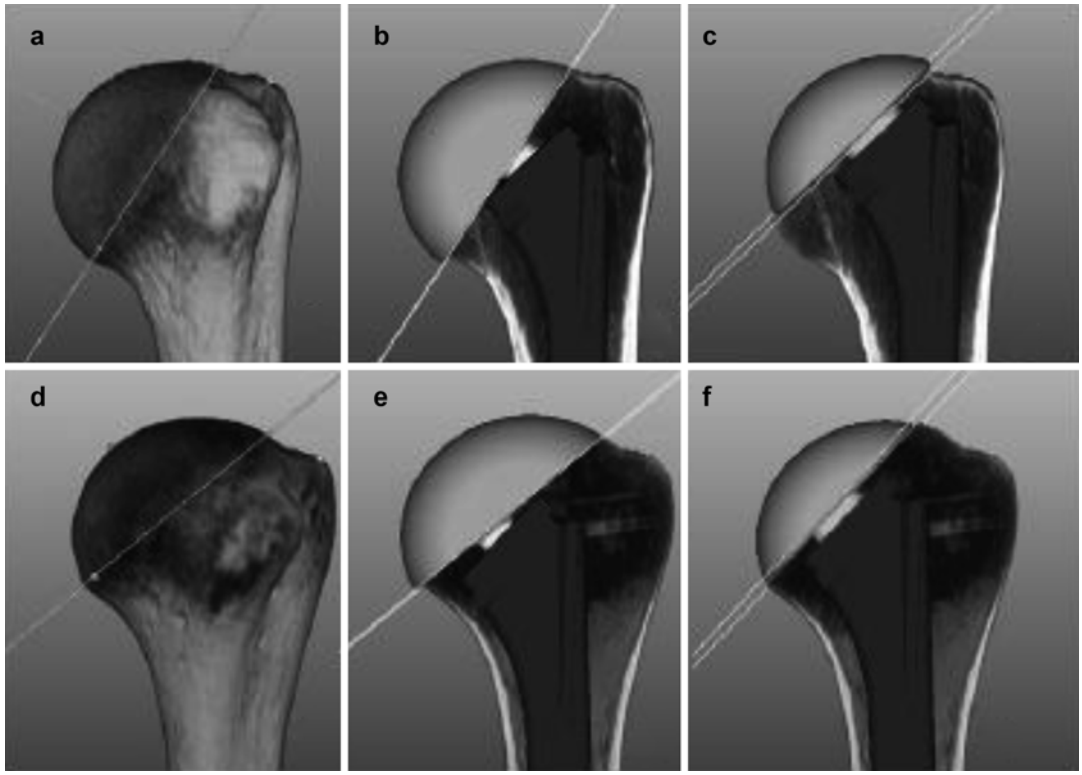


Fig. 2.10 Humeral head inclination. A humerus with a varus neck-shaft angle (**a**) can be treated with an adjustable-angle implant and a humeral osteotomy at the anatomic neck (**b**) or a fixed-angle implant and a 135° osteotomy with a modified cut started from the superolateral point of the neck plane (**c**). A humerus with a valgus neck-shaft angle (**d**) can be treated with an adjustable-angle implant and a humeral osteotomy at the anatomic neck (**e**) or a fixed-angle implant and a 135° osteotomy with a modified cut started from the inferomedial point of the neck plane (**f**). Recognizing that variability in humeral head inclination exists, the surgeon may approach recreating this angle in one of two ways: (1) utilize an adaptable implant with a variable neck-shaft angle or; (2) if using an implant with a fixed neck-shaft angle, plan the osteotomy and insertion depth to achieve an appropriate articular surface arc for the humerus (Reproduced with permission from Jeong et al. [25])

the stem within the canal. This relationship is more constrained in uncemented stems, but both types of stems may be mal-inserted which effectively changes the position of the head and the associated soft tissue balance. However, in certain circumstances, intentionally inserting the stem off axis may be used to correct deformity when using an implant with less modularity.

Proximal Humeral Bone Quality

Knowledge about the bone quality of the proximal humerus may serve as a tool to guide surgeons in the selection of an appropriate humeral stem size to achieve a press fit in a patient with poor bone quality and/or the need for either impaction grafting techniques or cement fixation to achieve a stable prosthesis [38]. The use of a stemless implant may not be preferable in patients with osteoporotic bone, many of whom are elderly women [37]. Furthermore, surgeons must be aware that decreased bone quality can result in a higher incidence of surgical complications, particularly intraoperative periprosthetic fracture and/or postoperative implant subsidence or loosing.

The Rotator Cuff

The rotator cuff integrity and function has a large impact on both implant selection and postoperative outcomes for proximal humeral arthroplasty. Adequate knowledge of the rotator cuff anatomy

and function and its effect on shoulder biomechanics will aid in pre- and intraoperative evaluation of the rotator cuff integrity and function. The decision to perform either an anatomic or a reverse TSA is often based on preoperative physical exam findings, imaging findings (e.g., degree of fatty atrophy in rotator cuff muscles), and functional demands, as well as intraoperative examination of the rotator cuff. If the rotator cuff is absent or nonfunctional or, in some situations, if the tendons seem thin, or the surgeon is concerned about their long-term integrity, a reverse shoulder arthroplasty may be preferred. Newer modular anatomic humeral implants that permit revision to reverse shoulder arthroplasty provide another option to the surgeon in this scenario. Ultimately, it is the surgeon's understanding of the rotator cuff anatomy and function that will facilitate correct implant selection and positioning, allowing optimization of function and longevity.

Summary

Anatomy

- The bony anatomy of the proximal humerus demonstrates considerable variability.
- Detailed studies have been conducted to characterize this variation including head size, radius of curvature, humeral head offset, humeral head inclination, retroversion, proximal humeral shaft morphology, and proximal humerus bone quality.
- Most modern implants, now have the capability to, at least in part, address this variability.
- Careful preoperative assessment of these anatomical variables, as well as appropriate intra-op trialing, will allow the surgeon to optimize bony and soft tissue balancing of the prosthesis.

Biomechanics

- The biomechanics of the shoulder girdle are a balance between mobility and stability.
- Static and dynamic constraints contribute to joint stability, and understanding their respective roles in the normal and diseased shoulder will help the surgeon achieve an anatomic reconstruction.
- Research studies have demonstrated that the native and prosthetic joint can see loads that surpass body weight: hence, the reconstruction must be optimized to withstand these loads.
- There is now a wide array of implant types, each with numerous options to allow the surgeon to "customize" an implant to the patient's geometry.

References

1. Bankes MJ, Emery RJ. Pioneers of shoulder replacement: Themistocles Gluck and Jules Emile Pean. J Shoulder Elbow Surg. 1995;4(4):259–62.
2. Ballmer FT, et al. Humeral head prosthetic arthroplasty: surgically relevant geometric considerations. J Shoulder Elbow Surg. 1993;2(6):296–304.
3. Neer 2nd CS, Watson KC, Stanton FJ. Recent experience in total shoulder replacement. J Bone Joint Surg Am. 1982;64(3):319–37.
4. Figgie 3rd HE, et al. An analysis of factors affecting the long-term results of total shoulder arthroplasty in inflammatory arthritis. J Arthroplasty. 1988;3(2):123–30.
5. Boileau P, Walch G. The three-dimensional geometry of the proximal humerus. Implications for surgical technique and prosthetic design. J Bone Joint Surg Br. 1997;79(5):857–65.
6. Walch G, Boileau P. Prosthetic adaptability: a new concept for shoulder arthroplasty. J Shoulder Elbow Surg. 1999;8(5):443–51.
7. Iannotti JP, et al. The normal glenohumeral relationships. An anatomical study of one hundred and forty shoulders. J Bone Joint Surg Am. 1992;74(4):491–500.
8. Hertel R, Knothe U, Ballmer FT. Geometry of the proximal humerus and implications for prosthetic design. J Shoulder Elbow Surg. 2002;11(4):331–8.
9. Pearl ML. Proximal humeral anatomy in shoulder arthroplasty: implications for prosthetic design and surgical technique. J Shoulder Elbow Surg. 2005;14(1 Suppl S):99S–104.
10. Roberts SN, et al. The geometry of the humeral head and the design of prostheses. J Bone Joint Surg Br. 1991;73(4):647–50.
11. Soslowsky LJ, et al. Articular geometry of the glenohumeral joint. Clin Orthop Relat Res. 1992;285:181–90.
12. Robertson DD, et al. Three-dimensional analysis of the proximal part of the humerus: relevance to arthroplasty. J Bone Joint Surg Am. 2000;82-A(11):1594–602.

13. Wataru S, et al. Three-dimensional morphological analysis of humeral heads: a study in cadavers. Acta Orthop. 2005;76(3):392–6.
14. Pearl ML, Volk AG. Coronal plane geometry of the proximal humerus relevant to prosthetic arthroplasty. J Shoulder Elbow Surg. 1996;5(4):320–6.
15. Roche C, et al. Anatomic validation of an "anatomic" shoulder system. Bull Hosp Joint Dis. 2006;63 (3–4):93–7.
16. Iannotti JP, et al. Prosthetic positioning in total shoulder arthroplasty. J Shoulder Elbow Surg. 2005;14(1 Suppl S):111S–21.
17. Iannotti JP, Lippitt SB, Williams Jr GR. Variation in neck-shaft angle: influence in prosthetic design. Am J Orthop (Belle Mead NJ). 2007;36(12 Suppl 1): 9–14.
18. Hernigou P, Duparc F, Hernigou A. Determining humeral retroversion with computed tomography. J Bone Joint Surg Am. 2002;84-A(10):1753–62.
19. Hromadka R, et al. Lesser tuberosity is more reliable than bicipital groove when determining orientation of humeral head in primary shoulder arthroplasty. Surg Radiol Anat. 2010;32(1):31–7.
20. Harrold F, Wigderowitz C. A three-dimensional analysis of humeral head retroversion. J Shoulder Elbow Surg. 2012;21(5):612–7.
21. Doyle AJ, Burks RT. Comparison of humeral head retroversion with the humeral axis/biceps groove relationship: a study in live subjects and cadavers. J Shoulder Elbow Surg. 1998;7(5):453–7.
22. Boileau P, et al. CT scan method accurately assesses humeral head retroversion. Clin Orthop Relat Res. 2008;466(3):661–9.
23. Edelson G. Variations in the retroversion of the humeral head. J Shoulder Elbow Surg. 1999;8(2): 142–5.
24. DeLude JA, et al. An anthropometric study of the bilateral anatomy of the humerus. J Shoulder Elbow Surg. 2007;16(4):477–83.
25. Jeong J, Bryan J, Iannotti JP. Effect of a variable prosthetic neck-shaft angle and the surgical technique on replication of normal humeral anatomy. J Bone Joint Surg Am. 2009;91(8):1932–41.
26. Antoniades L, et al. A cotwin control study of the relationship between hip osteoarthritis and bone mineral density. Arthritis Rheum. 2000;43(7):1450–5.
27. Cooper C, et al. Osteoarthritis of the hip and osteoporosis of the proximal femur. Ann Rheum Dis. 1991;50(8):540–2.
28. Healey JH, Vigorita VJ, Lane JM. The coexistence and characteristics of osteoarthritis and osteoporosis. J Bone Joint Surg Am. 1985;67(4):586–92.
29. Stewart A, et al. Bone density and bone turnover in patients with osteoarthritis and osteoporosis. J Rheumatol. 1999;26(3):622–6.
30. Broussard DL, Magnus JH. Risk assessment and screening for low bone mineral density in a multiethnic population of women and men: does one approach fit all? Osteoporos Int. 2004;15(5): 349–60.
31. David C, et al. Severity of osteoporosis: what is the impact of co-morbidities? Joint Bone Spine. 2010;77 Suppl 2:S103–6.
32. Papaioannou A, et al. Risk factors for low BMD in healthy men age 50 years or older: a systematic review. Osteoporos Int. 2009;20(4):507–18.
33. Waugh EJ, et al. Risk factors for low bone mass in healthy 40-60 year old women: a systematic review of the literature. Osteoporos Int. 2009;20(1):1–21.
34. Mather J, et al. Proximal humerus cortical bone thickness correlates with bone mineral density and can clinically rule out osteoporosis. J Shoulder Elbow Surg. 2013;22(6):732–8.
35. Tingart MJ, et al. The cortical thickness of the proximal humeral diaphysis predicts bone mineral density of the proximal humerus. J Bone Joint Surg Br. 2003;85(4):611–7.
36. Pervaiz K, et al. Osteoporosis and shoulder osteoarthritis: incidence, risk factors, and surgical implications. J Shoulder Elbow Surg. 2013;22(3):e1–8.
37. Barvencik F, et al. Age- and sex-related changes of humeral head microarchitecture: histomorphometric analysis of 60 human specimens. J Orthop Res. 2010;28(1):18–26.
38. Curtis AS, et al. The insertional footprint of the rotator cuff: an anatomic study. Arthroscopy. 2006;22(6): 609 e1.
39. Dugas JR, et al. Anatomy and dimensions of rotator cuff insertions. J Shoulder Elbow Surg. 2002;11(5): 498–503.
40. Ruotolo C, Fow JE, Nottage WM. The supraspinatus footprint: an anatomic study of the supraspinatus insertion. Arthroscopy. 2004;20(3):246–9.
41. Minagawa H, et al. Humeral attachment of the supraspinatus and infraspinatus tendons: an anatomic study. Arthroscopy. 1998;14(3):302–6.
42. Mochizuki T, et al. Humeral insertion of the supraspinatus and infraspinatus. New anatomical findings regarding the footprint of the rotator cuff. J Bone Joint Surg Am. 2008;90(5):962–9.
43. McPherson EJ, et al. Anthropometric study of normal glenohumeral relationships. J Shoulder Elbow Surg. 1997;6(2):105–12.
44. Poppen NK, Walker PS. Normal and abnormal motion of the shoulder. J Bone Joint Surg Am. 1976;58(2):195–201.
45. Burkhart SS. Arthroscopic treatment of massive rotator cuff tears. Clin Orthop Relat Res. 2001;390: 107–18.
46. Mura N, et al. The effect of infraspinatus disruption on glenohumeral torque and superior migration of the humeral head: a biomechanical study. J Shoulder Elbow Surg. 2003;12(2):179–84.
47. Sharkey NA, Marder RA. The rotator cuff opposes superior translation of the humeral head. Am J Sports Med. 1995;23(3):270–5.
48. Lee SB, et al. Dynamic glenohumeral stability provided by the rotator cuff muscles in the mid-range and end-range of motion. A study in cadavera. J Bone Joint Surg Am. 2000;82(6):849–57.

49. Ackland DC, et al. Moment arms of the muscles crossing the anatomical shoulder. J Anat. 2008;213(4): 383–90.
50. Liu J, et al. Roles of deltoid and rotator cuff muscles in shoulder elevation. Clin Biomech (Bristol, Avon). 1997;12(1):32–8.
51. Anglin C, Wyss UP, Pichora DR. Glenohumeral contact forces. Proc Inst Mech Eng H. 2000;214(6): 637–44.
52. Bergmann G, et al. In vivo gleno-humeral joint loads during forward flexion and abduction. J Biomech. 2011;44(8):1543–52.
53. Vaesel MT, et al. Humeral head size in shoulder arthroplasty: a kinematic study. J Shoulder Elbow Surg. 1997;6(6):549–55.
54. Harryman DT, et al. The effect of articular conformity and the size of the humeral head component on laxity and motion after glenohumeral arthroplasty. A study in cadavera. J Bone Joint Surg Am. 1995;77(4): 555–63.
55. Jun BJ, et al. The effects of prosthetic humeral head shape on glenohumeral joint kinematics: a comparison of non-spherical and spherical prosthetic heads to the native humeral head. J Shoulder Elbow Surg. 2013;22(10):1423–32.
56. Sassoon A, et al. The role of eccentric and offset humeral head variations in total shoulder arthroplasty. J Shoulder Elbow Surg. 2013;22(7):886–93.
57. Pearl ML, Volk AG. Retroversion of the proximal humerus in relationship to prosthetic replacement arthroplasty. J Shoulder Elbow Surg. 1995;4 (4):286–9.
58. Takase K, et al. The radiographic study in the relationship of the glenohumeral joint. J Orthop Res. 2004;22(2):298–305.
59. Peltz C, Moutzouros V, Bey M. Joint mechanics of the shoulder. In: Winkelstein B, editor. Orthopaedic Biomechanics. CRC Press, Boca Raton, Florida; 2012. p. 203–32.
60. Massimini, et al. In-vivo glenohumeral translation and ligament elongation during abduction and abduction with internal and external rotation. J Orthop Surg Res. 2012;7:29.
61. Matsen FA, Lippitt SB. In: Matsen FA, Lippitt SB, editors. Shoulder surgery: principles and procedures. Philadelphia: Saunders; 2003.
62. Kempf JF, Lacaze F, Nerisson D, Bonnomet F. Biomechanics of the shoulder. In: Walch G, Boileau P, editors. Shoulder arthroplasty. Springer Science & Business Media, Heidelberg, Germany; 1999. p. 13–22.

Stemmed Humeral Replacement

3

Peter N. Chalmers and Jay D. Keener

Introduction

Although the first stemmed humeral replacement, constructed out of platinum and rubber and performed for an indication of tuberculosis, was performed by Péan in 1893, the procedure did not begin to be widely performed until Neer described his results in 1955 [1, 2]. Recently, both humeral hemiarthroplasty and total shoulder arthroplasty have increased remarkably in frequency. Between 1993 and 2008, the number of humeral components placed in the United States increased from 13,837 to 46,951 per year [3]. Given the frequency of placement of a humeral component, a thorough understanding of the surgical indications and goals, design features, techniques, and outcomes associated with the humeral component is critical not only for a shoulder surgeon but also for the general orthopedic surgeon.

Goals of Humeral Component Design

There are four primary goals in humeral component design. The first is to replicate, as faithfully as possible, pre-injury/pre-deformity anatomy. Numerous biomechanical studies have demonstrated that this provides the highest likelihood for restoration of native kinematics and that differences as small as 4 mm can have marked biomechanical consequences [4–6]. The anatomy and biomechanics of the proximal humerus is covered in detail in Chap. 2. The second is to achieve initial implant stability [7, 8], which allows immediate range of motion, prevents implant subsidence that could lead to malalignment, and is a prerequisite for biologic ingrowth and implant incorporation in cementless designs [9]. The third goal is to achieve long-term implant fixation, thus avoiding aseptic loosening and the consequences of humeral revision [10–13]. These goals are ideally attained while avoiding proximal humeral bone loss via osteolysis and [14, 15] stress shielding [14–16] as these can complicate revision options and potentially lead to periprosthetic fracture [17–19]. The fourth goal relates to ease of extraction in cases of unanticipated need for revision such as infection or loss of rotator cuff function. Ideally, the humeral stem can be extracted with minimal loss of metaphyseal bone to maximize revision options. This final goal highlights the importance of achieving a balance between long-term fixation and ease of potential extraction. A variety of design- and technique-driven strategies are employed to achieve these goals.

P.N. Chalmers, MD • J.D. Keener, MD (✉)
Department of Orthopedic Surgery,
Washington University School of Medicine,
660 South Euclid Ave, Campus Box 8233,
St. Louis, MO 63110, USA
e-mail: p.n.chalmers@gmail.com;
keenerj@wudosis.wustl.edu

© Springer International Publishing Switzerland 2016
A.D. Armstrong, A.M. Murthi (eds.), *Anatomic Shoulder Arthroplasty*,
DOI 10.1007/978-3-319-29164-2_3

Humeral Stem Design Evolution

Most strategies implemented to restore humeral anatomy have focused on implant design. Neer's initial humeral component design of a straight stem with fins was based upon his measurements of 50 cadaveric humeri [5]. However, subsequent detailed radiographic and anatomic research has demonstrated that humeral head inclination varies widely [6, 20–22]. Newer designs have thus introduced modularity, primarily at the head/body junction, to increase the options available to the surgeon [4]. Another advance is the introduction of variable head-shaft angles (Fig. 3.1) [20, 21, 23–25]. Components are also available to offer similar variability in version to match the wide variability in proximal humeral version [19, 26–29]. However, it should be recognized that humeral version is primarily determined by surgical technique rather than component design. The center of rotation of the humeral head is offset posteriorly, medially, and superiorly in relation to the humeral shaft and varies from patient to patient. Thus, most modern designs provide a humeral head with an eccentrically placed receptacle for the Morse taper [6, 20, 21, 24, 30], and modern designs also provide variability in humeral head thickness to accommodate individual anatomy [20, 21]. Many early systems were designed without variable inclination, which tends to lead to displacement of the center of rotation superiorly and laterally, resulting in a relative "overstuffing" of the joint [20, 31, 32]. This issue was worsened by the early introduction of modularity combined with overly thick humeral heads, as many designs did not account for the thickness of the collar and the gap between the humeral head

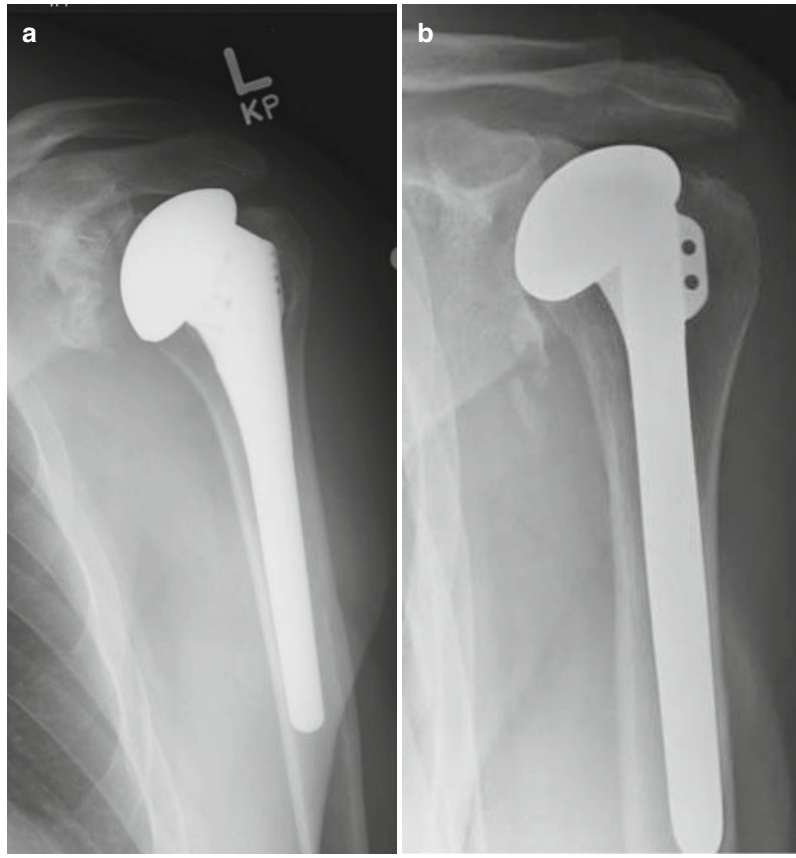


Fig. 3.1 These anteroposterior radiographs demonstrate two components, (**a**) one with variable offset and inclination and (**b**) one with fixed offset and inclination. As can be seen, the implant with fixed inclination has been placed in varus to attempt to replicate anatomic inclination

and collar [6, 21]. Subsequent biomechanical studies have demonstrated that "overstuffing" decreases range of motion and translation [31, 32] and thus may place more stress through the glenoid component and may lead to increased rates of glenoid loosening [33, 34]. Subsequent designs have accounted for these findings [6]. Finally, degenerative conditions of the glenohumeral joint are associated with contracture and imbalance of the capsule, musculature, and other periarticular tissues. Perfect recreation of pre-deformity anatomy acts only as a supplement to soft tissue balancing. Indeed, in the setting of significant deformity, soft tissue balancing may become even more important to reduce stress placed on the implant, recenter the humeral head, and maximize range of motion [4].

Recently, "platform" stems have been released that provide modularity at both the diaphyseal/metaphyseal junction and the head/body junction, achieving fixation within the diaphyseal region. This potentially allows for revision from a hemiarthroplasty or anatomic total shoulder to a reverse total shoulder arthroplasty without revision of the fixated portion of the humeral component [13]. While these advances offer the surgeon the ability to best replicate the patient's anatomy, each additional modular junction also serves as an additional potential location for component dissociation and component fracture [4]. Increased modularity also serves as a potential location for fretting wear and metallosis, as has been experienced in total hip arthroplasty [35]. Furthermore, the desired version and depth of stem seating may vary between anatomic and reverse total shoulder arthroplasty. Therefore, for accurate and optimal humeral prosthetic positioning using platform stems, the additional modularity should enable the surgeon to adapt to the fundamental differences between ideal implant placements in different arthroplasty designs.

Indications for a Stemmed Humeral Replacement

A stemmed implant remains the gold standard. A stemmed humeral component is indicated for anatomic total shoulder arthroplasty performed for glenohumeral osteoarthritis [15, 23, 28, 34, 36–41], avascular necrosis [42, 43], inflammatory arthritis [17, 36, 37, 44, 45], and various traumatic conditions [17, 36, 46–48]. Particular indications for a stemmed over a stemless implant include proximal humeral bone loss preventing adequate stemless fixation, poor vascularity of the proximal humeral bone that might compromise long-term fixation, poor biology of proximal humeral bone such as prior radiation that might compromise long-term fixation, and proximal humeral deformity that would prevent anatomic placement of a stemless implant. Particular scenarios where a stemless or resurfacing-style implant may be relatively indicated are the presence of prior proximal humeral hardware that precludes placement of a stemmed humeral component, such as a humeral nail, hardware extending toward the proximal humerus, or a long-stemmed distal humeral component of a total elbow arthroplasty.

Humeral Fixation Options

Most of the strategies used for initial implant stability have been technique driven. Given that humeral component aseptic loosing is relatively uncommon, it is important to recognize that adequate initial and long-term stability can be achieved with a variety of techniques. In North America, stemmed humeral prostheses remain the gold standard at this point. First method of fixation is to cement the stem, using either a proximal or diaphyseal technique [7, 8, 11, 15, 37, 38, 40, 49–52]. The second is to machine the proximal humerus to be slightly undersized relative to the dimensions of the component, which allows a press fit that provides implant stability via hoop stresses [20, 39]. Within the humerus press-fit fixation may be insufficient – in one retrospective comparative study 49 % of press-fit stems shifted during early follow-up, while no cemented stems shifted [53]. For all modern prostheses, press-fit fixation is combined with osseous ingrowth and on-growth surfaces on the humeral component that provide friction for a "scratch fit" [39, 41, 45, 54–56]. Following Neer's initial designs, many prostheses also

incorporate fins that provide additional initial torsional stability [4, 5]. Finally, many authors have used cancellous bone graft from the humeral head for impaction grafting to improve initial stability and to fill voids that could impede component incorporation [57, 58]. Biomechanical studies have demonstrated that while there is no difference in axial [8] micromotion between cemented and cementless initial fixation, rotational [7] micromotion is decreased in cemented as compared to press-fit stems.

Both implant design- and technique-based strategies have been utilized to maximize long-term humeral fixation. With cementless implants, initial designs led to a 55 % rate of radiographic loosening [52], mirroring the prosthetic design experience in total hip arthroplasty [9]. This problem led to the adoption of biologic on-growth and ingrowth surfaces developed for total hip arthroplasty [9] into humeral component design [45]. Subsequent studies using components of a similar design but with an incorporated ingrowth surface reduced rates of radiographic loosening over fivefold from 55 % to 10 % [55]. These results were achieved despite retrieval studies demonstrating that only 11 % of the ingrowth surface incorporates, with 95 % of the ingrowth occurring at the medial and lateral bone-to-implant interfaces [54].

Another major change in long-term fixation has been a shift in emphasis from diaphyseal to metaphyseal fixation [14, 39], again paralleling the development of taper-wedge stems in total hip arthroplasty [59]. The humeral endosteal diaphysis has an ellipsoid [60], highly variable shape [22] with a proximal to distal torsion [22, 39]. Thus, even with reaming, the diaphyseal portion of the implant has a relatively poor fit and more implant/bone voids in comparison to the metaphyseal region of the component [39]. Comparative studies have demonstrated lower rates of radiographic loosening with metaphyseal compared to diaphyseal fixation for cementless components, which has led to the suggestion that if diaphyseal fixation is required, the component should be cemented [39]. Metaphyseal bone may also be more well vascularized and may thus allow more rapid ingrowth than diaphyseal bone [61].

The use of metaphyseal fixation may also ease humeral stem removal during revision [10–13]. Bone preservation is enhanced as metaphyseal fixation minimizes proximal humeral bone loss from stress shielding [14–16]. Furthermore, access to diaphyseal bone is not needed during revision, which is bone preserving [17]. Metaphyseal fixation may also reduce the incidence and complications associated with periprosthetic fracture while paradoxically increasing the likelihood for intraoperative periprosthetic fractures during implantation [17–19]. A large, diaphyseally fixated stem acts to stress shield the proximal humerus while also acting as a large lever arm and concentrating stress at the tip of the stem [17]. Diaphyseal periprosthetic fractures likely have a lower healing potential than metaphyseal periprosthetic fractures (Fig. 3.2) [61]. Concern for diaphyseal periprosthetic fractures is one reason for the development of stemless implants, which will be covered in more detail in Chap. 5.

The use of cemented versus cementless implants continues to be a source of significant controversy, with each having relative advantages and disadvantages (Table 3.1). Cemented implants can achieve immediate and lasting fixation, overcoming voids, irregularities, and other sources of mismatch between the component and the endosteal surface that could compromise cementless fixation [22, 39]. Cemented components are generally smaller than uncemented stems, which may prevent stress shielding and intraoperative periprosthetic fractures, which can occur with bulkier cementless implants [14]. In cases with significant proximal humeral osseous deficiencies or poor bone quality and ingrowth potential, cement fixation has distinct advantages over cementless techniques [41].

Cemented fixation has several distinct disadvantages. At the time of implantation, cementation is more time-consuming, and it can be technically challenging to achieve good cement technique. Prior cementation substantially complicates subsequent humeral revision [13]. In particular, diaphyseal cementation can make stem removal difficult. In infection cases all prior cement must be removed or it can serve as a reservoir of biofilm-protected bacteria. Attempts at stem or

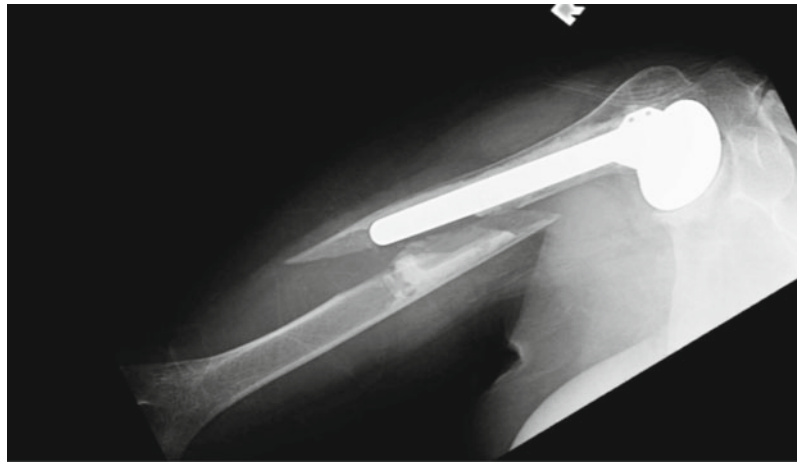


Fig. 3.2 This anteroposterior radiograph of the right humerus demonstrates a diaphyseal humeral periprosthetic fracture around a cemented, diaphyseally fixated component where stress concentrates at the distal aspect of the component

Table 3.1 Advantages and disadvantages of cemented and cementless fixation

Cemented		Cementless	
Advantages	Disadvantages	Advantages	Disadvantages
Strong initial fixation	Time-consuming	Rapid	Stress shielding, radiolucent line formation
Can be used in the presence of prior radiation or osteonecrosis	Technically demanding	May ease revision and facilitates component removal	Relies upon a closer match between the component and the humerus, increasing the likelihood for intraoperative periprosthetic fracture
Antibiotic-laden cement may provide additional sepsis prevention in cases with prior infection	Complicates revision and may predispose toward iatrogenic humeral fracture	No concern for extrusion in cases with humeral perforation	Possibly decreased strength of initial fixation
Supported by randomized clinical trial data	Can extrude through perforations and compromise neurovascular structures	Technically simple	May not incorporate with bone with compromised blood supply or viability

cement removal can frequently lead to iatrogenic humeral fracture or perforation, especially in osteoporotic bone. Indeed, in one series of 80 cases, removal of cemented humeral stems was the most common cause of intraoperative complications during revision shoulder arthroplasty [11, 13]. In revision settings, in which there may be cortical bone perforation in the humeral canal, cement pressurization can lead to extrusion [11] potentially compromising neurovascular structures, in particular the radial nerve. The introduction of variable inclination components may reduce the need for cementation. With nonvariable designs, surgeons often fill voids created by the mismatch between the optimal prosthetic head location and the optimal stem location with cement as these may differ widely with anatomic variability [6].

Clinical Outcomes

Overall excellent outcomes have been described for modern humeral components, with low rates of radiographic loosening, symptomatic loosening,

or need for revision (Table 3.2) [14, 15, 34, 36, 37, 40, 44, 49–52, 62]. Indeed, clinical outcomes on the humeral side have been excellent since initial implant designs. For instance, in a 1987 prospective cohort study of 50 anatomy total shoulder arthroplasties with cemented Neer II components followed for a mean of 3.5 years, while 10 % of humeral components had at least one radiolucent line, only one component (2 %) had to be revised for a subsequent humeral fracture [36]. Although humeral component designs have changed substantially in the over 25 years since this report was published, these results are difficult to improve upon. However, although rare, humeral loosening does occur, and revisions for humeral loosening are fraught with complications and should thus be avoided if possible [10, 13]. For instance, when the Mayo Clinic described their experience with 35 revisions performed for loosening of the humeral component in anatomic

Table 3.2 Outcomes regarding the humeral component in primary anatomic total shoulder arthroplasty from the largest available series with rates of radiographic and clinical humeral loosening

Study characteristics			Implant characteristics			Clinical outcomes (%)			
Author (year)	*N*	Mean f/u (years)	M/D	C/U	PF/PC	Radiographic loosening	Symp. loosening	Revision for loosening	Humeral revision
Barrett (1987) [36]	50	3.5	D	72 % C	PF	0	0	0	4.0
Sperling (2000) [55]	62	4.6	D	U	PC	9.7	1.6	1.6	NA
Sanchez-Sotelo (2001) [51]	43	6.6	D	C	NA	2	0	0	0
Sanchez-Sotelo (2001) [52]	72	4.1	D	U	PC	56	1.3	1.3	4.2
Godenéche (2002) [34]	268	2.5	M	99 % C	PC	8	0.4	0.4	2.2
Matsen (2003) [39]	131	2.0	M	U	PF	0	0	0	0
Verborgt (2007) [56]	37	9.2	D	U	PF	19	0	0	2.7
Khan (2009) [37]	25	10.6	M	C	NA	0	0	0	0
Cil (2010) [62]	1,112	8.1	D	15 % C	86 % PC	NA	NA	1.1	9.4
Throckmorton (2010) [41]	76	4.3	D	U	PC	0	0	0	0
Litchfield (2011) [38]	80	2.0	D	C	NA	NA	0	0	0
Litchfield (2011) [38]	81	2.0	D	U	PF	NA	0	0	0
Raiss (2012) [40]	39	11.0	M	C	NA	0	0	0	0
Owens (2014) [64]	35	6.5	D	29 % C	PC	0	0	0	2.9
Raiss (2014) [15]	262	8.2	M	74 % C	PC	1	1	0	3.8
Cemented weighted mean						2.4	0.4	0.4	4.0
Uncemented weighted mean						3.3	0.2	0.9	6.8

Comparative studies have been broken into their comparative groups when possible
N number of shoulders, *f/u* follow-up, *M* metaphyseal, *D* diaphyseal, *C* cemented, *U* uncemented, *NA* not applicable/not available, *PF* press fit, *PC* proximal on-growth or ingrowth coating, *Loose* loosening, *Symp* symptomatic

total shoulder arthroplasty, only 71 % satisfactory or excellent results were achieved using Neer's criteria, 23 % of patients had cement extrusions, 17 % of patients had iatrogenic intraoperative humeral fractures, and 11 % of patients required reoperation [10].

The most common reasons for revision of the humeral component are problems on the glenoid side [63] and within the rotator cuff [13], with isolated aseptic loosening accounting for the vast minority of humeral revisions. In a large retrospective series with 1,112 anatomic total shoulder arthroplasties, of the 104 humeral revisions, only 12 (11.5 % of all humeral revisions, 1.1 % of all total shoulder arthroplasties) were performed for humeral loosening, and of these 9 (75 %) were in association with either glenoid polyethylene wear or instability. Therefore, isolated humeral loosening thus only occurred in 0.3 % of cases and accounted for only 2.9 % of humeral revisions [62]. Rates of humeral loosening requiring revision have been similarly low in other series, ranging from 0 % to 1.6 % [15, 34, 36–41, 51, 52, 55, 56, 62, 64]. When data from these series was pooled, the weighted mean rates of humeral loosening requiring revision was 0.4 % for cemented and 0.9 % for uncemented components. The overall humeral revision rates were 4.0 % for cemented components and 6.8 % for uncemented components in these weighted mean averages, again suggesting that issues independent of the humeral component such as instability, glenoid loosening, rotator cuff dysfunction, and infection play the largest role in humeral component revision [15, 34, 36–41, 51, 52, 55, 56, 62, 64]. Of note, given the technical difficulty and high complication rate associated with revision of a cemented stem [13], the improved "survival" of cemented components may reflect the resistance of the surgeon to revise a cemented components [62].

The debate between the use of cemented and cementless fixation of humeral components continues with no clear distinction in outcomes or performance between designs in routine shoulder arthroplasty. A prospective, double-blind, randomized clinical trial comparing cemented and cementless fixation in anatomic total shoulder arthroplasty performed for primary osteoarthritis demonstrated better Western Ontario Osteoarthritis Scores in the cemented group [38]. However, this study was conducted with a fixed inclination, diaphyseally fixated stem instead of a variable inclination, and metaphyseally fixated stem. In addition, there were no differences in other validated measures of shoulder function, shoulder range of motion, or the complication rates or rates of loosening or revision between groups in the short term [38]. As a result, this study remains difficult to interpret given the implants currently available. Many studies suggest that with modern metaphyseal on-growth and ingrowth stems, functional outcomes and survival rates to loosening or revision are equivalent between cemented and cementless fixation [14, 39, 49, 62]. In the largest series to date with 395 anatomic total shoulder arthroplasties with a mean follow-up of 8 years and a minimum follow-up of 4 years with a metaphyseal, on-growth fixation design, no difference could be found between cemented and uncemented stems [15]. The best available evidence for modern stems thus suggests that unless a specific indication exists for one method of fixation, both cemented and uncemented stems can be recommended.

Beyond measuring component survival to revision for symptomatic aseptic loosening, many authors have also described humeral radiographic outcomes with respect to radiolucent lines, stress shielding, and osteolysis. Radiolucent lines are variably described and their clinical significance remains a subject of debate. Generally, radiolucent lines have been classified using Gruen zones translated from total hip arthroplasty, with three medial zones, three lateral zones, one zone at the tip of the component, and one zone for the undersurface of the humeral head with each numbered beginning at the proximolateral aspect of the component [65]. Lines can then be described based upon their thickness and by which zones they involve [41, 51, 52, 55]. While subsidence or change in component position on serial radiographic is almost universally agreed to be a sign of a loose component, whether a threshold degree of severity of radiolucent line formation is also a portent of progressive radiolucencies or aseptic

loosening remains controversial. In cementless components, these lines are most commonly described at or near the tip of the component in zones 3–5, although in diaphyseal fixation designs, they are also common within the more proximal aspects of the component [39, 52]. In cemented designs radiolucent lines are most common in the mid-body and proximal aspects of the component in zones 1–2 and 6–7 [51].

Radiolucent line formation is common, especially in cementless components [50]. In a series of 39 cemented, metaphyseally fixated components followed for a minimum of 10 years, 50 % of components had at least one radiolucent line 2 mm wide, but none were symptomatically loose and none had required revision [37]. Similarly, in a series of 43 cemented, diaphyseally fixated components followed for a mean of 6.6 years, 37 % of components had at least one radiolucent line of at least 1 mm, but no revisions were required. In another series of 131 uncemented, metaphyseally fixated, press-fit components followed for a minimum of 2 years, 57 % of components had a radiolucent line of at least 1 mm in some portion of the component, but none had shifted or subsided and none required revision [39]. In another recent series of 67 uncemented, metaphyseally fixated total shoulder arthroplasties with an on-growth coating followed for a mean of 5.5 years, condensation lines were described around the tip of the stem in 85 % of cases, although no cases of revision for humeral loosening were described [15].

In components with metaphyseal fixation, whether due to isolated proximal cementation or as a result of cementless metaphyseal fixation, distal radiolucent lines likely represent signs of stress shielding, which is of unknown clinical relevance (Fig. 3.3). Other studies have reported stress shielding with cementless components. In one series spot-welds were described in 82 %, and other signs of osseous remodeling were described in 63 % [15]. This phenomenon appears to be more frequent in cementless than cemented designs [14, 15]. Given that the proximal humerus is largely non-weight bearing and that forces are transmitted to most proximal aspect of proximal humerus through the rotator cuff, some authors have theorized that stress shielding may be a consequence of biological abnormalities within the underlying bone and abnormalities within the rotator cuff instead of implant designs [14], which has been supported by a computer modeling analysis [16].

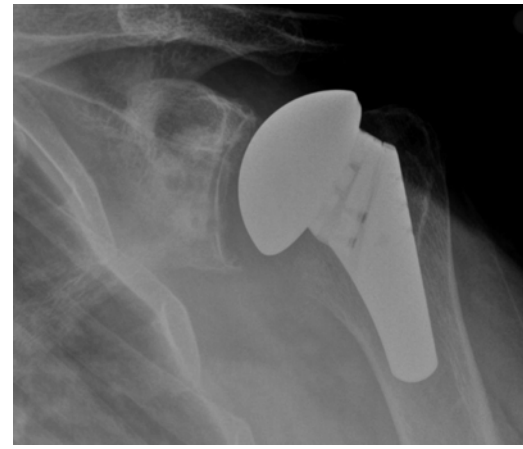


Fig. 3.3 This anteroposterior radiograph of the *left* shoulder in a patient status-post placement of an uncemented, metaphyseally fixated humeral component demonstrates signs of stress shielding including osteopenia of the calcar, a condensation line at the distolateral aspect of the component, and internal remodeling with trabecular streaming toward the taper of the component

Finally, proximal humerus osteolysis can occur [14, 15] which may predispose patients to periprosthetic fracture [17–19] and complicate revision surgery [10–12]. In the largest series to comment on osteolysis, of the 262 total shoulder arthroplasties followed for a mean of 8.2 years, osteolysis was encountered in 54 % of patients [15]. However, this process appears to be associated with glenoid loosening [15, 62] and thus may be a consequence of an inflammatory response to particulate wear, analogous to osteolysis seen with hip and knee arthroplasty, and not a consequence of humeral component design or implantation technique (Fig. 3.4) [66–68]. Perhaps the strongest argument in favor of the association between osteolysis and polyethylene glenoid wear is the observation that osteolysis does not occur with hemiarthroplasties [15]. One aspect of component design that may, however, play a role in this regard is whether the porous coating is circumferential, as this may “seal” the

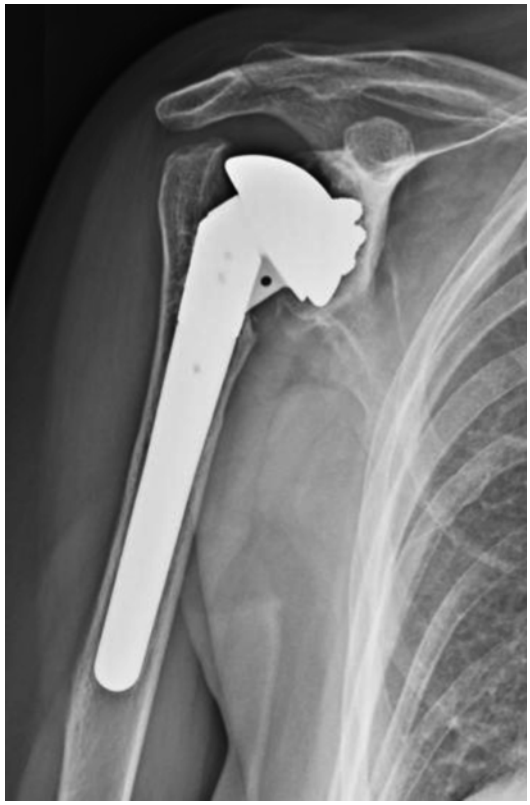


Fig. 3.4 This anteroposterior radiograph of the *right* shoulder demonstrates a patient with osteolysis and humeral component loosening due to loosening of a metal-backed glenoid component

distal aspect of the component from wear debris and may thus reduce distal osteolysis [69]. Some authors have theorized that the inflammatory response to wear debris may explain almost all cases of "isolated" humeral loosening – in one report a case of "isolated" humeral loosening retrieval analysis demonstrated a giant cell foreign body reaction to wear debris at the bone-component interface [63].

Technical Tips and Pearls

Based upon the current best available evidence, several technical tips and pearls can be provided. Recreation of the pre-injury/pre-deformity humeral articular anatomy provides the best chance for normal glenohumeral kinematics. Even small deviations from normal anatomy can significantly alter glenohumeral kinematics. The anatomy of the proximal humerus is highly variable, and the primary goal is to implant the humeral component in a position allowing for humeral head positioning that recreates the articular anatomy. Thus, whenever possible, the surgeon should avoid a "one-size-fits-all" approach.

Preoperative planning is important, and failure to do so may result in both intraoperative and postoperative complications. Several factors must be considered in choosing a humeral stem system that can both recreate the anatomy and provide durable fixation, including individual variation in proximal humeral anatomy, bone quality/bone loss, posttraumatic deformity, previous surgery, and potential for future rotator cuff dysfunction, as occurs in the setting of inflammatory arthritides. Preoperative templating helps to judge the size and position of components in relation to the patients' size and anatomy and to determine if a given system can achieve the operative goals. When templating, magnification must be accounted for when using standard plain films. If a diaphyseally fixated component is chosen, it is important to realize that the diaphysis humeral endosteum is, on average, 20% smaller from anterior to posterior than it is from medial to lateral, and thus templating solely on the anteroposterior view will cause the surgeon to systematically overestimate the component size [60].

For uncomplicated glenohumeral arthritis, both cemented and cementless designs provide both reliable and durable results. In general, cementless designs are ideally indicated in younger patients, those with good metaphyseal bone quality and in primary surgery. Cemented implants are ideal in cases with poorer bone quality, a very large endosteal diaphyseal canal, revision surgeries with bone loss, and when aberrant proximal humeral anatomy is encountered. Platform systems may be idea in cases with higher risk of future cuff dysfunction such as inflammatory arthritis. In cases with either mismatch between humeral anatomy and the prosthetic humeral component, consider cemented fixation or impaction grafting. Components with greater modularity, variability, and metaphyseal fixation can also assist in achieving this goal, while monoblock, diaphyseally fixated components make this

goal harder to achieve. Consider the use of a long-stemmed prosthesis in cases with an exceptionally large canal or with significant metaphyseal/diaphyseal bone loss. A recent series of long-stemmed primary total shoulder arthroplasties demonstrated excellent outcomes and no humeral loosening, suggesting that when necessary use of a long-stem does not negatively impact the patients outcome [64].

The surgical approach to humeral preparation will vary depending on the chosen system and the experience of the surgeon. If a cementless humeral component is preferred a smaller lesser tuberosity osteotomy should be considered to avoid compromise of the anterior metaphyseal bone. The frequently encountered anatomic neck osteophytes should be removed to define the anatomic neck prior to making the humeral head osteotomy. Systems with fixed inclination angles often provide cutting guides based on an endosteal diaphyseal reamer to recreate the inclination angle, while systems with variable angles of inclination allow a freehand cut to replicate the patients' anatomy. The version of the humeral osteotomy should be angled to recreate the patient native retroversion angle, except in cases of humeral head subluxation where a correction may be preferred. For cemented implants, over-reaming slightly compared to the chosen diameter of the implant improves the cement mantle, although the optimal mantle thickness in the humerus is unknown. For cementless implants, careful broaching of the metaphysis can prevent intraoperative fracture. If soft metaphyseal bone or gaps are encountered, impacting grafting or conversion to a cemented implant should be considered. Consider leaving a trial in place when performing glenoid preparation to avoid retractor damage to the metaphyseal bone. Finally, a trial of humeral component stability should be considered after glenoid placement but prior to final humeral component placement if there are concerns for instability or subluxation.

Regardless of the implant selection or technique, the surgeon must be aware that long-term complications related to the humeral component are rare, and often those issues that do arise are usually related to the glenoid component, and thus in those cases where "isolated" humeral loosening is suspected as the cause of failure, the surgeon must search for other potential causes of failure and should be prepared for a full revision.

References

1. Flatow EL, Harrison AK. A history of reverse total shoulder arthroplasty. Clin Orthop Relat Res. 2011; 469:2432–9.
2. Lugli T. Artificial shoulder joint by Péan (1893): the facts of an exceptional intervention and the prosthetic method. Clin Orthop Relat Res. 1978;133:215–8.
3. Kim SH, Wise BL, Zhang Y, Szabo RM. Increasing incidence of shoulder arthroplasty in the United States. J Bone Joint Surg Am. 2011;93:2249–54.
4. Flatow EL. Prosthetic design considerations in total shoulder arthroplasty. Semin Arthroplasty. 1995;6(4): 233–44.
5. Neer CS. Articular replacement for the humeral head. J Bone Joint Surg Am. 1955;37-A:215–28.
6. Pearl ML. Proximal humeral anatomy in shoulder arthroplasty: implications for prosthetic design and surgical technique. J Shoulder Elbow Surg. 2005;14: 99S–104.
7. Harris TE, Jobe CM, Dai QG. Fixation of proximal humeral prostheses and rotational micromotion. J Shoulder Elbow Surg. 2000;9:205–10.
8. Peppers TA, Jobe CM, Dai QG, Williams PA, Libanati C. Fixation of humeral prostheses and axial micromotion. J Shoulder Elbow Surg. 1998;7:414–8.
9. Galante J, Rostoker W, Lueck R, Ray RD. Sintered fiber metal composites as a basis for attachment of implants to bone. J Bone Joint Surg Am. 1971;53: 101–14.
10. Cil A, Veillette CJH, Sanchez-Sotelo J, Sperling JW, Schleck C, Cofield RH. Revision of the humeral component for aseptic loosening in arthroplasty of the shoulder. J Bone Joint Surg Br. 2009;91:75–81.
11. Owens CJ, Sperling JW, Cofield RH. Utility and complications of long-stem humeral components in revision shoulder arthroplasty. J Shoulder Elbow Surg. 2013;22:e7–12.
12. Van Thiel GS, Halloran JP, Twigg S, Romeo AA, Nicholson GP. The vertical humeral osteotomy for stem removal in revision shoulder arthroplasty: results and technique. J Shoulder Elbow Surg. 2011;20: 1248–54.
13. Wieser K, Borbas P, Ek ET, Meyer DC, Gerber C. Conversion of stemmed hemi- or total to reverse total shoulder arthroplasty: advantages of a modular stem design. Clin Orthop Relat Res. 2015;473: 651–60.
14. Mélis B, DeFranco M, Lädermann A, Molé D, Favard L, Nérot C, Maynou C, Walch G. An evaluation of the radiological changes around the Grammont reverse geometry shoulder arthroplasty after eight to 12 years. J Bone Joint Surg Br. 2011;93:1240–6.

15. Raiss P, Edwards TB, Deutsch A, Shah A, Bruckner T, Loew M, Boileau P, Walch G. Radiographic changes around humeral components in shoulder arthroplasty. J Bone Joint Surg Am. 2014;96:e54.
16. Quental C, Folgado J, Fernandes PR, Monteiro J. Bone remodelling analysis of the humerus after a shoulder arthroplasty. Med Eng Phys. 2012;34: 1132–8.
17. Atoun E, Van Tongel A, Hous N, Narvani A, Relwani J, Abraham R, Levy O. Reverse shoulder arthroplasty with a short metaphyseal humeral stem. Int Orthop (SICOT). 2014;38:1213–8.
18. Sewell MD, Kang SN, Al-Hadithy N, Higgs DS, Bayley I, Falworth M, Lambert SM. Management of peri-prosthetic fracture of the humerus with severe bone loss and loosening of the humeral component after total shoulder replacement. J Bone Joint Surg Br. 2012;94:1382–9.
19. Andersen JR, Williams CD, Cain R, Mighell M, Frankle M. Surgically treated humeral shaft fractures following shoulder arthroplasty. J Bone Joint Surg Am. 2013;95:9–18.
20. Pearl ML, Kurutz S. Geometric analysis of commonly used prosthetic systems for proximal humeral replacement. J Bone Joint Surg Am. 1999;81:660–71.
21. Pearl ML, Kurutz S, Robertson DD, Yamaguchi K. Geometric analysis of selected press fit prosthetic systems for proximal humeral replacement. J Orthop Res. 2002;20:192–7.
22. Robertson DD, Yuan J, Bigliani LU, Flatow EL, Yamaguchi K. Three-dimensional analysis of the proximal part of the humerus: relevance to arthroplasty. J Bone Joint Surg Am. 2000;82-A:1594–602.
23. Razmjou H, Holtby R, Christakis M, Axelrod T, Richards R. Impact of prosthetic design on clinical and radiologic outcomes of total shoulder arthroplasty: a prospective study. J Shoulder Elbow Surg. 2013;22:206–14.
24. Boileau P, Walch G. The three-dimensional geometry of the proximal humerus. Implications for surgical technique and prosthetic design. J Bone Joint Surg Br. 1997;79:857–65.
25. Jeong J, Bryan J, Iannotti JP. Effect of a variable prosthetic neck-shaft angle and the surgical technique on replication of normal humeral anatomy. J Bone Joint Surg Am. 2009;91:1932–41.
26. Moon SC, Cho NS, Rhee YG. Analysis of "Hidden Lesions" of the extra-articular biceps after subpectoral biceps tenodesis: the subpectoral portion as the optimal tenodesis site. Am J Sports Med. 2014. doi:10.1177/0363546514554193.
27. Rhee YG, Cho NS, Moon SC. Effects of humeral component retroversion on functional outcomes in reverse total shoulder arthroplasty for cuff tear arthropathy. J Shoulder Elbow Surg. 2015. doi:10.1016/j.jse.2015.03.026.
28. Spencer EE, Valdevit A, Kambic H, Brems JJ, Iannotti JP. The effect of humeral component anteversion on shoulder stability with glenoid component retroversion. J Bone Joint Surg Am. 2005;87:808–14.
29. Berhouet J, Garaud P, Favard L. Influence of glenoid component design and humeral component retroversion on internal and external rotation in reverse shoulder arthroplasty: a cadaver study. Orthop Traumatol Surg Res. 2013;99:887–94.
30. Iannotti JP, Spencer EE, Winter U, Deffenbaugh D, Williams G. Prosthetic positioning in total shoulder arthroplasty. J Shoulder Elbow Surg. 2005;14: 111S–21.
31. Harryman DT, Sidles JA, Harris SL, Lippitt SB, Matsen FA. The effect of articular conformity and the size of the humeral head component on laxity and motion after glenohumeral arthroplasty. A study in cadavera. J Bone Joint Surg Am. 1995;77:555–63.
32. Blevins FT, Pollo FE, Torzilli PA, Warren RF. Effect of humeral head component size on hemiarthroplasty translations and rotations. J Shoulder Elbow Surg. 1998;7:591–8.
33. 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:1775–81.
34. Godenèche A, Boileau P, Favard L, Le Huec J-C, Levigne C, Nové-Josserand L, Walch G, Edwards TB. Prosthetic replacement in the treatment of osteoarthritis of the shoulder: early results of 268 cases. J Shoulder Elbow Surg. 2002;11:11–8.
35. Cook RB, Bolland BJRF, Wharton JA, Tilley S, Latham JM, Wood RJK. Pseudotumour formation due to tribocorrosion at the taper interface of large diameter metal on polymer modular total hip replacements. J Arthroplast. 2013;28:1430–6.
36. Barrett WP, Franklin JL, Jackins SE, Wyss CR, Matsen FA. Total shoulder arthroplasty. J Bone Joint Surg Am. 1987;69:865–72.
37. Khan A, Bunker TD, Kitson JB. Clinical and radiological follow-up of the Aequalis third-generation cemented total shoulder replacement: a minimum ten-year study. J Bone Joint Surg Br. 2009;91: 1594–600.
38. Litchfield RB, McKee MD, Balyk R, Mandel S, Holtby R, Hollinshead R, Drosdowech D, Wambolt SE, Griffin SH, McCormack R. Cemented versus uncemented fixation of humeral components in total shoulder arthroplasty for osteoarthritis of the shoulder: a prospective, randomized, double-blind clinical trial-A JOINTs Canada Project. J Shoulder Elbow Surg. 2011;20:529–36.
39. Matsen FA, Iannotti JP, Rockwood CA. Humeral fixation by press-fitting of a tapered metaphyseal stem: a prospective radiographic study. J Bone Joint Surg Am. 2003;85-A:304–8.
40. Raiss P, Schmitt M, Bruckner T, Kasten P, Pape G, Loew M, Zeifang F. Results of cemented total shoulder replacement with a minimum follow-up of ten years. J Bone Joint Surg Am. 2012;94:e1711–10.
41. Throckmorton TW, Zarkadas PC, Sperling JW, Cofield RH. Radiographic stability of ingrowth humeral stems in total shoulder arthroplasty. Clin Orthop Relat Res. 2010;468:2122–8.

42. Feeley BT, Fealy S, Dines DM, Warren RF, Craig EV. Hemiarthroplasty and total shoulder arthroplasty for avascular necrosis of the humeral head. J Shoulder Elbow Surg. 2008;17:689–94.
43. Smith RG, Sperling JW, Cofield RH, Hattrup SJ, Schleck CD. Shoulder hemiarthroplasty for steroid-associated osteonecrosis. J Shoulder Elbow Surg. 2008;17:685–8.
44. Broström LA, Wallensten R, Olsson E, Anderson D. The Kessel prosthesis in total shoulder arthroplasty. A five-year experience. Clin Orthop Relat Res. 1992;277:155–60.
45. McElwain JP, English E. The early results of porous-coated total shoulder arthroplasty. Clin Orthop Relat Res. 1987;218:217–24.
46. Olerud P, Ahrengart L, Ponzer S, Saving J, Tidermark J. Hemiarthroplasty versus nonoperative treatment of displaced 4-part proximal humeral fractures in elderly patients: a randomized controlled trial. J Shoulder Elbow Surg. 2011;20:1025–33.
47. Boons HW, Goosen JH, van Grinsven S, van Susante JL, van Loon CJ. Hemiarthroplasty for humeral four-part fractures for patients 65 years and older: a randomized controlled trial. Clin Orthop Relat Res. 2012;470:3483–91.
48. Sebastiá-Forcada E, Cebrián-Gómez R, Lizaur-Utrilla A, Gil-Guillén V. Reverse shoulder arthroplasty versus hemiarthroplasty for acute proximal humeral fractures. A blinded, randomized, controlled, prospective study. J Shoulder Elbow Surg. 2014;23:1419–26.
49. King JJ, Farmer KW, Struk AM, Wright TW. Uncemented versus cemented humeral stem fixation in reverse shoulder arthroplasty. Int Orthop (SICOT). 2015;39:291–8.
50. Gilot G, Alvarez-Pinzon AM, Wright TW, Flurin P-H, Krill M, Routman HD, Zuckerman JD. The incidence of radiographic aseptic loosening of the humeral component in reverse total shoulder arthroplasty. J Shoulder Elbow Surg. 2015. doi:10.1016/j.jse.2015.02.007.
51. Sanchez-Sotelo J, O'Driscoll SW, Torchia ME, Cofield RH, Rowland CM. Radiographic assessment of cemented humeral components in shoulder arthroplasty. J Shoulder Elbow Surg. 2001;10:526–31.
52. Sanchez-Sotelo J, Wright TW, O'Driscoll SW, Cofield RH, Rowland CM. Radiographic assessment of uncemented humeral components in total shoulder arthroplasty. J Arthroplasty. 2001;16:180–7.
53. Torchia ME, Cofield RH, Settergren CR. Total shoulder arthroplasty with the neer prosthesis: long-term results. J Shoulder Elbow Surg. 1997;6:495–505.
54. Cook SD, Barrack RL, Salkeld SL, Prewett AB, Edmunds JO. Bone ingrowth into a porous-coated total shoulder component retrieved postmortem. J Arthroplasty. 1993;8:189–94.
55. Sperling JW, Cofield RH, O'Driscoll SW, Torchia ME, Rowland CM. Radiographic assessment of ingrowth total shoulder arthroplasty. J Shoulder Elbow Surg. 2000;9:507–13.
56. Verborgt O, El-Abiad R, Gazielly DF. Long-term results of uncemented humeral components in shoulder arthroplasty. J Shoulder Elbow Surg. 2007;16:S13–8.
57. Wirth MA, Lim M-S, Southworth C, Loredo R, Kaar TK, Rockwood CA. Compaction bone-grafting in prosthetic shoulder arthroplasty. J Bone Joint Surg Am. 2007;89:49–57.
58. Hacker SA, Boorman RS, Lippitt SB, Matsen FA. Impaction grafting improves the fit of uncemented humeral arthroplasty. J Shoulder Elbow Surg. 2003;12:431–5.
59. Bourne RB, Rorabeck CH. A critical look at cementless stems. Taper designs and when to use alternatives. Clin Orthop Relat Res. 1998;355:212–223.
60. Lee M, Chebli C, Mounce D, Bertelsen A, Richardson M, Matsen F. Intramedullary reaming for press-fit fixation of a humeral component removes cortical bone asymmetrically. J Shoulder Elbow Surg. 2008;17:150–5.
61. Rhinelander FW. Tibial blood supply in relation to fracture healing. Clin Orthop Relat Res. 1974;105:34–81.
62. Cil A, Veillette CJH, Sanchez-Sotelo J, Sperling JW, Schleck CD, Cofield RH. Survivorship of the humeral component in shoulder arthroplasty. J Shoulder Elbow Surg. 2010;19:143–50.
63. Klimkiewicz JJ, Iannotti JP, Rubash HE, Shanbhag AS. Aseptic loosening of the humeral component in total shoulder arthroplasty. J Shoulder Elbow Surg. 1998;7:422–6.
64. Owens CJ, Sperling JW, Cofield RH. Long-stemmed humeral components in primary shoulder arthroplasty. J Shoulder Elbow Surg. 2014;23:1492–8.
65. Gruen TA, McNeice GM, Amstutz HC. "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. Clin Orthop Relat Res. 1979;141:17–27.
66. Dapunt U, Giese T, Prior B, Gaida MM, Hänsch GM. Infectious versus non-infectious loosening of implants: activation of T lymphocytes differentiates between the two entities. Int Orthop (SICOT). 2014;38:1291–6.
67. Nich C, Takakubo Y, Pajarinen J, et al. Macrophages-key cells in the response to wear debris from joint replacements. J Biomed Mater Res A. 2013;101:3033–45.
68. Jämsen E, Kouri V-P, Olkkonen J, Cör A, Goodman SB, Konttinen YT, Pajarinen J. Characterization of macrophage polarizing cytokines in the aseptic loosening of total hip replacements. J Orthop Res. 2014;32:1241–6.
69. Throckmorton T, Zarkadas P, Sanchez-Sotelo J, Morrey B. Failure patterns after linked semiconstrained total elbow arthroplasty for posttraumatic arthritis. J Bone Joint Surg Am. 2010;92:1432–41.

Humeral Head Resurfacing Arthroplasty

4

Ofer Levy

Introduction

Cementless shoulder resurfacing arthroplasty (CSRA) differs in many aspects from the non-constrained stemmed shoulder prostheses (Figs. 4.1, 4.2 and 4.3). The design concept is replacement only of the damaged joint-bearing surfaces and restoration of normal anatomy with minimal bone resection. The concept of shoulder resurfacing has gained popularity in the recent years, following the publications of very good long-term results [1–5].

Early attempts at shoulder replacement in Europe involved constrained stemmed prostheses for cases of infection and tumour, in order to deal with the considerable loss of bone and soft tissues. In the USA, Neer [6] developed a stemmed unconstrained humeral prosthesis specifically for the treatment of four-part fractures. The stem served as a scaffold around which the proximal humerus could be rebuilt. As this was a successful design, it was later used for arthritis and a glenoid component was developed. Neither of these prostheses was specifically designed for use in arthritis of the shoulder. The idea of developing a surface replacement arthroplasty for use in the degenerative shoulder, which was less deformed, came about in the early 1980s. There were a few cemented implants like the small 'Indiana hip cup' used by Steffee and Moore [7] and the scan cup by Rydholm and Sjögen [8, 9]. The first cementless resurfacing design was by Stephen Copeland, and this implant has now 29 years of clinical experience [1, 10] (Figs. 4.1, 4.2 and 4.3).

In recent years, new designs of stemless shoulder replacement prostheses have been developed in Europe. These designs have been developed based on the good results of the shoulder resurfacing that showed that the stem is not necessarily indicated in all cases of shoulder arthritis.

Design Concept

The design concept is to mimic the normal anatomy as closely as possible, replacing the damaged surfaces of the joint with minimal interference. This consists of surface replacement with minimal bone removal, cementless fixation with primary press-fit mechanical fixation with grooved taper peg and hydroxyapatite coating to promote biological fixation with bone ingrowth [1–5, 11].

Bone removed for the central drill hole for the prosthesis is used for grafting any defects under the humeral cup so that no bone is wasted.

O. Levy, MD, MCh (Orth), FRCS
Reading Shoulder Unit, Royal Berkshire Hospital and Berkshire Independent Hospital, Reading, UK
e-mail: oferlevy@readingshoulderunit.com

© Springer International Publishing Switzerland 2016
A.D. Armstrong, A.M. Murthi (eds.), *Anatomic Shoulder Arthroplasty*,
DOI 10.1007/978-3-319-29164-2_4

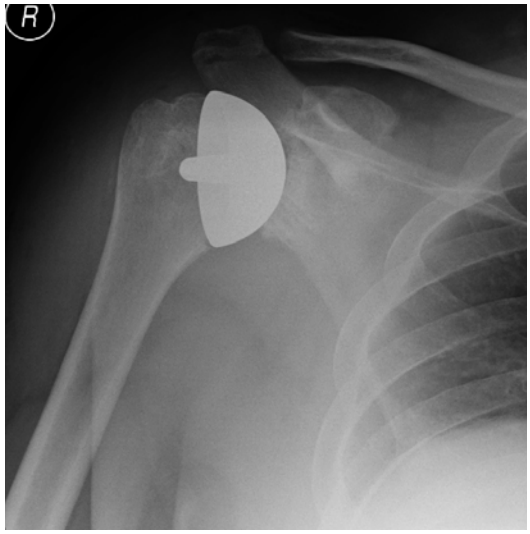


Fig. 4.1 X-rays of shoulder resurfacing

Using the resurfacing prosthesis, normal anatomy including humeral head version, inclination and offset can be restored with no need for complicated instrumentation [1, 12, 13]. This allows the surgeon unlimited flexibility to adapt the prosthesis to the patient's own anatomy rather than imposing the prosthetic anatomy on the patient. Even in the presence of severe head erosion, the anatomic neck can be visualised after removal of osteophytes and the head drill guide jig sited correctly centred.

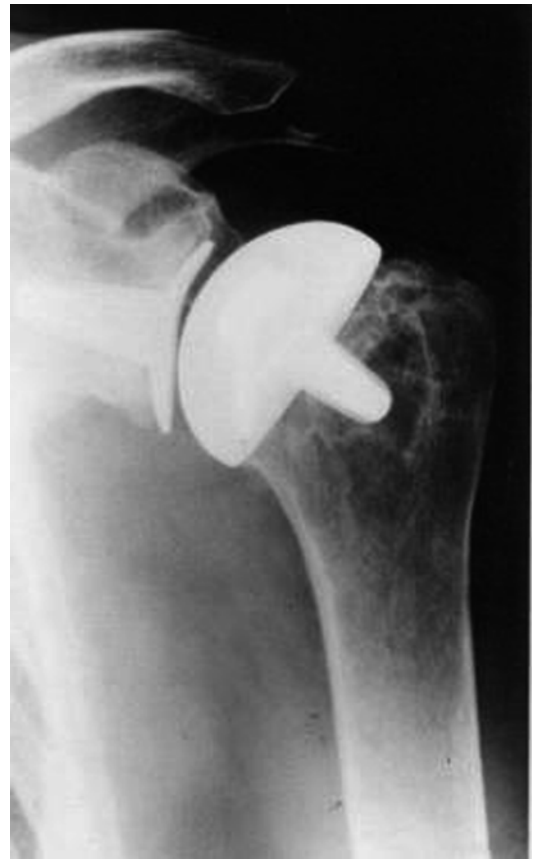


Fig. 4.2 X-rays of total shoulder resurfacing with metal-backed glenoid

Indications

All patients with shoulder arthritis can be considered for resurfacing. Only in cases of severe bone loss (with no surface to replace) or cases of acute fractures and nonunion of humeral neck fractures require a stemmed prosthesis and cannot be considered for resurfacing.

Resurfacing has been used successfully for osteoarthritis, rheumatoid and other inflammatory arthritides, avascular necrosis (osteonecrosis), cuff tear arthropathy, instability arthropathy, post-trauma arthritis, postinfective arthritis and arthritis secondary to epiphysial dysplasia [1–3, 5, 11, 14, 15]. The surface replacement arthroplasty can be used as well, in cases of moderate-to-severe erosion of the humeral head, in conjunction with bone graft or bone graft substitute. Up to 40 % of the humeral head may be replaced by bone graft or bone graft substitute [15].

Contraindications

Absolute Contraindications

Absolute contraindications for the use of surface replacement arthroplasty are the same as for any shoulder arthroplasty. These include presence of active infection, paralysis of the shoulder girdle muscles (rotator cuff and the deltoid muscle) and Charcot disease of the shoulder. Specific contraindications for surface replacement are extreme bone loss where the whole humeral head is gone and there is no surface to be replaced, acute humeral head and neck fractures and nonunions.

Relative Contraindications

Relative contraindications include severe bone loss of the humeral head exceeding 40% of the surface. The presence of humeral head soft bone with large bone cyst (void) (in rheumatoid patients) will not support the surface replacement prosthesis [15]. However, if the vault of the proximal humerus and the humeral head rim are still preserved, resurfacing with bone graft impaction technique can be performed (Fig. 4.4).

In cases of cuff-deficient shoulders (cuff arthropathy or massive cuff tears), patients must be advised about realistic outcome with relative good pain relief but not much improvement in range of motion (as with any stemmed shoulder replacement). For these indications, reverse TSA should be advised.

Fig. 4.3 The Copeland resurfacing prosthesis

Technique

Approach and Exposure for Shoulder Resurfacing

Shoulder resurfacing can be performed via the standard anterior deltopectoral approach or through the anterosuperior approach, as described by Neviaser and Mackenzie [16].

Our preferred approach is the anterosuperior approach ('Neviaser-Mackenzie' approach). This provides good exposure of the glenohumeral joint, the humeral head and the tuberosities, through a smaller incision.

There is an easier access to the glenoid 'en face' via the rotator interval (Fig. 4.5), as well as good access to the posterior and superior rotator cuff for reconstruction. It also allows for excision

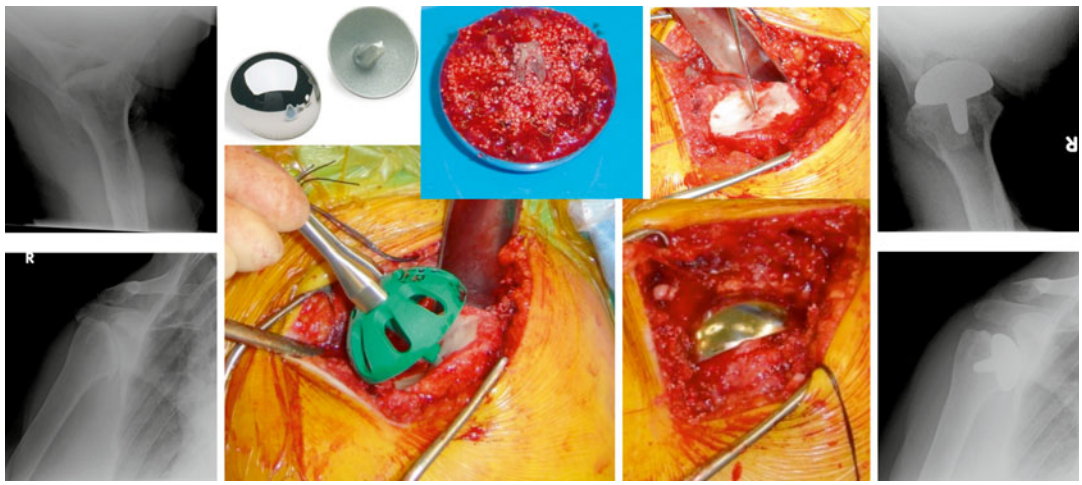


Fig. 4.4 Reconstruction and build-up of severe bone deficiency of the humeral head with bone graft substitute and patient's blood underneath the resurfacing prosthesis

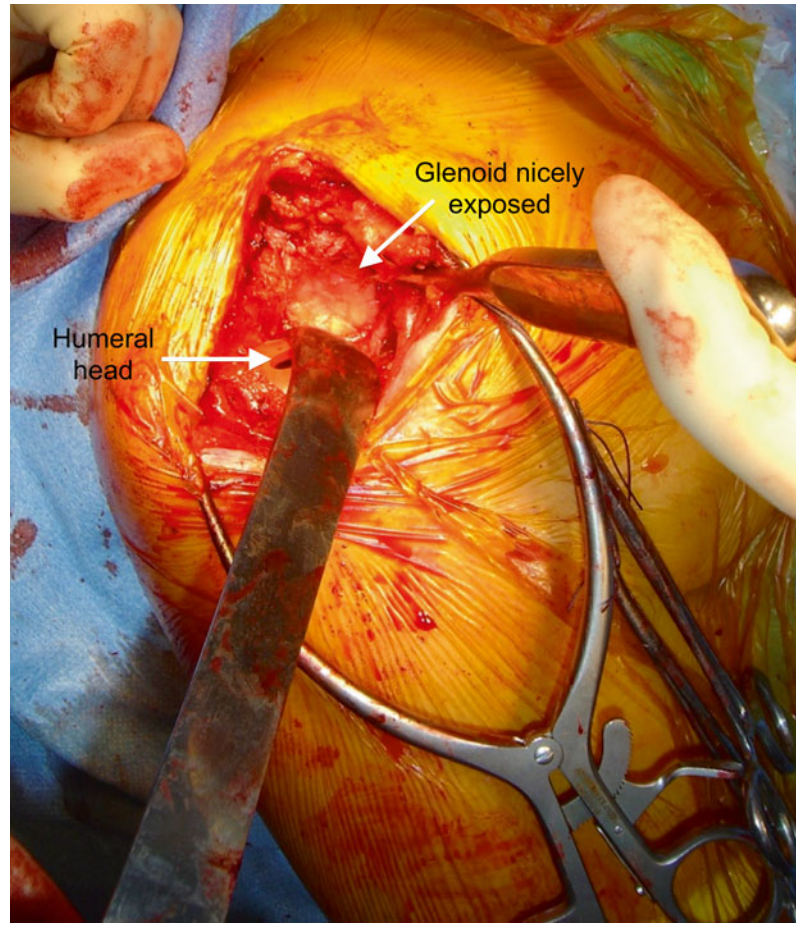


Fig. 4.5 Glenoid exposure with the humeral head in situ

arthroplasty of the acromio-clavicular joint and acromioplasty if these are required.

In primary and secondary osteoarthritis, as much of the sclerotic surface of bone is retained in order to provide a good solid seating for the prosthesis. However, because the prosthesis is hydroxyapatite coated, the surface needs to be made reactive to allow bony ingrowth by multiple drilling of the surface with a fine drill. The fragments of bone from the drilling are left in situ. The bone saved from the initial pilot drill hole and the shaper mixed with the patient's blood is smeared onto the back of the prosthesis before insertion and irregularities in the humeral head routinely bone grafted.

Clearly it is more difficult to access the glenoid with the humeral head in situ and not resected. However, when performing a good thorough release around the glenoid and retracting the humeral head posteriorly and inferiorly, the glenoid can be exposed very nicely (Fig. 4.5).

Long-Term Results with Humeral Resurfacing

Between 1986 and 2003, we implanted 340 cementless Copeland surface replacement prostheses in our institution [11, 22], 218 humeral surface arthroplasties (hemiarthroplasty) (HSAs) and 122 TSAs. There was very little difference in the functional outcome and pain between the groups early as well as later after surgery (Fig. 4.7). An important point is that even when performing hemiarthroplasty, we addressed the glenoid in relation to soft tissue release and soft

tissue balance as if we intend to insert a glenoid implant. In our series we use the microfracture technique on the glenoid surface to encourage fibrocartilage cover [18–20] (Fig. 4.6).

Mean post-operative Constant score for all diagnoses was 89.2 % (59.8 points) for TSA with resurfacing and 87.9 % (62.3 points) for humeral resurfacing only (HSA) (but with thorough release around the glenoid and microfracture of the glenoid face) with no statistically significant differences (*t*-test, $p = 0.61$) (Fig. 4.7). A highly significant difference between the overall proportions of revised cases was observed, with (21/122) 17.2 % and (6/218) 2.8 % of TSA and HSA cases revised, respectively ($p < 0.0001$).

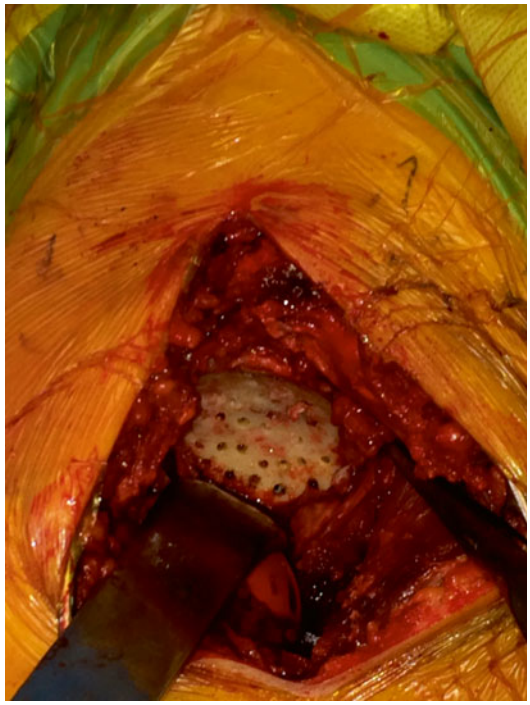


Fig. 4.6 The microfracture technique on the glenoid surface to encourage fibrocartilage cover

One hundred and eighty-nine CSRAs were implanted for osteoarthritis in 173 patients with 16 bilateral replacements (8.5 %). There were 141 women (74.6 %) and 48 men (25.4 %) with a mean age at the time of surgery of 70.9 years (range 37–89 years). Of them 166 shoulders were available for follow-up. The mean follow-up period was 7.1 years (range, 4–17.8 years).

The rheumatoid arthritis cohort consisted of 103 CSRA implanted in 88 patients with 15 bilateral replacements (12.6 %). There were 82 women (79.6 %) and 21 men (20.4 %) with a younger mean age at the time of surgery of 61.1 years (range 22–87 years) compared to the osteoarthritic group. Of them 95 shoulders were available for follow-up. The mean follow-up period was 8.6 years (range, 4–16.3 years).

The results of surface replacement, as in any other shoulder replacement, depend on the underlining aetiology especially regarding the state of the rotator cuff. The best results are achieved in osteoarthritis with an intact cuff and the worst results in cuff tear arthropathy. The rotator cuff was intact in 75 % of osteoarthritis cases whereas was found deficient (torn or atrophic) in more than two thirds of the patients with rheumatoid

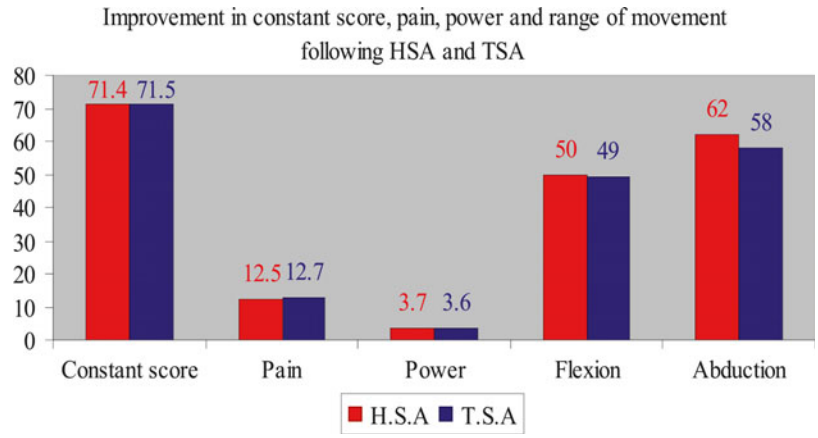


Fig. 4.7 Improvement in Constant score, pain, power and range of movement following HSA and TSA

arthritis. The functional results were assessed by the Constant score, the age- and sex-adjusted Constant score, the range of motion (Table 4.1) and a patient satisfaction score. The average Constant score improved from 12.3 points (16.9 % age-/sex-adjusted score) preoperatively to 65.5 points raw score (94.7 % age-/sex-adjusted score) in the last follow-up for the osteoarthritis patients. The rheumatoid arthritis patients showed slightly more modest improvement from preoperative average Constant score of 8.8 points (11.6 % age-/sex-adjusted score) to 57.2 points raw score (78.1 % age-/sex-adjusted score) in the last follow-up. The mean range of active elevation improved from 69° to 121° in the osteoarthritis group and from 54° to 104° in the rheumatoid arthritis group (Table 4.1). However, both groups showed very high patient satisfaction rate with 96.8 % of the rheumatoid arthritis patients and 93.9 % of the osteoarthritis patients reported that their shoulder was much better or better following the surface replacement.

Radiological results for the Mark 2 (non-HA-coated) prosthesis showed no lucencies around the humeral component in 69.3 %, in the TSA group, whereas no lucencies were seen in 93.9 % of the HSA (humeral surface arthroplasty) group. On the glenoid side, more than half of the glenoids (59.3 %) have shown lucencies (a partial lucent line), and in 5.1 % definite signs of loosening were seen [22]. However, no lucencies were found so far around the hydroxyapatite-coated (Mark 3) humeral implants for more than 12 years [22]. Laser cutting on Copeland surface replacement prosthesis in a cadaveric specimen from a deceased patient that donated his body for research showed that the impaction grafting provides good bony ingrowth and new bone formation under the prosthesis (Fig. 4.8).

Table 4.1 Functional outcome of shoulder resurfacing for primary OA and rheumatoid arthritis

Diagnosis	Primary OA	Rheumatoid arthritis
CS pre-op (points)	12.3	8.8
CS post-op (points)	65.5	57.2
CS adj. pre-op (%)	16.9	11.6
CS adj. post-op (%)	94.7	78.1
FF pre-op (degrees)	69.1	54.0
FF post-op (degrees)	121.3	103.8
Abd. pre-op (degrees)	51.9	40.4
Abd. post-op (degrees)	115.5	101.2

Mean follow-up 7.6 years (between 4 and 17.8 years)
CS Constant score, *CS adj.* age-/sex-adjusted, *FF* forward flexion and *Abd.* abduction

CSRA in Young Patients Less Than 50 Years of Age with 10–25-Year Follow-Up

Between 1990 and 2003, 54 CSRAs were performed on 49 patients (25 men, 24 women) aged younger than 50 years. Mean age was 38.9 years (range, 22–50 years) [21]. Three patients (four shoulders) died over time and eight were lost to follow-up, leaving 38 patients (42 shoulders) with a mean follow-up of 14.5 years (range, 10–25 years). There were 17 total shoulder replacements with metal-backed glenoid, and 37 underwent humeral head resurfacing with microfracture of the glenoid. The indications were avascular necrosis, 16; rheumatoid arthritis, 20; instability arthropathy, 7; primary osteoarthritis, 5; fracture sequelae, 3; postinfection arthritis, 2; and psoriatic arthritis, 1. The mean relative Constant score increased from 11.5 % to 71.8 % ($P < 0.0001$), and the mean patient satisfaction at final follow-up was 8.7 of 10. The mean relative Constant score for the humeral head resurfacing with microfracture of the glenoid

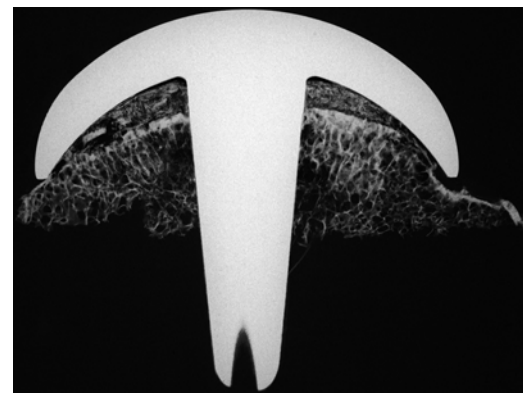


Fig. 4.8 Laser cut of the resurfacing implant showing good integration with the bone and the bone graft underneath the prosthesis

improved to 77.7 % compared with 58.1 % for total resurfacing arthroplasty (Fig. 4.9).

The range of motion and the Constant scores were similar in the total replacement and in the humeral resurfacing group. Two patients required early arthrodesis due to instability and deep infection. Seven were revised to stemmed prosthesis: one for traumatic periprosthetic fracture and one for glenoid erosion 16 years after the index procedure. Five shoulders in four patients (four rheumatoid arthritis, one avascular necrosis) were revised at 8–14 years after surgery for cuff failure and loosening. Three were revised to a stemless reverse total shoulder arthroplasty due to rotator cuff failure at 23, 16 and 13 years after surgery (Fig. 4.10).

Radiological Review

Thirty-five of 38 shoulders were available for radiographic follow-up (92 %). The humeral implants showed no lucencies, two showed localised lucent lines of less than 1 mm and one implant was loose [21]. All the lucencies were observed in TSAs. There were nine glenoid implants (TSAs), of which four were loose (44 %) and one (11 %) showed localised lucent line less than 1 mm thick.

Fifty-eight percent of the 38 shoulders showed some degree of superior migration as an indication for rotator cuff failure or incompetence: 15 (39 %) severe superior migration, 5 (13 %) moderate superior migration and 2 (5 %) mild superior migration. Sixteen shoulders (42 %) showed no superior migration.

Moderate-to-severe glenoid erosion was present in 32 % (four severe and eight moderate) of the shoulders at an average follow-up of more than 14.5 years; however, most of these patients still had a continued good result in measured outcomes. The glenoid erosion was correlated to the rotator cuff failure with superior migration of the humeral head and was more prevalent in the rheumatoid arthritis patients.

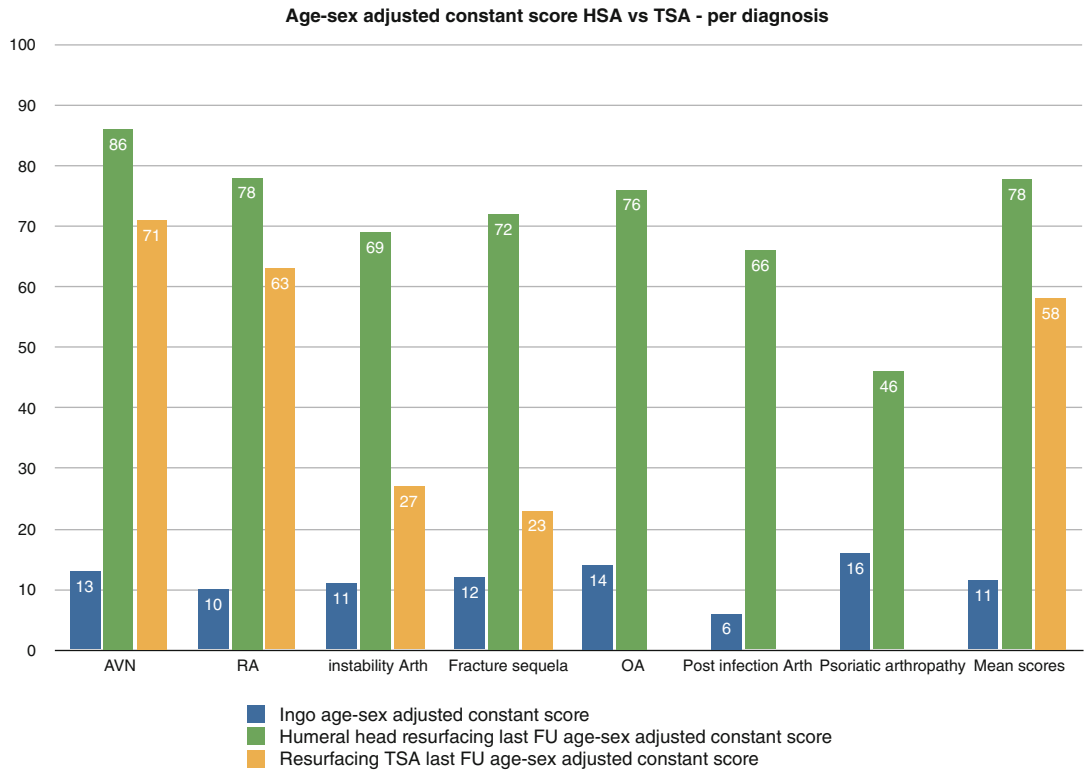


Fig. 4.9 Age-/sex-adjusted long-term Constant score for HSA and TSA in young patients less than 50 years of age

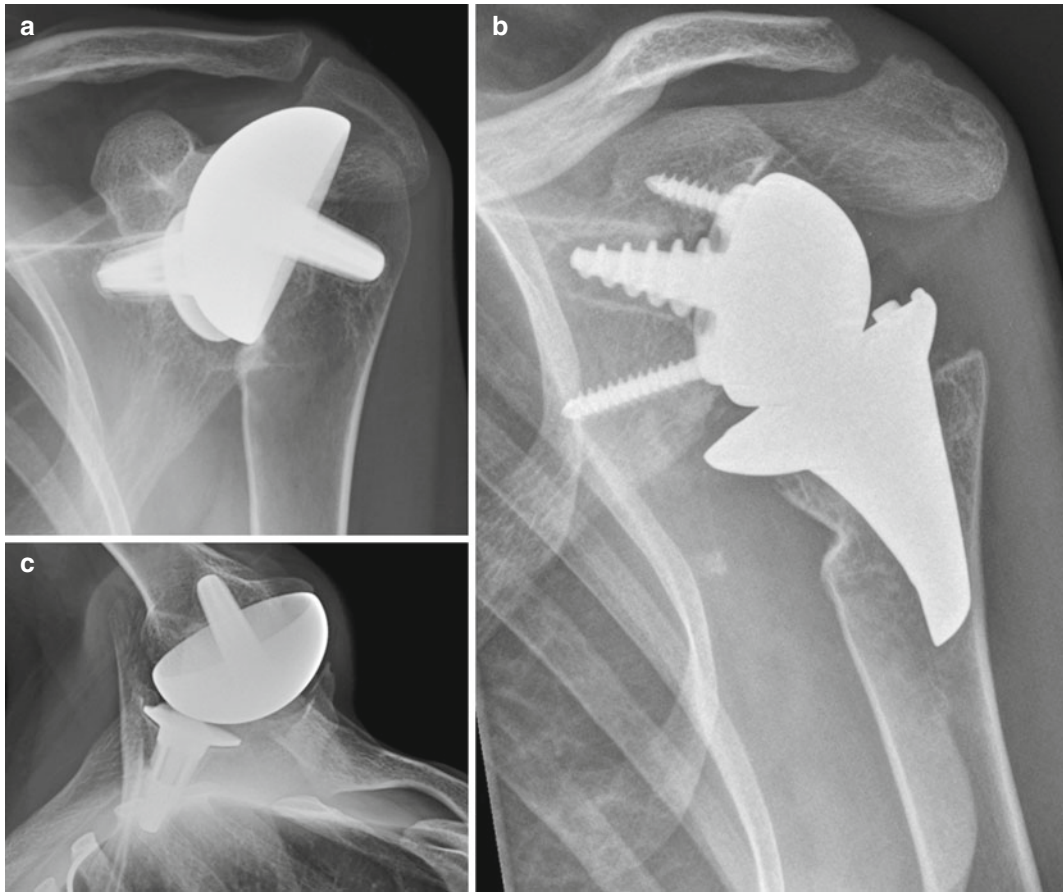


Fig. 4.10 Revision of CSRA to stemless reverse TSA for rotator cuff failure 23 years following CSRA for juvenile RA at the age of 22 years

Survivorship Analysis

Levy et al. [22] showed significantly longer survivorship of HSA resurfacing prostheses than TSA resurfacing prostheses with 97.1 % (92.3–99.3 %) and 81.7 % (81.0–95.5 %), respectively (95 % CI).

The difference between the survival curves was highly significant, both in the earlier postoperative period (Wilcoxon's test, $p = 0.0053$) and later on (log-rank test, $p = 0.0028$) (Fig. 4.11) [17, 22].

The causes for reoperations are listed in Table 4.2. The most common reoperation performed on these shoulder arthroplasty patients in our unit is arthroscopic subacromial decompression (ASD) and AC joint excision arthroplasty for impingement syndrome [20]. This is not a complication of arthroplasty. The prevalence of impingement syndrome and AC joint arthritis symptoms, some time after shoulder arthroplasty, is similar to that of the normal population at the same age range. Prior to the shoulder arthroplasty surgery, none of these patients had had a history of impingement symptoms. They developed subacromial impingement at an average interval of 1.9 years following arthroplasty. It may be that their range of shoulder motion only became sufficient to reach the painful impingement arc after arthroplasty [20].

The Kaplan-Meier survival curve for patients aged 50 years or younger receiving shoulder resurfacing arthroplasty [21] showed estimated revision-free survival rate at 11 years of 97 % for

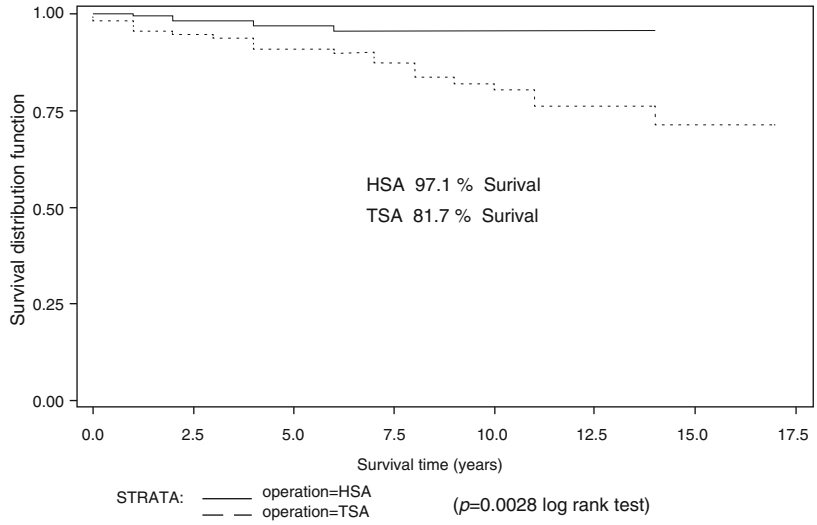


Fig. 4.11 Kaplan-Meier survivorship analysis of resurfacing TSA vs. resurfacing HSA

Table 4.2 Post-operative complications and reoperations

Complication	No. of cases	Action taken
Superficial wound infection	3	Antibiotics – settled
Late haematogenic deep infection	1	Repeated arthroscopic washout and antibiotics – joint saved
Impingement syndrome and AC joint arthritis symptoms[a]	14	Arthroscopic decompression and AC joint excision arthroplasty
Severe instability including anterior-superior escape	6	2 – arthrodesis
		4 – revision to reversed prosthesis
Severe stiffness – capsular and subacromial fibrosis	6	Arthroscopic release
Humeral neck fracture after a fall	7	5 – treated conservatively healed
		2 – revised with stemmed prosthesis
Painful hemiarthroplasty – glenoid erosion	3	Revision to TSA
Reflex sympathetic dystrophy	1	Physiotherapy

[a]Not a complication of arthroplasty

humeral head resurfacing (HSA or hemiarthroplasty) compared with 71 % for TSA, survival of 91 % for HSA compared with 71 % for TSA at 14 years and 85 % for HSA compared with 61 % for TSA at 22 years after resurfacing (Fig. 4.12). Our survival rates for HSA (85 % at 22 years) are similar to Sperling et al. [23] who reported 84 % survival for TSA at 20 years. Our survival rates for TSA (61 % at 22 years) are slightly inferior to survival reported by Sperling et al. of 75 % at 20 years for stemmed hemiarthroplasty. We believe that the increased polyethylene wear and loosening in our series was due to use of metal-backed glenoids.

CSRA provides good long-term symptomatic and functional results in the treatment of glenohumeral arthropathy in patients aged younger than 50 years in 81.6 % of the patients. This improvement is maintained over more than 10 years after surgery, with high patient satisfaction (8.7 of 10). However, ten shoulders (of 54) (18.5 %) underwent revision arthroplasty. Resurfacing offers a valuable tool in treating young patients with glenohumeral arthritis, providing reasonably good long-term results in 81.6 % of the patients, while allowing preservation of bone stock if the need for revision arises. All the revision arthroplasty options are preserved (Fig. 4.10).

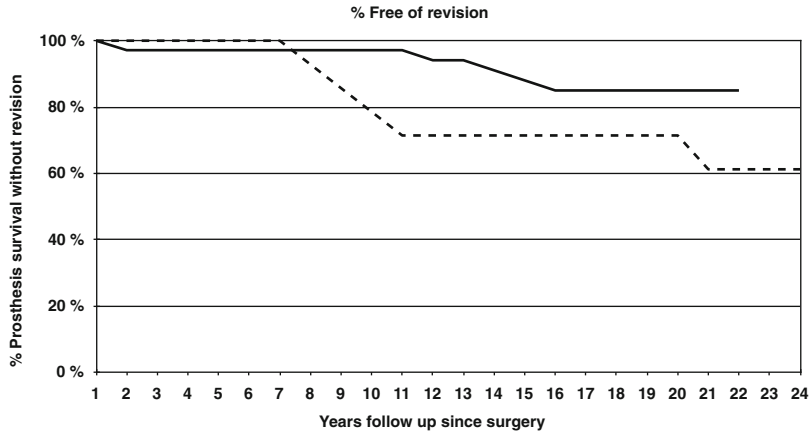


Fig. 4.12 Kaplan-Meier survivorship analysis of resurfacing in young patients – humeral head resurfacing (HSA or hemiarthroplasty) compared with TSA resurfacing. The solid line represents humeral head resurfacing (HSA or hemiarthroplasty) and the dotted line TSA resurfacing with implantation of glenoid component

Table 4.3 Comparison of active movement (degrees) following shoulder resurfacing with other series using stemmed shoulder prosthesis

	Prosthesis	Post-operative active elevation	Gain in active elevation	Post-op ER	Gain in ER
Neer (1982)	Stemmed		+77°		+51°
Cofield (1984)	Stemmed	141°	+55°	49°	+35°
Barrett (1987)	Stemmed	117°	+73°		+33°
Cofield (1992)	Stemmed	154°	+47°	61°	+49°
Boileau (1994)	Stemmed	127°	+48°	41°	+55°
Torchia (1997)	Stemmed	117°	+40°	48°	+19°
Gartsman (1997)	Stemmed	129°	+47°	55°	+39°
Levy and Copeland (2001)	Resurfacing	133°	+68°	48°	+40°
Thomas (2005)	Resurfacing	120°	+47°	46°	+41°
Raj, Levy (2005)	Resurfacing	123°	+51°	61°	+50°
Levy (Young Pts) (2015)	Resurfacing	116°	+38°	51°	+38°

Discussion

Cementless shoulder resurfacing arthroplasty of the shoulder differs in many aspects from a non-constrained stemmed shoulder prosthesis, but the results of shoulder resurfacing are at least comparable with those for stemmed prostheses with a similar follow-up and case mix (Tables 4.3 and 4.4). However, using the cementless shoulder resurfacing arthroplasty diminishes the risk of complications involving the humeral shaft and periprosthetic fractures. Revision or arthrodesis, if the need arises, can be undertaken easier since the bone stock has been maintained with no loss of length. The results with the CSRA were reproducible in other series as well. Thomas et al. [5] reported very similar results to those of Levy and Copeland with the CSRA.

The Glenoid: To Replace or Not To Replace?

Considerable controversy remains in the literature as to whether hemiarthroplasty (HHR) or total shoulder arthroplasty (TSA) is the better treatment option for patients with shoulder arthritis.

Radnay et al. [24, 25] found in their meta-analysis, when comparing hemiarthroplasty (HHR) with total shoulder arthroplasty (TSA) in stemmed prostheses, greater pain relief, forward elevation, gain in external rotation and patient satisfaction in stemmed TSA. Only 6.5 % of all TSAs required revision surgery, compared with 10.2 % of patients undergoing HHR.

AAOS Clinical Practice Guidelines regarding the treatment of glenohumeral osteoarthritis (2010) [25], based on only two level II evidence

Table 4.4 Comparison of the results of shoulder resurfacing in rheumatoid arthritis with other series using stemmed shoulder prosthesis

	Good pain relief	Def. cuff	ROM elevation	ROM ER	ROM IR	Sup. subluxation
Sneppen et al. *JSES 5; 47–52; 1996*	89 %		90°	35°		55 %
7.6-year FU (4–12 years)						
Stewart and Kelly *JBJS (79-B) 68–72; 1997*	89 %	81 %	75°	38°	Buttock-T7	57 %
9.5-year FU (7–13 years)						
Torchia and Cofield *JSES 6; 495–505; 1997*	81 %	74 %	103°	47°	T8	33 %
12.2-year FU (5–17 years)						
Levy and Copeland *JBJS (AM) 86-A; 2004*	96.8 %	68 %	103°	46°	L4	57 %
6.5-year FU (2–14 years)						

studies, Gartsman et al. [26] and Lo et al. [27]), concluded that global health assessment scores and pain relief were statistically significantly better after TSA (with stemmed prostheses). Function and quality-of-life outcome measures in both studies showed no statistically significant differences between groups. No TSA required revision to hemiarthroplasty in these studies; however, 14 % of patients treated with hemiarthroplasty required revision to a TSA.

Levy et al. [22] found in their series, with resurfacing, very little difference in the functional outcome and pain between total shoulder replacement with resurfacing and humeral resurfacing only. An important point is that even when performing hemiarthroplasty, we address the glenoid in relation to soft tissue release and soft tissue balance as if we intend to insert a glenoid implant.

It may be that 'ignoring' the glenoid at the time of surgery and not performing thorough release around the glenoid, as is done when performing TSA, could have some contribution to the difference in results and later glenoid erosion with the stemmed implants as seen in the other series.

In our experience we have found that humeral head recentring can occur following hemiarthroplasty with resurfacing even with Walch type B2 glenoids. The recentring is related to burring the ridge down resulting in an improvement in external rotation, which we believe can be used as an indicator of good soft tissue balance. This may explain why humeral surface arthroplasty (HSA) has excellent outcomes even when there is glenoid erosion and biconcavity preoperatively. It is believed that soft tissue imbalance may lead to glenoid erosion [18, 22].

Kaplan-Meier Survivorship Analysis: Comparison with Stemmed Series

Edwards et al. [28, 29] reported the results of the multicentre study comparing hemiarthroplasty with total shoulder arthroplasty for the treatment of osteoarthritis using a stemmed prosthesis (1542 primary shoulder arthroplasties). Fifty-six percent of TSA had radiolucent lines around the glenoid components. The estimated survival of TSA was much worse than HHR (approximately 97 % for HHR and 69 % for TSA at 9 years). The poor longevity of TSA was ascribed to the use of the metal-backed glenoid component. However, in a follow-up report using data from the same multicentre group, Pfahler et al. [29] found radiolucent lines around 67.9 % of the cemented glenoid implants when metal-backed components were excluded; 50 % of these radiolucent lines were progressive.

In Levy et al. [22] series as well, HSA prostheses survive significantly longer than TSA prostheses with 97.1 % (92.3–99.3 %) and 81.7 % (81.0–95.5 %), respectively (95 % CI). The difference between the survival curves was highly significant, both in the earlier post-operative period (Wilcoxon's test, $p = 0.0053$) and later on (log-rank test, $p = 0.0028$) (Fig. 4.11) [22].

In the young patient cohort [21] as well, the Kaplan-Meier survival curve showed estimated revision-free survival rate at 11 years of 97 % for humeral head resurfacing (HSA or hemiarthroplasty) compared with 71 % for TSA, survival of 91 % for HSA compared with 71 % for TSA at 14 years and 85 % for HSA compared with 61 % for TSA at 22 years post-resurfacing. These survival rates for HSA (85 % at 22 years) are similar to Sperling et al. [23] that reported 84 % survival for TSA at 20 years. These survival rates for TSA (61 % at 22 years) are slightly inferior to Sperling's survival of 75 % at 20 years for stemmed hemiarthroplasty. We believe that the increased polyethylene wear and loosening in our series was due to the use of metal-backed glenoids.

In the young patient group, Levy et al. [21] found no loosening in the HSA group; lucent lines and implant loosening were seen only in the TSA group. We feel that this is the result of glenoid polyethylene wear and reaction to the polyethylene wear debris particles which is worsened with a metal-backed glenoid.

Glenoid Erosion

Theoretically, the difference between the resurfacing series and those with stemmed prostheses regarding the incidence of glenoid erosion may be explained by the fact that with surface replacement, the normal anatomy for each patient can be mimicked with less difficulty [13] and with less place for error than with stemmed prostheses. With stemmed prostheses, the surgeon has more room for error to determine stem positioning, height and version as they are separately controlled, as well as offset and modular head sizing. Any mistake in any of these variables may lead to glenoid uneven or point pressure that may lead to glenoid erosion, deficient soft tissue balance and less favourable result.

We have found in our studies [1–3, 14, 21] symptomatic glenoid erosion as the cause of pain and failure very rarely. In the majority of patients with painful and symptomatic hemiarthroplasty, it is related to other causes such as impingement syndrome and rotator cuff problems, tears and insufficiency, long head of biceps problems and AC joint pain. Unfortunately, we as surgeons have a 'knee-jerk reaction' to blame the glenoid (glenoid erosion) in any painful hemiarthroplasty.

In the young patient group, Levy et al. [21] found moderate-to-severe glenoid erosion in 32 % (four severe and eight moderate) of the shoulders at an average follow-up of more than 14.5 years. The glenoid erosion correlated to the rotator cuff failure with superior migration of the humeral head and was more prevalent in the rheumatoid arthritis patients.

Lee et al. [30] found 56 % of moderate-to-severe glenoid erosion in shoulder resurfacing with anterior capsule interposition on the glenoid at an average follow-up of more than 5 years. It is possible that the capsule interposition created tightness in the joints and led to increased glenoid erosion. However, most of their patients had a continued good result in measured outcomes. Sperling et al. reported 72 % of glenoid erosion for a stemmed prosthesis hemiarthroplasty [23].

Rheumatoid Arthritis

Shoulder replacement in patients with rheumatoid arthritis presents similar soft tissue (rotator cuff) problems irrespective of the implant used (i.e. stemmed or resurfacing). Thus, one should anticipate deterioration of cuff function with time as part of the rheumatoid disease with superior subluxation of the humeral head. This was found in most of the different series to be in the range of 55–57 % of the shoulders [3, 31–33] (Table 4.4). It is not uncommon for patients with rheumatoid arthritis to have involvement of several joints, including the ipsilateral elbow and shoulder. If a stemmed elbow prosthesis and the conventional stemmed shoulder prosthesis are used, a stress riser is created in a very narrow bone bridge between the stems in the mid-part of the humeral shaft (Fig. 4.13a). A periprosthetic fracture in this area would be an extremely difficult problem to treat. The use of resurfacing arthroplasty decreases this risk (Fig. 4.13a, b) [3].

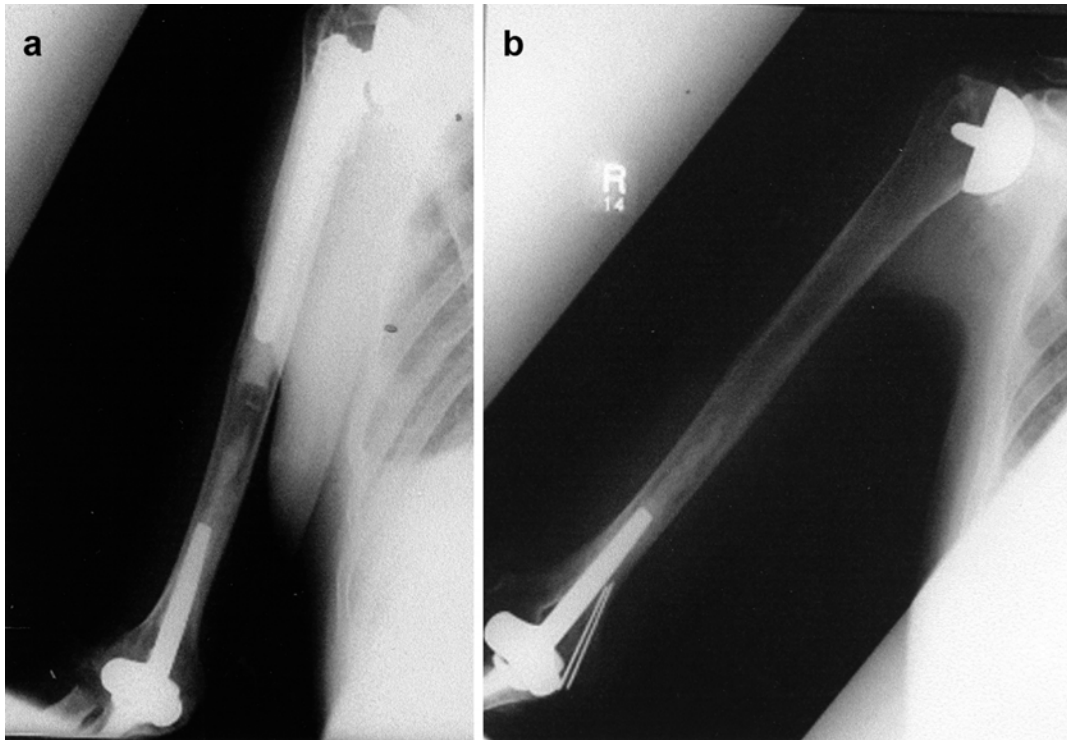


Fig. 4.13 (**a**) Ipsilateral stemmed elbow and conventional shoulder prostheses in a patient with rheumatoid arthritis. A stress riser is created in the very narrow bone bridge between the stems in the mid-part of the humeral shaft. (**b**) Use of ipsilateral stemmed elbow and Copeland cementless surface replacement prostheses decreases the risk of creating a localised stress riser in the humerus between the stems (Courtesy of Michael Thomas, FRCS; Reproduced with permission from Levy et al. [3])

CSRA in Young Patients

Cementless surface replacement arthroplasty has previously been reported to be successful in patients with different aetiologies of glenohumeral arthritis for the elderly with a mean age of 73.4 years [1–4, 34]. Copeland and Levy [34], Bailie et al. [35] and Lee et al. [30] have also reported good short- and midterm results with resurfacing arthroplasty in young patients. Bailie et al. [35] reported significant improvement of the ASES and the SANE scores from preoperatively to 2 years post-operatively, and 30 of the 36 patients were able to participate in their desired level of activity (including sports) after cementless humeral resurfacing arthroplasty.

Lee et al. [30] reported the results of surface replacement hemiarthroplasty of the shoulder with biologic resurfacing of the glenoid with interposed anterior capsule, in 18 shoulders of patients younger than 55 years old with average follow-up of 4.8 years. The post-operative Constant score was 71.4 points (AS adjusted 83.9 %), with average active forward elevation of 130°; 83 % were satisfied with their shoulder resurfacing. None of the implants were loose, but 56 % of shoulders showed moderate-to-severe glenoid erosion.

Sperling et al. reported the results of shoulder arthroplasty with stemmed prostheses in patients younger than 50 years of age [23]. Follow-up at 15 years showed pain relief and improvement in motion after both humeral head replacement (HHR) and total shoulder arthroplasty (TSA). The rates of survival of the HHRs were 82 % at 10 years and 75 % at 20 years, and the rates of survival of the TSAs were 97 % and 84 %, respectively. Revision rate was 22 % in the HHRs and 14 % in the TSAs. Patient satisfaction was poor with 60 % of those with HHR and 48 % of those with TSA were unsatisfied with the results.

A more recent study from Bartelt and Sperling et al. [36] showed similar results to their previous study [23] with a high rate of revision surgery or radiographic failure particularly in hemiarthroplasty. Thirty percent of the patients with HHR were revised at mean time of 4.5 years from the index arthroplasty, and 7 % of the patients with TSA were revised at mean time of 10.9 years from the index arthroplasty; 10/34 (29.4 %) of the patients with TSA had glenoid loosening at a mean follow-up of 7 years.

In recent Levy et al. [21] series, 40 out of 49 young patients (81.6 %) with shoulder resurfacing were pleased with their shoulders and felt much better and better from preoperatively with overall mean satisfaction score of 8.7/10.

The revision rate in the young patients according to Levy et al. [21] seems to be higher than in the elderly age group, yet slightly lower than in the stemmed series [23, 36, 37]. Unlike in Sperling et al. series [23, 36, 37], with CSRA, most of the revisions were needed in the TSA group, mainly due to polyethylene wear and consequently loosening. There were four cases that required revision due to rotator cuff tear and dysfunction.

Should a surface replacement fail, revision to a stemless or stemmed total shoulder arthroplasty (anatomic or reverse) can be easily achieved with simple removal of the humeral surface component. Especially, as there is no cement or prosthetic stem in the humerus, bone stock is consequently maintained and the original anatomy largely preserved.

All revision arthroplasties [21] were considered easy to perform and of the seven shoulders that underwent revision arthroplasty to a stemmed implant, six had satisfactory outcome of the secondary procedure.

The patients that required revision to reverse TSA could be revised to a stemless reverse TSA, which is a bone-preserving prosthesis. These patients showed excellent results with no pain, full function and near full range of motion. They rated their satisfaction as 10/10 with Constant scores of 82–87 points [21, 38, 39]. These patients were revised to a metaphyseal stemless/short reverse arthroplasty (Verso, IDO, London, UK) at the ages of 45 years 52 and 59 years [21, 38, 39].

Return to Sports

Shoulder resurfacing allowed most of the patients to return to their desired activities at a satisfactory level. Most patients returned to sports activities such as resistance training, yoga, Pilates, tennis, squash, golf, horse riding, polo, gym, weight lifting, sailing, windsurfing, skiing, flying, judo and martial arts, cycling, trail mountain biking, bike riding, hockey, cricket and others [19].

Conclusion

Resurfacing offers a valuable tool in treating patients with glenohumeral arthritis, especially young patients. Cementless shoulder resurfacing arthroplasty of the shoulder differs in many aspects from a non-constrained stemmed shoulder prosthesis, but the results of shoulder resurfacing are at least comparable with those for stemmed prostheses. However, using the shoulder resurfacing reduces the risk of complications involving the humeral shaft. Revision or arthrodesis, if the need arises, can be undertaken easier since the bone stock has been preserved. Glenoid exposure for implantation of a glenoid component could be considered more difficult for those less experienced with shoulder replacement. The long-term follow-up has proven the good outcome and the longevity of the cementless resurfacing prosthesis that remains our procedure of choice for the treatment of advanced arthritis of the shoulder.

References

1. Levy O, Copeland SA. Cementless surface replacement arthroplasty of the shoulder. 5- to 10-year results with the Copeland mark-2 prosthesis. J Bone Joint Surg Br. 2001;83(2):213–21.
2. Levy O, Copeland SA. Cementless surface replacement arthroplasty (Copeland CSRA) for osteoarthritis of the shoulder. J Should Elb Surg/Am Should Elb Surg. 2004;13(3):266–71.
3. Levy O, Funk L, Sforza G, Copeland SA. Copeland surface replacement arthroplasty of the shoulder in rheumatoid arthritis. J Bone Joint Surg Am. 2004;86-A(3):512–8.
4. Mullett H, Levy O, Raj D, Even T, Abraham R, Copeland SA. Copeland surface replacement of the

shoulder. Results of a hydroxyapatite-coated cementless implant in patients over 80 years of age. J Bone Joint Surg Br. 2007;89(11):1466–9.
5. Thomas SR, Wilson AJ, Chambler A, Harding I, Thomas M. Outcome of Copeland surface replacement shoulder arthroplasty. J Shoulder Elbow Surg. 2005;14(5):485–91.
6. Neer 2nd CS, Watson KC, Stanton FJ. Recent experience in total shoulder replacement. J Bone Joint Surg Am. 1982;64(3):319–37.
7. Steffee AD, Moore RW. Hemi-resurfacing arthroplasty of the shoulder. Contemp Orthop. 1984; 9:51–9.
8. Jonsson E, Egund N, Kelly I, Rydholm U, Lidgren L. Cup arthroplasty of the rheumatoid shoulder. Acta Orthop Scand (Res Support Non-US Gov't). 1986;57(6):542–6.
9. Rydholm U. J. S. Surface replacement of the humeral head in the rheumatoid shoulder. J Shoulder Elbow Surg. 1993;2:286–95.
10. Copeland S. The continuing development of shoulder replacement: "reaching the surface". J Bone Joint Surg Am (Congresses). 2006;88(4):900–5.
11. Raj D, Mullett H, Even T, Abraham R, Copeland SA, Levy O. Hydroxyapatite-coated Copeland surface replacement arthroplasty. Long term follow up. 19th Congress of the European Society for Surgery of the Shoulder and Elbow (ESSSE); 21–24 Sept 2005; Rome; 2005.
12. Boileau P, Walch G. The three-dimensional geometry of the proximal humerus. Implications for surgical technique and prosthetic design. J Bone Joint Surg Br. 1997;79(5):857–65.
13. Thomas SR, Sforza G, Levy O, Copeland SA. Geometrical analysis of Copeland surface replacement shoulder arthroplasty in relation to normal anatomy. J Shoulder Elbow Surg. 2005;14(2):186–92.
14. Copeland S, Funk L, Levy O. Surface-replacement arthroplasty of the shoulder. Curr Orthop. 2002;16:21–31. Current Orthopaedics 16, 21–31 2002 2002;16, 21–31. 2002. :21–31.
15. Levy O, Raj D, Copeland S. Copeland surface replacement arthroplasty of the shoulder for severe bone loss – extending the frontiers. J Bone Joint Surg Br. 2006;88-B:346. Orthopaedic Proceedings.
16. Mackenzie D. The anterosuperior exposure of a total shoulder replacement. Arthop Traumatol. 1993; 2:71–7.
17. Levy O. Shoulder resurfacing: is it really as good as total shoulder replacement? Curr Orthop Pract. 2012;23(1):2–9.
18. Levy O. The glenoid – to replace or not to replace? – Instructional course lectures 3. 11th International conference on Shoulder and Elbow Surgery ICSES 2010; Edinburgh; 2010.
19. Levy O. Surface replacement arthroplasty. In: Zuckerman JD, editor. Advanced reconstruction: shoulder. AAOS; 2007.
20. Tytherleigh-Strong GM, Levy O, Sforza G, Copeland SA. The role of arthroscopy for the problem shoulder arthroplasty. J Shoulder and Elbow Surg. 2002;11(3): 230–4.
21. Levy O, Tsvieli O, Merchant J, Young L, Trimarchi A, Dattani R, et al. Surface replacement arthroplasty for glenohumeral arthropathy in patients aged younger than fifty years: results after a minimum ten-year follow-up. J Shoulder Elbow Surg. 2015;24(7):1049–60.
22. Ofer Levy, Eyiyemi Pearse, Tirtza Even, Dipak Raj, Ruben Abrahams, Copeland S. Hemiarthroplasty versus total shoulder arthroplasty with the surface replacement arthroplasty. Functional outcome and survival analysis. 11th International conference on Shoulder and Elbow Surgery ICSES 2010; Edinburgh; 2010.
23. 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 Should Elb Surg/Am Should Elb Surg. 2004;13(6):604–13.
24. 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 Should Elb Surg (Comp Study Meta Anal Rev). 2007;16(4):396–402.
25. Rolando Izquierdo MD C. AAOS – The treatment of glenohumeral joint osteoarthritis guideline and evidence report. 2009; Available from: http://www.aaos.org/research/guidelines/gloguideline.pdf.
26. Bryant D, Litchfield R, Sandow M, Gartsman GM, Guyatt G, Kirkley A. A comparison of pain, strength, range of motion, and functional outcomes after hemiarthroplasty and total shoulder arthroplasty in patients with osteoarthritis of the shoulder. A systematic review and meta-analysis. J Bone Joint Surg Am (Comp Study Meta Anal Rev). 2005;87(9):1947–56.
27. Lo IK, Litchfield RB, Griffin S, Faber K, Patterson SD, Kirkley A. Quality-of-life outcome following hemiarthroplasty or total shoulder arthroplasty in patients with osteoarthritis. A prospective, randomized trial. J Bone Joint Surg Am (Clin Trial Comp Study Random Control Trial Res Support Non-US Gov't). 2005;87(10):2178–85.
28. Edwards TB, Kadakia NR, Boulahia A, Kempf JF, Boileau P, Nemoz C, et al. A comparison of hemiarthroplasty and total shoulder arthroplasty in the treatment of primary glenohumeral osteoarthritis: results of a multicenter study. J Should Elb Surg (Clin Conf Comp Study Multicenter Study Res Support Non-US Gov't). 2003;12(3):207–13.
29. Pfahler M, Jena F, Neyton L, Sirveaux F, Mole D. Hemiarthroplasty versus total shoulder prosthesis: results of cemented glenoid components. J Should Elb Surg (Comp Study Multicenter Study). 2006;15(2): 154–63.
30. Lee KT, Bell S, Salmon J. Cementless surface replacement arthroplasty of the shoulder with biologic resurfacing of the glenoid. J Shoulder and Elbow Surg. 2009;18(6):915–9.
31. Sneppen O, Fruensgaard S, Johannsen HV, Olsen BS, Sojbjerg JO, Andersen NH. Total shoulder replacement

in rheumatoid arthritis: proximal migration and loosening. J Should Elb Surg (Clin Trial). 1996;5(1): 47–52.
32. Stewart MP, Kelly IG. Total shoulder replacement in rheumatoid disease: 7- to 13-year follow-up of 37 joints. J Bone Joint Surg Br. 1997;79(1):68–72.
33. 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.
34. Copeland SA, Levy O, Brownlow HC. Resurfacing arthroplasty of the shoulder. Tech Should Elb Surg. 2003;4(4):199–210.
35. Bailie DS, Llinas PJ, Ellenbecker TS. Cementless humeral resurfacing arthroplasty in active patients less than fifty-five years of age. J Bone Joint Surg Am. 2008;90(1):110–7.
36. Bartelt R, Sperling JW, Schleck CD, Cofield RH. Shoulder arthroplasty in patients aged fifty-five years or younger with osteoarthritis. J Shoulder Elbow Surg. 2011;20(1):123–30.
37. 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):464–73.
38. Levy O, Atoun E, Narvani A, Abraham R, Hous N, Even T, et al. Does reverse shoulder need a stem? 2–7 years follow-up with stemless reverse total shoulder prosthesis. J Shoulder Elbow Surg. 2013;22(4):e32–3.
39. Atoun E, Van Tongel A, Hous N, Narvani A, Relwani J, Abraham R, et al. Reverse shoulder arthroplasty with a short metaphyseal humeral stem. Int Orthop (SICOT). 2014;38:1213–8.

Stemless Humeral Head Replacement

5

Brian Lee and Joseph Abboud

Introduction

Neer first published on prosthetic replacement of the proximal humerus as a treatment for fractures in 1955, and with time, the use of this prosthesis expanded to the treatment of glenohumeral arthritis [1]. This first-generation shoulder prosthesis included a monoblock stem with a single head size, fixed geometry and utilized a press fit system. Neer then modified his original design with the Neer II prosthesis, featuring two head sizes, a glenoid component, and allowed for cement fixation of the humeral stem. However, fluoroscopic studies demonstrated that this implant did not accurately reproduce the kinematics of the native shoulder [2, 3].

The second generation of the shoulder prosthesis was highlighted by introducing modularity, separating the head and stem. The neck continued to maintain a fixed angle of inclination, version, and offset until the third generation of the shoulder prosthesis, which allowed for variation of these orientations of the humeral head, granting the prosthesis' three-dimensional modularity. Since that time, further variability in the humeral stem has been developed, including changes in shape, use of cement for fixation, and different types of surface finish material.

Despite the evolution of shoulder arthroplasty and notably the humeral prosthesis, complications remain. Stem-related complications include humeral fracture during placement, proximal stress shielding (up to 43 %*), [4] loosening (up to 17 %) [5], and periprosthetic fracture (1–2 %) [6]. Such complications can require the use of increased operating room time, risk to the patient as well as need for more costly intervention such as the need for a longer stemmed prosthesis, and change in postoperative rehabilitation. In the revision setting, complications include osteolysis, difficulty with cement or stem extraction, and bone loss due to stress shielding.

Stemless designs represent the next generation in shoulder arthroplasty. Adapted from the experience in hip resurfacing, the first humeral head resurfacing prostheses were made from stainless steel, lacked a central stem, and relied on cement fixation. In 1986, Copeland introduced the Mark I prosthesis (Zimmer Biomet, Warsaw, IN), which had a large central stem and a screw engaging the head from the lateral humeral cortex [7]. A cementless peg glenoid was utilized to resurface

B. Lee, MD (✉)
Department Orthopaedic Surgery,
Kerlan Jobe Orthopaedic Clinic,
6801 Park Terrace, Los Angeles, CA 90045, USA
e-mail: BLee127@gmail.com

J. Abboud, MD
Department Orthopaedic Surgery,
Rothman Institute, Thomas Jefferson University,
925 Chestnut St., 5th Floor,
Philadelphia, PA 19107, USA
e-mail: Abboudj@gmail.com

© Springer International Publishing Switzerland 2016
A.D. Armstrong, A.M. Murthi (eds.), *Anatomic Shoulder Arthroplasty*,
DOI 10.1007/978-3-319-29164-2_5

the glenoid. Subsequent screw removal and biomechanical testing revealed that the screw was not necessary for adequate fixation and was therefore absent in the Mark II design. This design also presented a metal-backed, fluted taper fit-pegged glenoid component. The Copeland design is a form of resurfacing, which fits the humeral head by placing a specialized reamer over the head to fit a metal prosthesis. These can sometimes be coupled with a glenoid prosthesis, as will be described. More recently, a newer design of stemless humeral arthroplasty has been introduced. In contrast to a resurfacing, these models call for a resection of the humeral head, similar to with a stemmed shoulder replacement. While this results in a larger bone resection proximally, it facilitates glenoid exposure, which can be difficult with resurfacing. This may be particularly desirable given that total shoulder arthroplasty has favorable functional outcomes when compared with hemiarthroplasty [8–10].

The anatomy of the proximal humerus demonstrates a wide range of offsets, inclinations, and versions. Retroversion is markedly variable, ranging from 0 to 55°. The inclination of the humerus can range from 30 to 55° [11], and the humeral shaft has a posterior and medial offset with regard to the humeral head [12, 13]. One goal of arthroplasty is to perform an anatomic reconstruction, which should result in stability and mobility of the prosthesis and improve durability [14]. This can be accomplished by restoring normal soft tissue tension, replicating the original center of rotation, and allowing for an arc of motion within the normal range. Alterations of only 4–5 mm from normal can cause alterations in the kinematics of the glenohumeral joint and the forces acting across it [15–18]. The components, especially the stem, must be placed in anatomic position to best recreate anatomy and restore function. A stem placed in varus alignment can cause joint overstuffing, with resultant decreased range of motion and increased risk of subsequent rotator cuff tear, including failure of subscapularis tendon repair. A stem that is not fully seated results in a head sitting higher than normal, which results in the infraspinatus and subscapularis functioning more along adductor rather than abductor vectors [19]. This puts further strain on the supraspinatus to abduct the humerus. Replicating the size of the native head is also very important, as a correctly sized head restores the proper lever arms of the rotator cuff muscles. While a prosthetic head that is larger than the native can similarly cause overstuffing, a head that is too small can result in diminished range of motion [20].

Although there have been studies demonstrating adequacy of third-generation implant systems in recreating anatomy, with a stemmed shoulder replacement system, the surgeon would require an infinite amount of modularity in the final prosthesis in order to perfectly recreate every individual's anatomy [21, 22]. The advantage of stemless replacement designs lies in the preservation of bone. An intramedullary stem is not necessary for fixation of the head; thus, the variable offset between head and shaft does not need to be addressed in the final prosthesis. Perfect positioning/alignment of a stem and head is not required to achieve an anatomic reconstruction, and intraoperative complications such as humeral perforation during stem placement are minimized.

Another advantage of the stemless humeral prosthesis lies in situations where the arthroplasty requires revision. Multiple authors have described easy removal of the humeral component because of the absence of an intramedullary stem and/or cement fixation [11, 23]. The morbidity of revision surgery, including extended surgical times, blood loss, risk of fracture, need for osteotomies and bone loss associated with extraction of a well-fixed, cemented humeral stem, is thereby prevented. One report remarkably described the use of a stemless prosthesis after removing a stemmed prosthesis [24]. This may be a treatment option if sufficient bone remains to support a stemless prosthesis after the stem is removed and adds the aforementioned benefits should future revision surgery become necessary.

In the case of postoperative periprosthetic fractures, the location of the fractures with an implanted stemless replacement seems to differ from traditional shoulder arthroplasty. Stemmed prostheses create a stress riser at the midshaft of the humerus, which can predispose to diaphyseal

fracture [25]. Often, these fractures require the use of a long-stemmed prosthesis once the stem is removed, as the prosthesis should extend at least two cortical diameters distal to the extent of the fracture [6]. With stemless arthroplasty, periprosthetic fractures are more likely to involve the metaphyseal region and do not require the use of a long-stemmed prosthesis during revision [2, 26]. As the number of total shoulder arthroplasties performed each year continues to increase [27], so too will the burden of revision cases, and stemless models provide significant advantages in this setting.

Indications

Historically, stemless humeral resurfacing and replacement have been thought to be a treatment option for osteoarthritis or advanced osteonecrosis of the humeral head in the physiologically young patient. By relying on proximal metaphyseal fixation, minimal bone resection is required. With increased activity level and expected lifespan in younger patients comes a higher likelihood of revision surgery. Stemless implants offer advantages in this setting, avoiding complications associated with stem extraction such as bone loss and fracture as previously mentioned. Stemless designs also offer an advantage over the stemmed components in the ability to perform an anatomic reconstruction regardless of the stem/head offset which can lie outside the normal ranges. The original indications have thus been expanded to include metaphyseal dysplasia, posttraumatic arthritis and proximal humeral malunion. In the setting of a malunion, without the necessary articulation with an intramedullary stem, stemless humeral replacement may be able to better recreate the center of rotation of the head and avoid a greater tuberosity osteotomy [28, 29].

Currently, the indications for stemless humeral replacement are nearly the same as those for a stemmed prosthesis. The major indication that requires a stemmed humeral component is the setting of significant humeral bone loss. Similarly, proximal humerus fractures involving the surgical neck also require a stemmed prosthesis in order to gain adequate stability of the head. Adequate bone (at least 60 % of the humeral head) must be present in the humeral metaphysis to support the stemless head.[7] Investigators are examining the possibility of augmenting deficient metaphyseal bone. While polymethyl methacrylate (PMMA) cement provides excellent initial fixation, it is a permanent foreign body that causes a significant exothermic reaction during polymerization. A recent cadaveric study examined the biomechanical properties of a bone graft substitute to augment fixation of a stemless humeral component in the setting of compromised metaphyseal bone [30]. They found no significant difference in fixation when compared with PMMA bone cement. Future studies are required to examine in vivo and long-term efficacy of this and other options for the augmentation of insufficient proximal metaphyseal bone.

In younger patients with a focal chondral defect, partial humeral resurfacing remains a treatment option when nonoperative management fails. Rather than resurface the entire humeral head, replacing the defect alone preserves the remaining unaffected cartilage and bone for future procedures. While short-term results were very promising [31–33], with longer follow-up, conflicting results have been reported, including loosening rates of up to 25 % [34, 35].

Technical Tips and Pearls

Preoperative radiographs of the shoulder, including an anteroposterior/Grashey view with the humerus in 30° external rotation, should be used to template the size of the head. The final decision is made intraoperatively after exposure and trialing of the humeral head. Degenerative changes, bone loss, and osteophytes should be evaluated to estimate the position of the prosthetic head. The axillary view should be reviewed to identify glenoid wear pattern and for the presence of humeral subluxation.

Stemless total shoulder arthroplasty can be performed through a deltopectoral or superior Mackenzie approach [36].

Deltopectoral Approach

We prefer the deltopectoral approach as it is extensile and allows for easier visualization and release of the anterior capsule and soft tissues, which is important in allowing for adequate exposure, minimizing intraoperative complications such as fracture, and allowing for improved postoperative range of motion. This approach also leaves the deltoid muscle intact, utilizing the internervous plane between the deltoid and pectoralis major.

The patient is positioned in the beach chair with the torso and head elevated 30°. The upper extremity is prepped and draped in usual sterile fashion. The incision is carried sharply over the deltopectoral interval down to the level of the deep fascia, and the cephalic vein and deltoid are retracted laterally. The clavipectoral fascia is released lateral to the conjoint tendon, and the axillary nerve is palpated and protected throughout the procedure. Carefully, the conjoint tendon is then retracted medially, and the anterior humeral circumflex vessels are identified and ligated in order to prevent bleeding. Subsequently the biceps tendon is identified, the rotator interval is released sharply to the base of the coracoid, and the biceps can be tenodesed or tenotomized according to surgical plan.

The subscapularis and capsule are then released in a single layer off the lesser tuberosity. It is important to release the capsule down past the 6 o'clock position of the humerus. The humeral head can then be dislocated into the surgical field with simultaneous adduction, extension, and external rotation. We advocate a controlled external rotation in particular, as the torsional forces on the proximal humerus can result in spiral fractures [37]. It is imperative to be able to visualize the posterior rotator cuff, in order to accurately determine the size of the humeral head and to prevent resection of the rotator cuff insertion. Humeral osteophytes can be resected with curved osteotomes and rongeurs to visualize the native head. Inadequate osteophyte removal can result in overstuffing of the joint, malpositioning of the prosthesis, rotator cuff tear, and decreased postoperative range of motion.

Preoperative templating gives the surgeon a plan of what head size will most accurately recreate the patient's native anatomy. The humeral head is visualized and templated according to the system utilized. If the system calls for a freehand anatomic cut, we advocate the use of electrocautery to outline the anatomic neck. Posteriorly the insertion of the cuff is visualized, taking care to leave the "bare spot" intact. This corresponds to the region of infraspinatus and teres minor and is 6–8 mm in length without cartilage or tendon insertion. The cut is then made with the use of a sagittal saw, taking care to avoid resecting the insertion of the rotator cuff.

Superior Approach

The superior approach has been favored by Copeland [7] and allows direct access to the glenoid through a deltoid or acromial takedown. It also has the advantage of a smaller scar, no disturbance of the cephalic vein, and more direct access to the posterior and superior rotator cuff for reconstruction, if required. However, there is more risk of injury to the axillary nerve branches to the anterior deltoid and difficulty or failure with deltoid muscle repair.

The patient is positioned with the head of the bed elevated at least 60°. An incision is made in line with the anterior edge of the acromion starting at the posterior aspect of the acromioclavicular joint extending laterally. The deltoid muscle is carefully dissected off the subcutaneous tissue, and the raphe of the deltoid is identified. It is then incised sharply with a Bovie, taking care to leave deltoid tendon on both sides for future repair. This incision should not be made more than 6 cm distal to the acromion, as the axillary nerve runs deep to the deltoid muscle beyond that distance.

The coracoacromial ligament is left intact if the rotator cuff is torn. The rotator interval is identified and incised sharply following the course of the long head of the biceps tendon. The biceps can be tenodesed, tenotomized, or dislocated posteriorly at this point. The subscapularis is then dissected sharply off the lesser tuberosity, and the shoulder is

dislocated anteriorly. Blunt Holman retractors can be placed around the surgical neck of the humerus from posterior and anterior to facilitate visualization of the head and retract the deltoid muscle. All osteophytes are resected, and the posterior cuff is visualized. The humeral head can then be resected using a freehand cut or guided by the specific instrumentation of the selected prosthesis.

If the glenoid is to be resurfaced, a variety of retractors can be utilized to facilitate glenoid exposure. A Fukuda retractor, Bankart retractors, and/or blunt Holman retractors can be used to retract the humeral head posteriorly, deltoid laterally, and the subscapularis medially. These retractors should be held carefully as excessive retraction can result in iatrogenic fracture of the glenoid or impaction of the cut surface of the proximal humerus. The axillary nerve should be palpated and protected throughout this stage. The labrum is resected sharply, and the axillary nerve is palpated and protected inferiorly during release of the inferior capsule. Optimal exposure of the glenoid is required to assess the degree of disease, to contour the glenoid surface to a concentric surface, and to resurface the fossa with polyethylene. While we prefer to use a central-pegged component with multiple peripheral pegs, placing a keeled glenoid component may be more feasible in the setting of a difficult exposure.

The humeral component is then placed according to the system's instrumentation. Care must be taken to accurately identify the native humeral head and recreate it accurately in order to prevent the aforementioned complications associated with improper head sizing. Once the head is implanted, the glenohumeral joint is reduced, and with the arm held in the scapular plane, the humeral head should be able to be translated 50 % of its diameter posteriorly, with spontaneous reduction when the posterior force is removed. The head should also be able to translate inferiorly 25 % of its diameter, and the arm should externally rotate 40° when the subscapularis tendon repair is approximated. When preparing the humerus if there is any evidence of stemless instability or poor fixation, then conversion to a stemmed implant is recommended.

The subscapularis is then repaired carefully according to surgeon preference. The repair and healing of the subscapularis is of paramount importance; we prefer to place sutures through bone tunnels running under the bicipital groove. The axillary nerve is palpated to ensure integrity, range of motion is again confirmed, and the wound is closed in layered fashion.

Results

Stemless Humeral Arthroplasty

Biomet TESS

The stemless arthroplasty with the longest follow-up is the Biomet Total Evolutive Shoulder System (TESS). This design features a six-armed metaphyseal fixation device, the "corolla," made of cobalt chrome with titanium plasma spray and hydroxyapatite coating. The TESS has the option to have stemmed or stemless fixation. First implanted in 2004, early results were reported by Huguet and colleagues [38]. At minimum 3 years of follow-up, 72 stemless shoulder replacements in 70 patients demonstrated no radiolucencies or implant migration and functional results comparable with traditional glenohumeral arthroplasty.

The Biomet TESS system is unique in that it allows for the option of stemless reverse arthroplasty as well. The same corolla is used to maintain fixation in the humeral metaphysis and also has the option for a stemmed prosthesis. In 2012, the results of 105 stemless reverse TESS procedures were reported. With minimum 2-year follow-up, the authors reported favorable outcomes with no component loosening and 96 % patient satisfaction [39]. A subsequent study with mean follow-up of 58 months (minimum 38) in 56 stemless reverse arthroplasties demonstrated no humeral loosening and 4 cases of instability/dissociation requiring conversion to a stemmed prosthesis [40]. The authors concluded that the results of stemless reverse were similar to those of a stemmed prosthesis at midterm follow-up.

Arthrex Eclipse

The Arthrex (Arthrex, Naples, FL) Eclipse (Fig. 5.1) was first implanted in 2005. It features a titanium rough-blasted trunnion (Fig. 5.2)

coated with BONIT and plasma spray. The trunnion is fixed near the center of rotation of the humeral head with a self-tapping cage screw that compresses the trunnion onto the resection surface. The outer margin of the trunnion gains support from the cortical bone, and fins on the back surface are present to gain additional fixation and prevent rotation of the prosthesis. The humeral head is affixed by a cone mechanism and is also supported by cortical bone. By placing the fixation of the trunnion close to the center of rotation, a short lever arm is generated at the articulation between the head and trunnion, resulting in lower shear forces on the trunnion and cage screw. A finite element analysis of the Eclipse demonstrated that the highest load is found at the medial cortex of the cut humerus, similar to a healthy proximal humerus [41]. The system also features a metal-backed glenoid or an all polyethylene component for glenoid resurfacing.

Fig. 5.1 The Arthrex Eclipse prosthesis

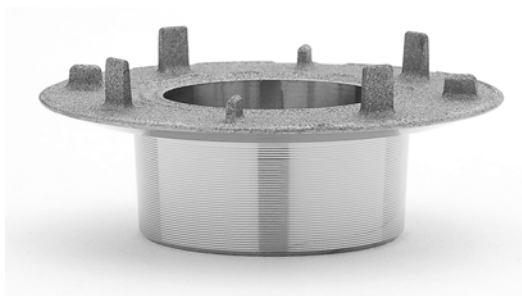


Fig. 5.2 Close-up of the trunnion with close-up of fins providing additional stability and BONIT coating

Schoch et al. reported on their experience with the Arthrex Eclipse stemless humeral replacement system in 2011 [42]. With short-term follow-up (mean 13.2 months) on 96 shoulder replacements, Constant-Murley scores improved significantly in both primary osteoarthritis and posttraumatic arthritis. Range of motion also improved to flexion >140°, abduction >100°, and external rotation >35° for both indications with the primary osteoarthritis group demonstrating slightly increased range of motion.

In 2012, Brunner et al. published their report on 233 patients who underwent stemless shoulder arthroplasty with the Eclipse for a variety of diagnoses (100 primary OA, 29 instability, 16 rheumatoid arthritis, 6, avascular necrosis, 3 cuff tear arthropathy, and 4 postinfectious arthritis) [43]. Of these, 114 were hemiarthroplasties and 119 total shoulder arthroplasties. With average 23-month follow-up, they found significant improvement in Constant-Murley scores for all indications, with primary osteoarthritis patients demonstrating best results. The overall complication rate was 9.8% with one case of prosthetic loosening, two cases of periprosthetic fracture, and 11 cases of revision surgeries. Although long-term studies are necessary, they concluded that the Eclipse had promising results in the variety of indications studied.

More recently, Habermeyer and colleagues reported their results with the prosthesis [29]. Seventy-eight patients with average age of 58 years underwent 96 stemless humeral head replacements and were prospectively followed for a mean of 6 years. A cementless metal-backed glenoid was utilized in the first 15 total shoulder arthroplasty cases, while the next ten received a keeled polyethylene component. For both primary osteoarthritis and posttraumatic arthritis, Constant-Murley score and all subcategories of the scoring (pain, ADL, ROM, strength) improved significantly, except for abduction strength. Active flexion, abduction, and external rotation were found to improve for both groups significantly.

An area of diminished bone density in the area of the greater tuberosity was seen in 35 % of patients, which did not seem to be associated with hemiarthroplasty or shoulder arthroplasty. One patient demonstrated osteolysis of the greater tuberosity and loss of trunnion bony support; however, he/she did not undergo revision. Three patients were revised to reverse shoulder arthroplasty and one hemiarthroplasty underwent secondary implantation of a glenoid component. The overall complication rate in this series was reported as 12.8 % with revision surgery in 9 % of patients. No implant-specific complications were noted, and the authors noted that the Eclipse demonstrated results equivalent to third-generation stemmed shoulder arthroplasty.

Tornier Simpliciti

The Tornier Simpliciti (Tornier, Edina, MN) arthroplasty was first implanted in France in 2010. It is composed of a two-piece humeral system, including a humeral head implant and humeral metaphyseal implant. The humeral head has a male Morse taper, while the metaphyseal implant features three fins with a collar and a female Morse taper (Fig. 5.3). The entire unit is impacted into the humeral metaphysis. The collar and fins are covered with porous bony ingrowth coating, and the collar has nine slots to aid with future extraction (Fig. 5.4).

The Investigational Device Exemption (IDE) trial recently completed its 2-year minimum follow-up in November 2014 leading to FDA approval and therefore is now the first FDA-approved system available for use in the United States.

Zimmer Sidus

The Zimmer Sidus (Figs. 5.5, 5.6, and 5.7) was recently introduced, and an IDE has been initiated in the United States. It features a four open-fin humeral anchors composed of titanium alloy to gain metaphyseal fixation and prevent rotational forces (Fig. 5.8). Each fin has an anti lever out surface to resist shear loads, and surfaces are rough blasted to promote bone ingrowth. The male taper on the anchor is compatible with the Bigliani/Flatow Standard heads.

Fig. 5.3 The Tornier Simpliciti two-part prosthesis, with three-finned metaphyseal component and head affixed by Morse taper

Fig. 5.4 Close-up of bony ingrowth coating and slots to facilitate extraction during revision

Stemmed Versus Stemless Humeral Replacement

To date, only two studies have been published comparing the results of stemless and traditional stemmed humeral arthroplasty. In 2013, one study randomized 19 shoulders with end-stage

Fig. 5.5 The Zimmer Sidus

Fig. 5.6 Schematic of the Zimmer Sidus after implantation

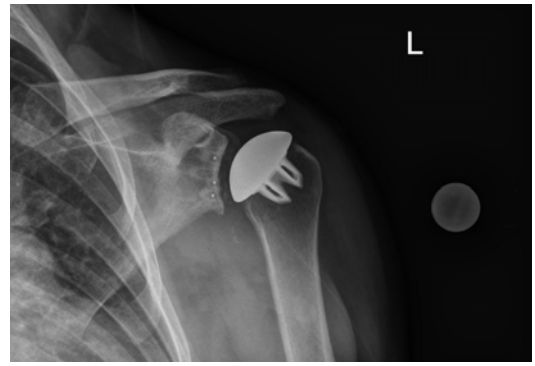


Fig. 5.7 Postoperative radiographs of the Zimmer Sidus

Fig. 5.8 The anchor of the Sidus features four open titanium alloy fins and a male taper compatible with the standard Bigliani/Flatow system heads

osteoarthritis to total shoulder arthroplasty with the Tornier Aequalis stemmed or stemless system [44]. At 2-year follow-up, no patients experienced complications in either cohort, and no difference in Constant score, Simple Shoulder Test score, and range of motion was observed between the two groups.

In 2012, Berth et al. published a larger prospective trial comparing the results of 82 patients with osteoarthritis refractory to nonoperative management treated with primary shoulder arthroplasty [45]. The patients were randomized to two groups, one treated with the Mathys Affinis stemmed

shoulder arthroplasty and the other with the stemless Biomet TESS. The stemmed arthroplasty group had a two-pegged glenoid component placed, while the stemless group had a keeled glenoid component. At a mean of 32 months after surgery, they found no significant difference in Constant or DASH score, but did find increased operative time and estimated blood loss in the stemmed arthroplasty group. It should be noted that although the two studies demonstrate encouraging results, they were not powered to detect a difference in the scores assessed, and both studies recommend further studies with larger sample sizes and longer follow-up.

Conclusion

Stemless systems represent the next generation in the evolution of the humeral prosthesis. The lack of a stem theoretically allows the surgeon to more accurately recreate the native anatomy, prevents intraoperative complications such as fracture during stem placement, minimizes periprosthetic fractures, and facilitates revision surgery. Indications for stemless humeral replacement have expanded and are now thought to encompass nearly all indications for traditional stemmed arthroplasty. The majority of the stemless humeral replacement literature thus far has examined humeral resurfacing, with encouraging short- and midterm results. Newer systems are now being released which allow for an anatomic resection of the humeral head and facilitate total shoulder arthroplasty, and while further studies are required to examine long-term outcomes, it appears that stemless replacement will continue to provide surgeons and patients another option in the treatment of glenohumeral arthropathy.

References

1. Neer II CS. Articular replacement for the humeral head. J Bone Joint Surg Am. 1955;37:215–28.
2. Boileau P, Walch G, Liotard JP. Etude radio-cinématographique de l'élévation active de l'épaule prothésée. Rev Chir Orthop Reparatrice Appar Mot. 1992;78:355–64.
3. Walch G, Boileau P. Prosthetic adaptability: a new concept for shoulder arthroplasty. J Should Elbow Surg. 1999;8:443–51.
4. Raiss P, Edwards TB, Deutsch A, Shah A, Bruckner T, Loew M, Boileau P, Walch G. Radiographic changes around humeral components in shoulder arthroplasty. J Bone Joint Surg. 2014;96:e54(1–9).
5. Sperling JW, Cofield RH, O'Driscoll SW, Torchia ME, Rowland CM. Radiographic assessment of ingrowth total shoulder arthroplasty. J Should Elbow Surg. 2000;9:507–13.
6. Campbell JT, Moore RS, Iannotti JP, Norris TR, Williams GR. Periprosthetic humeral fractures: mechanisms of fracture and treatment options. J Should Elbow Surg. 1998;7:406–13.
7. Levy O, Copeland SA. Cementless surface replacement arthroplasty of the shoulder: 5 to 10 year results with the Copeland Mark-2 prosthesis. J Bone Joint Surg (Br). 2001;83-B:213–21.
8. Bryant D, Litchfield R, Sandow M, Gartsman GM, Guyatt G, Kirkley A. A comparison of pain, strength, range of motion, and functional outcomes after hemiarthroplasty and total shoulder arthroplasty in patients with osteoarthritis of the shoulder. J Bone Joint Surg. 2005;87:1947–56.
9. Edwards TB, Kadakia NR, Boulahia A, Kempf JF, Boileau P, Nemoz C, Walch G. A comparison of hemiarthroplasty and total shoulder arthroplasty in the treatment of primary glenohumeral osteoarthritis: results of a multicenter study. J Should Elbow Surg. 2003;12:207–13.
10. 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 osteoarthritis: a systematic review. J Should Elbow Surg. 2007;16:396–402.
11. Pearl ML. Proximal humeral anatomy in shoulder arthroplasty: implications for prosthetic design and surgical technique. J Should Elbow Surg. 2005;14:99S–104.
12. Boileau P, Walch G. The three-dimensional geometry of the proximal humerus: implications for surgical technique and prosthetic design. J Bone Joint Surg (Br). 1997;79-B:857–65.
13. Roberts SN, Foley AP, Swallow HM, Wallace WA, Coughlan DP. The geometry of the humeral head and the design of prostheses. J Bone Joint Surg (Br). 1992;73-B:647–50.
14. Iannotti JP, Spencer EE, Winter U, Deffenbaugh D, Williams GR. Prosthetic positioning in total shoulder arthroplasty. J Should Elbow Surg. 2005;14:111S–21S.
15. Harryman DT, Sidles JA, Harris SL, Lippitt SB. The effect of articular conformity and the size of the humeral head component on laxity and motion after glenohumeral arthroplasty: a study in cadavera. J Bone Joint Surg Am. 1995;77A:555–63.
16. Karduna AR, Williams GR, Williams JL, Iannotti JP. Glenohumeral joint translations before and after

total shoulder arthroplasty. A study in cadavera. J Bone Joint Surg Am. 1997;79:1166–74.
17. Karduna AR, Williams GR, Williams JL, Iannotti JP. Joint stability after total shoulder arthroplasty in a cadaver model. J Should Elbow Surg. 1997;6: 506–11.
18. Williams GR, Wong DL, Pepe MD, Ta V, Siverberg D, Ramsey ML, Karduna A, Iannotti JP. The effect of articular malposition after total shoulder arthroplasty on glenohumeral translation, range of motion, and subacromial impingement. J Should Elbow Surg. 2001;10:399–409.
19. Nyffeler RW, Sheikh R, Jacob HA, Gerber C. Influence of humeral prosthesis height on biomechanics of glenohumeral abduction: an in vitro study. J Bone Joint Surg Am. 2004;86-A:575–80.
20. Jobe CM, Iannotti JP. Limits imposed on glenohumeral motion by joint geometry. J Should Elbow Surg. 1995;4:281–5.
21. Pearl ML, Kurutz S, Postachini R. Geometric variables in anatomic replacement of the proximal humerus: how much prosthetic geometry is necessary? J Should Elbow Surg. 2009;18:366–70.
22. Wirth MA, Ondrla J, Southworth C, Kaar K, Anderson BC, Rockwood CA. Replicating proximal humeral articular geometry with a third-generation implant: a radiographic study in cadaveric shoulders. J Should Elbow Surg. 2007;16:11S–6.
23. Pritchett JW. Long-term results and patient satisfaction after shoulder resurfacing. J Should Elbow Surg. 2011;20:771–7.
24. Vanhees M, Jaspars KCJ, van Riet R, Verborgt O, Declerq G. Stemless revision of a failed hemiarthroplasty: case report and surgical technique. J Should Elbow Surg. 2013;22:e14–8.
25. Boyd AD, Thornhill TS, Barnes CL. Fractures adjacent to humeral prostheses. J Bone Joint Surg. 1992;74:1498–504.
26. Thomas SR, Wilson AJ, Chambler A, Harding I, Thomas M. Outcome of Copeland surface replacement arthroplasty. J Should Elbow Surg. 2005;14:485–91.
27. Day JS, Lau E, Ong KL, Williams GR, Ramsey ML, Kurtz SM. Prevalence and projections of total shoulder and elbow arthroplasty in the United States to 2015. J Should Elbow Surg. 2010;19:1115–20.
28. Boileau P, Trojani C, Walch G, Krishnan SG, Romeo A, Sinnerton R. Shoulder arthroplasty for the treatment of the sequelae of fractures of the proximal humerus. J Should Elbow Surg. 2001;10:299–308.
29. Habermeyer P, Lichtenberg S, Tauber M, Magosch P. Midterm results of stemless shoulder arthroplasty: a prospective study. J Shoulder Elbow Surg 2015;24: 1463–72.
30. Kim MS, Kovacevic D, Milks RA, Jun BJ, Rodriguez E, DeLozier KR, Derwin KA, Iannotti JP. Bone graft substitute provides metaphyseal fixation for a stemless humeral implant. Orthopedics. 2015;38:e597–603.
31. Dawson CK, Rolf RH, Holovacs TF. The management of localized articular cartilage lesions of the humeral head in the athlete. Oper Tech Sports Med. 2008;16:14–20.
32. Scalise JJ, Miniaci A, Iannotti JP. Resurfacing arthroplasty of the humerus: indications, surgical technique and clinical results. Tech Should Elbow Surg. 2007;8:152–60.
33. Uribe JW, Botto-van Bemden A. Partial humeral head resurfacing for osteonecrosis. J Should Elbow Surg. 2009;18:711–6.
34. Delaney RA, Freehill MT, Higgins LD, Warner JJP. Durability of partial head resurfacing. J Should Elbow Surg. 2014;23:e14–22.
35. Sweet SJ, Takara T, Ho L, Tibone JE. Primary partial humeral head resurfacing: outcomes with the HemiCAP implant. Am J Sports Med. 2015;43:579–87.
36. Mackenzie DB. The antero-superior exposure for total shoulder replacement. Orthop Traumatol. 1993; 2:71–7.
37. Bosali KI, Wirth MA, Rockwood CA. Complications of total shoulder arthroplasty. J Bone Joint Surg. 2006;88-A:2279–92.
38. Huguet D, DeClerq G, Rio B, Teissier J, Zipoli B. Results of a new stemless shoulder prosthesis: radiologic proof of maintained fixation and stability after a minimum of three years' follow-up. J Should Elbow Surg. 2010;19:847–52.
39. Teissier P, Teissier J, Kouyoumdjian P, Asencio G. The TESS reverse shoulder arthroplasty without a stem in the treatment of cuff-deficient shoulder conditions: clinical and radiographic results. J Should Elbow Surg. 2015;24:45–51.
40. Ballas R, Beguin L. Results of a stemless reverse shoulder prosthesis at more than 58 months mean without loosening. J Should Elbow Surg. 2013;22:e1–6.
41. Magosch P, Habermeyer P, Bachmaier S, Metcalfe N. Biomechanische grundlagen des metaphysear verankerten humeruskopfersatzes. Obere Extremiteat. 2012;7:11–6.
42. Schoch C, Huth J, Aghajev E, Bauer G, Mauch F. Diemetaphysear verankerte Prothese bei posttraumatischer und primarer Omarthrose, kurzfristige ergebnisse. Obere Extremitat. 2011;4:275–81. German.
43. Brunner UH, Fruth M, Reuckl K, Magosch P, Tauber M, Resch H, Habermeyer P. Die schaftfreie Eclipse -prothese - indikation und mittelfristige ergebnisse. Eine prospektive Multicenterstudie. Obere Extremiteat. 2012;7:22–8. German.
44. Mariotti U, Motta P, Stucchi A, Ponti di Sant'Angelo F. Stemmed versus stemless total shoulder arthroplasty: a preliminary report and short-term results. Musculoskelet Surg. 2014;98:195–200.
45. Berth A, Pap G. Stemless shoulder prosthesis versus conventional anatomic shoulder prosthesis in patients with osteoarthritis: a comparison of the functional outcome after a minimum two years follow-up. J Orthop Traumatol. 2013;14:31–7.

Glenoid Anatomy and Biomechanics

6

Michael Codsi

Normal Glenoid Anatomy

The glenoid anatomy has classically been defined by the articular surface anatomy. The height and width of the glenoid have been measured in anthropomorphic studies, and each study has used a slightly different methodology to measure the glenoid. Mallon et al. evaluated 28 cadaver scapulae and measured the height and width in both men and women [65]. They found the average height of the glenoid was 38 mm (range, 33–45) for men and was 36.2 mm (range, 32–43) for women. Iannotti et al. measured the height of the glenoid in 140 cadaver scapulae and found the average height was 39 mm (range, 30–48 mm) and the average glenoid width was 29 mm (range, 21–35 mm) [49]. He also reported the distribution of the sizes of the glenoid and separated them into five groups according to their height and four groups according to their width. Churchill et al. measured the height and width of the glenoid using 344 cadaver scapulae from the Hamann-Todd Osteological Collection, the Museum of Natural History in Cleveland, Ohio [19]. They used scapulae from persons who were between 20 and 30 years old at the time of death. The average glenoid height in men was 37.5 mm (range, 30–43 mm), and the average width was 27.8 mm (range, 24–33 mm). For women, the average height was 32.6 mm (range, 29–37 mm), and the average width was 23.6 mm (range, 20–26 mm). Checroun et al. measured the glenoid dimensions in 412 cadaver scapulae and found an average height of 37.9 mm (range, 31–50 mm) [17]. The average width of the glenoids was 29.3 mm (range, 23–42 mm). Kwon et al. measured the height and width of the glenoid in 12 cadaver specimens using both manual measurements and CT scan measurements to determine the accuracy of CT scan measurements and found that the difference in measurements was within 2 mm [60]. The median glenoid height was 37.8 mm (range, 30–47 mm), and the median width was 26.8 mm (range, 22–35 mm) when the measurements from the specimens were used (Table 6.1).

Glenoid Version

Glenoid version has been measured in multiple studies, and the methodology used to measure the version is an important variable to understand, because two different methods can give different version measurements for the same scapula. It is also difficult to obtain radiographs with excellent technique because the patient with severe arthritis often has difficulty moving the shoulder in the

M. Codsi, MD
Department of Evergreen Orthopedic Sports Care, Evergreen Hospital, 12333 NE 130th Lane Suite 410, Kirkland, WA 98034, USA
e-mail: mjcodsi@evergreenhealth.com

© Springer International Publishing Switzerland 2016
A.D. Armstrong, A.M. Murthi (eds.), *Anatomic Shoulder Arthroplasty*,
DOI 10.1007/978-3-319-29164-2_6

Table 6.1 Glenoid height and width measurements

Author	Year	Specimens	Glenoid height	Glenoid width
Mallon et al.	1992	28	38 mm (range, 33–45 mm)	
Iannotti et al.	1992	140	39 mm (range, 30–48 mm)	29 mm (range, 21–35 mm)
Churchill et al.	2001	344	37.5 mm (range, 30–43 mm)	23.6 mm (range, 20–26 mm)
Checroun et al.	2002	412	37.9 mm (range, 31–50 mm)	29.3 mm (range, 23–42 mm)
Kwon et al.	2005	12	37.8 mm (range, 30–47 mm)	26.8 mm (range, 22–35 mm)

positions needed to get the best views of the glenoid. Surprisingly, radiographs are often easier to obtain after total shoulder arthroplasty because the patient's range of motion is better and the landmarks on the radiograph are easier to measure because the joint space has been restored with the prosthetic implants. Glenoid version has been traditionally measured using standard radiographs, but the accuracy of this method was questioned in a study done by Nyffeler et al. [73]. They measured glenoid version in 25 patients without arthritis and 25 patients after total shoulder arthroplasty using radiographs and CT scans. They found that glenoid retroversion was overestimated with radiographs 86% of the cases and the difference between the CT scan and radiographic measurement was 6.5° (range, 0–21°). The correlation between the CT measurements and the radiographs was higher (0.67) in the total shoulder group compared to the instability group (0.33). Based on these results, the authors recommended the use of CT scan as the preferred modality to measure postoperative glenoid version in total shoulder arthroplasty. A similar study was done by Ho et al. to evaluate the accuracy of radiographs compared to CT scans for the measurement of glenoid version in cases before and after total shoulder arthroplasty [43]. Thirty-two patients had radiographs and CT scans taken before and after surgery, and multiple measurements were made including glenoid version. There was moderate agreement between CT scan and radiographic measurements (0.69) and the radiographs overestimated glenoid version by 4.2°.

As the use of standard two-dimensional CT scans has increased for the measurement of glenoid version, other methods have emerged with the advent of three-dimensional CT software. This software allows for the measurements of glenoid version to be done on the same scapula with different methods. Bryce et al. described this variation in an elegant study using 40 scapulae CT scans [10]. The scans were imported into a software program called MATLAB that allowed for manipulation of the scapula orientation and calculation of the resulting glenoid version. It helps to understand the variation in measurement by starting with the classic method of measuring glenoid version. First, a plane of the scapula must be defined from which the version of the glenoid articular surface can be measured against. The plane of the scapula is typically defined by three points on the scapula, the center of the glenoid, the tip of the inferior scapular angle, and a point at the intersection of the spine of the scapula with the medial border of the scapula (Fig. 6.1). Second, the plane of the glenoid articular surface is defined. This can be done using two points on the anterior and posterior edges of the glenoid surface halfway between the superior and inferior pole of the glenoid. It can also be done using three points anywhere around the edge of the glenoid articular surface. Third, the version measurement can then be made using the angle formed by the two planes. This seems easy to do when using a three-dimensional model or when measuring the version with a real scapula. The variation in the measurement occurs when the scapula is shown using two-dimensional images. If the two-dimensional images are rendered with the scapula rotated in abduction or adduction, then the plane of the glenoid articular surface changes and so does the version. The variation in the version measurements can be quite substantial and can range from 4.7° of anteversion to 10.6° of retroversion on the same scapula depending on the orientation of the scapula. Regression analysis for scapula rotation in the coronal plane showed that

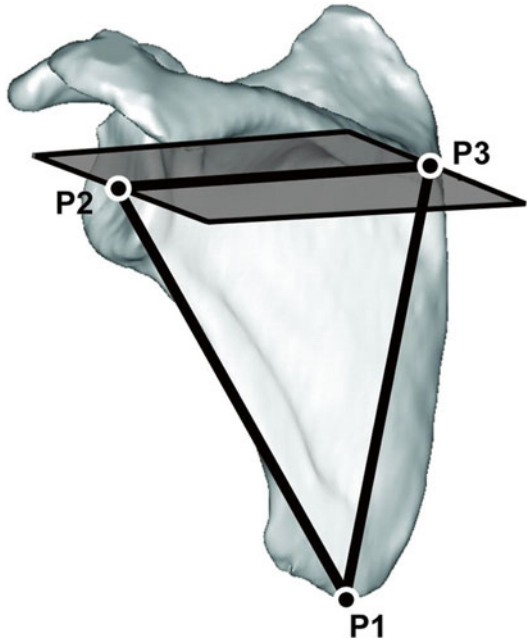


Fig. 6.1 The plane of the scapula is defined by the most distal point of the inferior scapular angle (*P1*), the center of the glenoid fossa (*P2*), and the point at the vertebral border where the scapular spine intersects the medial border of the scapular (*P3*) (Reprinted with permission from Bryce et al. [10])

Table 6.2 Glenoid version measurements

Author	Year	Specimens	Glenoid version
Cyprien et al.	1983	50	8 degrees of retroversion
Friedman et al.	1992	62	2 degrees of anteversion
Mallon et al.	1992	28	6 degrees of retroversion
Couteau et al.	2001	28	8 degrees of retroversion
Churchill et al.	2001	344	1 degrees of retroversion
Scalise et al.	2008	14	7 degrees of retroversion
Ganapathi et al.	2011	19	7 degrees of retroversion
Matsumura et al.	2012	410	1 degree of retroversion

every one degree of scapular abduction led to 0.42° of version variability and every one degree of scapular adduction resulted in 0.16° of version variability. The effect of abduction on version variability was significantly stronger than the effect of adduction on version variability. At 20° of scapular abduction, the mean version variation was 9.4°, and for 20° of adduction, the mean version variation was 2.4°. These findings were confirmed in another follow-up study by the same group [13] (Table 6.2).

Cyprien et al. measured the version of the glenoid using x-rays from 50 normal patients and 15 patients who had recurrent anterior dislocations [25]. They found the average normal version was 7.1° for retroversion compared to 8.9° for retroversion in the patients with recurrent dislocations. Friedman et al. used two-dimensional CT scans of 63 normal patients and compared them to a group of 20 patients with glenohumeral arthritis [31]. The average anteversion of the normal group was 2° (range, +14 to −12°), and the average retroversion of the arthritis group was 11° (range, +2 to −32°). Mallon et al. evaluated the version in 28 cadaver scapulae and found the average retroversion was 6° (range, +2 to −13°) [65]. Couteau et al. measured the version of 28 scapula using two-dimensional CT scan measurements [24]. The patients included in the study had rotator cuff tears without glenohumeral arthritis, glenohumeral arthritis, and rheumatoid arthritis. The average retroversion of the group of patients with rotator cuff tears was 8° (range, 2–17°), with glenohumeral arthritis 16° (range, 0–50°), and the patients with rheumatoid arthritis have an average retroversion of 15° (range, 6–22°).

Churchill et al. measured the version of 344 scapulae from the Hamann-Todd Osteological Collection at the Museum of Natural History, in Cleveland, Ohio [19]. This collection contains skeletons of Cleveland's unclaimed dead from 1912 through 1938. The ages of the specimens were between 20 and 30 years. They measured the version using two different points to define the plane of the scapula. One measurement used the junction of the spine of the scapula with the medial border of the scapula, and the other measurement used a point closer to the superior medial angle of the scapula (Fig. 6.2). The average version using the junction of the spine of the scapula and the medial border of the scapula was 1.23° (range, −10 to +10°). There was no difference when

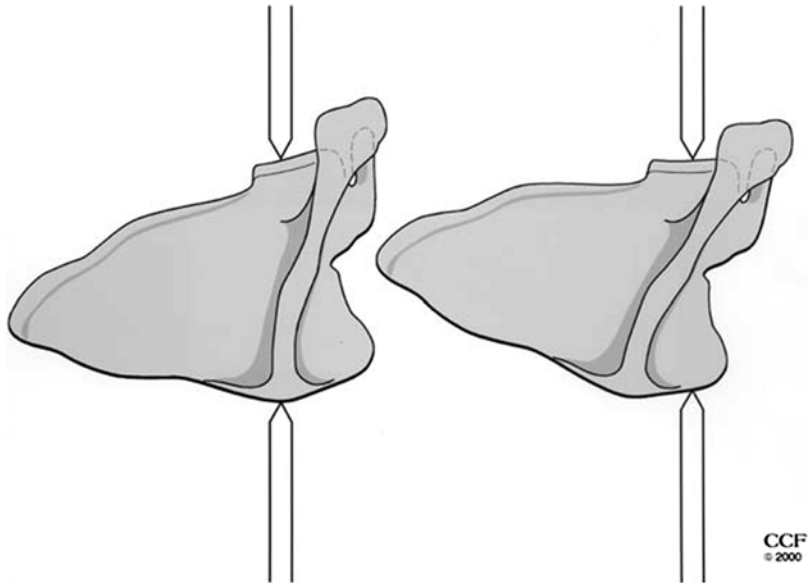


Fig. 6.2 Comparison of the two different scapular positions studied. *Left*, The transverse axis of the scapula is identified by the platform pins. *Right*, The scapula has been rotated such that the glenoid inclination is parallel to the base plate. Note that the moving platform pin maintains the same position as before, but the base platform pin no longer is positioned along the scapular spine (Reprinted from Churchill et al. [19] with permission from Elsevier)

comparing the men and women in the group. When using the alternative point on the superior medial angle of the scapula, the average version was not statistically different.

Matsumura et al. performed a more recent study in a population of healthy Japanese volunteers and found a wide range of glenoid version measurements [66]. The average glenoid retroversion was 1° with a range from 9° of anteversion to 13° of retroversion. Glenoid retroversion was higher on the dominant side in all patients, and it was higher in men compared to women.

Scalise et al. measured the version of 14 patients with osteoarthritis in one shoulder and measured the version of the opposite normal shoulder using a three-dimensional CT [87]. A custom software program was used to define the plane of the scapula so the measurements would match the technique described by Churchill et al. in their study. The average retroversion of the normal shoulders was 7° (range, 0–14°), and the average retroversion for the arthritic side was 15.6° (range, −1–33°).

Ganapathi et al. measured the version of 58 normal scapulae from the Hamann-Todd Collection using three-dimensional CT scan renderings [33]. They compared the normal cadaver scapulae to humans who had osteoarthritis in one shoulder and their normal non-arthritic shoulders. The humans with normal bilateral shoulders had an average version of 2.59°. The average retroversion of the glenoids on the normal side of the matched pairs was 6.8°, and the average retroversion of the arthritic matched pair of glenoids was 14.7°. This data suggests, but does not prove, that patients with a retroverted glenoid are more likely to develop osteoarthritis of the shoulder. It may also suggest that the normal version for patients with osteoarthritis is different from the normal version of patients without osteoarthritis. This has important implications for surgeons who must decide how much version should be corrected when performing a total shoulder replacement with a glenoid implant.

Hendel et al. studied the effect of using patient-specific instruments to position the glenoid component during anatomic total shoulder replacement surgery [41]. They used three-dimensional CT scans for 34 patients with osteoarthritis and found the average retroversion for the glenoid was 14.3° (range, +7–27°). The importance of all of these

studies, which report their measurements of glenoid version, is that there is a wide range of version measurements to take into consideration. The range of version measurements can be due to differences in the techniques used to measure the version based on the rotation of the scapula and the tilt of the scapula. Many of the studies, however, used three-dimensional renderings of the CT scans, which correct for any variation in the techniques used to obtain the CT scan data. A few of the studies used the same patient population, namely, the Hamann-Todd Osteological Collection, which may not be generalizable to the general population.

Glenoid Vault

While a lot of study has focused on describing the anatomy of the glenoid articular surface, relatively few studies in the past have described the anatomy of the glenoid walls and the bone beneath the articular surface. This anatomy has become more important to understand as surgeons start to deal with bone deformity and bone loss due to severe disease and to failure of shoulder replacements. In complex cases, glenoid implants require fixation points beyond the articular surface, and with the advent of the reverse total shoulder, the glenoid component relies on fixation points in the glenoid vault and further medial into the body of the scapula. Investigations into the unique shape of the glenoid vault have also led to a better understanding of glenoid version and its relationship to glenohumeral arthritis.

Bicknell et al. measured the endosteal dimensions of the glenoid vault in 72 scapulae with a mean age of 70 years [7]. The dimensions were larger for males compared to females, but there was no relationship between the dimensions and age or between the presence and absence of arthritis. The shape of the endosteal dimensions was relatively consistent, and there was a small distribution of sizes. The shape of the glenoid vault is relatively straight-sided, or rectangular, in the coronal plane and more highly fluted, or triangular, in the transverse plane.

Codsi et al. selected 61 cadaver scapulae from the Hamann-Todd Osteological Collection to study the shape of the glenoid vault [21]. A wide range of sizes were selected in order to define the normal glenoid vault anatomy. CT scans of each scapula were performed, and the data were analyzed using a custom software program to measure and manipulate the images. The two-dimensional slices of the glenoid vault in the axial plane were used to trace the inner surface area of the glenoid vault (Fig. 6.3). The points on the tracings were recorded, and then the points from each CT slice were stacked on top of one another to create a three-dimensional shape of each vault (Figs. 6.4, 6.5, and 6.6). The vaults were then standardized to one size based on the height of the glenoid articular surface, which allowed for comparison of the shape of the glenoid vault among the different sized scapulae. The right-sided vaults were mirrored about the XZ plane so they could be compared to the left-sided vaults. Two vaults were overlapped, and the distance between the closest tracing points on each vault was measured. The average distance between 85% of all the tracing points was less than 2 mm from each other, indicating that the shapes of the glenoid vaults in this study were relatively uniform. The shape of the standardized glenoid vault was then made into a plastic model along with four other sizes that were 10% and 20% larger and smaller to correspond with the sizing characteristics for a traditional anatomic glenoid implant. These plastic models were then implanted into cadaver scapulae that were not included in the original 61 scapulae used to generate the shape of the models. The cadavers with the plastic models were then scanned with a CT scanner, and the distances between the models and the endosteal bone of the cadaver glenoid vaults were measured. The average distance between the plastic models and endosteal bone was 2.4 mm, and 80% of the points measured were within 3 mm.

When confronted with a deformity of the glenoid, the surgeon needs to decide how much of the deformity to correct when implanting a glenoid component. Based on the anatomic studies, there is a wide range of normal glenoid version, so it can be difficult to determine what the patient's normal glenoid anatomy was like before the pathology became severe and deformed the glenoid. Scalise et al. wanted to use the shape of

the glenoid vault to find out if there was a way to predict what the vault and the articular surface looked like before the pathology deformed the glenoid [87]. Fourteen patients had CT scans of the arthritic shoulder and the normal opposite shoulder. Using a custom three-dimensional software program, the shape of the glenoid vault was place inside the pathologic glenoid, and the version of the glenoid vault shape was measured. Then at a separate sitting, the glenoid vault shape was placed into the glenoids of the normal shoulders and the version of the glenoid vault shape was measured. The version of the glenoid vault was the same for the arthritic shoulders and the normal shoulder for each patient. These data suggest that the version of the native arthritic glenoid can be predicted using the glenoid vault shape (Fig. 6.7). This may be helpful for surgeons to know when they are deciding how much correction of retroversion should be done during placement of the glenoid component.

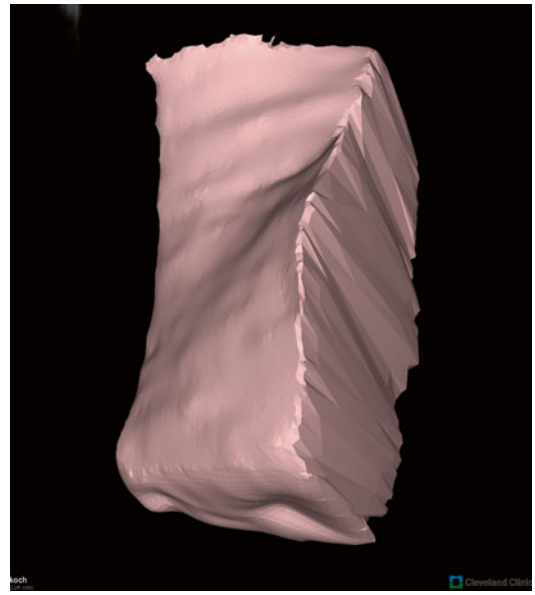


Fig. 6.4 Three-dimensional left glenoid vault model showing the articular surface and the anterior wall of the glenoid vault

Scapula Anatomy

With the advent of the reverse total shoulder replacement that uses a glenoid implant fixed to the scapula with screws, more research was done to understand the anatomy of the scapula medial to the glenoid surface and the glenoid vault. Codsi et al. used three-dimensional CT scans to determine the best locations to place screws from the

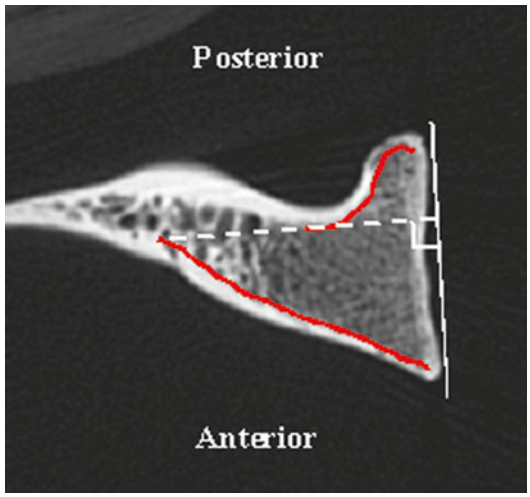


Fig. 6.3 This axial CT scan image shows the inner endosteal walls of the glenoid vault (Reprinted from Codsi et al. [21] with permission from Elsevier)

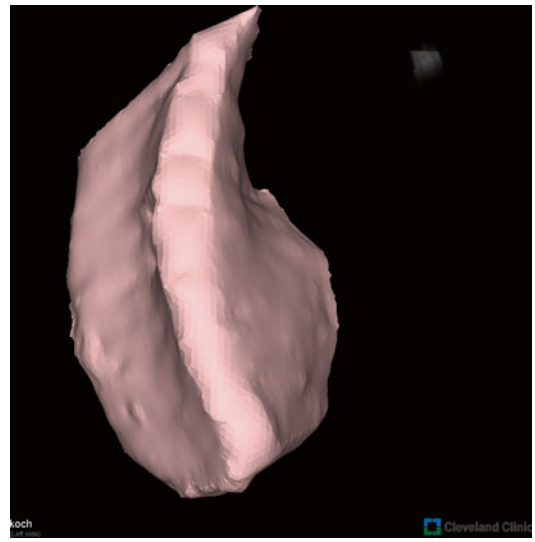


Fig. 6.5 Three-dimensional left glenoid vault model showing the medial ridge of the vault. The articular surface is facing away from the drawing (not seen). The posterior wall is to the left of the photo, and the anterior wall is on the right side of the photo

glenoid articular surface to the body of the scapula [22]. Twenty-seven scapulae were scanned into a custom software program that allowed the manipulation of the scapula to virtually implant screws of different lengths into the bone. Three locations in the scapula body were found that could accommodate long screws. The first was the superior screw, which started in the superior portion of the glenoid and was directed toward the base of the coracoid. The second screw started in the middle of the glenoid and went through the middle of the scapula (Fig. 6.8a–c). The third screw location started on the inferior glenoid surface and was directed along the lateral cortical border of the scapula. The length of the screws could be as long as 75 mm if placed perfectly, but any deviation in the angle of the insertion by 15° would alter the length of the screws between 17 and 30 mm. When the constraint of an implant was introduced, the lengths of the screws were much shorter as well. Using the current implant designs that feature a central screw or fixation, this screw can be placed in the location described as the central screw in this study. The other superior and inferior screw locations are not typically useful with the current implants available because they do not allow for the high angle of insertion needed to place the screw in those positions of the scapula.

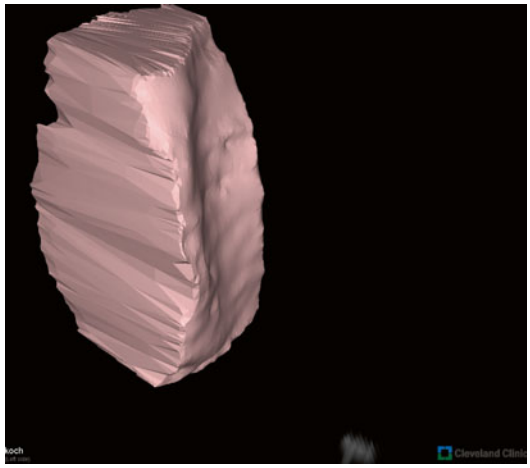


Fig. 6.6 Three-dimensional left glenoid vault model showing the articular surface and the posterior wall of the vault

Humphrey et al. studied the anatomy of the ten cadaver scapulae to find the best locations for screw placement to secure metal glenoid implants [48]. They described three columns of bone in the scapula body that could be used for screw placement, which were similar to the ones described previously. These include the base of the coracoid, the scapula spine, and the scapula pillar. They implanted a glenoid baseplate for a reverse total shoulder into the scapula and measured the

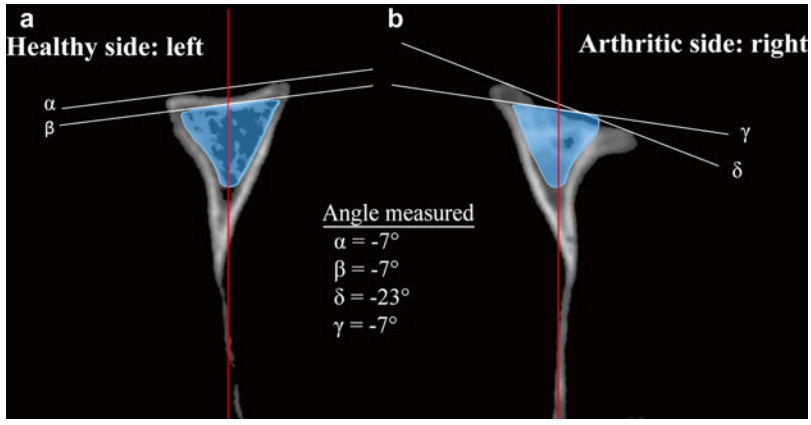


Fig. 6.7 Example of glenoid version measurements after vault model placement in both scapulae of a subject with unilateral osteoarthritis. The plane of the scapula is represented by the red line. (**a**) On the healthy side, the glenoid version measures -7 degrees (*α line*), and the vault model also measures -7 degrees (*β line*). (**b**) On the arthritic side, the glenoid version measures -23 degrees (*δ line*). However, in the arthritic glenoid, the vault model measures -7degrees, (*γ line*) just as measured on the healthy, contralateral side (Reprinted from Scalise et al. [87] with permission from Elsevier)

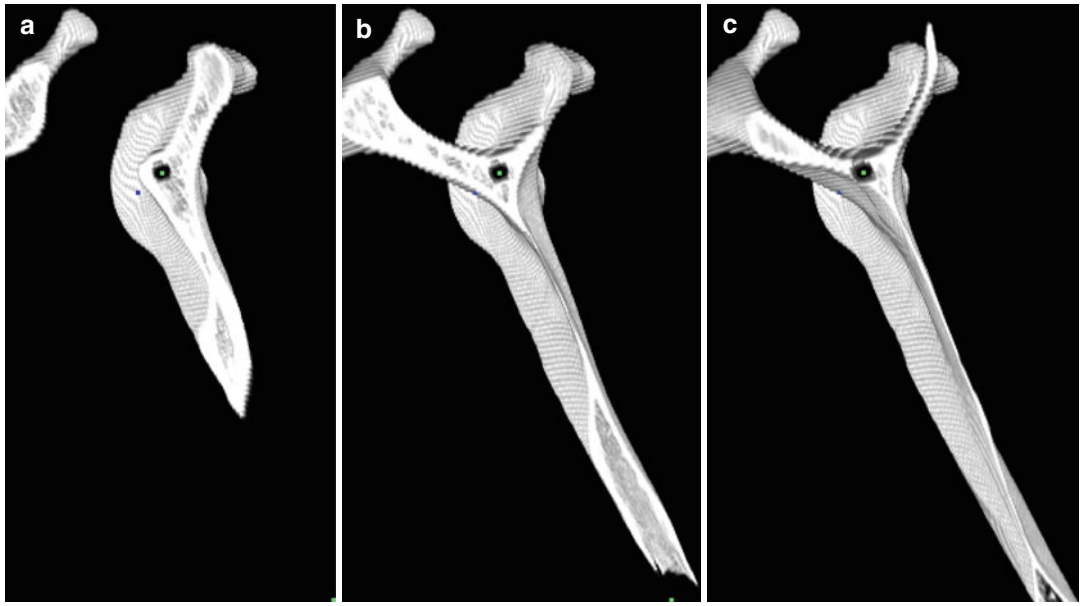


Fig. 6.8 Cross-sectional CT scan images of a scapula with a central screw hole starting at the center of the glenoid articular surface and exiting at the junction of the scapula spine and medial border of the scapula (Reprinted from Codsi et al. [22] with permission from Elsevier). (**a**) Cross section of the scapula 2 cm medial to the glenoid surface, (**b**) Cross section in the middle of the scapula, (**c**) Cross section 2 cm from the medial border of the scapula

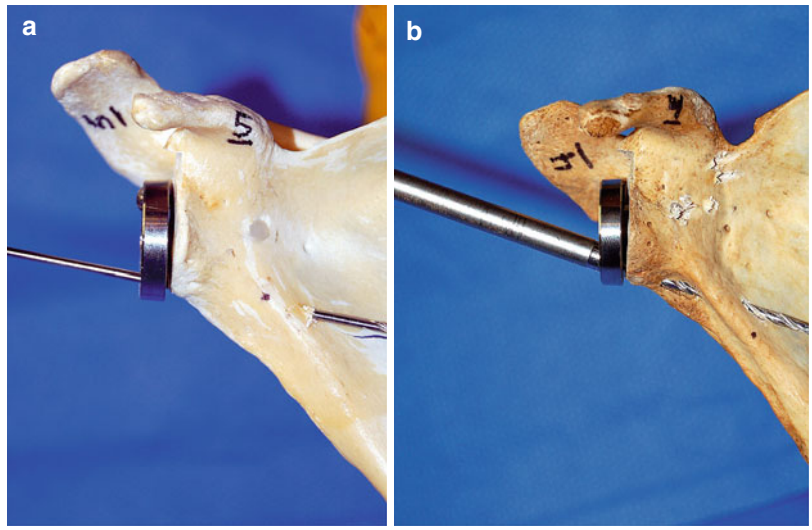


Fig. 6.9 (**a**) The drill bit stays completely within the bone before exiting the cortex medially. (**b**) An "in-out-in" configuration. The drill bit comes out of bone and then goes back into bone before engaging the medial cortex (Reprinted from Humphrey et al. [48] with permission from Elsevier)

length of the screws that could be placed. The average superior screw length was 36 mm (range, 29–40 mm) and the inferior screw was 47 mm (range, 45–54 mm). The authors also noted that the use of a variable angle screw allowed for longer screws because the superior screw could be angled toward the base of the coracoid and the inferior screw could be angled toward the scapular pillar. These two locations are not 180° from each other, so a fixed angle baseplate would only allow perfect placement into one of these locations (Figs. 6.9, 6.10, and 6.11).

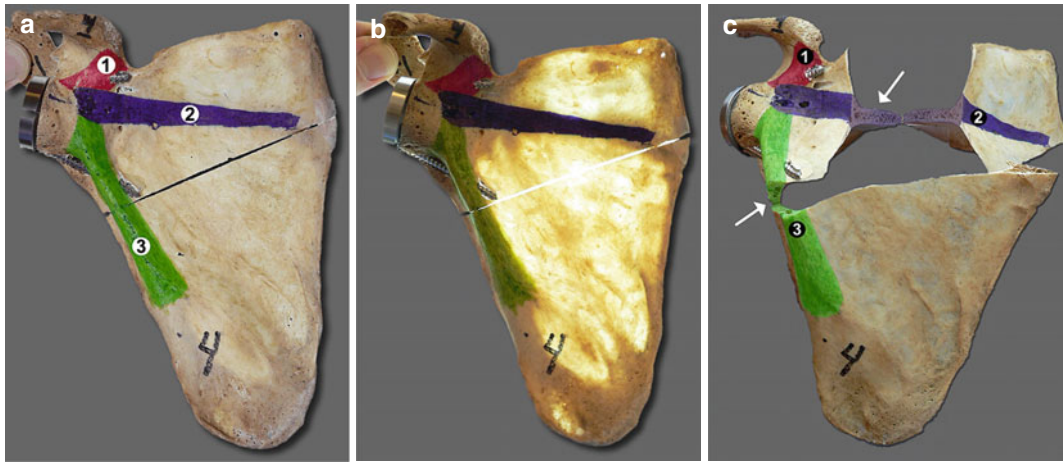


Fig. 6.10 The three-column concept. (**a**) Each column consists of bone that is suitable for achieving strong screw purchase. The columns are the base of the coracoid (*1*), the spine of the scapula (*2*), and the scapular pillar (*3*). (**b**) The paucity of bone between the columns becomes evident when the scapula is transilluminated. (**c**) An exploded view of the scapula demonstrates the columns. The thick bone can be seen at the cross sections of the scapular spine and the pillar (*white arrows*). The bone in between the columns is often paper thin (Reprinted from Humphrey et al. [48] with permission from Elsevier)

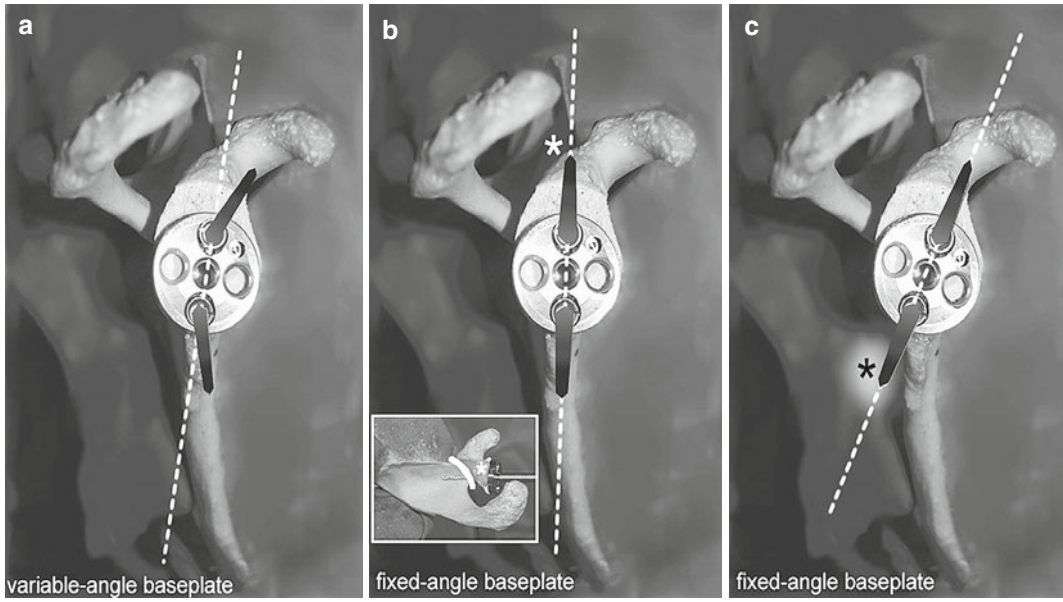


Fig. 6.11 The effect of baseplate rotation on superior and inferior screw trajectory. (**a**) The variable angle baseplate allows the surgeon to direct the screws to the appropriate bony columns. (**b**) With a fixed-angle baseplate, rotating the component so that the inferior screw captures the pillar will lead to penetration of the superior screw outside of the scapular "safe zone" (*white asterisk*). The subwindow shows a drill bit violating the path of the suprascapular nerve. (**c**) Rotating the fixed-angle baseplate to achieve appropriate superior screw positioning causes the inferior screw to miss the scapular pillar completely (*black asterisk*) (Reprinted from Humphrey et al. [48] with permission from Elsevier)

Parsons et al. studied the effect of the rotation of the glenoid baseplate used in reverse total shoulder arthroplasty on screw fixation [79]. They implanted the baseplate into 12 cadaver scapulae in neutral rotation where the superior and inferior screw lined up with the 12 o'clock and 6 o'clock

positions. Then they rotated the baseplate 20° toward the base of the coracoid and 20° the opposite direction toward the spine of the scapula. The baseplates rotated toward the spine of the scapula had the shortest screws, and the baseplates rotated toward the base of the coracoid and neutral rotation resulted in the longest screws. Interestingly, the angle of the screw also affected the length of the screw. Perpendicular placement for the inferior screw yielded better results than an inferior angle. Perpendicular placement also allowed for similar lengths in screws for the superior screw when the baseplate was rotated toward the coracoid or in neutral rotation.

Stephens et al. evaluated the 73 scapulae using three-dimensional CT scans to determine the best rotation of the glenoid baseplate used for a reverse total shoulder that would allow for variable screw fixation into the three pillars of bone in the scapula body [90]. The optimal rotation of the baseplate was 11° anterior, which corresponds to rotating the superior hole of the baseplate toward the base of the coracoid. The average length of the superior and inferior screws was 33 mm.

Scapular neck length is a relatively new anatomic description that is taken on more interest with the recognition of scapular notching seen after reverse total shoulder replacement [93]. Paisley et al. evaluated the scapular neck length in a series of patients who underwent reverse total shoulder arthroplasty, and they found a significantly higher rate of notching in patients who had a scapular neck length less than 9 mm [77] (Figs. 6.12 and 6.13).

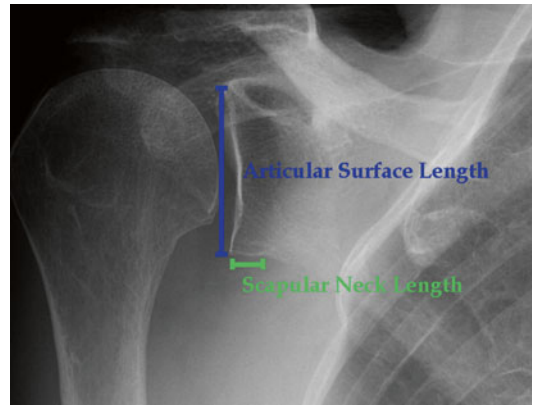


Fig. 6.12 Radiograph showing short scapular neck length (Reprinted from Paisley et al. [77] with permission from Elsevier)

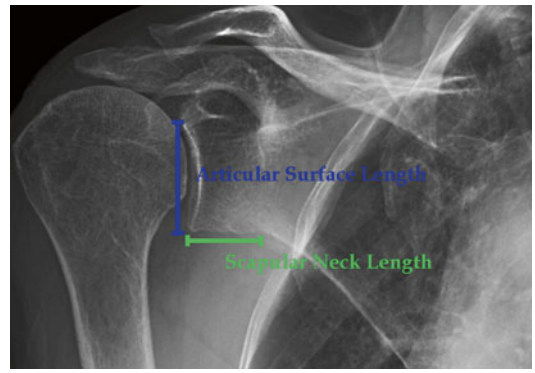


Fig. 6.13 Radiograph showing long scapular neck length (Reprinted from Paisley et al. [77] with permission from Elsevier)

Glenoid Pathology

Walsh et al. described one of the most commonly used glenoid classification systems to describe the different wear patterns seen in osteoarthritis of the shoulder [96]. Type A glenoids are characterized as having the humeral head in the center of the glenoid. Type A1 glenoids have minor central erosions, and type A2 glenoids have major central erosions. Type B glenoids are characterized by subluxation of the humeral head by more than 5% of the diameter of the humeral head. Type B1 glenoids have subluxation of the humeral head with narrowing of the joint space with osteophytes and sclerosis. Type B2 glenoids have posterior erosions of the glenoid that result in a biconcave articular surface. Type C glenoids are characterized as having retroversion greater than 25°, regardless of the extent of the erosion (Fig. 6.14). This classification system has been studied and validated as a reliable classification system with the same interobserver reliability as other orthopedic classifications [70, 86].

Seebauer et al. described another classification system for the pathology of the glenoid that

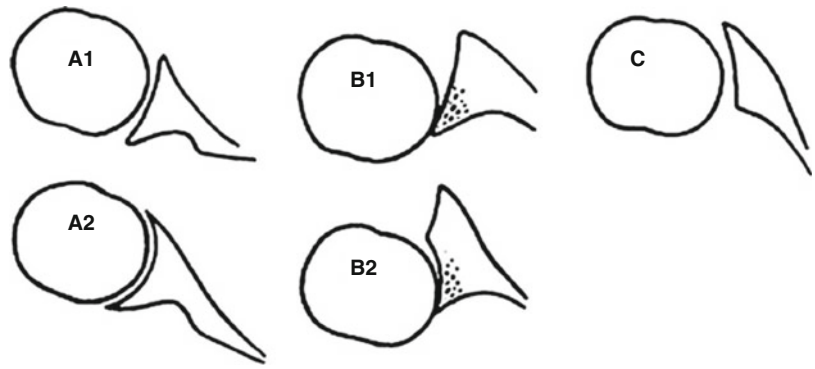


Fig. 6.14 Walch classification of glenoid erosion in primary glenohumeral arthritis (Reprinted from Walch et al. [96] with permission from Elsevier)

often occurs with rotator cuff tear arthropathy [95]. Type 1A cuff tear arthropathy has minimal superior migration of the humeral head, so the glenoid has minimal pathologic changes. Type 1B cuff tear arthropathy is characterized by minimal superior migration of the humeral head with medial and centralized glenoid erosion. Type 2A cuff tear arthropathy is characterized by superior translation of the humeral head with superior erosion of the glenoid. Type 2B cuff tear arthropathy is characterized by superior escape of the humeral head through the CA arch restraints.

Glenoid dysplasia is another pathologic disease that causes significant deformity of the glenoid [89]. These glenoid deformities fall under the category of a Walsh type C glenoid. The glenoids have decreased bone inferior and posterior, and the coracoid is typically very prominent. The posterior labrum can be hypertrophic. The humeral head usually has some form of dysplasia as well, and it is often subluxated posteriorly. As the disease progresses, the joint becomes arthritic, and this can occur at an early age.

Antuna et al. described a classification system to describe the different types of glenoid bone loss that typically occur after the removal of a glenoid implant [4]. The first type of defect is centralized, and it can be further characterized into mild, moderate, and severe. The second type of defect is characterized by some defect in the periphery of the glenoid or a defect in the glenoid walls. This can also be further characterized as mild, moderate, or severe. The third type of defect is a combined central defect that extends out to the walls of the glenoid vault. This can also be characterized as mild, moderate, or severe (Fig. 6.15).

Glenoid Implant Options

The glenoid implant is difficult to design because of the relatively small amount of bone available for the implant. Glenoid implant loosening is the most common complication of a total shoulder arthroplasty, so the majority of the research done to improve total shoulder arthroplasty has focused on the biomechanics and design of the glenoid implant. Earlier designs of the glenoid implant were fixed to the bone with cement, and this method continues to be the gold standard for glenoid implant design. In an attempt to improve the fixation strength of the implant, metal backings were added to the implant to allow for screw fixation into the glenoid and scapula. Biomechanical studies on the initial fixation of these designs showed great promise, but due to the altered mechanics specific to metal-backed glenoid implants of the total shoulder, these early designs failed at a higher rate than the traditional cemented all-polyethylene designs. The next generation of glenoid design included methods to incorporate bone ingrowth into the implant in addition to cement in an effort to minimize the use of cement in the hopes that the long-term fixation could be improved. Several companies have a slightly different hybrid method for glenoid fixation. It is important to understand

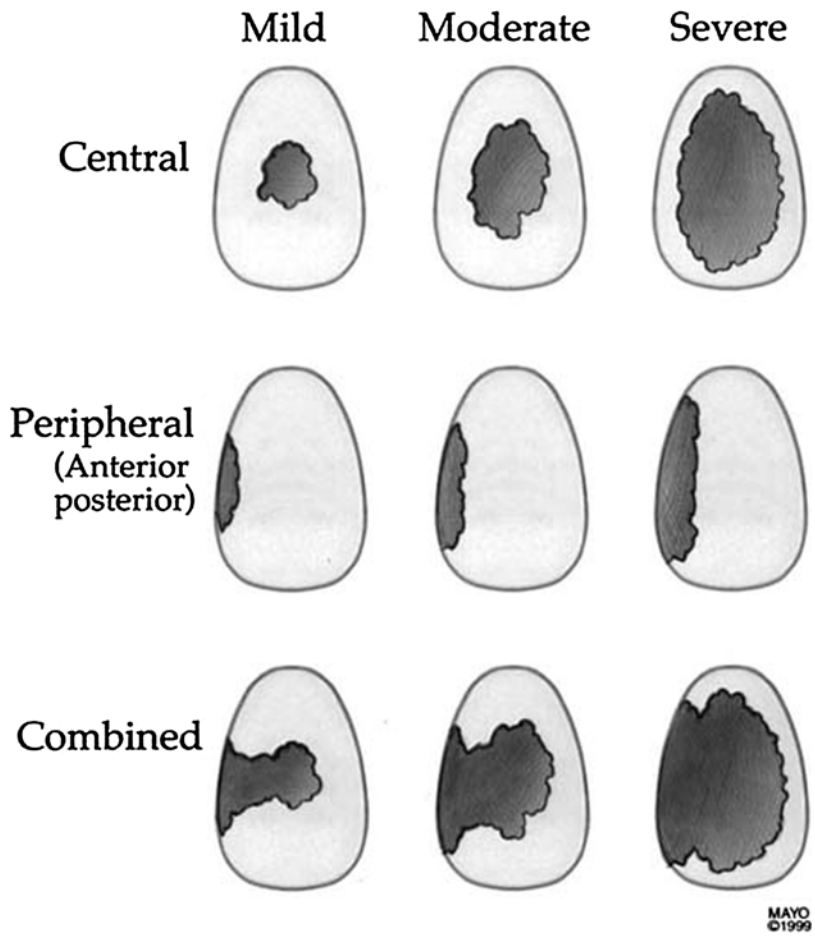


Fig. 6.15 Classification of bone deficiencies in the glenoid after glenoid component loosening and osteolysis. Most deficiencies are central or combined (Reprinted from Antuna et al. [4] with permission from Elsevier)

the differences in fixation among all the choices on the market and how the fixation is studied in the lab and in clinical studies.

Besides fixation design for glenoid implants, there are other considerations to take into account that may affect the long-term survival of the glenoid implant. The radius of curvature of the glenoid and its relationship to the humeral head radius of curvature, also described as the radial mismatch, can influence glenoid loosening during clinical follow-up. The alignment of the glenoid in terms of the version and inclination of the implant has an impact on the fixation of the implant and the forces that can potentially lead to early loosening of the implant. Bone quality is another factor that can affect the stability of the glenoid implant, and the difference in support that the subchondral bone can give compared to the softer cancellous bone found more medial in the glenoid vault may play a big role in the long-term stability of the glenoid implant. This can be a complicated decision-making process because the more a surgeon wants to correct the alignment of the pathologic glenoid to maximize the biomechanical stresses on the glenoid implant, the stronger the subchondral bone that must be removed to correct that alignment. The geometry of the backside of the glenoid implant can also influence the stability and long-term survival of the implant. Some implants have a flat back, and others have a curved backside of the implant. The radius of curvature of the backside of the implant can also play a role in both the stability of the implant to resist early loosening, and it can influence the amount of bone that is removed during the reaming process. The closer the geometry of the backside of the implant matches the geometry of the articular

surface of the glenoid, the less bone that will need to be removed during the surgery.

A final design consideration that can affect the long-term survivorship of the glenoid implant is the type of ultrahigh-molecular-weight polyethylene that is used for the material of the implant. The amount of cross-links in the polyethylene can change the biomechanical strength of the material to resist shear forces and friction forces [100].

Biomechanics of Glenoid Implants

Glenoid component loosening is the most common complication of total shoulder arthroplasty, so it is important to use laboratory testing of new designs before they are used in a clinical setting. Once a standard testing method is designed, then the different designs of implants can be compared and the effect of the individual factors can be determined. Anglin et al. described a method to test glenoid implants that is now the current standard adopted by ASTM International [2]. Their method was based on the clinical descriptions of glenoid implant failure by other investigators who thought the major contributing factor to glenoid loosening was off-center or eccentric loading of the implant. Off-center loading of the glenoid is caused by migration of the humeral head in one direction, often caused by a rotator cuff tear. Tears of the supraspinatus are the most common and can result in superior migration of the humeral head and eccentric loading of the superior glenoid. The same effect can occur when the subscapularis tendon is torn, which would result in migration of the humeral head anteriorly. Soft tissue imbalance can be another cause, which is often seen after instability surgery where the anterior soft tissue is less compliant compared to the posterior structures. Malposition of the glenoid component with excessive superior inclination can also contribute [54]. Bone deformity and subluxation of the humeral head can lead to an imbalance of the humeral head after a total shoulder if the surgeon cannot balance the humeral head with the appropriate releases and implant selection. This can then lead to eccentric loading of the posterior edge of the glenoid implant. The common term that is used to describe this eccentric loading is the "rocking horse" phenomenon, and it is the basis for testing standard that Anglin et al. described.

A biaxial apparatus was made that allowed constant compression of the humeral head into the glenoid implant (Fig. 6.16). Then the glenoid implant was moved until the center of the humeral head was over the edge of the glenoid rim. The direction of the glenoid movement was then changed until the humeral head moved to the other side of the glenoid rim. Multiple cycles were performed to simulate the 25 high-load activities a day such as lifting a briefcase or pushing on a chair to stand up over a 10-year period. The displacement of the glenoid rim during and after the cycles was measured to determine the stability of the construct. The investigators used this testing method to compare glenoid implants with the following variables: (1) flat backed, (2) curve backed, (3) keel, (4) two pegs, (5) four pegs, (6) smooth or rough backed, and (7) conformity between the humeral head and glenoid radius of curvature. The results showed less micromotion for the rough-backed glenoids compared to the smooth-backed glenoids due to less debonding of the cement from the backside of the implant. The curve-backed glenoids also had half the micromotion compared to the flat-backed glenoids. The less conforming radius of curvature had less micromotion compared to the implants with a more conforming radius of curvature.

Glenoid Cementing

Cement is currently the most common fixation method for a glenoid implant, and there have been several studies on cementing technique to improve the fixation and stability of the implant. Nyffeler et al. conducted a study to determine the best glenoid implant design of the implant pegs [72]. They used pullout tests rather than cyclical loading tests described by Anglin et al. They found that the threaded pegs had a higher pullout strength than the notched pegs and that the smooth pegs had the least resistance to pullout. The cement mantle thickness around the pegs was also studied, and

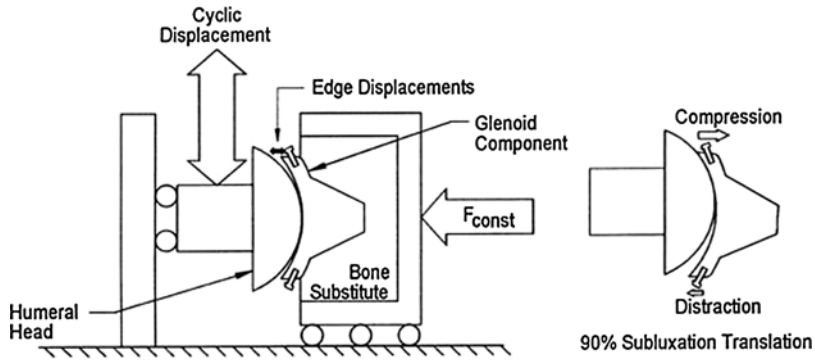


Fig. 6.16 Schematic of the biaxial testing apparatus. The humeral head was compressed into the glenoid with 750 N, then vertically translated inferiorly and superiorly to 90% of the predetermined subluxation distance to mimic the rocking-horse phenomenon. The corresponding compression and distraction displacements of the glenoid were measured before and after 100,000 cycles (Reprinted from Anglin et al. [2] with permission from Elsevier)

they found that a mantle of 0.6 mm showed a significantly higher pullout strength than a cement mantle of 0.1 mm. Furthermore, a cement mantle of 0.1 mm usually resulted in a nonuniform thickness around each peg.

As mentioned above, Anglin et al. studied the effect of the backside geometry of the glenoid and found that a smooth-backed glenoid would quickly debond from the cement after only one cycle of loading. Nyffeler et al. studied the effect of cementing technique on the fixation of pegged glenoid implants [74]. One implant was fixed in cadavers using a syringe to inject cement into the peg holes, and cement was covered on the backside of the implant before it was implanted. Another set of cadavers was prepared by packing the cement with a finger into the peg holes. Cement was not placed on the backside of the implants. Micro-CT scans were taken to evaluate the cement mantle and the implant support by either bone or cement. The results showed a more uniform cement mantle around all the pegs when a syringe was used to fill the peg holes. The backsides of the implants were better supported with cement when the backside of the implant was covered with cement prior to implantation. More importantly, the glenoid implants were not uniformly supported by bone or cement, and some specimens had residual cartilage under the implant. This suggests that in vivo preparation of the glenoid, with the limits of surgical exposure, surgeon variability, and variability of the reamers used to prepare the glenoid, will result in an imperfect surface between the implant and the bone. Cement can fill those imperfections and support the glenoid, but there is a risk that the thin cement mantle could fragment.

In order to determine the quality of the cement technique used during surgery, and to determine whether the glenoid implant fixed with cement was loosening over time, a classification system was developed to evaluate the cement on postoperative x-rays [30]. Franklin et al. evaluated seven cases of total shoulder arthroplasty with irreparable rotator cuff tears and compared the x-rays to a control group of total shoulder replacements that did not have a rotator cuff tear. They described a tipping of the glenoid implant superiorly in the group of patients with a rotator cuff tear that was not seen in the control group. They described a radiographic grading system that was further modified by Lazarus et al. in a study that included 493 total shoulder replacements [63]. The grading system had two parts. The first part graded the radiolucency around the pegs of the glenoid implant, and the second part graded the completeness of glenoid component seating on the glenoid bone. They found radiolucencies about the glenoid component on initial radiographs in 308 of the 328 shoulders. They also found incomplete seating in a large number of shoulders, with incomplete posterior seating being the most common pattern (Tables 6.3 and 6.4). Other classification systems have been used as

Table 6.3 Lazarus grading scale for radiolucencies around a pegged glenoid implant

Grade	Description
0	No radiolucency
1	Incomplete radiolucency around one or two pegs
2	Complete radiolucency around one peg only, with or without incomplete radiolucency around one other peg
3	Complete radiolucency less than 2 mm wide around two or more pegs
4	Complete radiolucency more than 2 mm wide around two or more pegs
5	Gross loosening

Table 6.4 Grading scale for completeness of glenoid component seating

Grade	Description
A	Complete implant seating
B	<25 % incomplete contact, one x-ray
C	25–50 % incomplete contact, one x-ray
D	<50 % incomplete contact, two x-rays
E	>50 % incomplete contact, one x-ray

well [8, 15, 34, 102]. The clinical findings were further validated in a finite element analysis [46]. Malalignment of the glenoid component in the superior inferior plane provided the worst configuration for cement mantle stresses, and the quality of the supporting bone significantly affected the survivability of the cement mantle.

Klepps et al. studied the effect of using a syringe to deliver cement along with mechanical compression of the cement prior to seating of the implant, and they found similar improvements compared to manual finger packing of cement into the peg holes [56]. Barwood et al. studied the effect of cement pressurization and radiolucent lines on early postoperative radiographs [6]. The authors used a mechanical compression device to compress the cement into the peg holes, and this resulted in 90 % of the glenoid implants having zero radiolucencies around the pegs. Choi et al. compared the early postoperative radiographs of glenoid implants that were placed with two different cementing techniques [18]. The first series of implants were cemented with finger packing of the peg holes. The second series of glenoid implants were cemented using a syringe to fill the peg holes, followed by an impaction tool to compress the cement in the holes, followed by finger packing of doughy cement in the peg holes before the implant was put in place. No cement was placed on the backside of the implant. The radiolucent line score was greater than 1 in 45 % of the unpressurized group compared to 19 % in the pressurized group.

In an effort to improve the preparation of the glenoid peg holes for the glenoid implant, Edwards et al. evaluated three different drying techniques of the peg holes prior to insertion of the cement [27]. Twenty-one patients had the peg holes soaked in thrombin, 24 patients had the peg holes dried with compressed carbon dioxide, and 26 patients had the peg holes washed with saline and dried with sponges. The postoperative x-rays were compared among the three groups, and there was no statistical difference found. Forty-one percent of all the glenoids had radiolucency in at least one zone.

Another technique that has been described to improve the cementing technique for the glenoid was originally described for the implantation of stemmed components into the femur. Gross et al. studied the effect of creating a weep hole in the glenoid to allow excess air between the cement and the bone to escape and to allow application of suction to the glenoid vault to pull the cement into the vault [35]. The authors used postoperative x-rays to determine that the amount of cement around the pegs and the keel inside the vault was significantly larger than the glenoid implanted without the weep hole.

Peg vs. Keel

Biomechanical studies have been done in the lab to determine whether pegged or keeled glenoid implants conferred better stability to the implant. Wirth et al. implanted keeled and pegged glenoid implants into dogs and then tested the resistance to axial pullout of the implants after 0, 3, and 6 months [101]. The keeled implant had less resistance to pullout stress than the pegged implants. The radiographic and histologic examination showed partial or complete radiolucent

lines around the keel in each dog, which correlated with the mechanical testing results.

Lacroix et al. studied the failure of fixation of keeled and pegged glenoid components using finite element analysis [61]. They implanted a keeled component and a pegged component into cadaver bone using cement. The stresses around the cement were calculated, and they found that pegged implants had less failure when normal bone was used. When the bone was modified to mimic the structure of a patient with rheumatoid arthritis, the keeled implant had less failure of the cement mantle.

Multiple clinical studies have been done to determine the effect of the keel and peg design of the glenoid component. Gartsman et al. randomized 23 patients to receive a keeled glenoid component and 20 patients to receive a pegged glenoid component [34]. Postoperative radiographs were obtained at 6 weeks from the surgery, and radiographic lucency around the implant was measured. The pegged implants had a mean radiolucency score of 0.5, and the keeled implants had a mean radiolucency score of 1.4. Thirty-nine percent of the keeled components had a radiolucency score greater than 2, while only 5 % of the pegged components had a radiolucency score above 2.

Edwards et al. compared the results of pegged and keeled implants in a randomized study [26]. Fifty-three patients were randomized to each group, and the radiographs during the immediate postoperative period and at an average of 26 months after surgery were compared. The radiolucencies during the immediate postoperative period were 15 % in the keeled group compared to 0 % in the pegged group. After an average of 26 months, 46 % of the keeled implants had radiolucencies compared to 15 % in the pegged implant group. The strengths of this study included the fact that it was randomized so the selection bias, often attributed to the use of keel implants for the most challenging cases, was controlled. The same modern cementing techniques were used in both groups.

Lazarus et al. reviewed 328 postoperative shoulder radiographs and found a statistical trend toward a better result for pegged glenoid implants [63]. When the 0–5 scale was used, the keeled components were more likely to have a grade of 2 or greater when compared to the pegged implants.

Nuttall et al. used a different approach to measuring loosening of the glenoid component [71]. Rather than using radiolucency scores like other studies in the past, the group measured the micromotion of the implants over time using radiostereometric analysis. Beads were placed in five different locations around the scapula during surgery, and four beads were embedded into the keeled and pegged glenoid components. Stereoradiographs were obtained at multiple time points for the first 2 years after surgery. The highest maximum total point movement was 2.57 mm for the keeled components and 1.64 mm for the pegged components. All the components rotated into anteversion, 4.5° for the keeled components and 2.3° for the pegged components.

In contrast, Rahme et al. studied the stability of pegged and keeled glenoid components using radiostereometric analysis in 28 patients [81]. After 2-year follow-up, the authors did not find a difference in motion between the pegged and keeled glenoid components.

A more recent meta-analysis by Vavken et al. reviewed eight studies with a total of 1,460 patients that underwent total shoulder replacement with pegged and keeled components [94]. They found no significant difference in the risk of any radiolucency (risk ratio, 0.42; 95 % CI, 0.12–1.42) or in the risk of severe radiolucency (risk ratio, 0.65; 95 % CI, 0.23–1.82). The risk of revision was 0.27 (95 % CI, 0.08–0.88) in favor of pegged components ($p = 0.028$).

Radial Mismatch

The radii of the humeral head and the glenoid are not the same in the normal shoulder, and this radial mismatch has important effects on the biomechanics of the glenoid component in total shoulder arthroplasty. There is more conformity in the superior-inferior direction compared to the anterior-posterior direction in the normal shoulder [67]. When the mismatch between the humeral head and the glenoid component is low, there is

more conformity of the articular surface. This conformity makes the joint more stable, but it also increases the stress applied to the glenoid component during normal shoulder joint motion. Anglin et al. compared the displacement of a glenoid with radial mismatch of 1.77 mm to a glenoid with a mismatch of 5 mm and found that the displacement was half as much in the 5 mm mismatch group [3]. When the mismatch is higher, the stress over the entire glenoid is less during shoulder motion, but the point contact stress is higher. This point contact stress can impact the structure of the glenoid component and leads to earlier mechanical wear of the polyurethane. When the mismatch becomes too high, the humeral head can translate to the edge of the glenoid component and increase the risk of eccentric loading of the implant, a phenomenon described as the rocking horse effect by Franklin et al. [30].

Many implant designs incorporate a radial mismatch into the system in order to mimic the normal glenohumeral joint mechanics, and the amount of mismatch has been studied in both clinical and biomechanical studies. One of the most important studies that has been published on this topic was done by Walch et al. who evaluated the results of 319 total shoulder arthroplasties [97]. They divided the patients into four groups based on the amount of radial mismatch: (1) <4 mm, (2) 4.5–5.5 mm, (3) 6–7 mm, and (4) >7 mm. They evaluated the radiographs of these patients postoperatively at a mean follow-up of 54 months, and they found a linear relationship between the amount of radiolucencies around the implants and the amount of radial mismatch. The authors recommended that the amount of radial mismatch should be between 6 and 7 mm to obtain optimal results.

Radial mismatch is also another way to describe joint congruity. The more mismatch between the humeral and glenoid radius of curvature, the less congruity of the system. This is different than joint constraint, which is determined by the wall height of the glenoid component. One negative effect of increasing the radial mismatch is the potential for joint instability. Karduna et al. evaluated the effect of articular surface conformity on glenohumeral joint stability [53]. They controlled the effect of constraint by using the same glenoid component for each experiment, and they used different humeral head sizes to test the effect of varying conformity or radial mismatch of the system. The authors found that variations in joint conformity only accounted for 3 % of the force needed to dislocate the joint. In other words, increasing radial mismatch did not lead to increased risk of dislocation as long as the constraint or wall height of the glenoid implant is unchanged.

In order to better define the amount of radial mismatch that will minimize micromotion of the glenoid component, Sabesan et al. tested multiple size configurations of a cemented pegged all-polyethylene glenoid component [85]. The glenoids were loaded cyclically using the ASTM standard testing configuration described earlier, and the micromotion of the glenoids was measured. The micromotions of the implants with a radial mismatch of +2, +6, and +10 were not statistically different. The implants with a +14 and +18 mm mismatch could not complete the 50,000 cycles because of catastrophic failure. These results suggest that radial mismatch should be 10 mm or less.

Metal-Backed Glenoids

In an effort to improve the fixation of the all-polyethylene glenoid component, engineers developed polyethylene components that were fixed to the glenoid with some form of metal backing [80]. Earlier designs incorporated a metal platform that was secured to the glenoid with screws. This often resulted in an implant that was thicker than the all-polyethylene components, which had the potential to lateralize the joint line. Lateralization of the joint line can result in overstuffing of the joint, which in turn will alter the mechanics of the rotator cuff and lead to weakness or loss of shoulder motion. The lateralization can also increase the joint reactive forces that contribute to edge loading of the glenoid component, leading to wear of the polyethylene or premature loosening [78].

The material properties of the titanium metal, which is often used, have a different stiffness

than the bone or the polyethylene. The Young's modulus of titanium is >100 GPa, while the Young's modulus of bone is <10 GPa, and even lower is the Young's modulus of polyethylene <1 GPa. The differences in stiffness at the interfaces among the materials can lead to increased motion and wear of the softer polyethylene. The higher stiffness of the metal can also lead to stress shielding of portions of the glenoid bone, which risks loss of critical bone support that can already be small.

One of the first biomechanical studies that evaluated the stresses around a glenoid implant was done by Orr et al. [76]. The authors performed a two-dimensional finite element analysis to determine how a metal-backed glenoid component would change the stresses on the native glenoid compared to its normal state. The authors found that a metal implant similar to the Neer II system decreased the subchondral stresses, which explain why a metal-backed glenoid implant could cause osteolysis behind the implant. Another finite element analysis by Friedman et al. showed that an all-polyethylene component provides more physiologic stress distributions under nonaxial loading compared to metal-backed implants [32]. Stone et al. used the above data and performed an analysis using an all-polyethylene component and metal-backed component from the Cofield Total Shoulder System (Smith Nephew Richards, Inc, Memphis, Tenn). Using a two-dimensional finite element analysis, the authors found that the metal-backed implants reduced the subchondral bone stress, and this was more pronounced during eccentric loading [92].

Further biomechanical studies have shown that metal-backed glenoid implants have more stress concentration between the transition zone of the polyethylene and the metal [36]. They also show less stress at the metal-bone interface, which can explain the stress shielding and early failures seen in clinical follow-up studies [62].

Porous tantalum backing of the glenoid component was investigated by Andreykiv et al. [1]. Finite element models were used to determine the effect of porous tantalum on initial fixation, elastic properties of the implant, and friction at the bone-implant interface. The authors found that the major role of the tantalum backing was not to firmly fix the prosthesis but, instead, to distribute the load across the entire area of the bone-implant interface, which will limit the micromotion and allow for optimal bone ingrowth.

Zimmer, Inc. introduced a porous tantalum-backed glenoid component, and the initial fixation of the implant was compared to an all-polyethylene glenoid component by Budge et al. [12]. The tantalum implant was fixed to polyurethane bone substitute with a press-fit technique, PMMA cement, or calcium phosphate cement. The implants were loaded with the ASTM testing protocol, and glenoid distraction, compression, and translation were measured. The all-polyethylene implant fixed with cement demonstrated the least amount of micromotion, followed by the tantalum implant fixed with polymethyl methacrylate cement. A 2-year clinical follow-up study of tantalum-backed glenoid components was presented by the same research group, and they found a surprising number of early failures due to catastrophic dissociation between the polyethylene and tantalum keel [14].

Posterior Glenoid Bone Loss

One of the most challenging glenoid deformities to treat during total shoulder replacement is posterior glenoid bone loss that is often seen with Walch type B2 or C glenoids. Clinical studies have shown worse results for total shoulder arthroplasty in patients with posterior glenoid bone loss [51, 64]. The options to treat these types of glenoids include correction of retroversion of the glenoid by reaming the "high side" of the anterior glenoid bone, implantation of the glenoid component in retroversion, implantation of an augmented glenoid component, correction of the posterior bone loss with bone graft, hemiarthroplasty, or reverse total shoulder arthroplasty [47, 91]. Reaming the high side of the glenoid to correct the retroversion of the glenoid is the most commonly used technique to correct glenoid version, but it can lead to medialization of the joint line and perforation of the implant pegs [20, 69, 84]. This technique can also take

away the strong subchondral bone anteriorly, which may compromise the long-term fixation of the glenoid component. Medialization of the joint line or incomplete correction of the retroversion can also lead to posterior instability of the humeral head or early loosening of the glenoid component [42, 44]. When the posterior bone loss is severe, reaming of the glenoid with any technique may still leave a significant portion of the glenoid unsupported by bone. Reports of bone grafting the posterior glenoid showed some promise, but there are complications associated with the technique including early loosening of the glenoid implant and broken hardware [57, 83].

Augmentation of the posterior glenoid implant is another method used to treat glenoids with posterior bone loss. The glenoid component can be augmented with different types of geometry on the backside of the implant. The Depuy Step Tech implant uses a dual curved back design where the posterior and anterior portions of the implant have the same curved geometry at two different heights with a step in the middle. This requires removal of bone from the posterior and central portions of the glenoid, but this allows for better biomechanical resistance to micromotion compared to other backside geometries [50]. The Exactech posterior glenoid augment design has a curved backside with one curve designed to match the retroversion of the glenoid. The pegs are perpendicular to the articular surface, which is angled in relation to the backside of the glenoid so that the articular surface is aligned with the neutral version of the scapula. The benefit of this design is that it requires less bone removal, so it preserves the strong subchondral bone layer that may play an important role in the long-term survival of the implant [58]. The geometry of the backside of the implant may, however, lead to early loosening because it does not resist micromotion as well as other designs. Future designs will likely have even more variation in the design and geometry that impacts fixation and long-term survivorship. Hopefully, the results of biomechanical studies and clinical outcome studies can help surgeons make the best choice for each individual patient.

Bryce et al. studied the effect of posterior glenoid bone loss on humeral head translation [11]. They used eight cadaver scapulae and removed the posterior glenoid bone in 5° increments. The humeral head was loaded onto the glenoid in various positions, and the amount of humeral head translation was measured. They found that the humeral head translated posteriorly to a significant degree after 20° of posterior bone was removed when the humeral head was in neutral rotation. They also found that as little as 5° of posterior bone loss resulted in significant posterior humeral head translation when the humerus was in forward flexion. Five degrees of posterior bone loss equated to 2.5° of retroversion in this study.

Nyffeler et al. used a cadaver model to determine the effects of glenoid version on humeral head instability and glenoid component loosening [75]. They implanted a total shoulder into cadaver specimens and altered the glenoid component version in steps of 4°. The shoulders were loaded with physiologic loads, and the translation of the humeral head and the loads across the glenoid component were measured. They found that any retroversion of the glenoid component led to posterior translation of the humeral head and that small degrees of retroversion resulted in eccentric loading of the glenoid component that could result in early loosening. Furthermore, anteversion of the humeral head did not compensate for retroversion of the glenoid component.

To determine the risks of loosening of the glenoid component when it is implanted in retroversion, Farron et al. used a finite element model [28]. A keeled glenoid component was implanted into a normal glenoid in neutral version and 4 other positions of retroversion, 5°, 10°, 15°, and 20°. The model used a 1 mm layer of cement around the implant. Glenoid retroversion of 20° increased the peak cement stress by 326 % at the posterior part of the cement mantle. In the neutral position, the cement loads were evenly distributed around the keel and glenoid back. Micromotion increased with retroversion above 5°, and the maximal micromotion was +706 %. The stress of the glenoid bone was also increased +162 % when the implant was retroverted to 20°,

and this stress was localized at the posterior aspect of the glenoid.

Youngpravat et al. performed an elegant study that takes into account both the subchondral bone density and the orientation of the glenoid component in the case of posterior glenoid bone loss. The investigators used a homogenous bone model as well as a model with cortical and cancellous bone. The glenoid component was implanted with complete correction, partial correction, and partial component backside bone support. In the homogeneous bone model, complete correction with reaming of the high side bone resulted in the strongest configuration. Implantation of the glenoid component in retroversion without correction had the highest risk of failure. In the heterogeneous bone model, complete correction of the retroversion by reaming the high side of the anterior glenoid had the highest risk of failure [103] (Fig. 6.17).

Kirane et al. evaluated the biomechanical characteristics of an all-polyethylene and titanium step used to augment a polyethylene glenoid component in cadaver specimens [55]. The investigators created a posterior defect in the glenoid and implanted a pegged all-polyethylene implant augmented with either a polyethylene augment or a titanium augment. The control group for the experiment was a normal glenoid implant used in a normal glenoid without a posterior defect. Loads were applied through the

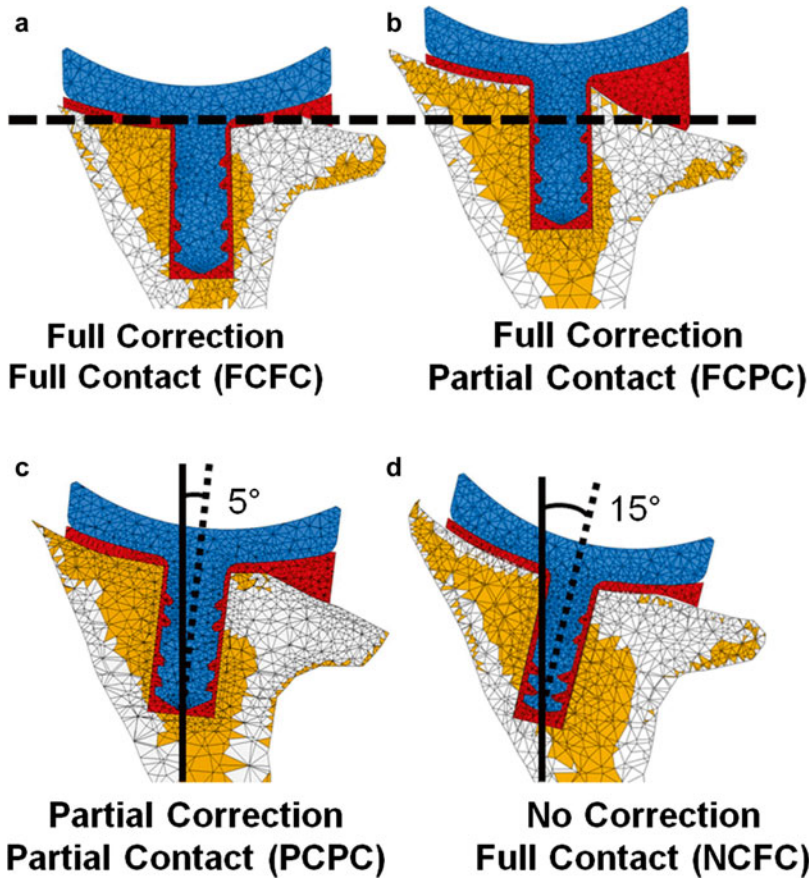


Fig. 6.17 Total shoulder arthroplasty scenarios are shown for study group 2 (heterogeneous scapula): (**a**) full correction, full contact (FCFC); (**b**) full correction, partial contact (FCPC); (**c**) partial correction, partial contact (PCPC); (**d**) no correction, full contact (NCFC). The *blue, red, white*, and *orange* indicate, respectively, implant, cement, cortical bone, and trabecular bone. Note the occurrence of glenoid decortication, particularly in the FCFC scenario, when correcting significant bony pathology (Reprinted from Yongpravat et al. [103] with permission from Elsevier)

rotator cuff muscles to simulate the force generated when a patient pushes his/her body weight away from a wall. The peri-glenoid strains recorded during the experiments were similar for the controls and the polyethylene augmented glenoid. The peri-glenoid strains were higher in the group augmented by the titanium augment.

Wang et al. compared the initial stability of standard all-polyethylene component that was prepared with eccentric reaming to correct retroversion to neutral with the initial stability of a posterior augmented all-polyethylene component with an 8° angle-backed posterior augment [99]. Cyclic loading was applied to all specimens according to the ASTM standard F2028-08 with 100,000 cycles. Superior and edge displacements were recorded during the loading protocol. Three of the six specimens in the posterior augmented group did not survive the loading protocol of the experiment, while five of the six implants in the eccentric anterior reaming group did survive the loading protocol. These data suggest that an angled-back geometry may not resist shear stress as well as the standard glenoid implant.

Iannotti et al. tested the biomechanical characteristics of four different glenoid designs with posterior augmentation with one non-augmented glenoid design [50]. The glenoids studied included the following types: (1) spherical asymmetric glenoid, (2) spherical symmetric glenoid, (3) flat angled glenoid, (4) stepped glenoid, and (5) standard symmetrical curved back glenoid. These glenoids all had the same central peg design (Fig. 6.18). The glenoid components were implanted into foam bone and cyclically loaded according to the ASTM standard protocol, and the micromotion of the anterior edge of the implant was measured. In the group that used cement for the peripheral pegs, after 100,000 cycles, the standard glenoid lift off was 34 ± 0 μ, the step tech was 87 ± 66 μ, the flat angled was 334 ± 179 μ, the spherical symmetric was 294 ± 174 μ, and the spherical asymmetric implant was 310 ± 23 μ. When the spherical symmetric design was compared to the step tech, there was a statistical difference at the initial loading of the implant, but there was not a statistically significant difference after 100,000 cycles.

Reverse Baseplate Fixation

Since the initial use of the reverse total shoulder, the glenoid component fixation has been a common reason for early implant failure. The first generation of reverse total shoulder designs used a lateralized center of rotation for the glenoid side of the implant. Modifications of the design

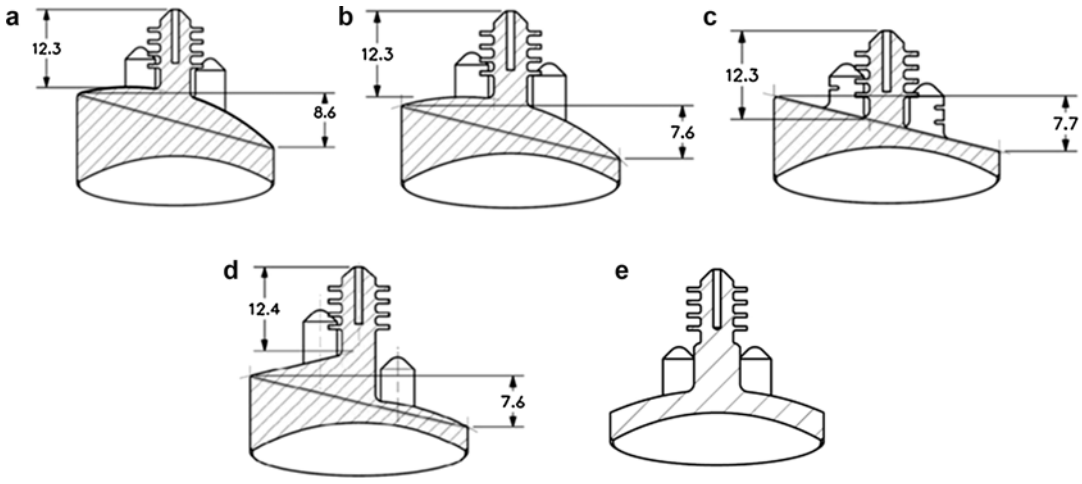


Fig. 6.18 Cross sections of five glenoid designs: (**a**) spherical asymmetric glenoid, (**b**) spherical symmetric glenoid, (**c**) flat angled glenoid, (**d**) stepped glenoid, and (**e**) Anchor Peg Glenoid (Reprinted from Iannotti et al. [50] with permission from Elsevier)

that medialized the center of rotation of the implant decreased the stresses of the glenoid baseplate and resulted in less loosening and less early failure [9]. New designs that allow for larger screws, locking screws, and variable screw angle insertion have improved the initial fixation of the glenoid baseplate as well. As the implant fixation methods have improved, implant designers have changed the center of rotation of the reverse constructs to more lateralized designs to help minimize the complications that occur with medialization. Some authors have described less scapular notching when the center of rotation is lateralized because the medial calcar of the humeral implant is less likely to impinge on the scapula [5, 59, 82, 88]. Other biomechanical considerations have improved the surgical technique used to insert the baseplate, and these have been tested in biomechanical studies. Some modifications that are more difficult to test in the lab include bone ingrowth technology. These biologic solutions cannot be simulated with our current biomechanical experiments, so we must rely on long-term clinical follow-up before knowing how well these factors affect the stability of the glenoid baseplates.

Some of the earlier biomechanical studies focused on the effect of the screws used to fix the glenoid baseplate. Chebli et al. used a sawbone model to fix a glenoid baseplate with multiple variations in screw configurations [16]. The authors found that the inferior screw was the most important because fixation strength was 35 % weaker when that screw was omitted. The strength of the fixation was 16 % weaker if the superior screw was omitted. Harmen et al. compared the fixation of the Encore reverse baseplate fixation, which uses 4 locking screws and a central non-locking screw with a flat baseplate to the Depuy Delta III baseplate fixation, which uses two locking screws and two non-locking screws to fix a flat baseplate with a central peg [39]. The Encore design used a lateralized center of rotation which exerts a 69 % higher load onto the baseplate compared to the Delta III design that has a more medialized center of rotation. The micromotion of both designs was below the threshold of 150 μ that is required to obtain bone ingrowth into the implants. If the Encore baseplate was fixed with non-locking screws, the micromotion was above the 150 μ threshold.

The number of screws used to fix the glenoid has also become a question for debate as different designs use multiple screw configurations. All designs incorporate at a minimum a superior and inferior screw, which are commonly locked to the plate. Many designs also include a screw that can be fixed in the center of the glenoid baseplate that engages the cortical bone in the middle column of the scapula. Other designs allow for an anterior and posterior screw to be placed, but the bone can be thin and soft in these positions after the glenoid has been reamed, especially in smaller women. When the posterior screw engages both the glenoid cortex and the cortex of the scapular spine, the stability of the glenoid implant has been shown to improve significantly by two separate studies [23, 45]. The problem with using this type of configuration is that the screw can potentially injure the suprascapular nerve as it courses around the base of the scapular spine [40, 68, 98]. James et al. studied the effect of using two locking screws alone compared to two locking screws in addition to two non-locking screws in the anterior and posterior positions. They did not find any difference between the micromotion of the glenoid baseplate in their cadaver model [52].

It is often difficult to apply the results of one biomechanical study that uses a specific implant to another implant that may have other important design characteristics that influence initial fixation of the implant. These design differences include backside geometry such as flat-backed or curve-backed designs. Curved-backed designs have been showed to improve initial stability in biomechanical testing, but they have the disadvantage of removing more cortical bone on the inferior glenoid due to the more inferior positioning of the implant compared to an anatomic implant [52]. This inferior placement is done to avoid notching of the scapula by the medial calcar of the humeral implant. The inclination of the glenoid implant also plays a critical role in the initial fixation of the implant and the likelihood of causing of scapular notching. Some authors have shown that inferior tilt of the glenosphere improves the mechanics of the implant and decreases the micromotion in sawbone models

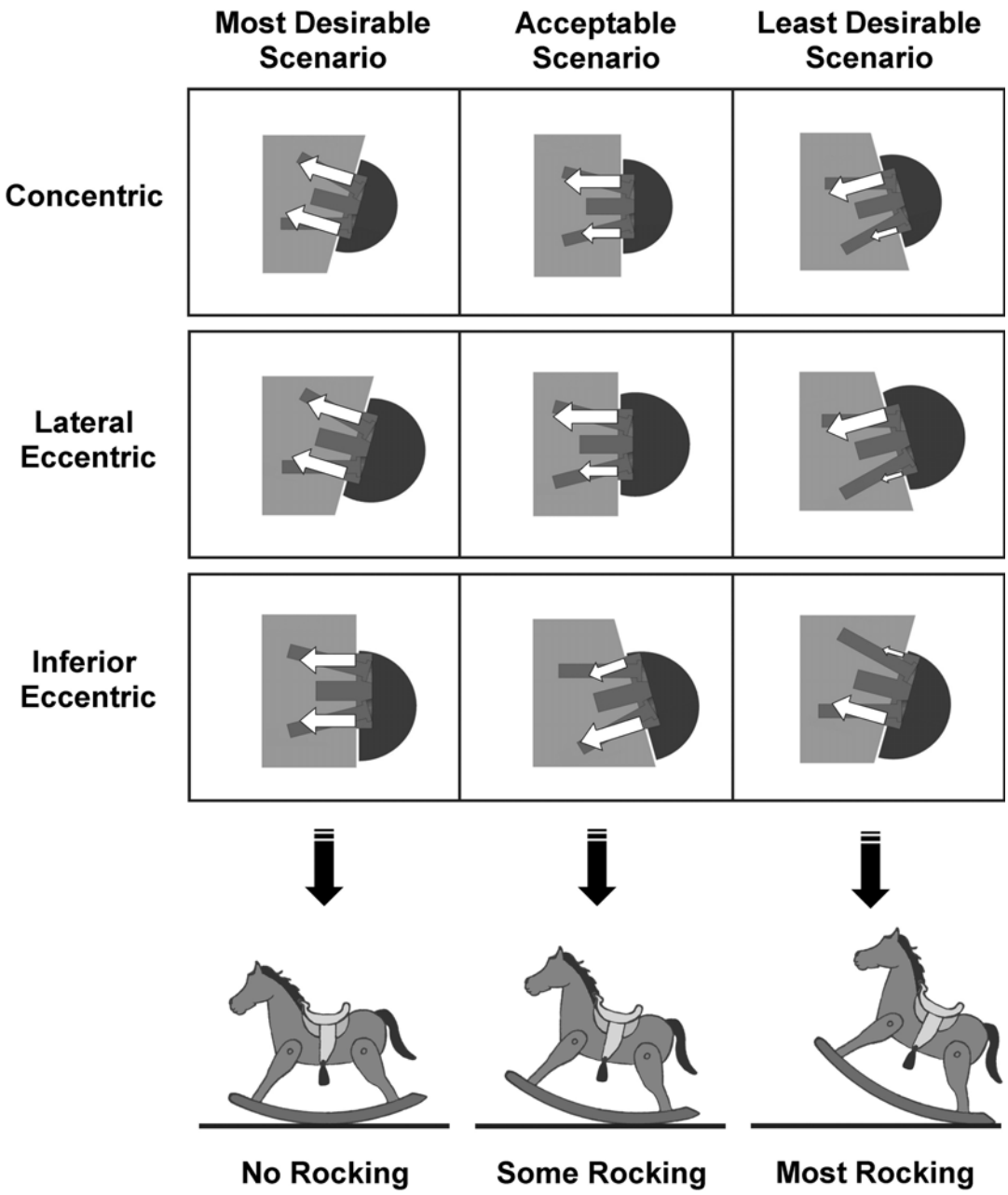


Fig. 6.19 This is an illustration of the effect of different forces at the baseplate-bone interface. Each glenosphere configuration (concentric, lateral eccentric, and inferior eccentric) can be placed in differing tilts to produce more even forces at the baseplate-bone interface. These forces are optimum for concentric and lateral eccentric glenospheres when placed in inferior tilt, while for inferior eccentric glenospheres, the optimal tilt is neutral; this placement will cause the least amount of rocking. The other tilts lead to more uneven forces at the baseplate-bone junction and hence, increased rocking (Reprinted from Gutierrez et al. [38] with permission from Elsevier)

[38]. In an effort to minimize notching that was often seen with medialized glenoid designs, the glenosphere was changed to allow for inferior eccentric placement of the glenosphere on the baseplate. This allows the humeral component to be pushed more inferior and allows for more clearance before the humerus could impinge on the scapula. The biomechanical effect of this

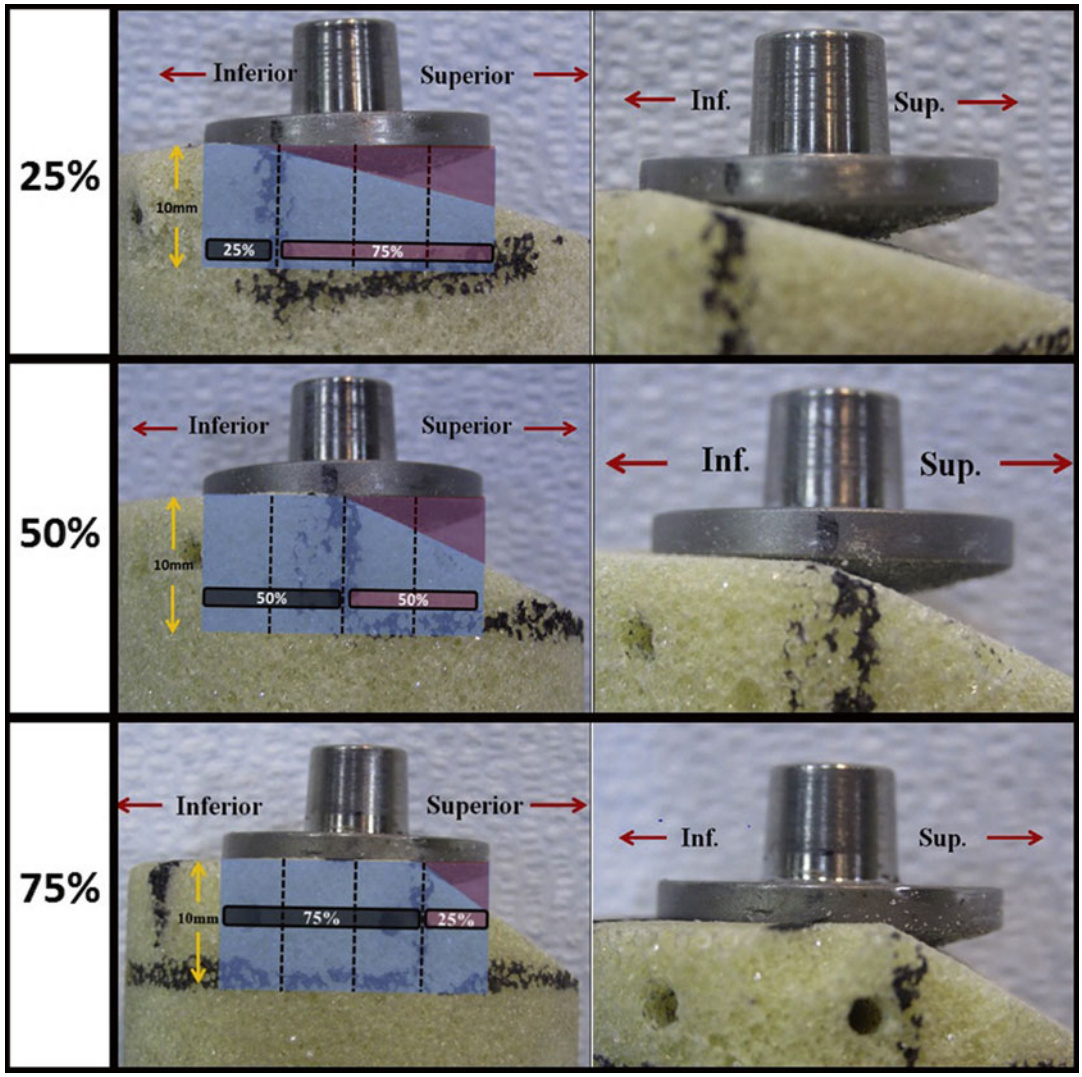


Fig. 6.20 Examples of the baseplate coverage experimental groups, demonstrating 25 % coverage, 50 % coverage, and 75 % coverage of the undersurface of the glenoid baseplate (100 % coverage not shown) (Reprinted from Formaini et al. [29] with permission from Elsevier)

design compared to the medialized concentric design and a lateralized design was studied by Gutierrez et al. They found better mechanics and less rocking horse potential when the concentric and lateralized design was placed with inferior tilt, but the eccentric design had the best biomechanical stability when it was placed without any tilt [37] (Fig. 6.19).

Bone loss can affect the stability of the reverse glenoid baseplate, and this is more commonly seen in difficult revision cases where the reverse total shoulder is used. Surgeons are also confronted with an intraoperative decision when reaming the glenoid with inferior tilt, a method shown to improve the stability of the implant. The surgeon often has to ream away good bone medially in order to achieve complete backside bone coverage of the baseplate. Should the surgeon stop reaming and implant the baseplate with 75 % or 50 % coverage, or continue to ream medially in order to obtain 100 % bone coverage of the baseplate? Formaini et al. tried to answer

this question, and they examined the effect of different levels of bone loss on the initial stability of the Encore reverse glenoid baseplate in a foam block model [29]. They found that the micromotion of the baseplate was above the 150 μ threshold needed for bone ingrowth, but that 50 %, 75 %, and normal glenoid bone conditions did not show any significant difference in micromotion (Fig. 6.20).

Summary

In summary, glenoid version can be accurately measured with axillary radiographs taken with good technique. CT scans can help get better version measurements in cases of glenoid deformity, and the method of image acquisition can affect the version measurements by 10° if not done properly. The shape of the glenoid vault can be used to predict the version of a glenoid before it was deformed with pathology. Glenoid retroversion is increased in patients with arthritis compared to patients without pathology of the glenohumeral joint. Stability of glenoid implants is improved when the implant is completely supported by subchondral bone, and the version of the implant is not retroverted. Glenoid cement should be applied with pressurization, and metal-backed glenoids used in anatomic total shoulders have shown a higher revision rate than polyethylene glenoids in multiple studies. Metal baseplates used in reverse total shoulders depend on a minimum of one screw in the inferior column, which provides the most resistance to micromotion, and one screw in the superior column of the scapula. The reverse total shoulder baseplate should not be implanted with any superior inclination, and at least 50 % of the backside of the implant should be supported by the bone.

References

1. Andreykiv A, Prendergast PJ, van Keulen F, Swieszkowski W, Rozing PM. Bone ingrowth simulation for a concept glenoid component design. J Biomech. 2005;38(5):1023–33.
2. Anglin C, Wyss UP, Pichora DR. Mechanical testing of shoulder prostheses and recommendations for glenoid design. J Shoulder Elbow Surg. 2000;9(4):323–31.
3. Anglin C, Wyss UP, Pichora DR. Shoulder prosthesis subluxation: theory and experiment. J Shoulder Elbow Surg. 2000;9(2):104–14.
4. Antuna SA, Sperling JW, Cofield RH, Rowland CM. Glenoid revision surgery after total shoulder arthroplasty. J Shoulder Elbow Surg. 2001;10(3):217–24.
5. Athwal GS, MacDermid JC, Reddy KM, Marsh JP, Faber KJ, Drosdowech D. Does bony increased-offset reverse shoulder arthroplasty decrease scapular notching? J Shoulder Elbow Surg. 2015;24(3):468–73.
6. Barwood S, Setter KJ, Blaine TA, Bigliani LU. The incidence of early radiolucencies about a pegged glenoid component using cement pressurization. J Shoulder Elbow Surg. 2008;17(5):703–8.
7. Bicknell RT, Patterson SD, King GJ, Chess DG, Johnson JA. Glenoid vault endosteal dimensions: an anthropometric study with special interest in implant design. J Shoulder Elbow Surg. 2007;16(3 Suppl):S96–101.
8. Boileau P, Avidor C, Krishnan SG, Walch G, Kempf JF, Mole D. Cemented polyethylene versus uncemented metal-backed glenoid components in total shoulder arthroplasty: a prospective, double-blind, randomized study. J Shoulder Elbow Surg. 2002;11(4):351–9.
9. Boileau P, Watkinson DJ, Hatzidakis AM, Balg F. Grammont reverse prosthesis: design, rationale, and biomechanics. J Shoulder Elbow Surg. 2005;14(1 Suppl S):147S–61.
10. Bryce CD, Davison AC, Lewis GS, Wang L, Flemming DJ, Armstrong AD. Two-dimensional glenoid version measurements vary with coronal and sagittal scapular rotation. J Bone Joint Surg Am. 2010;92(3):692–9.
11. Bryce CD, Davison AC, Okita N, Lewis GS, Sharkey NA, Armstrong AD. A biomechanical study of posterior glenoid bone loss and humeral head translation. J Shoulder Elbow Surg. 2010;19(7):994–1002.
12. Budge MD, Kurdziel MD, Baker KC, Wiater JM. A biomechanical analysis of initial fixation options for porous-tantalum-backed glenoid components. J Shoulder Elbow Surg. 2013;22(5):709–15.
13. Budge MD, Lewis GS, Schaefer E, Coquia S, Flemming DJ, Armstrong AD. Comparison of standard two-dimensional and three-dimensional corrected glenoid version measurements. J Shoulder Elbow Surg. 2011;20(4):577–83.
14. Budge MD, Nolan EM, Heisey MH, Baker K, Wiater JM. Results of total shoulder arthroplasty with a monoblock porous tantalum glenoid component: a prospective minimum 2-year follow-up study. J Shoulder Elbow Surg. 2013;22(4):535–41.
15. Carke IC, Sew Hoy AL, Gruen TA, Amstutz HC. Clinical and radiographic assessment of a non-constrained total shoulder. Int Orthop. 1981;5(1):1–8.

16. Chebli C, Huber P, Watling J, Bertelsen A, Bicknell RT, Matsen 3rd F. Factors affecting fixation of the glenoid component of a reverse total shoulder prosthesis. J Shoulder Elbow Surg. 2008;17(2):323–7.
17. Checroun AJ, Hawkins C, Kummer FJ, Zuckerman JD. Fit of current glenoid component designs: an anatomic cadaver study. J Shoulder Elbow Surg. 2002;11(6):614–7.
18. Choi T, Horodyski M, Struk AM, Sahajpal DT, Wright TW. Incidence of early radiolucent lines after glenoid component insertion for total shoulder arthroplasty: a radiographic study comparing pressurized and unpressurized cementing techniques. J Shoulder Elbow Surg. 2013;22(3):403–8.
19. Churchill RS, Brems JJ, Kotschi H. Glenoid size, inclination, and version: an anatomic study. J Shoulder Elbow Surg. 2001;10(4):327–32.
20. Clavert P, Millett PJ, Warner JJ. Glenoid resurfacing: what are the limits to asymmetric reaming for posterior erosion? J Shoulder Elbow Surg. 2007;16(6): 843–8.
21. Codsi MJ, Bennetts C, Gordiev K, Boeck DM, Kwon Y, Brems J, et al. Normal glenoid vault anatomy and validation of a novel glenoid implant shape. J Shoulder Elbow Surg. 2008;17(3):471–8.
22. Codsi MJ, Bennetts C, Powell K, Iannotti JP. Locations for screw fixation beyond the glenoid vault for fixation of glenoid implants into the scapula: an anatomic study. J Shoulder Elbow Surg. 2007;16(3 Suppl):S84–9.
23. Codsi MJ, Iannotti JP. The effect of screw position on the initial fixation of a reverse total shoulder prosthesis in a glenoid with a cavitary bone defect. J Shoulder Elbow Surg. 2008;17(3):479–86.
24. Couteau B, Mansat P, Mansat M, Darmana R, Egan J. In vivo characterization of glenoid with use of computed tomography. J Shoulder Elbow Surg. 2001;10(2):116–22.
25. Cyprien JM, Vasey HM, Burdet A, Bonvin JC, Kritsikis N, Vuagnat P. Humeral retrotorsion and glenohumeral relationship in the normal shoulder and in recurrent anterior dislocation (scapulometry). Clin Orthop Relat Res. 1983;175:8–17.
26. Edwards TB, Labriola JE, Stanley RJ, O'Connor DP, Elkousy HA, Gartsman GM. Radiographic comparison of pegged and keeled glenoid components using modern cementing techniques: a prospective randomized study. J Shoulder Elbow Surg. 2010; 19(2):251–7.
27. Edwards TB, Sabonghy EP, Elkousy H, Warnock KM, Hammerman SM, O'Connor DP, et al. Glenoid component insertion in total shoulder arthroplasty: comparison of three techniques for drying the glenoid before cementation. J Shoulder Elbow Surg. 2007;16(3 Suppl):S107–10.
28. Farron A, Terrier A, Buchler P. Risks of loosening of a prosthetic glenoid implanted in retroversion. J Shoulder Elbow Surg. 2006;15(4):521–6.
29. Formaini NT, Everding NG, Levy JC, Santoni BG, Nayak AN, Wilson C, et al. The effect of glenoid bone loss on reverse shoulder arthroplasty baseplate fixation. J Shoulder Elbow Surg. 2015;24:e312–9.
30. Franklin JL, Barrett WP, Jackins SE, Matsen 3rd FA. Glenoid loosening in total shoulder arthroplasty. Association with rotator cuff deficiency. J Arthroplast. 1988;3(1):39–46.
31. Friedman RJ, Hawthorne KB, Genez BM. The use of computerized tomography in the measurement of glenoid version. J Bone Joint Surg Am. 1992;74(7): 1032–7.
32. Friedman RJ, Laberge M, Dooley RL, O'Hara AL. Finite element modeling of the glenoid component: effect of design parameters on stress distribution. J Shoulder Elbow Surg. 1992;1(5):261–70.
33. Ganapathi A, McCarron JA, Chen X, Iannotti JP. Predicting normal glenoid version from the pathologic scapula: a comparison of 4 methods in 2- and 3-dimensional models. J Shoulder Elbow Surg. 2011;20(2):234–44.
34. Gartsman GM, Elkousy HA, Warnock KM, Edwards TB, O'Connor DP. Radiographic comparison of pegged and keeled glenoid components. J Shoulder Elbow Surg. 2005;14(3):252–7.
35. Gross RM, High R, Apker K, Haggstrom J, Fehringer JA, Stephan J. Vacuum assist glenoid fixation: does this technique lead to a more durable glenoid component? J Shoulder Elbow Surg. 2011;20(7):1050–60.
36. Gupta S, van der Helm FC, van Keulen F. Stress analysis of cemented glenoid prostheses in total shoulder arthroplasty. J Biomech. 2004;37(11):1777–86.
37. Gutierrez S, Greiwe RM, Frankle MA, Siegal S, Lee 3rd WE. Biomechanical comparison of component position and hardware failure in the reverse shoulder prosthesis. J Shoulder Elbow Surg. 2007;16(3 Suppl):S9–12.
38. Gutierrez S, Walker M, Willis M, Pupello DR, Frankle MA. Effects of tilt and glenosphere eccentricity on baseplate/bone interface forces in a computational model, validated by a mechanical model, of reverse shoulder arthroplasty. J Shoulder Elbow Surg. 2011;20(5):732–9.
39. Harman M, Frankle M, Vasey M, Banks S. Initial glenoid component fixation in "reverse" total shoulder arthroplasty: a biomechanical evaluation. J Shoulder Elbow Surg. 2005;14(1 Suppl S):162s–7.
40. Hart ND, Clark JC, Wade Krause FR, Kissenberth MJ, Bragg WE, Hawkins RJ. Glenoid screw position in the encore reverse shoulder prosthesis: an anatomic dissection study of screw relationship to surrounding structures. J Shoulder Elbow Surg. 2013;22(6):814–20.
41. Hendel MD, Bryan JA, Barsoum WK, Rodriguez EJ, Brems JJ, Evans PJ, et al. Comparison of patient-specific instruments with standard surgical instruments in determining glenoid component position: a randomized prospective clinical trial. J Bone Joint Surg Am. 2012;94(23):2167–75.
42. Ho JC, Sabesan VJ, Iannotti JP. Glenoid component retroversion is associated with osteolysis. J Bone Joint Surg Am. 2013;95(12), e82.

43. Ho JC, Youderian A, Davidson IU, Bryan J, Iannotti JP. Accuracy and reliability of postoperative radiographic measurements of glenoid anatomy and relationships in patients with total shoulder arthroplasty. J Shoulder Elbow Surg. 2013;22(8):1068–77.
44. Hoenecke Jr HR, Tibor LM, D'Lima DD. Glenoid morphology rather than version predicts humeral subluxation: a different perspective on the glenoid in total shoulder arthroplasty. J Shoulder Elbow Surg. 2012;21(9):1136–41.
45. Hoenig MP, Loeffler B, Brown S, Peindl R, Fleischli J, Connor P, et al. Reverse glenoid component fixation: is a posterior screw necessary? J Shoulder Elbow Surg. 2010;19(4):544–9.
46. Hopkins AR, Hansen UN, Amis AA, Emery R. The effects of glenoid component alignment variations on cement mantle stresses in total shoulder arthroplasty. J Shoulder Elb Surg. 2004;13(6):668–75.
47. Hsu JE, Ricchetti ET, Huffman GR, Iannotti JP, Glaser DL. Addressing glenoid bone deficiency and asymmetric posterior erosion in shoulder arthroplasty. J Shoulder Elbow Surg. 2013;22(9): 1298–308.
48. Humphrey CS, Kelly 2nd JD, Norris TR. Optimizing glenosphere position and fixation in reverse shoulder arthroplasty, Part two: the three-column concept. J Shoulder Elbow Surg. 2008;17(4):595–601.
49. Iannotti JP, Gabriel JP, Schneck SL, Evans BG, Misra S. The normal glenohumeral relationships. An anatomical study of one hundred and forty shoulders. J Bone Joint Surg Am. 1992;74(4):491–500.
50. Iannotti JP, Lappin KE, Klotz CL, Reber EW, Swope SW. Liftoff resistance of augmented glenoid components during cyclic fatigue loading in the posterior-superior direction. J Shoulder Elbow Surg. 2013; 22(11):1530–6.
51. 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):251–8.
52. James J, Huffman KR, Werner FW, Sutton LG, Nanavati VN. Does glenoid baseplate geometry affect its fixation in reverse shoulder arthroplasty? J Shoulder Elbow Surg. 2012;21(7):917–24.
53. Karduna AR, Williams GR, Williams JL, Iannotti JP. Joint stability after total shoulder arthroplasty in a cadaver model. J Shoulder Elbow Surg. 1997;6(6): 506–11.
54. Karelse A, Van Tongel A, Verstraeten T, Poncet D, De Wilde LF. Rocking-horse phenomenon of the glenoid component: the importance of inclination. J Shoulder Elbow Surg. 2015;24(7):1142–8.
55. Kirane YM, Lewis GS, Sharkey NA, Armstrong AD. Mechanical characteristics of a novel posterior-step prosthesis for biconcave glenoid defects. J Shoulder Elbow Surg. 2012;21(1):105–15.
56. Klepps S, Chiang AS, Miller S, Jiang CY, Hazrati Y, Flatow EL. Incidence of early radiolucent glenoid lines in patients having total shoulder replacements. Clin Orthop Relat Res. 2005;435:118–25.
57. Klika BJ, Wooten CW, Sperling JW, Steinmann SP, Schleck CD, Harmsen WS, et al. Structural bone grafting for glenoid deficiency in primary total shoulder arthroplasty. J Shoulder Elbow Surg. 2014; 23(7):1066–72.
58. Knowles NK, Ferreira LM, Athwal GS. Augmented glenoid component designs for type B2 erosions: a computational comparison by volume of bone removal and quality of remaining bone. J Shoulder Elbow Surg. 2015;24(8):1218–26.
59. Kowalsky MS, Galatz LM, Shia DS, Steger-May K, Keener JD. The relationship between scapular notching and reverse shoulder arthroplasty prosthesis design. J Shoulder Elbow Surg. 2012;21(10): 1430–41.
60. Kwon YW, Powell KA, Yum JK, Brems JJ, Iannotti JP. Use of three-dimensional computed tomography for the analysis of the glenoid anatomy. J Shoulder Elbow Surg. 2005;14(1):85–90.
61. Lacroix D, Murphy LA, Prendergast PJ. Three-dimensional finite element analysis of glenoid replacement prostheses: a comparison of keeled and pegged anchorage systems. J Biomech Eng. 2000; 122(4):430–6.
62. Lawrence TM, Ahmadi S, Sperling JW, Cofield RH. Fixation and durability of a bone-ingrowth component for glenoid bone loss. J Shoulder Elbow Surg. 2012;21(12):1764–9.
63. Lazarus MD, Jensen KL, Southworth C, Matsen FA. The radiographic evaluation of keeled and pegged glenoid component insertion. J Bone Joint Surg Am. 2002;84-a(7):1174–82.
64. 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):449–54.
65. Mallon WJ, Brown HR, Vogler JB, 3rd, Martinez S. Radiographic and geometric anatomy of the scapula. Clin Orthop Relat Res. 1992;277:142–54.
66. Matsumura N, Ogawa K, Kobayashi S, Oki S, Watanabe A, Ikegami H, et al. Morphologic features of humeral head and glenoid version in the normal glenohumeral joint. J Shoulder Elbow Surg. 2014; 23(11):1724–30.
67. McPherson EJ, Friedman RJ, An YH, Chokesi R, Dooley RL. Anthropometric study of normal glenohumeral relationships. J Shoulder Elbow Surg. 1997; 6(2):105–12.
68. Molony DC, Cassar Gheiti AJ, Kennedy J, Green C, Schepens A, Mullett HJ. A cadaveric model for suprascapular nerve injury during glenoid component screw insertion in reverse-geometry shoulder arthroplasty. J Shoulder Elbow Surg. 2011;20(8): 1323–7.
69. Nowak DD, Bahu MJ, Gardner TR, Dyrszka MD, Levine WN, Bigliani LU, et al. Simulation of surgical glenoid resurfacing using three-dimensional computed tomography of the arthritic glenohumeral joint: the amount of glenoid retroversion that can be

corrected. J Shoulder Elbow Surg. 2009;18(5):680–8.
70. Nowak DD, Gardner TR, Bigliani LU, Levine WN, Ahmad CS. Interobserver and intraobserver reliability of the Walch classification in primary glenohumeral arthritis. J Shoulder Elbow Surg. 2010;19(2):180–3.
71. Nuttall D, Haines JF, Trail II. A study of the micromovement of pegged and keeled glenoid components compared using radiostereometric analysis. J Shoulder Elbow Surg. 2007;16(3 Suppl):S65–70.
72. Nyffeler RW, Anglin C, Sheikh R, Gerber C. Influence of peg design and cement mantle thickness on pull-out strength of glenoid component pegs. J Bone Joint Surg Br Vol. 2003;85(5):748–52.
73. Nyffeler RW, Jost B, Pfirrmann CWA, Gerber C. Measurement of glenoid version: conventional radiographs versus computed tomography scans. J Shoulder Elb Surg. 2003;12(5):493–6.
74. Nyffeler RW, Meyer D, Sheikh R, Koller BJ, Gerber C. The effect of cementing technique on structural fixation of pegged glenoid components in total shoulder arthroplasty. J Shoulder Elbow Surg. 2006;15(1):106–11.
75. Nyffeler RW, Sheikh R, Atkinson TS, Jacob HA, Favre P, Gerber C. Effects of glenoid component version on humeral head displacement and joint reaction forces: an experimental study. J Shoulder Elbow Surg. 2006;15(5):625–9.
76. Orr TE, Carter DR, Schurman DJ. Stress analyses of glenoid component designs. Clin Orthop Relat Res. 1988;232:217–24.
77. Paisley KC, Kraeutler MJ, Lazarus MD, Ramsey ML, Williams GR, Smith MJ. Relationship of scapular neck length to scapular notching after reverse total shoulder arthroplasty by use of plain radiographs. J Shoulder Elbow Surg. 2014;23(6):882–7.
78. Papadonikolakis A, Matsen 3rd FA. Metal-backed glenoid components have a higher rate of failure and fail by different modes in comparison with all-polyethylene components: a systematic review. J Bone Joint Surg Am. 2014;96(12):1041–7.
79. Parsons BO, Gruson KI, Accousti KJ, Klug RA, Flatow EL. Optimal rotation and screw positioning for initial glenosphere baseplate fixation in reverse shoulder arthroplasty. J Shoulder Elbow Surg. 2009;18(6):886–91.
80. Pilliar RM, Cameron HU, Macnab I. Porous surface layered prosthetic devices. Biomed Eng. 1975;10(4):126–31.
81. Rahme H, Mattsson P, Wikblad L, Nowak J, Larsson S. Stability of cemented in-line pegged glenoid compared with keeled glenoid components in total shoulder arthroplasty. J Bone Joint Surg Am. 2009;91(8):1965–72.
82. Roche CP, Stroud NJ, Martin BL, Steiler CA, Flurin PH, Wright TW, et al. The impact of scapular notching on reverse shoulder glenoid fixation. J Shoulder Elbow Surg. 2013;22(7):963–70.
83. Sabesan V, Callanan M, Ho J, Iannotti JP. Clinical and radiographic outcomes of total shoulder arthroplasty with bone graft for osteoarthritis with severe glenoid bone loss. J Bone Joint Surg Am. 2013;95(14):1290–6.
84. Sabesan V, Callanan M, Sharma V, Iannotti JP. Correction of acquired glenoid bone loss in osteoarthritis with a standard versus an augmented glenoid component. J Shoulder Elbow Surg. 2014;23(7):964–73.
85. Sabesan VJ, Ackerman J, Sharma V, Baker KC, Kurdziel MD, Wiater JM. Glenohumeral mismatch affects micromotion of cemented glenoid components in total shoulder arthroplasty. J Shoulder Elbow Surg. 2015;24(5):814–22.
86. Scalise JJ, Codsi MJ, Brems JJ, Iannotti JP. Interrater reliability of an arthritic glenoid morphology classification system. J Shoulder Elbow Surg. 2008;17(4):575–7.
87. Scalise JJ, Codsi MJ, Bryan J, Iannotti JP. The three-dimensional glenoid vault model can estimate normal glenoid version in osteoarthritis. J Shoulder Elbow Surg. 2008;17(3):487–91.
88. Simovitch RW, Zumstein MA, Lohri E, Helmy N, Gerber C. Predictors of scapular notching in patients managed with the Delta III reverse total shoulder replacement. J Bone Joint Surg Am. 2007;89(3):588–600.
89. Smith SP, Bunker TD. Primary glenoid dysplasia. A review of 12 patients. J Bone Joint Surg Br Vol. 2001;83(6):868–72.
90. Stephens BF, Hebert CT, Azar FM, Mihalko WM, Throckmorton TW. Optimal baseplate rotational alignment for locking-screw fixation in reverse total shoulder arthroplasty: a three-dimensional computer-aided design study. J Shoulder Elbow Surg. 2015;24(9):1367–71.
91. Stephens SP, Paisley KC, Jeng J, Dutta AK, Wirth MA. Shoulder arthroplasty in the presence of posterior glenoid bone loss. J Bone Joint Surg Am. 2015;97(3):251–9.
92. Stone KD, Grabowski JJ, Cofield RH, Morrey BF, An KN. Stress analyses of glenoid components in total shoulder arthroplasty. J Shoulder Elbow Surg. 1999;8(2):151–8.
93. Torrens C, Corrales M, Gonzalez G, Solano A, Caceres E. Cadaveric and three-dimensional computed tomography study of the morphology of the scapula with reference to reversed shoulder prosthesis. J Orthop Surg Res. 2008;3:49.
94. Vavken P, Sadoghi P, von Keudell A, Rosso C, Valderrabano V, Muller AM. Rates of radiolucency and loosening after total shoulder arthroplasty with pegged or keeled glenoid components. J Bone Joint Surg Am. 2013;95(3):215–21.
95. Visotsky JL, Basamania C, Seebauer L, Rockwood CA, Jensen KL. Cuff tear arthropathy: pathogenesis, classification, and algorithm for treatment. J Bone Joint Surg Am. 2004;86-A Suppl 2:35–40.

96. Walch G, Badet R, Boulahia A, Khoury A. Morphologic study of the glenoid in primary glenohumeral osteoarthritis. J Arthroplast. 1999;14 (6):756–60.
97. Walch G, Edwards TB, Boulahia A, Boileau P, Mole D, Adeleine P. The influence of glenohumeral prosthetic mismatch on glenoid radiolucent lines: results of a multicenter study. J Bone Joint Surg Am. 2002; 84-a(12):2186–91.
98. Wang J, Singh A, Higgins L, Warner J. Suprascapular neuropathy secondary to reverse shoulder arthroplasty: a case report. J Shoulder Elbow Surg. 2010; 19(3):e5–8.
99. Wang T, Abrams GD, Behn AW, Lindsey D, Giori N, Cheung EV. Posterior glenoid wear in total shoulder arthroplasty: eccentric anterior reaming is superior to posterior augment. Clin Orthop Relat Res. 2015; 473:3928–36.
100. Wirth MA, Klotz C, Deffenbaugh DL, McNulty D, Richards L, Tipper JL. Cross-linked glenoid prosthesis: a wear comparison to conventional glenoid prosthesis with wear particulate analysis. J Shoulder Elbow Surg. 2009;18(1):130–7.
101. Wirth MA, Korvick DL, Basamania CJ, Toro F, Aufdemorte TB, Rockwood Jr CA. Radiologic, mechanical, and histologic evaluation of 2 glenoid prosthesis designs in a canine model. J Shoulder Elbow Surg. 2001;10(2):140–8.
102. Yian EH, Werner CM, Nyffeler RW, Pfirrmann CW, Ramappa A, Sukthankar A, et al. Radiographic and computed tomography analysis of cemented pegged polyethylene glenoid components in total shoulder replacement. J Bone Joint Surg Am. 2005;87(9):1928–36.
103. Yongpravat C, Kim HM, Gardner TR, Bigliani LU, Levine WN, Ahmad CS. Glenoid implant orientation and cement failure in total shoulder arthroplasty: a finite element analysis. J Shoulder Elbow Surg. 2013;22(7):940–7.

Standard Glenoid Replacement

7

Jonathan Levy

Introduction

Since the first introduction in 1974, total shoulder arthroplasty (TSA) has become a reliable and reproducible treatment for end-stage arthritis that has failed to respond to nonoperative measures [18, 19, 25, 43, 57]. The utilization of TSA continues to expand at exponential rates with a 319 % increase in TSA procedures between 1993 and 2007 [17]. Analysis of outcomes following shoulder arthroplasty suggests that the addition of a glenoid component improves pain relief and outcomes [24, 47], suggesting significant advantages of TSA over hemiarthroplasty. This observation as resulted in a moderate strength recommendation to perform a total shoulder arthroplasty over a hemiarthroplasty for patients with glenohumeral joint osteoarthritis (AAOS). Nonetheless, glenoid component loosening has been shown to be the most common middle-term and long-term complication of TSA and is one of the most common causes of revision surgery [6, 10, 27, 50, 51, 74, 75]. Glenoid implant loosening has been associated with worse functional outcomes, worse pain, and inferior strength [59, 76]. Improvements in preoperative surgical planning, intraoperative instrumentation, surgical technique, and implant designs have all helped to improve the ability to properly and securely implant a glenoid component which will likely contribute to improved long-term results of total shoulder arthroplasty.

J. Levy, MD
Department of Orthopedics, Holy Cross Orthopedic Institute, 5597 North Dixie Highway, Fort Lauderdale, FL 33334, USA
e-mail: jonlevy123@yahoo.com

Glenoid Anatomy

A basic understanding of the variations in glenoid anatomy is critical for optimal utilization of glenoid components. Glenoid height, width, inclination, version, and vault size all play influential roles in surgical planning. Recent literature has shed greater light into the complexities of glenohumeral anatomy in the setting of arthritis.

Glenoid Height

Glenoid height can be measured from the distance from the most superior and inferior points on the glenoid (Fig. 7.1). Checroun et al. [9] reported a mean height of 37.9 mm using an analysis of 412 cadavers, Iannottii et al. [30] reported a mean height of 39 mm using an analysis of 140 shoulders, and Churchill observed an average height of 37.5 mm for men and 32.6 mm for women [11]. Analysis of the glenoid height helps to define glenoid component size during glenoid component

© Springer International Publishing Switzerland 2016
A.D. Armstrong, A.M. Murthi (eds.), *Anatomic Shoulder Arthroplasty*,
DOI 10.1007/978-3-319-29164-2_7

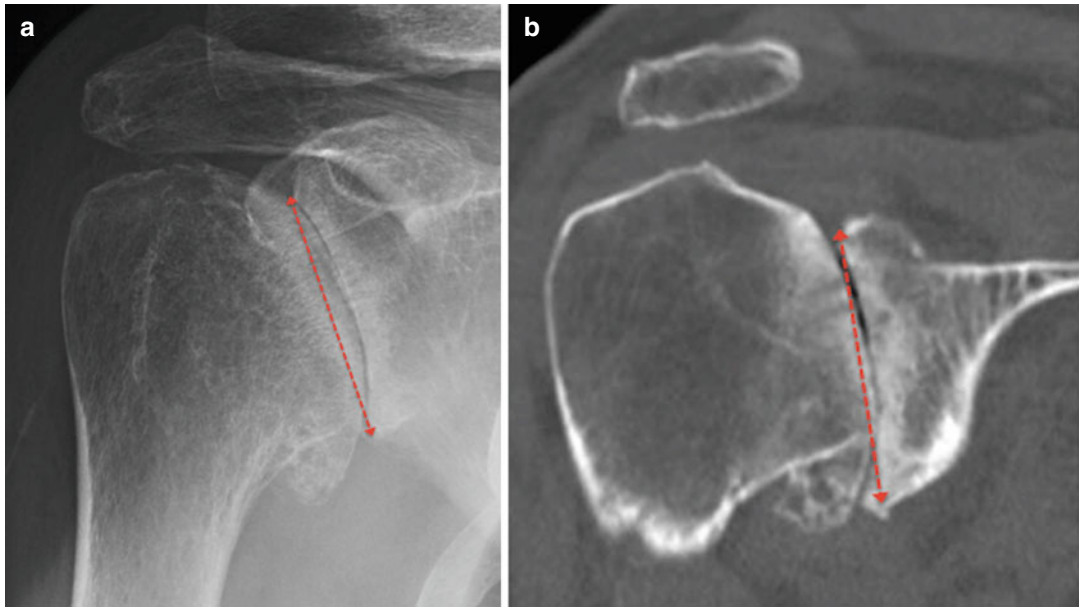


Fig. 7.1 *Glenoid height* – the *double arrows* are intended to outline the measurement of glenoid height on a AP radiograph (**a**) and CT coronal reconstruction (**b**). The *double arrows* in (**a**) seems to have been a bit shortened as it shoulder reach the top of the glenoid

preparation and implantation and is typically performed on coronal reconstruction of CT images.

Glenoid Width

Glenoid width can be measured from the most anterior and posterior points on the glenoid and is often influenced by osteophyte and wear patterns (Fig. 7.2). Variations in glenoid shape (Fig. 7.3) can influence the glenoid width, as pear-shaped and oval-shaped glenoids may have different variations in width. As an illustrative point, Ianottii [30] reported an average upper width of 23 mm and an average lower width of 29 mm. Others have reported averages of glenoid width without taking into consideration differences in shape. Kwon et al. [35] reported an average width of 26.8 mm, and Churchill et al. [11] reported an average width of 27.8 mm. Appreciation of the glenoid width also helps to define glenoid component size, as efforts should be made to prevent excessive overhang of the implant. Accurate measurement is often made difficult, as osteophytes and bone erosion often obscure the identification of the native glenoid limits.

Glenoid Inclination

Glenoid inclination is defined as the slope of the glenoid articular surface measured in the superior to inferior axis and can be measured both on AP radiographs and coronal reconstruction CT images (Fig. 7.4). Maur et al. found the angle between the glenoid fossa line (line from the superior to inferior tip of the glenoid), and the floor of the supraspinatus fossa was most reliable at measuring glenoid inclination [42]. Average inclination can range from 2.2° of inferior tilt to 4.2° of superior tilt with reported ranges from 12° of inferior tilt to 15° degrees of superior tilt [46]. Churchill et al. [11] found male patients to have an average of 4° of inferior tilt, whereas females had an average superior tilt of 4.5°. The observed range of inclination varied between 7° of inferior tilt to 15.8° of superior tilt. Appreciation of the glenoid inclination becomes important during

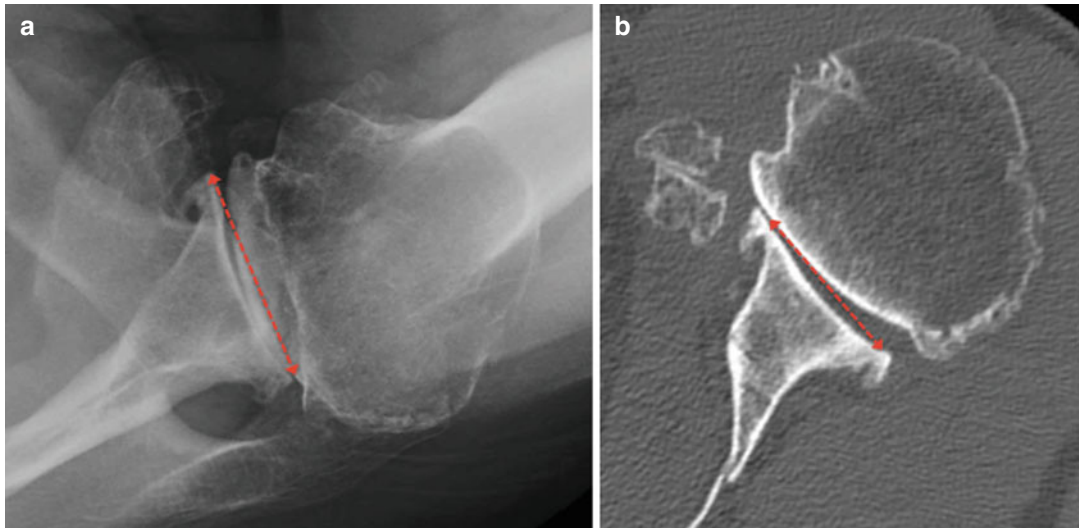


Fig. 7.2 *Glenoid width* – glenoid width can be measured from the most anterior and posterior points on the glenoid. This can be measured both on an AP radiograph (**a**) and CT coronal reconstruction image (**b**) (Note the osteophytes seen anteriorly and posteriorly which can overestimate the glenoid width)

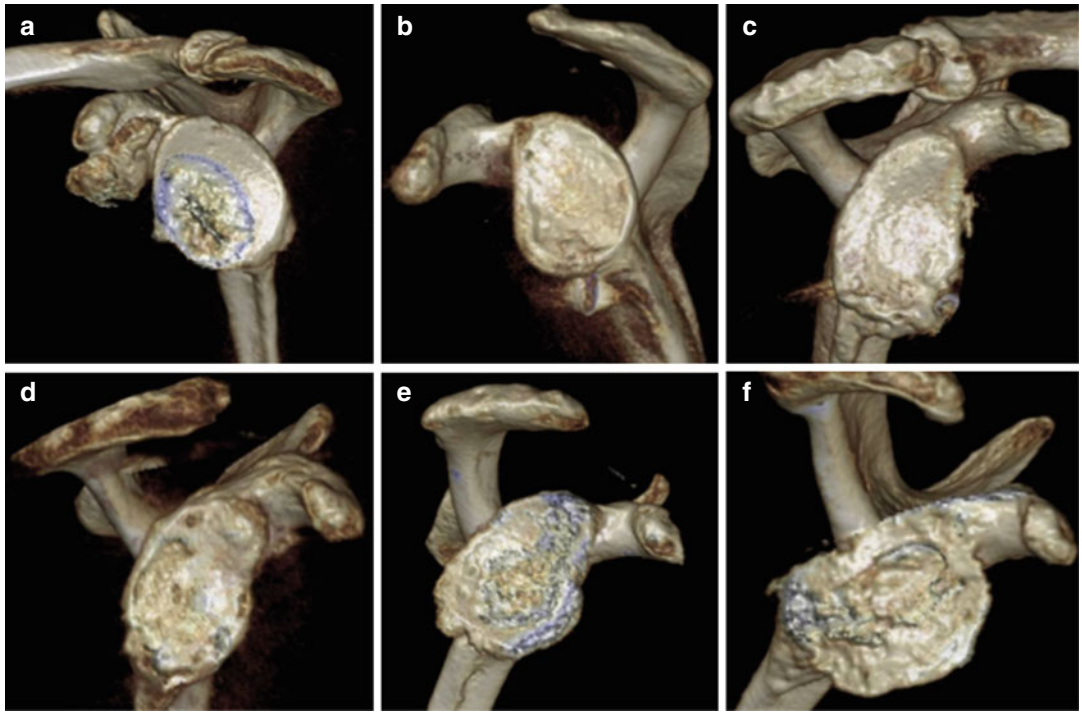


Fig. 7.3 *Glenoid shape* – variations in glenoid shape can be appreciated best by 3D CT reconstruction images. Osteophytes and wear patterns influence this shape. (**a**) Oval-shaped glenoid; (**b**) Pear-shaped glenoid with anterior-inferior osteophyte; (**c**–**e**). Pear-shaped glenoid with inferior osteophytes; (**f**) Posterior-superior glenoid wear alters the glenoid shape

glenoid implantation, as placement of the component with superior tilt has been associated with a greater incidence of rotator cuff disease postoperatively [78].

Glenoid Version

Glenoid version has gained a great deal of attention, as much of the pathologic changes in glenohumeral arthritis result in alterations in glenoid version. Glenoid version is most commonly calculated on axial CT images using the Friedman method [22], which is measured based on the glenoid axis (anterior to posterior rim of the glenoid) and the scapular axis (line connecting the medial boarder of the scapula and the center of the glenoid line) (Fig. 7.5). Alternatively, the vault method [41] is referenced based on the glenoid axis and the glenoid vault axis (line connecting the tip of the scapular vault to the glenoid axis) (Fig. 7.6). Matsumura et al. reported that both methods demonstrated high intra- and inter-rater reliability with normal glenoids having 1.1° ± 3.2° retroversion with the conventional method and 8.9° ± 2.7° retroversion with the vault method. In contrast, arthritic glenoids had average glenoid retroversion of 10.8° ± 9.3° measured with the conventional method and 18.2° ± 9.1° with the vault method. Variation in glenoid version in normal shoulders has been reported to average from 2° of anteversion to 9° of retroversion [11, 22, 39, 45], with greater degrees of average retroversion seen in arthritic shoulders [22] with wear patterns showing preferential wear in the posterior-inferior glenoid [12]. There has been criticism of the accuracy of 2D CT scans in calculating glenoid version due to alterations in pathologic anatomy,

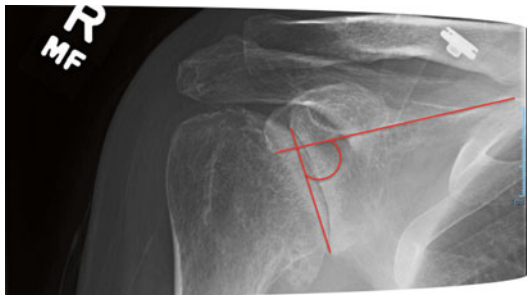


Fig. 7.4 *Glenoid inclination* – glenoid inclination can be measured by the angle between the glenoid fossa line (*vertical line*) and a horizontal scapular reference. This can be measured on radiographs as well as CT reconstructed images. Maur et al. found the angle between the glenoid fossa line (line from the superior to inferior tip of the glenoid) and the floor of the supraspinatus fossa was most reliable at measuring glenoid inclination [42]

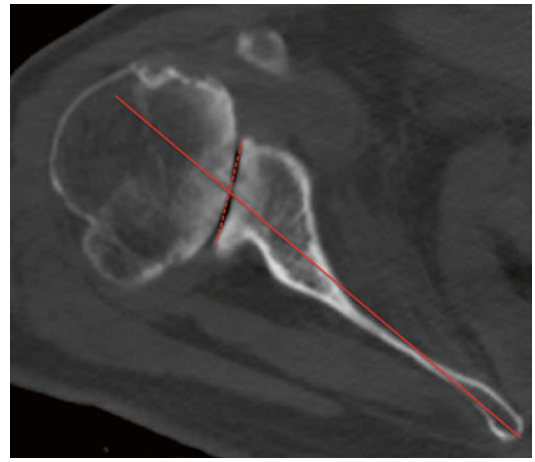


Fig. 7.5 *Glenoid version* – glenoid version can be measured using the Friedman method which defines glenoid version based on the relationship between the glenoid axis (*dotted line*; anterior to posterior rim of the glenoid) and the scapular axis (*solid line*; line connecting the medial boarder of the scapula and the center of the glenoid line)

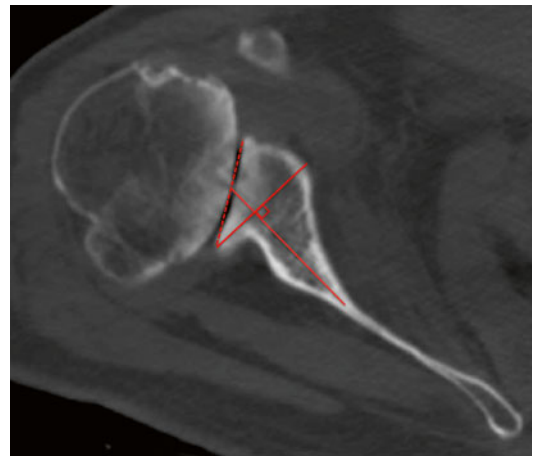


Fig. 7.6 *Glenoid version* – glenoid version can be measured using the vault axis method which defines glenoid version based on the relationship between the glenoid axis (*dotted line*; anterior to posterior rim of the glenoid) and the glenoid vault axis

orientation of the scapula for axial cuts, and wear patterns of the glenoid. Recently, Scalise et al. utilized 3D CT reconstructions to assess glenoid version and observed an average retroversion of 15.6° in the arthritic shoulder and 7° in the normal shoulder [51]. Using 3D CT reconstructions, the plane of the scapula is defined by three points: inferior tip of the scapula, scapula trigonum, and the center of the glenoid. Once the plane of the scapula is defined, 2D images are made in the axial, coronal, and sagittal planes to help calculate glenoid version and inclination [51]. While 3D CT reconstructions may provide a more accurate assessment of glenoid version, utilization of 3D reconstructions to define the scapular plane and then create a new 2D axial image along this plane resulted in no significant differences in glenoid version measurements between 3D and 2D images [8]. Appreciation of glenoid version is important as reports have suggested inferior outcomes when glenoid components are implanted in excessive retroversion [29, 53, 77].

Glenoid Vault

The glenoid vault has gained recent attention based on the work of Iannotti and Williams [15, 23, 48–51, 68]. The concept, first described by Ianotti and Williams [68], relates to opportunities for glenoid component fixation when glenoid wear and bone loss becomes significant. While this scenario is more common in the revision setting, pathologic patterns of arthritic wear and joint destruction may allow for preferential glenoid component fixation within the vault and rim rather than the typical subchondral bone surface. Codsi et al. utilized a custom software program to measure variations in glenoid vault anatomy in 61 cadaveric specimens. A group of 5 sized glenoid vault implants were created, representing the consistent triangular anatomy observed in the glenoid vault. Appreciation of the glenoid vault helps to anticipate the ability of the glenoid component to fit within the glenoid vault rather than violating the medial cortex of the glenoid. Moreover, by understanding the glenoid vault anatomy, it is possible to recognize the alterations in glenoid anatomy and facilitate reconstruction efforts aimed at restoring normal version without medialization of the joint.

Subchondral Bone Density

Nearly all glenoid components rely on the subchondral support of the glenoid. Violation of this subchondral surface during glenoid preparation has been shown to result in subsidence of the glenoid implant [66, 67]. It has thus been advocated that the subchondral plate be preserved during glenoid reaming. Simon et al. recently reported an analysis of 3D CT osteoabsorptiometry on 21 patients with concentric glenoid wear and 21 patients with eccentric glenoid wear [52]. They observed differences in subchondral bone patterns for concentric and eccentric wear patterns, with greater density in the posterior zone for eccentric glenoids, whereas concentrically worn glenoids had a homogeneous pattern of bone density. In evaluating CT scans, attention should be directed to the thickness of the subchondral bone. This can assist in preoperative planning when eccentric reaming is necessary.

Subluxation Index

Subluxation of the glenohumeral joint in the setting of arthritis is rather common. Walsh et al. [62] described a method for calculating the subluxation index by measuring the percent subluxation of the humeral head on axial CT images. Using the midpoint of the glenoid axis (line between the anterior and posterior limits of the glenoid), the distance between this center point and the posterior limit of the humeral head is divided by the distance between the anterior and posterior limits of the humeral head (Fig. 7.7). A centered head has a subluxation index of 35–65 %. Posterior subluxation is defined as a subluxation index of greater than 65 % and anterior subluxation as less than 35 %. Appreciation of the amount of subluxation seen on both axillary

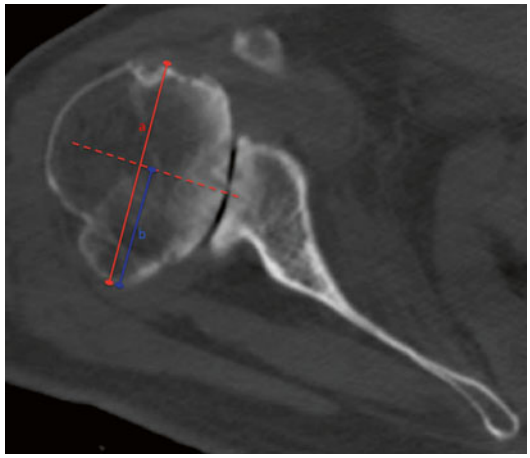


Fig. 7.7 *Subluxation* – subluxation of the humeral head can be appreciated best on axial CT images. Using the midpoint of the glenoid axis (line between the anterior and posterior limits of the glenoid), the distance between this center point and the posterior limit of the humeral head (*line b*) is divided by the distance between the anterior and posterior limits of the humeral head (*line a*). The glenohumeral relationship can then be classified as centered (35–65 %), posteriorly subluxated (>65 %), or anteriorly subluxated (<35 %)

radiographs and CT scans helps to understand wear patterns and formulate strategies for glenoid preparation.

Glenoid Morphology

Recognition of patterns of wear and the glenoid morphology is one of the most important aspects of surgical planning for glenoid component placement.

The most widely referenced classification of glenoid morphology was described by Walch et al. [61, 62] (Fig. 7.8). Five patterns of glenoid wear were described in a series of patients with osteoarthritis. Type A glenoids have a central pattern of wear with minor erosion (A1) and major erosion (A2). Type B glenoids have posterior subluxation without erosion (B1) and with posterior rim erosion (B2). B2 glenoids are commonly described as having a biconcave glenoid deformity. Type C glenoids have glenoid retroversion of more than 25° and are typically considered dysplastic glenoids. While this classification is typically observed on axial radiographs, axial CT images and 3D CT images help clarify the glenoid morphology.

Recently, Walch introduced the concept of the B3 glenoid, based on the recognition that as glenoid erosion advances in the setting of posterior subluxation, a biconcave wear pattern becomes difficult to recognize. This glenoid morphology typically has posterior subluxation of more than 70 %, retroversion of more than 10°, and no clear margin between the neoglenoid and paleoglenoid (CSSES Meeting, Tampa 2015).

Glenoid morphology patterns are different in the setting of rheumatoid arthritis. Levigne and Francheschi described a glenoid morphology classification based on a series of 50 shoulders treated with shoulder arthroplasty [36] (Fig. 7.9). Stage 1 represented an intact or minimally deformed subchondral bone plate. Stage 2 showed erosion reaching the base of the coracoid. Stage 3 patients demonstrated erosion beyond the coracoid base.

Surgical Plan

Common logic suggests that placement of the glenoid component in an ideal location should provide the best chance for long-term survivability of the implant. Ideally, the glenoid face should be prepared to perfectly match the backside of the glenoid component without overhang of the glenoid component or reaming past the subchondral bone. The fixation pegs or keels should be contained within the glenoid vault. The component should be placed in neutral to slight inferior inclination, specifically avoiding superior tilt. While there is no defined ideal version correction that has been shown to improve long-term fixation or wear, Iannotti et al. suggested that glenoid version should be corrected to within 5° of a plane perpendicular to the plane of the scapula [30]. Unfortunately, with increasing glenoid deformities, the ability to accurately place the glenoid component can be challenging [30], both in terms of planning and execution of the surgical plan.

Advances in imaging capabilities, integration of surgical planning software, improvements in

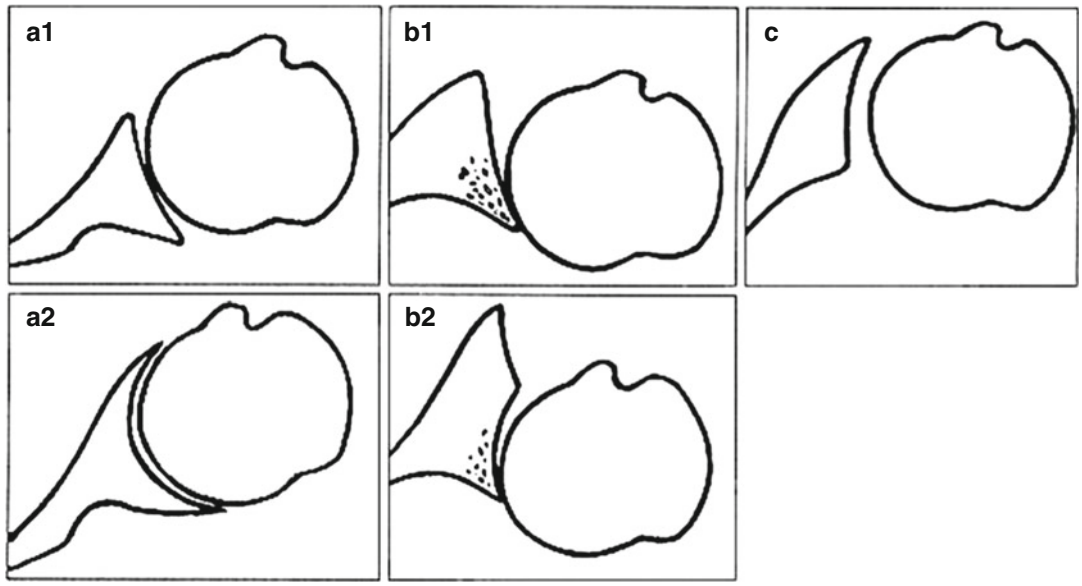


Fig. 7.8 *Glenoid wear morphology in osteoarthritis* – the most commonly referenced classification of glenoid morphology of glenohumeral osteoarthritis as described by Walch et al. [62]. The figure represents the Walch classification, (**a1**) centered humeral head with mild glenoid erosion. (**a2**) centered humeral head with major erosion, (**b1**) posterior subluxation with no erosion, (**b2**) posterior erosion with biconcave glenoid. (**c**) severe retroversion

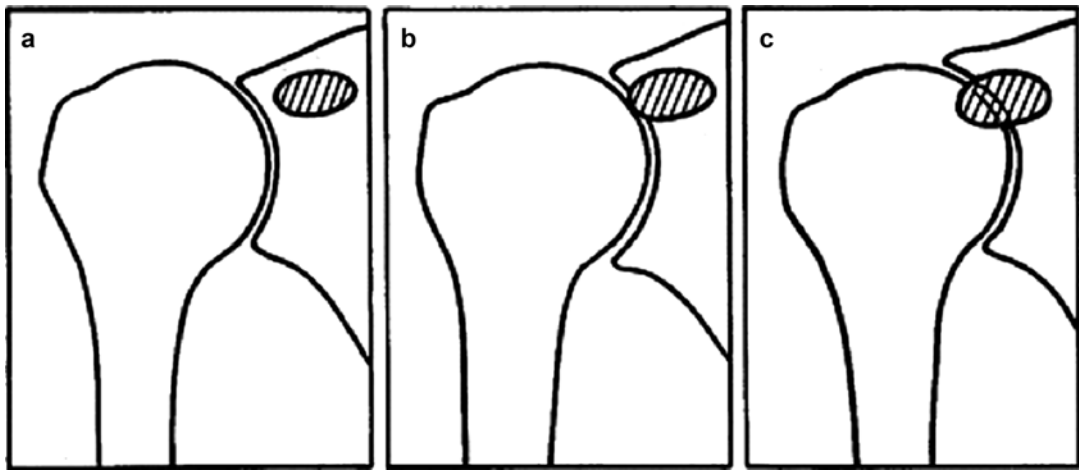


Fig. 7.9 *Glenoid morphology in rheumatoid arthritis* – stage 1 (**a**) intact or minimally deformed subchondral bone plate; stage 2 (**b**) erosion reaching the base of the coracoid; stage 3 (**c**) erosion beyond the coracoid base

implant innovation, and a greater understanding of glenoid anatomy and wear patterns have all contributed to the advancements in surgical planning of glenoid component implantation. The introduction of patient-specific instrumentation together with 3D modeling software developments has facilitated precise surgical planning with opportunities to carry out that plan with a high level of accuracy.

Radiographs continue to be the gold standard for the evaluation of glenohumeral arthritis. Properly oriented anteroposterior (AP) and axillary lateral views of the glenoid are critical [28, 69]. While properly performed axillary radiographs can be sufficient in evaluating glenoid wear patterns, the value of CT scan imaging with two- and three-dimensional reconstructions has

become invaluable in surgical planning for glenoid component implantation.

2D reconstructed CT scan images allow the analysis of several key components of shoulder anatomy that are critical in preoperative planning of glenoid component implantation. Axial images are used to calculate the glenoid version, humeral head subluxation, eccentric wear patterns, glenoid width, subchondral bone density and location, location of osteophytes, depth of the glenoid vault, analysis of the quality of the subscapularis muscle and tendon, and identification of bone defects which may be present. Coronal reconstructions help to appreciate the glenoid height, inclination angle, superior humeral head subluxation, and quality of the supraspinatus and infraspinatus muscle and tendons. Sagittal reconstructions help to appreciate muscle atrophy of the rotator cuff musculature. Using two-dimensional images, glenoid planning can be performed [31]. The central axis point can be estimated which will serve for the axis of glenoid reaming. The amount of glenoid reaming necessary to restore appropriate version can be estimated as well.

The introduction of 3D reconstructions with humerus subtraction has helped to better understand the limitations of 2D CT imaging as well as gain a better appreciation of the location of wear patterns in pathologic glenoids. Not only can calculations of version, inclination, and subluxation be performed more accurately [60], but the actual location of glenoid wear patterns can be appreciated. In recent years, 3D printing technology has become more widely available. Printing scapular models of patient anatomy brings the understanding of glenoid anatomy to the next level and is now a part of most patient-specific instrumentation platforms currently available. The recent interest in patient-specific instrumentation has taken surgical planning to a high level of precision [31, 37, 38, 58, 64, 65]. The combination of virtual surgical planning, 3D printing of the scapula, and instrumentation developed specifically for reproducing the virtual surgical plan has improved the accuracy of carrying out the surgical plan for glenoid component placement to within a few degrees of error. With accurate planning, it is now possible to place the glenoid component accurately in the properly planned location, correct deformities of version and inclination, define the appropriate component rotation on the face of the glenoid, and properly size the glenoid components to avoid medial vault penetration.

Implant Selection

There are numerous variations in glenoid implant designs. Differences are seen in component shape, radial mismatch, backside curvature, keel and peg size and orientation, and method of fixation. It is important to understand the rationale behind each of these implant features.

Glenoid Shape

Most of the original glenoid component designs were oval shaped despite the pear shape of the native glenoid. The surgeon was often left with a decision of how to best size the prosthetic glenoid component, as proper sizing of the inferior glenoid often resulted in implant overhang superiorly. With the advent of the Aequalis (Tornier, Edina, MN) and the Solar (Stryker, Kalamazoo, MI), attention was focused on more closely matching the glenoid anatomy using a pear-shaped design [9]. Several glenoid implants have since been introduced with a more anatomic glenoid shape. The theoretical risk of the anatomically matched glenoid component is increased instability [1, 16]; however, to date there are no reports of greater instability seen with anatomically shaped glenoid components. It is generally accepted that the optimal glenoid component size is one that most closely matches the prepared glenoid surface without allowing for the component to hang off the glenoid bone.

Radius of Curvature Mismatch

Nearly all glenoid components have a mismatch between the radius of curvature of the humeral

head and the glenoid. This is based on the rationale that normal glenohumeral mechanics result in translations between the humeral head and glenoid. In a cadaveric analysis, Karduna et al. observed that active translations seen in normal joints were best reproduced with glenoid components that were less conforming and determined that a radial mismatch of 4 mm best represents this relationship [32]. In a multicenter analysis of flat-back cemented polyethylene glenoids, Walch et al. observed that glenohumeral mismatch significantly influenced the incidence of radiolucent lines and described an ideal mismatch between 6 and 10 mm [63]. However, no study has defined the ideal radial mismatch for a glenoid component based on effects on outcomes, and variations in the radial mismatch remain common among different implant designs.

Glenoid Fixation

Critical to the long-term success of the glenoid component is implant fixation. There are several methods of component fixation that have been utilized in glenoid implant designs. Pegged and keeled designs are certainly the most common and have historically been cemented into the glenoid. Metal-backed glenoid components with polyethylene inserts allow for enhanced fixation using screws, pegs, and ingrowth metals. Recently, hybrid combinations of cemented and uncemented pegs have been utilized as methods of enhancing component fixation into the bone.

Fully cemented pegged and keel designs have been utilized since the first total shoulder arthroplasties performed by Charles Neer in the early 1970s. While keel designs remain the most popular worldwide, Edwards et al. reported significantly higher rates of radiolucent lines surrounding keeled implants than pegged implants both on initial postoperative radiographs and 2-year follow-up [20]. All cemented peg and keel designs vary with differences observed in the shape of the keel and the orientation and number of pegs.

The effect of cement technique on glenoid component fixation has been studied. Terrier et al. used an FEA to assess the stress interaction between the cement and glenoid bone and concluded that a 1.0 mm cement mantle thickness is ideal [55]. Nyffler performed axial pullout testing of variable glenoid component designs and observed that threaded pegs demonstrated higher pullout force than notched pegs, which were both higher than smooth pegs [45]. Additionally, they noted that increasing the cement mantle thickness from 0.1 to 0.6 mm increased the pullout force [45]. Roughened backside surface finish of glenoid components has also been shown to improve component stability in all-cemented glenoids [2, 45]. Finally, cement pressurization during glenoid component implantation has been associated with a low incidence of early radiolucent lines [4, 34].

Recently, enhanced fixation glenoids which support bone growth into or around pegs have gained interest based on improved biologic fixation. Early results are quite promising with high rates of bone growth observed between the flutes on the pegs [72, 73] in studies with up to 5-year follow-up [13]. With greater initial fixation of the component [14] and opportunity for biologic fixation of the pegs, enhanced fixation polyethylene glenoids may ultimately help to lower rates of radiolucent lines suggestive of glenoid loosening.

Metal-backed uncemented glenoid implants have lost popularity based upon a historical experience of high complications. The original designs utilized a metal casing secured with screw fixation and an exchangeable polyethylene insert. High rates of screw breakage, excessive polyethylene wear, dissociation, and high revision rates have been reported [40, 54]. Recently, new uncemented metal-backed designs utilizing modern fixation technologies have been introduced. These include implants with ingrowth metals and improved screw fixation methods that may help avoid the historical failures. However, to date there are no reports to suggest that the history of loosening and catastrophic failure has been avoided using these newer designs.

Glenoid Materials

As glenoid component fixation improves, initial failure modes may shift from component loosening due to loss of fixation to polyethylene wear and osteolysis. Cross-linked, ultrahigh molecular weight polyethylene is typically used for most glenoid components [71]. While polyethylene wear has been clearly linked with osteolysis in total hip arthroplasty, there are few reports of similar reactions following total shoulder arthroplasty [33, 79]. Osteolysis after TSA has been reported to be as high as 23 % [79] and has been shown to be more common with metal-backed glenoids [5, 33]. Wirth et al. evaluated the polyethylene debris particle size in retrievals of three failed total shoulder arthroplasties that were revised for aseptic loosening with osteolysis and compared them to failed total hip components revised for similar reasons. The wear debris was found to be larger and more fibrillary than the particles from failed total hip arthroplasty [70], suggesting a different mechanism of wear in shoulders than in hips. Differentiating between mechanical loosening from loss of fixation and osteolysis may ultimately be difficult as osteolytic regions can contribute to mechanical loosening.

Recently, the addition of vitamin E into highly cross-linked polyethylene has been introduced into total shoulder arthroplasty. This has been based on the success seen in total hip arthroplasty, which has demonstrated oxidative stability, low wear rates, and improved strength with the addition of vitamin E [7]. With enhanced fixation of glenoid components, efforts at utilizing this and other polyethylene materials with improved wear and strength properties will continue. Given the recent introduction of this technology, there is no clinical data supporting the use of these alternative polyethylene materials in total shoulder arthroplasty.

Surgical Execution

Proper glenoid exposure remains the critical step for placement of a glenoid component. This necessitates appropriate soft tissue releases, placement of retractors, and sufficient bone resections to allow clear visualization of the glenoid. Once the glenoid is exposed, all total shoulder arthroplasty systems now have instrumentation designed to prepare the glenoid surface to match the backside of the glenoid and precisely drill peg holes or a keel vault to match the selected glenoid component.

Glenoid Preparation

All glenoid components are defined based on a central axis. This axis, defined during surgical planning, defines all corrections in version, inclination, and translation. Once this axis is defined, glenoid reaming can be performed using glenoid reamers. These reamers are either cannulated based on a wire that has been placed down the central axis or non-cannulated utilizing a tip that fits within a hole in the central axis point on the glenoid face. The goal of glenoid preparation is to prepare a matching surface to the backside of the glenoid component. Early flat-back glenoid designs often required significant glenoid reaming, whereas concave glenoid designs typically require less glenoid reaming during preparation. A critical principle of glenoid preparation is to avoid reaming past the subchondral bone plate into more cancellous bone as this has been associated with early component subsidence [66, 67].

Once the glenoid is reamed to match the back surface of the glenoid component, the peripheral pegs or keels are created. For glenoids designed to utilize cement, the peg or keel preparation anticipates creating a cement mantle which is typically 1.0 mm [55]. Glenoid designs, which utilize pegs without the need for cement, create peg holes designed for a press fit.

The rotation of the glenoid component is defined during this step. Most TSA systems provide precision jigs which help to create the peripheral pegs or keel vault; however, the surgeon must define the rotation of the component. By referencing the biceps insertion on the supraglenoid tubercle, the proper rotation of the glenoid component can be selected. Patient-matched instrumentation systems have the capacity to integrate this step

into a guide that is used during surgery, defining both the central axis for reaming and a peripheral peg hole to maintain the accuracy of glenoid component rotation in addition to version, inclination, and translation position [56].

Glenoid Implantation

Most all-polyethylene glenoid components utilize cement for component fixation. Modern cement techniques have evolved with most emphasizing drying the glenoid [21], cement mantle thickness of 1.0 mm [55], and cement pressurization either by injection into the peg hole or keel vault using a syringe [4, 34] or weep-hole vacuum assistance [26]. Use of additional cement on the back of the glenoid component is more controversial based on concerns regarding fracture and fragmentation of thin areas of cement and associated risk of third-body wear from dislodged cement particles. Once the glenoid component is placed, all extruded cement must be removed from the periphery of the glenoid component.

Conclusion

Modernization of total shoulder arthroplasty has greatly improved the understanding and appreciation of variations in glenoid anatomy in severely arthritic shoulders. Appreciation of both normal and abnormal glenoid anatomy has helped the surgeon understand patient pathology and has enhanced glenoid component design and surgical technique. Collectively, the surgeon now has a greater understanding of how to appreciate anatomical variations, properly plan glenoid placement, and accurately execute standard glenoid component placement during total shoulder arthroplasty.

References

1. Anglin C, Wyss UP, Nyffeler RW, Gerber C. Loosening performance of cemented glenoid prosthesis design pairs. Clin Biomech. 2001;16:144–50.
2. Anglin C, Wyss UP, Pichora DR. Mechanical testing of shoulder prostheses and recommendations for glenoid design. J Should Elb Surg. 2000;9:323–31.
3. Barwood S, Setter KJ, Blaine TA, Bigliani LU. The incidence of early radiolucencies about a pegged glenoid component using cement pressurization. J Should Elb Surg. 2008;17:703–8.
4. Boileau P, Moineau G, Morin-Salvo N, Avidor C, Godenèche A, Lévigne C, Baba M, Walch G. Metal-backed glenoid implant with polyethylene insert is not a viable long-term therapeutic option. J Shoulder Elbow Surg. 2015. pii: S1058-2746(15)00085–3. doi:10.1016/j.jse.2015.02.012.
5. Boileau P, Sinnerton RJ, Chuinard C, Walch G. Arthroplasty of the shoulder. J Bone Joint Surg (Br). 2006;88:562–75. doi:10.1302/0301-620X.88B5.16466.
6. Bracco P, Oral E. Vitamin E-stabilized UHMWPE for total joint implants: a review. Clin Orthop Relat Res. 2011;469(8):2286–93. doi:10.1007/s11999-010-1717-6.
7. Budge MD, Lewis GS, Schaefer E, Coquia S, Flemming DJ, Armstrong AD. Comparison of standard two-dimensional and three-dimensional corrected glenoid version measurements. J Should Elb Surg. 2011;20(4):577–83. doi:10.1016/j.jse.2010.11.003.
8. Checroun AJ, Hawkins C, Kummer FJ, Zuckerman JD. Fit of current glenoid designs: an anatomic cadaver study. J Should Elb Surg. 2002;11:614–7. doi:10.1067/mse.2002.126099.
9. Chin PYk SJ, Boyd AD, Thomas WH, Sledge CB, Thornhill TS. Failed shoulder arthroplasty. Orthop Trans. 1990;14:255–61.
10. Churchill RS, Brems JJ, Kotschi H. Glenoid size, inclination, and version: an anatomic study. J Should Elb Surg. 2001;10:327–32.
11. Churchill RS, Spencer Jr EE, Fehringer EV. Quantification of B2 glenoid morphology in total shoulder arthroplasty. J Should Elb Surg. 2015;24(8):1212–7. doi:10.1016/j.jse.2015.01.007. Epub 2015 Mar 4.
12. Churchill RS, Zellmer C, Zimmers HJ, Ruggero R. Clinical and radiographic analysis of a partially cemented glenoid implant: 5-year minimum follow-up. J Should Elb Surg. 2010;19:1091–7. doi:10.1016/j.jse.2009.12.022.
13. Churchill RS. Trends in glenoid component design in unconstrained shoulder arthroplasty. J Should Elb Surg. 2011;20:S41–6.
14. Codsi MJ, Bennetts C, Gordiev K, Boeck DM, Kwon Y, Brems J, Powell K, Iannotti JP. Normal glenoid vault anatomy and validation of a novel glenoid implant shape. J Should Elb Surg. 2008;17(3):471–8. doi:10.1016/j.jse.2007.08.010.
15. Collins D, Tencer A, Sidles J, Matsen III FA. Edge displacement and deformation of glenoid components in response to eccentric loading. The effect of preparation of the glenoid bone. J Bone Joint Surg Am. 1992;74:501–7.
16. Day JS, Lau E, Ong KL, Williams GR, Ramsey ML, Kurtz SM. Prevalence and projections of total shoulder and elbow arthroplasty in the United States to 2015. J Should Elb Surg. 2010;19(8):1115–20.

17. Deshmukh AV, Koris M, Zurakowski D, Thornhill TS. Total shoulder arthroplasty: long-term survivorship, functional outcome, and quality of life. J Should Elb Surg. 2005;14(5):471–9.
18. Edwards TB, Kadakia NR, Boulahia A, Kempf JF, Boileau P, Némoz C, Walch G. A comparison of hemiarthroplasty and total shoulder arthroplasty in the treatment of primary glenohumeral osteoarthritis: results of a multicenter study. J Should Elb Surg. 2003;12(3):207–13.
19. Edwards TB, Labriola JE, Stanley RJ, O'Connor DP, Elkousy HA, Gartsman GM. Radiographic comparison of pegged and keeled glenoid components using modern cementing techniques: a prospective randomized study. J Should Elb Surg. 2010;19(2):251–7.
20. Edwards TB, Sabonghy EP, Elkousy H, Warnock KM, Hammerman SM, O'Connor DP, Gartsman GM. Glenoid component insertion in total shoulder arthroplasty: comparison of three techniques for drying the glenoid before cementation. J Should Elb Surg. 2007;16(3 Suppl):S107–10.
21. Friedman RJ, Hawthorne KB, Genez BM. The use of computerized tomography in the measurement of glenoid version. J Bone Joint Surg Am. 1992;74: 1032–7.
22. Ganapathi A, McCarron JA, Chen X, Iannotti JP. Predicting normal glenoid version from the pathologic scapula: a comparison of 4 methods in 2- and 3-dimensional models. J Should Elb Surg. 2011;20(2):234–44. doi:10.1016/j.jse.2010.05.024.
23. Gartsman GM, Roddey TS, Hammerman SM. Shoulder arthroplasty with or without resurfacing of the glenoid in patients who have osteoarthritis. J Bone Joint Surg Am. 2000;82(1):26–34.
24. Goldberg BA, Smith K, Jackins S, Campbell B, Matsen 3rd FA. The magnitude and durability of functional improvement after total shoulder arthroplasty for degenerative joint disease. J Should Elb Surg. 2001;10(5):464–9.
25. Gross RM1, High R, Apker K, Haggstrom J, Fehringer JA, Stephan J. Vacuum assist glenoid fixation: does this technique lead to a more durable glenoid component? J Should Elb Surg. 2011;20(7):1050–60. doi:10.1016/j.jse.2011.04.007.
26. Hawkins RJ, Greis PE, Bonutti PM. Treatment of symptomatic glenoid loosening following unconstrained shoulder arthroplasty. Orthopedics. 1999;22:229–34.
27. Hertel R, Ballmer FT. Observations on retrieved glenoid components. J Arthroplasty. 2003;18:361–6. doi:10.1054/arth.2003.50048.
28. Ho J, Sabesan VJ, Iannotti JP. Glenoid component retroversion is associated with osteolysis. J Bone Joint Surg Am. 2013;95(12):e82.
29. Iannotti JP, Gabriel JP, Schneck SL, Evans BG, Misra S. The normal glenohumeral relationships. An anatomical study of one hundred and forty shoulders. J Bone Joint Surg Am. 1992;74:491–500.
30. Iannotti JP, Greeson C, Downing D, Sabesan V, Bryan JA. Effect of glenoid deformity on glenoid component placement in primary shoulder arthroplasty. J Shoulder Elbow Surg. 2012;21(1):48–55. doi:10.1016/j.jse.2011.02.011.
31. Iannotti JP, Weiner S, Rodriguez E, Subhas N, Patterson TE, Jun BJ, Ricchetti ET. Three-dimensional imaging and templating improve glenoid implant positioning. J Bone Joint Surg Am. 2015;97(8):651–8. doi:10.2106/JBJS.N.00493.
32. Karduna AR, Williams GR, Williams JL, Iannotti JP. Glenohumeral joint translations before and after total shoulder arthroplasty. A study in cadavera. J Bone Joint Surg Am. 1997;79(8):1166–74.
33. Kepler CK, Nho SJ, Bansal M, Ala OL, Craig EV, Wright TM, Warren RF. Radiographic and histopathologic analysis of osteolysis after total shoulder arthroplasty. J Should Elb Surg. 2010;19(4):588–95. doi:10.1016/j.jse.2009.09.012. Epub 2009 Dec 29.
34. Klepps S, Chiang AS, Miller S, Jiang CY, Hazrati Y, Flatow EL. Incidence of early radiolucent glenoid lines in patients having total shoulder replacements. Clin Orthop Relat Res. 2005:118–25.
35. Kwon YW, Powell KA, Yum JK, Brems JJ, Iannotti JP. Use of three dimensional computed tomography for the analysis of the glenoid anatomy. J Should Elb Surg. 2005;14:85–90.
36. Levigne, Francheschi. Rheumatoid arthritis of the shoulder: radiological presentation and results of arthroplasty. In: Walch et al., editors. Shoulder arthroplasty. Berlin: Springer; 1999. p. 221–30.
37. Levy JC, Everding NG, Frankle MA, Keppler LJ. Accuracy of patient-specific guided glenoid baseplate positioning for reverse shoulder arthroplasty. J Should Elb Surg. 2014;23(10):1563–7. doi:10.1016/j.jse.2014.01.051.
38. Lewis GS, Stevens NM, Armstrong AD. J Shoulder Elbow Surg. 2015. pii: S1058-2746(15)00342–0. doi:10.1016/j.jse.2015.06.022.
39. Mallon WJ, Brown HR, Vogler JB 3rd, Martinez S. Radiographic and geometric anatomy of the scapula. Clin Orthop Relat Res. 1992; 142–54.
40. Martin SD, Zurakowski D, Thornhill TS. Uncemented glenoid component in total shoulder arthroplasty. J Bone Joint Surg. 2005;87A:1284–92. doi:10.2106/JBJS.C.00947.
41. Matsumura N, Ogawa K, Ikegami H, Collin P, Walch G, Toyama Y. Computed tomography measurement of glenoid vault version as an alternative measuring method for glenoid version. J Orthop Surg Res. 2014;9(1):17. doi:10.1186/1749-799X-9-17.
42. Maurer A, Fucentese SF, Pfirrmann CW, Wirth SH, Djahangiri A, Jost B, Gerber C. Assessment of glenoid inclination on routine clinical radiographs and computed tomography examinations of the shoulder. J Should Elb Surg. 2012;21(8):1096–103. doi:10.1016/j.jse.2011.07.010.
43. Norris TR, Iannotti JP. Functional outcome after shoulder arthroplasty for primary osteoarthritis: a multicenter study. J Should Elb Surg. 2002;11(2): 130–5.
44. Nyffeler RW, Anglin C, Sheikh R, Gerber C. Influence of peg design and cement mantle thickness on pull-out

strength of glenoid component pegs. J Bone Joint Surg (Br). 2003;85:748–52.
45. Nyffeler RW, Jost B, Pfirrmann CW, Gerber C. Measurement of glenoid version: conventional radiographs versus computed tomography scans. J Should Elb Surg. 2003;12:493–6.
46. Pinkas D, Wiater B, Wiater JM. The glenoid component in anatomic shoulder arthroplasty. J Am Acad Orthop Surg. 2015;23(5):317–26.
47. 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 Should Elb Surg. 2007;16:396–402.
48. Ricchetti ET, Hendel MD, Collins DN, Iannotti JP. Is premorbid glenoid anatomy altered in patients with glenohumeral osteoarthritis? Clin Orthop Relat Res. 2013;471(9):2932–9. doi:10.1007/s11999-013-3069-5.
49. Sabesan V, Callanan M, Sharma V, Iannotti JP. Correction of acquired glenoid bone loss in osteoarthritis with a standard versus an augmented glenoid component. J Should Elb Surg. 2014;23(7):964–73. doi:10.1016/j.jse.2013.09.019.
50. Scalise JJ, Codsi MJ, Bryan J, Brems JJ, Iannotti JP. The influence of three-dimensional computed tomography images of the shoulder in preoperative planning for total shoulder arthroplasty. J Bone Joint Surg Am. 2008;90(11):2438–45. doi:10.2106/JBJS.G.01341.
51. Scalise JJ, Codsi MJ, Bryan J, Iannotti JP. The three-dimensional glenoid vault model can estimate normal glenoid version in osteoarthritis. J Should Elb Surg. 2008;17:487–91. doi:10.1016/j.jse.2007.09.006.
52. Simon P, Gupta AK, Pappau I, Hussey MM, Santoni BG, Inoue N, Frankle MA. The relationship between the subchondral bone density distribution and glenoid depth: an -in-vivo pilot study of male total shoulder arthroplasty subjects. J Should Elb Surg. 2015;24(3):416–24. doi:10.1016/j.jse.2014.06.054.
53. Stephens SP, Paisley KC, Jeng J, Dutta AK, Wirth MA. Shoulder arthroplasty in the presence of posterior glenoid bone loss. J Bone Joint Surg Am. 2015;97(3):251–9. doi:10.2106/JBJS.N.00566. Review.
54. Taunton MJ, McIntosh AL, Sperling JW, Cofield RH. Total shoulder arthroplasty with a metal-backed, bone-ingrowth glenoid component: medium to long-term results. J Bone Joint Surg Am. 2008;90(10):2180–8.
55. Terrier A, Buchler P, Farron A. Bone-cement interface of the glenoid component: stress analysis for varying cement thickness. Clin Biomech (Bristol, Avon). 2005;20:710–7.
56. Testing of a novel pin array guide for accurate three-dimensional glenoid component positioning.
57. The treatment of glenohumeral joint osteoarthritis: guideline and evidence report. AAOS (http://www.aaos.org/Research/guidelines/glosummary.pdf).
58. Throckmorton TW, Gulotta LV, Bonnarens FO, Wright SA, Hartzell JL, Rozzi WB, Hurst JM, Frostick SP, Sperling JW. Patient-specific targeting guides compared with traditional instrumentation for glenoid component placement in shoulder arthroplasty: a multi-surgeon study in 70 arthritic cadaver specimens. J Should Elb Surg. 2015;24(6):965–71. doi:10.1016/j.jse.2014.10.013.
59. Torchia ME, Cofield RH, Settergren CR. Total shoulder arthroplasty with the Neer prosthesis: long-term results. J Should Elb Surg. 1997;6(6):495–505.
60. van de Bunt F, Pearl ML, Lee EK, Peng L, Didomenico P. Glenoid version by CT scan: an analysis of clinical measurement error and introduction of a protocol to reduce variability. Skelet Radiol. 2015;44:1627–35.
61. Walch G, Badet R, Boulahia A, Khoury A. Morphologic study of the glenoid in primary glenohumeral osteoarthritis. J Arthroplasty. 1999;14:756–60.
62. Walch G, Boulahia A, Boileau J, Kempf JF. Primary glenohumeral osteoarthritis: clinical and radiographic classification. Acta Orthop Belg. 1998;64(Suppl II):48.
63. Walch G, Edwards TB, Boulahia A, Boileau P, Mole D, Adeleine P. The influence of glenohumeral prosthetic mismatch on glenoid radiolucent lines: results of a multicenter study. J Bone Joint Surg Am. 2002;84:2186–91.
64. Walch G. Management of posterior bone loss in TSA. Presented at Current Solutions in Shoulder and Elbow Surgery. Tampa, Jan 2015.
65. Walch G, Vezeridis PS, Boileau P, Deransart P, Chaoui J. Three-dimensional planning and use of patient-specific guides improve glenoid component position: an in vitro study. J Should Elb Surg. 2015;24(2):302–9. doi:10.1016/j.jse.2014.05.029.
66. Walch G, Young A, Melis B, Gazielly D, Loew M, Boileau P. Results of the convex back cemented keeled glenoid component in primary osteoarthritis. Multicentric Study with a follow-up >5 years. Shoulder concepts 2010 the glenoid, Sauramps Medical, 2010. Montpellier/Paris; 2010. p. 117–30.
67. Walch G, Young AA, Boileau P, Loew M, Gazielly D, Mole D. Patterns of loosening of polyethylene keeled glenoid components after shoulder arthroplasty for primary osteoarthritis: results of a multicenter study with more than 5 years follow-up. J Bone Joint Surg Am. 2012;94(2):145–50.
68. Williams Jr GR, Iannotti JP. Options for glenoid bone loss: composites of prosthetics and biologics. J Should Elb Surg. 2007;16:S267–72. doi:10.1016/j.jse.2007.05.003.
69. Wirth CJ, Peters G, Milachowski KA, Weismeier KG, Kohn D. Longterm results of meniscal allograft transplantation. Am J Sports Med. 2002;30:174–81.
70. Wirth MA, Agrawal CM, Mabrey JD, Dean DD, Blanchard CR, Miller MA, et al. Isolation and characterization of polyethylene wear debris associated with osteolysis following total shoulder arthroplasty. J Bone Joint Surg Am. 1999;81:29–37.
71. Wirth MA, Klotz C, Deffenbaugh DL, McNultry D, Richards L, Tipper JL. Cross-linked glenoid prosthesis: a wear comparison to conventional glenoid prosthesis with wear particulate analysis. J Should Elb Surg. 2009;18(1):130–7. doi:10.1016/j.jse.2008.06.015.

72. Wirth MA, Korvick DL, Basamania CJ, Toto F, Aufdemorte TB, Rockwood Jr CA. Radiologic, mechanical, and histologic evaluation of 2 glenoid prosthesis designs in a canine model. J Should Elb Surg. 2001;10:140–8.
73. Wirth MA, Loredo R, Garcia G, Rockwood Jr CA, Southworth C, Iannotti JP. Total shoulder arthroplasty with an all-polyethylene pegged bone-ingrowth glenoid component: a clinical and radiographic outcome study. J Bone Joint Surg Am. 2012;94(3):260–7. doi:10.2106/JBJS.J.01400.
74. Wirth MA, Rockwood CA Jr. Complications of shoulder arthroplasty. Clin Orthop Relat Res. 1994;47–69.
75. Wirth MA, Rockwood Jr CA. Complications of total shoulder replacement arthroplasty. J Bone Joint Surg Am. 1996;78:603–16.
76. Yian EH, Werner CM, Nyffeler RW, Pfirrmann CW, Ramappa A, Sukthankar A, et al. Radiographic and computed tomography analysis of cemented pegged polyethylene glenoid components in total shoulder replacement. J Bone Joint Surg Am. 2005;87:1928–36.
77. Yongpravat C, Kim HM, Gardner TR, Bigliani LU, Levine WN, Ahmad CS. Glenoid implant orientation and cement failure in total shoulder arthroplasty: a finite element analysis. J Should Elb Surg. 2013;22(7):940–7. doi:10.1016/j.jse.2012.09.007.
78. Young AA, Walch G, Pape G, Gohlke F, Favard L. Secondary rotator cuff dysfunction following total shoulder arthroplasty for primary glenohumeral osteoarthritis: results of a multicenter study with more than five years of follow-up. J Bone Joint Surg Am. 2012;94(8):685–93. doi:10.2106/JBJS.J.00727.
79. Zilber S, Radier C, Postel JM, Van Driessche S, Allain J, Goutallier D. Total shoulder arthroplasty using the superior approach: influence on glenoid loosening and superior migration in the long-term follow-up after Neer II prosthesis installation. J Should Elb Surg. 2008;17:554–63.

Augmented Glenoid Replacement for Total Shoulder Arthroplasty

8

Wassim A. Aldebeyan, Nikolas K. Knowles, Louis M. Ferreira, and George S. Athwal

Introduction

Degenerative arthritis that results in asymmetric posterior glenoid wear presents potential challenges for the surgeon, including the management of the bone deficiency, joint subluxation, and soft tissue laxity or contracture. The primary objective with osteoarthritis with asymmetric glenoid wear is to effectively restore functional anatomy of the joint with implants that will lead to long-term survivability. Unfortunately, the literature to date is incomplete as it pertains to the long-term success rate of the various arthroplasty options for management of moderate to severe glenoid bone loss.

There are several options for management of glenoid bone loss and associated retroversion, which include hemiarthroplasty, glenoid realignment with bony reaming, bone grafting, reverse shoulder arthroplasty, and augmented implants. Unfortunately, no one management technique has demonstrated clinical superiority. Recently, there has been renewed interest in posteriorly augmented glenoid implants. Several orthopedic implant manufacturers have developed posteriorly augmented glenoid implants with various backside geometries to minimize anterior glenoid bone removal and maximize implant stability and survivability. These implants attempt to restore glenoid retroversion and re-center the humeral head during anatomic total shoulder arthroplasty by reconstructing the glenoid bony erosion with polyethylene.

W.A. Aldebeyan, MD, FRCSC • N.K. Knowles, MESc
G.S. Athwal, MD, FRCSC (✉)
Roth|McFarlane Hand and Upper Limb Centre, St. Joseph's Health Care, 268 Grosvenor Street, London, ON, Canada
e-mail: wdebeyan@gmail.com; nik_knowles@hotmail.com; gathwal@uwo.ca

L.M. Ferreira, PhD
Department of Mechanical and Materials Engineering, University of Western Ontario, London, ON, Canada
e-mail: Louis.Ferreira@uwo.ca

Glenoid Morphology

Osteoarthritis (OA) of the shoulder affects the biomechanics of the glenohumeral joint and results in morphology of the glenoid. These changes lead to posterior humeral head subluxation, increasing bony erosion of the posterior glenoid, and increased retroversion. These alterations on glenohumeral relationships were first noted by Neer et al. in 1982 [1]. They described severe cases of primary glenohumeral OA with posterior sloping of the glenoid and posterior subluxation of the humeral head resembling "an old posterior dislocation."

Walch et al. formally classified glenoid morphology into five types in 1999 [2]. This classification system was based on wear patterns and version and has become the most commonly used system to classify glenoid bone loss. Type

© Springer International Publishing Switzerland 2016

A.D. Armstrong, A.M. Murthi (eds.), *Anatomic Shoulder Arthroplasty*,
DOI 10.1007/978-3-319-29164-2_8

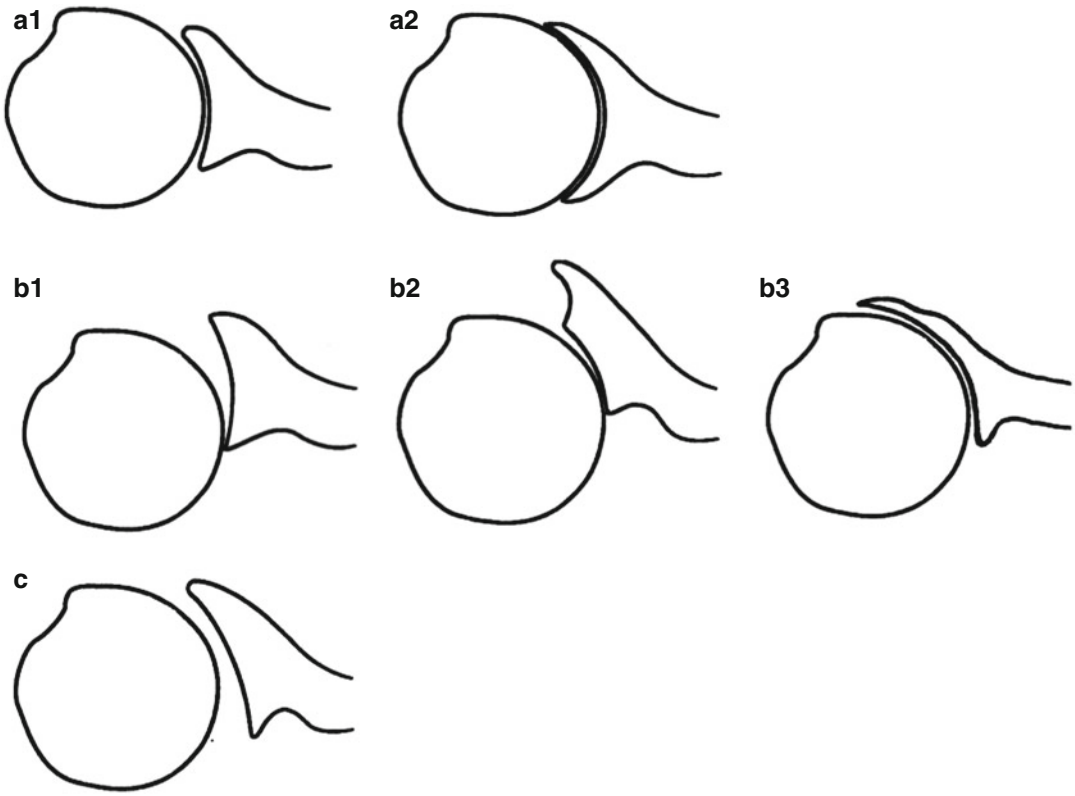


Fig. 8.1 Illustration of the Walch classification of glenoid morphology, which is based on wear patterns and version. *Type A1*, centered humeral head with minor glenoid erosion. *Type A2*, centered humeral head with major glenoid erosion. *Type B1*, posterior subluxation with no erosion. *Type B2*, posterior erosion with a biconcave glenoid. *Type B3*, severe posterior erosion with loss of the entire paleoglenoid (anterior) facet. *Type C*, dysplastic glenoid with severe retroversion

A glenoids, which represented 59 % of patients, had concentric wear with a centralized humeral head. These patients were subclassified into minor (A1) or major (A2). Type B glenoids, present in 32 % of cases, had posterior humeral head subluxation and joint space narrowing (B1) or a biconcave glenoid (B2). A type C glenoid was present in 9 % of cases and consisted of a dysplastic glenoid with retroversion of more than 25°. A type B3 glenoid has recently been described, which is a severe B2 deformity with posterior humeral head subluxation and erosion removing the entire paleoglenoid (anterior) facet (Fig. 8.1).

Static posterior humeral head subluxation has been associated with posterior glenoid erosion. Walch et al. reported on 13 male patients at a mean age of 40 with OA and symptoms of shoulder pain, stiffness, and locking. These patients were all found to have posterior humeral head subluxation with a mean subluxation index of 65 %, without posterior glenoid bony erosion. The authors suggested that posterior humeral head subluxation was the first stage of glenohumeral OA and that it might lead to the subsequent glenoid erosion and the B2 deformity [3].

Type B2 glenoids have a predictable wear pattern. The average erosion in a type B2 glenoid is directed toward the 8 o'clock position in a right shoulder [4–7]. This pattern of erosion causes potentially important regional variability in the density and porosity of the underlying subarticular bone, with the densest and least porous bone found in the neoglenoid, which tends to be located posteroinferiorly [8].

Biomechanics

Shoulder biomechanics pertaining to posterior erosions can be thought of as having three time periods: (1) the biomechanics leading to the onset of erosion, (2) the biomechanics present in specific Walch asymmetrical classifications, and (3) the biomechanics following treatment with an augmented component.

The Biomechanics or Events Leading to the Erosion

The onset of posterior erosion is initiated by a posterior shift of the normal articular motion pattern. This may not be a static subluxation at first, but with time, the suboptimal articular contact pattern leads to increased joint contact pressures in the posterior region, which eventually causes erosion and subchondral sclerosis. Once this is accompanied by static posterior subluxation and osteophytes, it is diagnosed as a Walch type B1. However, the factors that initiate the altered motion pattern are not fully understood or agreed on. In the normal midrange of motion, the dynamic muscle forces determine the normal range of compression and shear vector components, and it is the ratio of these that define stability [9]. For inferiorly directed loads, Halder et al. found that the ratio of shear to compressive loads was 0.6 [10]. An imbalance in muscle forces does not necessarily imply active forces, but can also be due to a shortening, which increases muscle load at the end of the muscle's extension range, which has been shown to play a role in anterior dislocations caused by a passive load from the pectoralis when it is fully extended [11].

Weber and Caspari reported that posterior instability is most likely a continuum between subluxation and dislocation with progressive injury to the posterior capsule and attachments, such as the labrum, which is the principal restraint to posterior displacement [12].

Some research has suggested that the compliance of the glenoid subchondral bone under a compressive load generates a congruent articulation that matches the humeral head radius of curvature [13]. This would be consistent with thin film principles of lubrication. In this scenario, it is hypothesized that the labrum provides an important function of retaining synovial fluid under compressive load and thus increasing intra-articular fluid pressure. Gibb et al. (1991) reported that, under a distraction force, negative pressure was capable of resisting a pulling force of about 22 N, plus the weight of the arm [14]. Thus, it is also possible that a labral tear, contracted through acute injury, could also result in a loss of the negative pressure traction force, leading to a posterior shift in the articular pattern.

Dysfunctioned proprioception may also play a role in altering the balance of muscle forces or in altering the timing with which different muscle groups are recruited to stabilize the joint. Stability of the glenohumeral joint is provided by a complex system of forces that are largely redundant, and as such, there is an infinite number of ways in which stability can be compromised. Thus, it is likely that a single etiological path of causality does not exist for the onset of posterior erosion, but rather that any insult to the complex balance may lead to this result.

The Biomechanics Present in Specific Walch Asymmetrical Classifications

Regardless of the cause which initiates posterior instability and erosion, the increased contact pressures result in significant bone formation in this region, as the subchondral bone remodels to account for the increased load distribution [8, 15]. Once a Walch type B1 is diagnosed, it is likely to progress to a type B2, which is identified by acquired retroversion due to erosion of the posterior osseous rim. The posterior erosion is often characterized as a concavity (forming a "biconcave" glenoid), which is the "neoglenoid" articular surface, in the posterior region, distinguishing this from the anterior native "paleoglenoid." In patients with glenoid erosion, the paleoglenoid typically maintains articular cartilage, indicating that this region has not undergone morphological changes or bony

erosions. The biomechanics of Walch type B glenoids are marked by static subluxation, which has chronically altered the normal motion pathways and forces in virtually all of the dynamic and other soft tissue structures, as well as the osseous anatomy. Essentially, a new balance of forces is established, although this may still progress further to a Walch type B3.

The Biomechanics Following Treatment with an Augmented Component

Most often, the operative plan is to restore a native joint rotation center; however, as mentioned in the previous section, there is a chronic change in the balance of forces once the humeral head becomes statically subluxated with posterior erosion. This represents an established and, in some cases, mechanically stable system. The consequences of instantly restoring – fully or partially – the native joint position are not understood, and it may be less disruptive to maintain something close to the neoglenoid articular position.

Postoperative biomechanics will determine the longevity of augmented glenoid implants. There is still no longitudinal data on the survivability of these designs, given their still short clinical history. In particular, augmented designs are intended to preserve anterior bone by minimizing high-side reaming; however, recent research shows that the anterior bone being preserved may have significantly high porosity and low density, caused by bone remodeling after long-term disuse of the paleoglenoid articular facet [8]. Moreover, it is now understood that the orientation of the average posterior erosion is not purely posterior, but rather somewhat inferior as well (toward 8 o'clock on a right shoulder) (Fig. 8.2) [4]. Thus, it is clear that the posteriorly eroded glenoid is different from the symmetrically eroded glenoid in shape and also in the composition of the subchondral bone, in terms of its density and porosity as a function of location.

Further biomechanics investigations are required to completely understand the glenoid in these complex cases and how augmented implants perform under these specific circumstances.

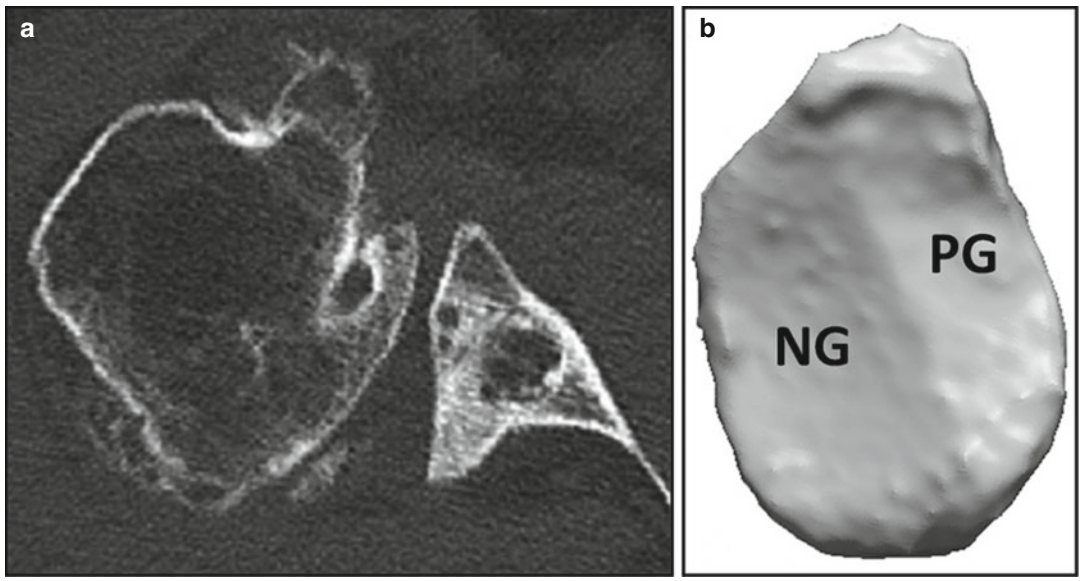


Fig. 8.2 (**a**) A 2D axial CT scan view of a right shoulder demonstrating an asymmetric type B2 glenoid. (**b**) A sagittal view of a 3D CT reconstruction demonstrating a B2 glenoid with posteroinferior erosion. The neoglenoid (*NG*) and the paleoglenoid (*PG*) are depicted (Reprinted from The Journal of Shoulder and Elbow Surgery, 24(4), Knowles et al. [4], Copyright (2015), with permission from Elsevier)

Treatment Options

There are several ways of treating patients with type B2 glenoids, including implanting a glenoid component in a retroverted position, i.e., without correcting the version, eccentric reaming, hemiarthroplasty, posterior bone grafting, and reverse shoulder arthroplasty (RSA).

Component placement in a retroverted position has been shown to cause early failure and loosening of the glenoid component if the retroversion is ≥15° [16]. A common method used to correct glenoid retroversion is eccentric reaming, or reaming the high side, where the anterior glenoid is reamed to the level of the posterior surface to recreate glenoid version and theoretically re-center the humeral head. However, this technique is limited by the amount of preoperative retroversion and the fact that reaming leads to loss of bone stock as the glenoid vault narrows medially. Cadaveric and computer simulation studies have indicated that approximately 15–18° is the amount of retroversion that can be successfully corrected without vault penetration [17–19]; however, vault perforation may not be the best metric to assess maximum correction.

Eccentric reaming has also been used with hemiarthroplasty. This technique, which was popularized by Matsen and termed "ream and run," aims to create a concentric socket by reaming the glenoid without implanting a glenoid component and resurfacing the humeral head with a hemiarthroplasty. Short-term follow-up of this procedure showed cases of progressive medial erosion and recurrent posterior glenoid erosion [20].

Biologic resurfacing of the glenoid with hemiarthroplasty of the humeral head has been tried in young adults where the longevity of a polyethylene glenoid component is of concern. Meniscal, fascia lata, and Achilles tendon allografts have been used with mixed outcomes. There is little high-quality evidence to support the use of these methods [21–24].

Posterior bone grafting of the glenoid using autograft or allograft is another method of managing type B2 glenoids. This method has the theoretical advantage of preserving bone stock while correcting glenoid version. There are varying outcomes for bone grafting, with some studies showing excellent to satisfactory results and others showing poor results [25–30].

Reverse shoulder arthroplasty (RSA) is most commonly used to treat rotator cuff tear arthropathy. However, RSA has recently been investigated for use in primary glenohumeral osteoarthritis with a type B2 glenoid [31]. The ability to bone graft the glenoid with screw fixation from the glenoid baseplate and the use of a long central post to engage native bone is particularly attractive, in addition to the constraint offered by the RSA which solves the problem of posterior subluxation. The use of RSA for this indication is promising but requires further follow-up to determine the long-term durability of this approach.

Augmented Glenoid Implants

The outcome of first-generation augmented glenoid implants was poor. Rice et al. reviewed 14 shoulders treated with an asymmetric wedge-shaped posteriorly augmented glenoid component with a mean follow-up of 5 years [32]. More than half of the implants showed radiolucent lines, and one third showed moderate or severe posterior humeral head subluxation. The authors concluded that the contribution of the modified glenoid component seemed marginal, and the use of this implant was discontinued [32, 33].

Second-generation augmented glenoid components are currently available on the market. There are three design concepts, posterior step, full wedge, and posterior wedge (Fig. 8.3).

Posterior Step

This design concept uses varying backside step heights encompassing the entire posterior hemisphere. This implant reduces joint medialization by minimizing eccentric "high-side" anterior reaming.

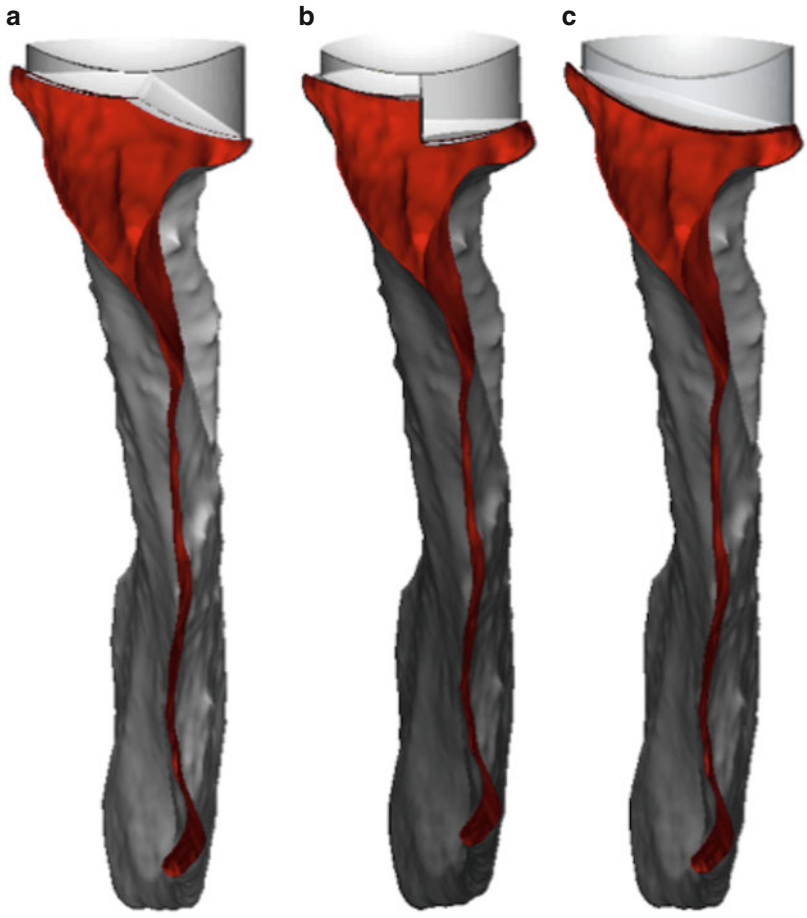


Fig. 8.3 Illustration showing the amount of bone removal required for each implant design. (**a**) Wright Medical Technology® PerFORM Plus Posterior Augment Glenoid. (**b**), DePuy® Global® StepTech® APG. (**c**) Exactech® Equinoxe® Posterior Augment Glenoid

Full Wedge

This implant acts to reduce anterior cortical bone removal for posterior eroded glenoids with retroversion and uses a full-wedge design from posterior to anterior.

Posterior Wedge

This implant design uses a wedge that encompasses the entire posterior hemisphere. This design acts to minimize reaming by mimicking the degree of retroversion exhibited in asymmetric glenoid erosion [34].

Advantages and Disadvantages of Augmented Glenoid Implants

All augmented implant designs aim to preserve bone stock and reduce medialization by decreasing the amount of eccentric reaming needed for glenoid implant seating. Sabesan et al. conducted a study comparing standard and augmented glenoid components on a virtual three-dimensional reconstruction and concluded that the use of an augmented component can allow complete correction of retroversion and minimize the effect of medialization [35]. Kersten et al. also conducted a study using virtual implantation of three-dimensional reconstructions of B2 glenoids to

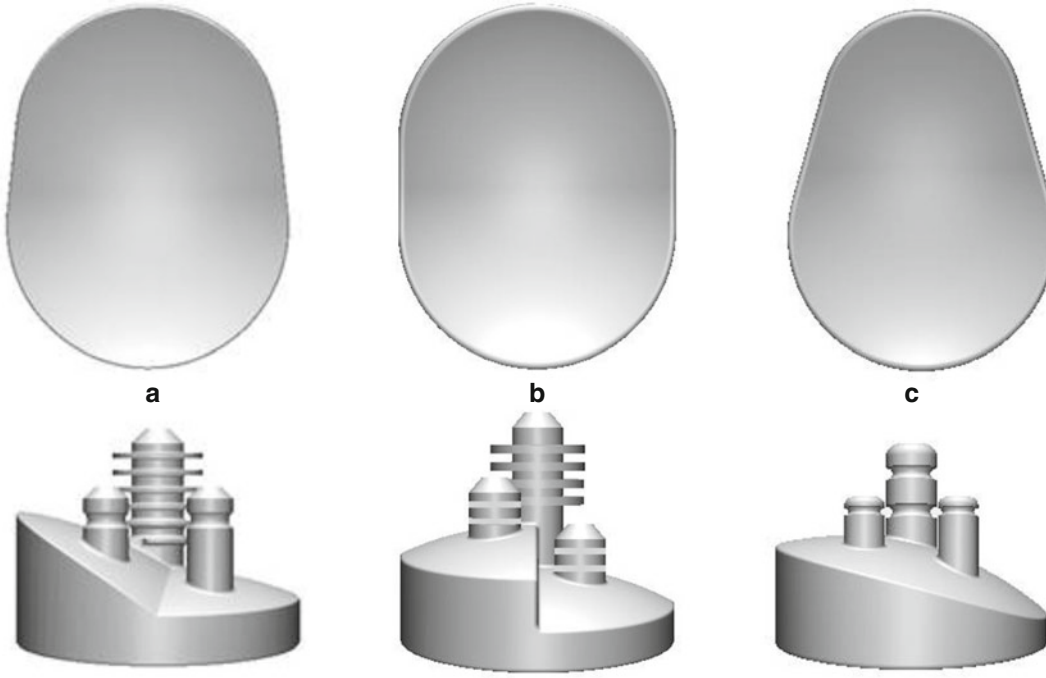


Fig. 8.4 Three commercially available augmented glenoid component designs: (**a**) Wright Medical Technology® PerFORM Plus Posterior Augment Glenoid. (**b**) DePuy® Global® StepTech® APG. (**c**) Exactech® Equinoxe® Posterior Augment Glenoid. *Bottom* figures are posterior views and *top* figures are articular surface views

compare the amount of bone removal using three glenoid designs, standard, wedged, and stepped. They concluded that both augmented components corrected glenoid version to neutral and required less bone removal, required less reaming depth, and were supported by more cortical bone than in the standard implant. The least amount of bone removed was with the wedged design [36].

However, these designs assume that the posterior erosion of the glenoid occurs directly posterior toward the 9 o'clock position in a right glenoid, when in fact the line of erosion is directed toward the posteroinferior quadrant with the orientation of bone loss directed toward the 8 o'clock position [4]. Furthermore, using an augmented glenoid implant could lead to removing more bone posteriorly to make room for the augment, which in a B2 glenoid is considered the bone with the highest density [8]. This may affect stability of the glenoid implant in the future. Knowles et al. showed, in a three-dimensional simulation study, that substantial variations in the volume of bone removal and the quality of the remaining glenoid bone were found between three different designs of augmented implants (full wedge, posterior wedge, and stepped). Simulations with the posterior-wedge implant resulted in substantially less glenoid bone removal, with the remaining supporting bone being of better quality (Fig. 8.4) [37].

Outcomes

Unfortunately, the outcomes of first-generation augmented glenoid implants were disappointing and they were discontinued [32]. Second-generation augmented glenoids have only recently been introduced and as such have limited data related to their clinical outcomes. Youderian et al. showed good short-term results using a stepped design with a minimum of 6-month follow-up, demonstrating excellent seating and clinical results. Postoperative computed tomography analysis demonstrated excellent correction (mean 16.7°) of glenoid version with minimal loss (mean 0.45 mm) of the premorbid joint line [38].

An in vitro study by Iannotti et al. [39] compared four different augmented glenoid designs (one stepped and three full-wedge designs with either an asymmetric spherical backside, a symmetric spherical backside, or a flat-angled backside) with a standard glenoid. They concluded that a stepped design for an augmented glenoid component has superior fixation and less anterior glenoid liftoff in the presence of eccentric loading and may have better long-term clinical results compared to a non-stepped augmented design [39]. Kirane et al. [40] also performed an in vitro biomechanical analysis in which a standard glenoid component implanted in neutral version was compared with two prototype stepped glenoid components (one all polyethylene and the other with a titanium posterior step) implanted into simulated biconcave glenoids. They measured peri-glenoid bone strains under consistent loading conditions. The titanium metal-backed prosthesis produced significantly increased anterior compressive and posterior tensile strains compared to the standard glenoid. However, they found no significant difference between the polyethylene posterior step and the standard glenoid [40]. Conversely, Wang et al. [41] compared eccentric reaming with a full-wedge augmented glenoid component in composite scapulae and recorded superior and inferior glenoid edge liftoff. They concluded that the use of angle-backed augmented glenoid components results in accelerated implant loosening compared with neutral-version glenoids after eccentric reaming [41].

Unfortunately, there are no medium or long-term outcomes on the use of contemporary augmented implants to manage type B2 glenoids. As such, patients should be educated on the unknown survivability of these particular implants.

Conclusion

Although studies have shown the benefits of implanting a posteriorly augmented glenoid component, their drawbacks are still poorly understood. Additionally, proposed solutions address the issue of correcting the bony anatomy with little information on how the soft tissue envelope is affected. Future studies are needed to show how altering this bony anatomy affects soft tissue balance.

Using posterior augments allows the surgeon to preserve bone and restore proper biomechanical forces across the shoulder joint. Although longer follow-up studies are needed, it appears that in the short-term follow-up, the use of augmented glenoid components is encouraging.

References

1. Neer C, Watson K, Stanton F. Recent experience in total shoulder replacement. J Bone Joint Surg. 1982; 64(3):319–37.
2. Walch G, Badet R, Boulahia A, Khoury A. Morphologic study of the glenoid in primary glenohumeral osteoarthritis. J Arthroplasty. 1999;14(6):756–60.
3. Walch G, Ascani C, Boulahia A, Nové-Josserand L, Edwards TB. Static posterior subluxation of the humeral head: an unrecognized entity responsible for glenohumeral osteoarthritis in the young adult. J Shoulder Elbow Surg. 2002;11(4):309–14.
4. Knowles NK, Keener JD, Ferreira LM, Athwal GS. Quantification of the position, orientation, and surface area of bone loss in type B2 glenoids. J Shoulder Elbow Surg. 2015;24(4):503–10.
5. Churchill RS, Spencer EE, Fehringer EV. Quantification of B2 glenoid morphology in total shoulder arthroplasty. J Shoulder Elbow Surg. 2015;24:1212–7.
6. Terrier A, Ston J, Larrea X, Farron A. Measurements of three-dimensional glenoid erosion when planning the prosthetic replacement of osteoarthritic shoulders. Bone Joint Surg. 2014;96(4):513–8.
7. Beuckelaers E, Jacxsens M, Van Tongel A, De Wilde LF. Three-dimensional computed tomography scan evaluation of the pattern of erosion in type B glenoids. J Shoulder Elbow Surg. 2014;23(1):109–16.
8. Knowles NK, Athwal GS, Keener JD, Ferreira LM. Regional bone density variations in osteoarthritic glenoids: a comparison of symmetric to asymmetric (type B2) erosion patterns. J Shoulder Elbow Surg. 2015;24(3):425–32.
9. Veeger H, Van Der Helm F. Shoulder function: the perfect compromise between mobility and stability. J Biomech. 2007;40(10):2119–29.
10. Halder A, Kuhl S, Zobitz M, Larson D, An K. Effects of the glenoid labrum and glenohumeral abduction on stability of the shoulder joint through concavity-compression. J Bone Joint Surg. 2001;83(7):1062–9.
11. Labriola JE, Lee TQ, Debski RE, McMahon PJ. Stability and instability of the glenohumeral joint: the role of shoulder muscles. J Shoulder Elbow Surg. 2005;14(1):S32–8.
12. Weber SC, Caspari RB. A biomechanical evaluation of the restraints to posterior shoulder dislocation. Arthrosc J Arthrosc Relat Surg. 1989;5(2):115–21.
13. Frich LH, Jensen NC, Odgaard A, Pedersen CM, Søjbjerg JO, Dalstra M. Bone strength and material

properties of the glenoid. J Shoulder Elbow Surg. 1997;6(2):97–104.
14. Gibb TD, Sidles JA, Harryman DT, McQuade KJ, Matsen III FA. The effect of capsular venting on glenohumeral laxity. Clin Orthop Relat Res. 1991; 268:120–7.
15. Simon P, Gupta A, Pappou I, Hussey MM, Santoni BG, Inoue N, et al. Glenoid subchondral bone density distribution in male total shoulder arthroplasty subjects with eccentric and concentric wear. J Shoulder Elbow Surg. 2015;24(3):416–24.
16. Ho JC, Sabesan VJ, Iannotti JP. Glenoid component retroversion is associated with osteolysis. J Bone Joint Surg. 2013;95(12):e82.
17. Clavert P, Millett PJ, Warner JJ. Glenoid resurfacing: what are the limits to asymmetric reaming for posterior erosion? J Shoulder Elbow Surg. 2007;16(6):843–8.
18. Gillespie R, Lyons R, Lazarus M. Eccentric reaming in total shoulder arthroplasty: a cadaveric study. Orthopedics. 2009;32(1):21.
19. Nowak DD, Bahu MJ, Gardner TR, Dyrszka MD, Levine WN, Bigliani LU, et al. Simulation of surgical glenoid resurfacing using three-dimensional computed tomography of the arthritic glenohumeral joint: the amount of glenoid retroversion that can be corrected. J Shoulder Elbow Surg. 2009;18(5):680–8.
20. Lynch JR, Franta AK, Montgomery WH, Lenters TR, Mounce D, Matsen FA. Self-assessed outcome at two to four years after shoulder hemiarthroplasty with concentric glenoid reaming. J Bone Joint Surg. 2007; 89(6):1284–92.
21. 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. 2009; 91(2):419–24.
22. Krishnan SG, Nowinski RJ, Harrison D, Burkhead WZ. Humeral hemiarthroplasty with biologic resurfacing of the glenoid for glenohumeral arthritis. J Bone Joint Surg. 2007;89(4):727–34.
23. Nicholson GP, Goldstein JL, Romeo AA, Cole BJ, Hayden JK, Twigg SL, 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):S261–6.
24. Wirth MA. Humeral head arthroplasty and meniscal allograft resurfacing of the glenoid. J Bone Joint Surg. 2009;91(5):1109–19.
25. Neer CS, Morrison D. Glenoid bone-grafting in total shoulder arthroplasty. J Bone Joint Surg. 1988; 70(8):1154–62.
26. Steinmann SP, Cofield RH. Bone grafting for glenoid deficiency in total shoulder replacement. J Shoulder Elbow Surg. 2000;9(5):361–7.
27. Hill JM, Norris TR. Long-term results of total shoulder arthroplasty following bone-grafting of the glenoid. J Bone Joint Surg. 2001;83(6):877–83.
28. Walch G, Moraga C, Young A, Castellanos-Rosas J. Results of anatomic nonconstrained prosthesis in primary osteoarthritis with biconcave glenoid. J Shoulder Elbow Surg. 2012;21(11):1526–33.
29. Sabesan V, Callanan M, Ho J, Iannotti JP. Clinical and radiographic outcomes of total shoulder arthroplasty with bone graft for osteoarthritis with severe glenoid bone loss. J Bone Joint Surg. 2013;95(14): 1290–6.
30. Klika BJ, Wooten CW, Sperling JW, Steinmann SP, Schleck CD, Harmsen WS, et al. Structural bone grafting for glenoid deficiency in primary total shoulder arthroplasty. J Shoulder Elbow Surg. 2014; 23(7):1066–72.
31. Mizuno N, Denard PJ, Raiss P, Walch G. Reverse total shoulder arthroplasty for primary glenohumeral osteoarthritis in patients with a biconcave glenoid. J Bone Joint Surg. 2013;95(14):1297–304.
32. Rice RS, Sperling JW, Miletti J, Schleck C, Cofield RH. Augmented glenoid component for bone deficiency in shoulder arthroplasty. Clin Orthop Relat Res. 2008;466(3):579–83.
33. Stephens SP, Paisley KC, Jeng J, Dutta AK, Wirth MA. Shoulder arthroplasty in the presence of posterior glenoid bone loss. J Bone Joint Surg. 2015; 97(3):251–9.
34. Knowles NK. Osteoarthritis induced glenoid morphology and bone quality: an evaluation of augmented glenoid components. 2015. Electronic thesis and dissertation repository. Paper 2752. http://ir.lib.uwo.ca/etd/2752
35. Sabesan V, Callanan M, Sharma V, Iannotti JP. Correction of acquired glenoid bone loss in osteoarthritis with a standard versus an augmented glenoid component. J Shoulder Elbow Surg. 2014;23(7): 964–73.
36. Kersten AD, Flores-Hernandez C, Hoenecke HR, D'Lima DD. Posterior augmented glenoid designs preserve more bone in biconcave glenoids. J Shoulder Elbow Surg. 2015;24:1135–41.
37. Knowles NK, Ferreira LM, Athwal GS. Augmented glenoid component designs for type B2 erosions: a computational comparison by volume of bone removal and quality of remaining bone. J Shoulder Elbow Surg. 2015;24:1218–26.
38. Youderian AR, Napolitano Jr LA, Davidson IU, Iannotti JP. Management of glenoid bone loss with the use of a new augmented all-polyethylene glenoid component. Tech Should Elbow Surg. 2012;13 (4):163–9.
39. Iannotti JP, Lappin KE, Klotz CL, Reber EW, Swope SW. Liftoff resistance of augmented glenoid components during cyclic fatigue loading in the posterior-superior direction. J Shoulder Elbow Surg. 2013;22(11):1530–6.
40. Kirane YM, Lewis GS, Sharkey NA, Armstrong AD. Mechanical characteristics of a novel posterior-step prosthesis for biconcave glenoid defects. J Shoulder Elbow Surg. 2012;21(1): 105–15.
41. Wang T, Abrams GD, Behn AW, Lindsey D, Giori N, Cheung EV. Posterior glenoid wear in total shoulder arthroplasty: eccentric anterior reaming is superior to posterior augment. Clin Orthop Relat Res®. 2015;473(12):3928–36.

Interposition Shoulder Arthroplasty

9

Jeremy S. Somerson, Aaron J. Bois, and Michael A. Wirth

Introduction

The young patient with glenohumeral arthritis presents a challenging clinical dilemma in which the surgeon and patient must balance goals of obtaining maximum pain relief and functional outcome, returning to activity with few limitations and ensuring long-term durability. When arthroplasty is indicated, total shoulder arthroplasty (TSA) is considered the gold standard by many surgeons due to superior results when compared to hemiarthroplasty in short-term studies [1, 2]. Long-term comparisons of TSA to hemiarthroplasty in young patients have not demonstrated substantial differences between groups [3, 4]. However, long-term follow-up of TSA has raised concern for glenoid loosening and declining outcomes [5–8]. As a result, surgeons have explored alternative approaches to arthroplasty that address glenoid-sided arthrosis without implantation of a prosthetic glenoid component.

J.S. Somerson, M.D. • M.A. Wirth, MD (✉)
Department of Orthopaedics, University of Texas Health Science Center at San Antonio, 7703 Floyd Curl Drive, San Antonio, TX 78229, USA
e-mail: jeremysomerson@gmail.com; wirth@uthscsa.edu

A.J. Bois, MD, MSc, FRCSC
Department of Surgery, Section of Orthopaedic Surgery, Cumming School of Medicine, University of Calgary, Calgary, AB, Canada
e-mail: ajmbois@gmail.com

Historical Considerations

The earliest discussion of interposition arthroplasty for the shoulder is thought to be from Jones in 1944, in which fascia lata resurfacing was described as a method of treatment for proximal humerus fractures [9]. With the emergence of silicone plastic implants, Varian provided a brief report using silicone cup interposition for the rheumatoid shoulder [10]. The positive results from this series were not reproduced by Spencer and Skirving, who reported a 58 % early failure rate in 1986, and the technique was largely abandoned [11].

Biological interposition became the subject of research interest in the 1990s, as Milbrink and Wigren published promising results of resection arthroplasty with interposition of freeze-dried dura mater graft [12]. In 1995, Burkhead and associates reported results of hemiarthroplasty with glenoid resurfacing using autogenous fascia lata, showing functional improvements at a minimum 2-year follow-up [13]. These results were maintained at 2–15-year follow-up, as reported by Krishnan et al. in 2007 [14]. This generated substantial interest over the following years, with multiple series reporting hemiarthroplasty in conjunction with resurfacing using lateral meniscal allograft (LMA) [15–18], animal-based xenografts [19, 20], and other combinations of allograft and/or local tissue [21–26].

© Springer International Publishing Switzerland 2016
A.D. Armstrong, A.M. Murthi (eds.), *Anatomic Shoulder Arthroplasty*,
DOI 10.1007/978-3-319-29164-2_9

Another approach to non-prosthetic arthroplasty of the glenoid was described in which the glenoid is concentrically reamed to provide a smooth concavity, known as "ream and run" [27]. In 2005, Matsen et al. [28] demonstrated in a canine histological study that this technique resulted in a viable layer of fibrocartilage tissue covering the reamed surface at 24 weeks postoperatively. Multiple therapeutic case series [29–31] as well as a large level II prognostic series [32] have been published regarding the ream and run technique with encouraging results.

Indications and Patient Selection

Understanding patient expectations is critical to managing the young arthritic population. In particular, younger patients have a high expectation for returning to sporting activities following arthroplasty. Henn et al. [33] showed that younger patients had greater expectations for outcomes after total shoulder arthroplasty, including improvement in exercise or sports participation. A high level of sports participation following arthroplasty procedures has also been demonstrated. Schumann et al. [34] reported an 89 % rate of return to sport among patients undergoing total shoulder arthroplasty, with athletic patients more likely to be younger. McCarty et al. [35] reported that younger patients were likely to return to sports such as downhill skiing, swimming, weight lifting, cross-country skiing, golf, and tennis. This raises concern for long-term loosening of an implanted glenoid component, although the effects of patient activity levels after TSA are currently unknown.

The primary indication for non-prosthetic glenoid arthroplasty with or without interposition is a diagnosis of glenohumeral arthritis that limits activities of daily living and causes pain that is refractory to conservative measures. Diagnoses may include osteoarthritis, post-capsulorrhaphy arthritis, or post-traumatic arthritis. Patients should have exhausted all nonoperative measures, including anti-inflammatory medication, activity modification, vocational rehabilitation, and analgesics for an extended length of time. The senior author (M. A. W.) does not recommend a specific age cutoff. Rather, after clear communication of risks and expected outcomes, patients who wish to avoid the risks and potential limitations associated with a polyethylene glenoid component due to physiological age and/or activity level are considered for non-prosthetic management. Patients must be highly motivated, have good mental and emotional health, and demonstrate good understanding of the options available. Furthermore, evidence of glenoid cartilage loss should be identified preoperatively and confirmed intraoperatively prior to proceeding with treatment.

Contraindications

Patients with inflammatory arthropathies are not good candidates for non-prosthetic glenoid treatment. In cases with instability, rotator cuff deficiency, or cuff tear arthropathy, other options should be pursued. Dependency on narcotics, alcohol, or tobacco is a relative contraindication.

Surgical Technique

Many different techniques have been described for non-prosthetic glenoid resurfacing, as shown in Table 9.1. Reported outcomes from these techniques are discussed below.

Authors' Preferred Technique

We perform shoulder arthroplasty in the beach-chair position using a deltopectoral approach. Meticulous attention is paid to preservation of the deltoid origin and insertion during the surgical exposure. A subscapularis peel is used to gain access to the joint, and the tendon is separated from underlying anterior capsule approximately 2 cm medial to the subscapularis footprint on the lesser tuberosity. Adhesions at the base of the coracoid process are released, and a 360° release of the subscapularis is performed about its long axis at the level of the anterior glenoid rim.

Table 9.1 Selected non-prosthetic glenoid arthroplasty technique descriptions

Author	Year	Technique
Burkhead et al. [13]	1995	Glenoid resurfacing with anterior capsule or fascia lata
Brislin et al. [19]	2004	Arthroscopic glenoid resurfacing with bovine tissue patch
Nicholson et al. [16]	2007	Glenoid resurfacing with lateral meniscal allograft
Krishnan et al. [36]	2008	Glenoid resurfacing with fascia lata or Achilles tendon
Lee et al. [22]	2009	Glenoid resurfacing with anterior capsule and humeral resurfacing arthroplasty
Wirth [17]	2009	Glenoid resurfacing with lateral meniscal allograft
Clinton et al. [37]	2009	Non-prosthetic glenoid reaming
de Beer et al. [23]	2010	Arthroscopic glenoid resurfacing with human dermal allograft

A Crego elevator is placed behind the humeral head, and the articular surface is resected at a plane just inside the rotator cuff insertion. The osteotomy usually varies between 20 and 30° of retroversion. The varus-valgus alignment of the cut is based on placing an osteotomy template along the shaft of the humerus and marking the intended resection site with electrocautery. The most superior and lateral portion of this mark is at the junction of the articular surface with the rotator cuff insertion.

Glenoid Reaming

After exposure of the glenoid, the articular surface is assessed for wear, eccentricity, and smoothness. Care is taken to preserve stable native labral tissue. A burr, curette, or hand-held elevators may be used to remove eburnated ridges of bone between concavities. A custom reamer size is selected with the final concavity diameter measuring 2 mm larger than the prosthetic humeral head diameter (Fig. 9.1). Bone stock should be preserved to the greatest extent possible rather than attempting to correct glenoid version to neutral (i.e., partial correction of version).

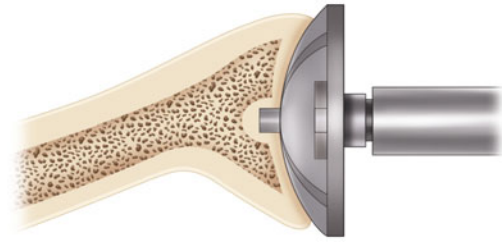


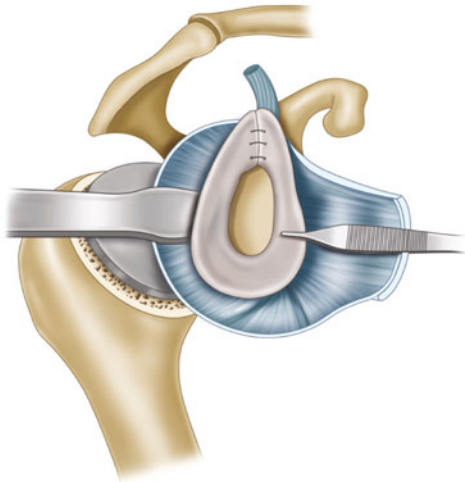
Fig. 9.1 Concentric reaming of the glenoid

Meniscal Allograft Interposition

Lateral meniscal allografts are obtained from proximal tibia specimens and dissected from underlying bone. The glenoid size is then estimated using a translucent glenoid-sizing disk used for TSA. The anterior and posterior horns of the meniscus are sutured together using number 2 Cottony Dacron suture (Deknatel, Fall River, MA, USA), creating an oval structure that is similar in size to the best-fit glenoid-sizing disk (Fig. 9.2). To secure the meniscus to bone, sutures are placed through the existing glenoid labrum whenever possible, although suture anchors may be used if labral tissue is inadequate. The meniscal graft is then held against the glenoid and the suture locations are marked with a surgical pen. Nine sutures are placed equidistant around the glenoid perimeter. The anchoring sutures are then placed into Gabbay-Frater suture guides (Deknatel) in a triangular fashion. One limb of each suture is placed through the meniscal graft at the marked site, and the meniscus is "parachuted" to the articular surface (Fig. 9.3). The graft is then anchored in place, tying one suture in each third of the graft in an alternating fashion analogous to tightening lug nuts on the rim of a tire (Fig. 9.4).

Humeral Component Insertion and Closure

After removal of periarticular osteophytes, an anatomically sized trial humeral component is inserted. Soft-tissue balancing is assessed based on the following criteria: (1) posterior drawer testing with 40–60 % translation of the prosthetic head relative to the glenoid center, (2) a minimum of 75° internal rotation with the arm in 90°



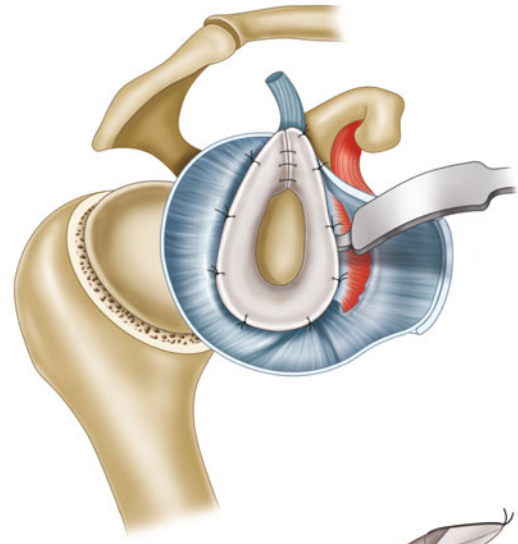


Fig. 9.2 Suturing the graft ends to create an oval ring

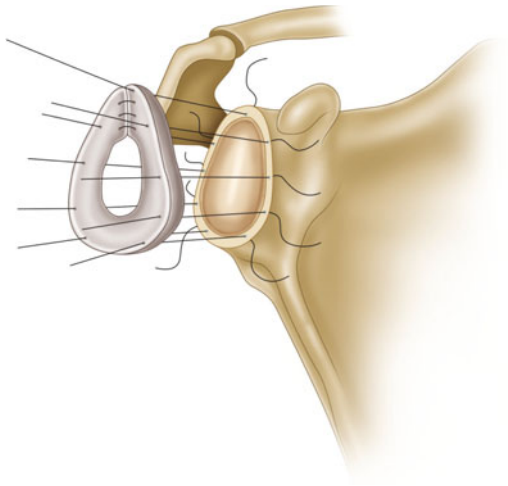


Fig. 9.3 The allograft is brought down to the face of the glenoid using a parachute technique

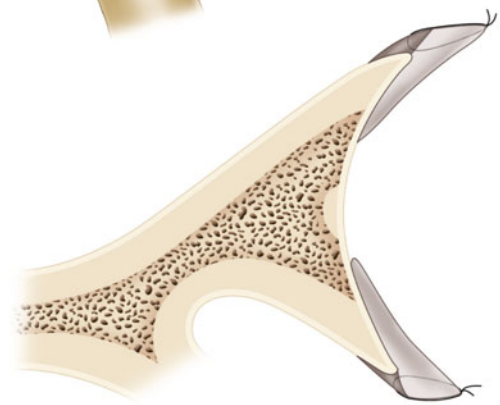


Fig. 9.4 Two views of the meniscal allograft after anchoring it to the glenoid surface

of abduction, (3) the ipsilateral hand can be placed on the superior contralateral shoulder without scapular protraction, and (4) 45° of external rotation is present with the subscapularis held at the osteotomy site. Bone tunnels for subscapularis attachment are created prior to implant insertion. The subscapularis is then reattached using 1-mm Cottony Dacron sutures (Deknatel) passed through 2-cm long bone tunnels extending from the osteotomy site to the humeral neck, resulting in medialization of the subscapularis insertion.

Postoperative Management

In the afternoon following surgery, the physician performs passive forward flexion of the arm up to 90° or to the maximum extent that is comfortable. Passive forward flexion with a pulley, passive external rotation with a meter stick, and pendulum exercises are initiated at postoperative day 1. These exercises are repeated five times each and performed three to four times a day.

Patients with inadequate passive motion at 4–6 weeks postoperatively are given additional stretching exercises. Strengthening exercises are initiated after achieving passive range of motion from 120 to 140° of flexion and 20–40° of external rotation, typically at 6–8 weeks after surgery. In addition to rotator cuff exercises, shoulder

shrug exercises and wall push-ups are performed to strengthen the scapular stabilizing muscle groups.

Outcomes

Glenoid resurfacing using lateral meniscal allograft (LMA) was first described by Ball et al. [15] in 2001 with encouraging early results. Other authors have similarly demonstrated short-term pain relief, functional improvement, improved glenohumeral registry, and preservation of glenoid bone following meniscal resurfacing [16, 17, 38]. However, recently published series at other academic centers reporting the midterm results of biological interposition do not seem as encouraging [18, 21, 24–26]. In 2013, Hammond et al. [24] performed a level III retrospective cohort study on 44 patients aged 50 years of age or younger at a mean follow-up of 3.7 years; 23 patients received hemiarthroplasty alone and 21 received hemiarthroplasty and biological resurfacing (LMA or dermis). Six patients (26 %) in the hemiarthroplasty group and 12 patients (57 %) in the resurfacing group were considered failures due to revision surgery or an American Shoulder and Elbow Surgeons (ASES) score less than 50. In the biological resurfacing group, the primary mode of failure was persistent pain, stiffness, infection (one patient), and ASES scores below 50 (six patients, or 50 %); all failures occurred within the first year with 28 % requiring revision surgery (six patients). Only 14 of 21 patients (66 %) were available for radiographic follow-up; data on humeral head subluxation and glenoid erosion was not available in the resurfacing group. Overall, improved outcomes and lower failure rates were observed in the hemiarthroplasty group.

In another recently published midterm follow-up study of previously published work by Nicholson et al. [23], Strauss et al. [26] found an overall clinical failure rate of 51.2 %. In this series, 41 patients were followed at an average of 2.8 years from LMA (31 patients) or dermal interposition (10 patients). Failure was defined as conversion (eight patients) or recommended conversion (five patients) to a shoulder arthroplasty, revision surgery for graft removal (one patient), an ASES score below 50 (five patients), or patient-reported disabling pain or loss of function (two patients). When the results were further stratified according to graft type, the LMA cohort had a failure rate of 45.2 % (mean time to failure 3.4 years), and the dermal interposition group had a failure rate of 70 % (mean time to failure 2.2 years). The overall rate of reoperation was 22 % (nine patients). Radiographic data on humeral head subluxation or glenoid erosion was not available. Despite significant improvements in clinical outcomes compared to baseline, biological resurfacing resulted in high failure rates according to the methods used in this study to define failure. In 2009, Wirth reported favorable short-term clinical outcomes of lateral meniscus allograft resurfacing of the glenoid in conjunction with uncemented humeral head arthroplasty for advanced glenohumeral joint arthritis. More recently, Bois et al. reported the midterm results of this patient cohort at 5–12 years postoperatively [39]. At a mean of 8 years postoperatively, patients showed improvement in ASES and SST scores, but 9 of 30 patients underwent reoperation (30 %). Only two of these reoperations took place in the first 2 years, and three reoperations were performed between 8 and 10 years postoperatively, indicating the need for long-term follow-up. A gradual decrease in joint space was noted on radiographs at latest follow-up, which likely represented progressive wear of the interposition tissue.

Concentric glenoid reaming with hemiarthroplasty ("ream and run") has had fewer published reports, although outcomes have shown improvement in function and comfort with relatively low reoperation rates. In the largest series to date, Gilmer et al. [32] assessed factors affecting the prognosis for improvement in function and comfort in 162 consecutive patients following ream and run. Of these, 124 patients (76 %) achieved the minimum clinically important difference in Simple Shoulder Test (SST) scores, while 22 patients (14 %) underwent reoperation. Results from a smaller series at a different academic center corroborated these findings, with 14 of 17

patients achieving a minimum clinically important difference in SST scores and three reoperations [31].

Results of arthroscopic glenoid resurfacing using a biologic animal-derived patch without humeral hemiarthroplasty were described by Savoie et al. in 2009 [20]. Twenty patients were evaluated at 3–6 years postoperatively, with 15 patients remaining satisfied at latest follow-up and 5 patients undergoing reoperation (25 %) for humeral head replacement at 1–5 years after the index procedure. Of note, biopsies taken from the resurfaced glenoid at the time of revision showed viable chondrocytes in a hyaline-like matrix. De Beer et al. [23] reported similar results in 2010 with arthroscopic resurfacing using human acellular dermal allograft. Thirty-two patients were followed for a minimum of 2 years with 23 of these (72 %) considered successful outcomes.

Conclusions

Young active patients with advanced degenerative joint disease present a treatment dilemma once the clinical condition progresses and the decision is made to proceed with a shoulder arthroplasty. Non-prosthetic glenoid resurfacing techniques include open concentric reaming with hemiarthroplasty and open and arthroscopic interposition techniques. Conflicting results exist in the literature regarding outcomes after glenoid resurfacing and humeral head replacement, and the optimal treatment of this population has yet to be determined. Patients should be counseled regarding the high potential for future reoperation. Further study is needed to determine whether the addition of meniscal allograft interposition tissue results in superior outcomes when compared to concentric reaming alone.

References

1. Gartsman GM, Roddey TS, Hammerman SM. Shoulder arthroplasty with or without resurfacing of the glenoid in patients who have osteoarthritis. J Bone Joint Surg Am. 2000;82(1):26–34.
2. Edwards TB, Kadakia NR, Boulahia A, Kempf J-F, Boileau P, Némoz C, et al. A comparison of hemiarthroplasty and total shoulder arthroplasty in the treatment of primary glenohumeral osteoarthritis: results of a multicenter study. J Shoulder Elbow Surg. 2003; 12(3):207–13.
3. 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): 604–13.
4. Schoch B, Schleck C, Cofield RH, Sperling JW. Shoulder arthroplasty in patients younger than 50 years: minimum 20-year follow-up. J Shoulder Elbow Surg. 2015;24(5):705–10.
5. Fox TJ, Cil A, Sperling JW, Sanchez-Sotelo J, Schleck CD, Cofield RH. Survival of the glenoid component in shoulder arthroplasty. J Shoulder Elbow Surg. 2009;18(6):859–63.
6. Raiss P, Schmitt M, Bruckner T, Kasten P, Pape G, Loew M, et al. Results of cemented total shoulder replacement with a minimum follow-up of ten years. J Bone Joint Surg Am. 2012;94(23):e171 1–10.
7. Denard PJ, Raiss P, Sowa B, Walch G. Mid- to long-term follow-up of total shoulder arthroplasty using a keeled glenoid in young adults with primary glenohumeral arthritis. J Shoulder Elbow Surg. 2013;22(7): 894–900.
8. Raiss P, Bruckner T, Rickert M, Walch G. Longitudinal observational study of total shoulder replacements with cement: fifteen to twenty-year follow-up. J Bone Joint Surg Am. 2014;96(3):198–205.
9. Jones L. The shoulder joint: observations on the anatomy and physiology with an analysis of a reconstructive operation following extensive injury. Surg Gynecol Obstet. 1944;75:433–44.
10. Varian J. Interposition Silastic cup arthroplasty of the shoulder. J Bone Joint Surg Br. 1980;62B:116–7.
11. Spencer R, Skirving AP. Silastic interposition arthroplasty of the shoulder. J Bone Joint Surg Br. 1986;68-B(3):375–7.
12. Milbrink J, Wigren A. Resection arthroplasty of the shoulder. Scand J Rheumatol. 1990;19(6):432–6.
13. Burkhead WZ, Hutton KS. Biologic resurfacing of the glenoid with hemiarthroplasty of the shoulder. J Shoulder Elbow Surg. 1995;4(4):263–70.
14. Krishnan SG, Nowinski RJ, Harrison D, Burkhead WZ. Humeral hemiarthroplasty with biologic resurfacing of the glenoid for glenohumeral arthritis: two to fifteen-year outcomes. J Bone Joint Surg Am. 2007;89(4):727–34.
15. Ball CMMB, Galatz LM, Yamaguchi K. Meniscal allograft interposition arthroplasty for the arthritic shoulder: description of a new surgical technique. Tech Should Elbow Surg. 2001;2(4):247–54.
16. Nicholson GP, Goldstein JL, Romeo AA, Cole BJ, Hayden JK, Twigg SL, 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):S261–6.
17. Wirth MA. Humeral head arthroplasty and meniscal allograft resurfacing of the glenoid. J Bone Joint Surg Am. 2009;91(5):1109–19.
18. Lee BK, Vaishnav S, Rick Hatch IIIGF, Itamura JM. Biologic resurfacing of the glenoid with meniscal allograft: long-term results with minimum 2-year follow-up. J Shoulder Elbow Surg. 2013;22(2):253–60.
19. Brislin KJ, Savoie III FH, Field LD, Ramsey JR. Surgical treatment for glenohumeral arthritis in the young patient. Tech Should Elbow Surg. 2004; 5(3):165–9.
20. Savoie FH, Brislin KJ, Argo D. Arthroscopic glenoid resurfacing as a surgical treatment for glenohumeral arthritis in the young patient: midterm results. Arthroscopy. 2009;25(8):864–71.
21. Elhassan B, Ozbaydar M, Diller D, Higgins LD, Warner JJP. 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):419–24.
22. 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):915–9.
23. De Beer JF, Bhatia DN, van Rooyen KS, Du Toit DF. Arthroscopic debridement and biological resurfacing of the glenoid in glenohumeral arthritis. Knee Surg Sports Traumatol Arthrosc. 2010;18(12): 1767–73.
24. Hammond LJ, Lin EC, Harwood DP, Juhan TW, Gochanour E, Klosterman EL, et al. Clinical outcomes of hemiarthroplasty and biological resurfacing in patients aged younger than 50 years. J Shoulder Elbow Surg. 2013;22(10):1345–51.
25. Muh SJ, Streit JJ, Shishani Y, Dubrow S, Nowinski RJ, Gobezie R. Biologic resurfacing of the glenoid with humeral head resurfacing for glenohumeral arthritis in the young patient. J Shoulder Elbow Surg. 2014;23(8):e185–90.
26. Strauss EJ, Verma NN, Salata MJ, McGill KC, Klifto C, Nicholson GP, et al. The high failure rate of biologic resurfacing of the glenoid in young patients with glenohumeral arthritis. J Shoulder Elbow Surg. 2014; 23(3):409–19.
27. Weldon EJI, Boorman RS, Parsons IMI, Matsen 3rd FA. "Ream and Run": the principles and procedures of non-prosthetic glenoid arthroplasty with prosthetic humeral hemiarthroplasty. Tech Should Elbow Surg. 2004;5(2):76–89.
28. Matsen 3rd FA, Clark JM, Titelman RM, Gibbs KM, Boorman RS, Deffenbaugh D, et al. Healing of reamed glenoid bone articulating with a metal humeral hemiarthroplasty: a canine model. J Orthop Res. 2005;23(1):18–26.
29. Lynch JR, Franta AK, MontgomeryJr WH, Lenters TR, Mounce D, MatsenIII FA. Self-assessed outcome at two to four years after shoulder hemiarthroplasty with concentric glenoid reaming. J Bone Joint Surg Am. 2007;89(6):1284–92.
30. Saltzman MD, Chamberlain AM, Mercer DM, Warme WJ, Bertelsen AL, Matsen III FA. Shoulder hemiarthroplasty with concentric glenoid reaming in patients 55 years old or less. J Shoulder Elbow Surg. 2011;20(4):609–15.
31. Somerson JS, Wirth MA. Self-assessed and radiographic outcomes of humeral head replacement with nonprosthetic glenoid arthroplasty. J Shoulder Elbow Surg. 2015;24(7):1041–8.
32. Gilmer BB, Comstock BA, Jette JL, Warme WJ, Jackins SE, Matsen 3rd FA. The prognosis for improvement in comfort and function after the ream-and-run arthroplasty for glenohumeral arthritis: an analysis of 176 consecutive cases. J Bone Joint Surg Am. 2012;94(14):e102.
33. Henn RF, Ghomrawi H, Rutledge JR, Mazumdar M, Mancuso CA, Marx RG. Preoperative patient expectations of total shoulder arthroplasty. J Bone Joint Surg Am. 2011;93(22):2110–5.
34. Schumann K, Flury MP, Schwyzer H-K, Simmen BR, Drerup S, Goldhahn J. Sports activity after anatomical total shoulder arthroplasty. Am J Sports Med. 2010; 38(10):2097–105.
35. McCarty EC, Marx RG, Maerz D, Altchek D, Warren RF. Sports participation after shoulder replacement surgery. Am J Sports Med. 2008;36(8):1577–81.
36. 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.
37. Clinton J, Warme WJ, Lynch JR, Lippitt SB, Matsen 3rd FA. Shoulder hemiarthroplasty with nonprosthetic glenoid arthroplasty: the ream and run. Tech Should Elbow Surg. 2009;10(1):43–52.
38. Lollino N, Pellegrini A, Paladini P, Campi F, Porcellini G. Gleno-Humeral arthritis in young patients: clinical and radiographic analysis of humerus resurfacing prosthesis and meniscus interposition. Musculoskelet Surg. 2011;95 Suppl 1:S59–63.
39. Bois AJ, Whitney IJ, Somerson JS, Wirth MA. Humeral head arthroplasty and meniscal allograft resurfacing of the glenoid: A concise follow-up of a previous report and survivorship analysis. J Bone Joint Surg Am. 2015;97(19):1571–7.

Revision Total Shoulder Arthroplasty

10

Tom Lawrence, Neil Pennington, and John Sperling

Introduction

Arthroplasty as a treatment for painful disabling conditions of the shoulder has undergone significant development since the first shoulder hemiarthroplasty (HA) performed by Neer in 1953 [1] for proximal humeral fracture. The two major advances in shoulder arthroplasty have been the introduction of the glenoid component for total shoulder arthroplasty (TSA) in 1974 [2] and the concept of semi-constrained reverse shoulder arthroplasty (RSA) popularised by Grammont [3]. With these advances in implant design, the indications for shoulder arthroplasty have increased dramatically, as has the need for revision surgery [4].

T. Lawrence, MD, MSc, FRCS (T&O)
Department of Trauma and Orthopaedics, University Hospitals Coventry and Warwickshire NHS Trust, Clifford Bridge Rd, Coventry CV2 2DX, UK
e-mail: tomlawrence75@hotmail.com

N. Pennington, MBChB(Hons), MSc, FRCS(Tr&Orth)
Department of Trauma and Orthopaedics, Calderdale & Huddersfield NHS Trust, Huddersfield Royal Infirmary, Huddersfield, West Yorkshire HD3 3EA, UK
e-mail: neil.pennington@cht.nhs.uk

J. Sperling, MD, MBA (✉)
Department of Orthopedic Surgery, Mayo clinic, 200 First Street, SW, Rochester, MN 55905, USA
e-mail: sperling.john@mayo.edu

Management of the failed shoulder arthroplasty is challenging for the patient and surgeon. There may be many reasons why a primary shoulder arthroplasty has not produced the desired successful outcome. It is important that the shoulder surgeon has a thorough understanding of the concepts of revision shoulder arthroplasty to minimise pitfalls and optimise outcomes.

This chapter considers the evaluation of a failed shoulder arthroplasty, addresses the specific indications for revision shoulder arthroplasty, along with the surgical techniques for undertaking such procedures and the likely outcomes.

Evaluation

Prior to revision surgery, the patient must be fully evaluated with a detailed history, clinical examination and appropriate tests. Documenting previous shoulder surgery, perioperative events and implants used provides invaluable information for the revision arthroplasty surgeon. When assessing the patient who presents with a failed arthroplasty, the surgeon must make an assessment of a number of key factors:

- Presence or absence of infection
- Component positioning and stability of the joint
- Loosening of either humeral or glenoid components

© Springer International Publishing Switzerland 2016
A.D. Armstrong, A.M. Murthi (eds.), *Anatomic Shoulder Arthroplasty*,
DOI 10.1007/978-3-319-29164-2_10

- Wear of bearing surfaces – native or prosthetic
- Integrity and function of the rotator cuff and deltoid

Patient Complaints

Pain is by far the most common reason for a patient to seek further treatment following shoulder arthroplasty. Pain may occur at rest, prevent activities of daily living and disturb sleep. Another common reason for revision is limited function. There are many patients with failed shoulder replacements that are willing to tolerate some pain and shoulder dysfunction rather than undergoing revision surgery. It is important to discuss expected goals of revision surgery with patients and balance them with the potential risks when considering further surgery.

Physical Examination

Clinical examination should focus on assessment of the soft tissue envelope of the shoulder, range of motion and integrity of the rotator cuff and anterior deltoid. Visual inspection should assess for signs of infection, previous scars and wasting of the deltoid and rotator cuff. Range of motion should be assessed, passively and actively, and the cuff strength determined. Loss of active motion in the presence of preserved passive motion may indicate deltoid failure, axillary nerve palsy or severe cuff deficiency. The subscapularis should be tested using the lift-off or belly-press tests; rotator cuff integrity is crucial if revision to an unconstrained implant is being considered.

Imaging Studies

Radiographic evaluation should include a true anteroposterior (AP) view, scapular Y view and an axillary view. These should be critically assessed for implant positioning, wear and evidence of loosening. The AP view may show proximal migration of the proximal humerus indicative of superior cuff failure. The axillary view may reveal evidence of humeral head subluxation and allows an initial assessment of the glenoid version and bone stock. A computed tomography (CT) scan is necessary to more accurately assess glenoid and humeral version, loosening of components and glenoid bone stock. A CT arthrogram can provide more information regarding the integrity of the surrounding soft tissues. In addition, the use of 3D reformats has been shown to be superior in aiding surgical decision-making in comparison to 2D scans [5]. Imaging of the rotator cuff may be considered where there is uncertainty from the clinical examination. Sperling et al. [6, 7] assessed the role of specialised MRI (magnetic resonance imaging) in painful shoulder arthroplasties undergoing revision surgery. MRI correctly predicted the presence of a cuff tear in 10 of 11 shoulders and the absence of a tear in 8 of 10. MRI also correctly predicted glenoid cartilage wear in eight of nine shoulders. The authors suggest that MRI might be a useful technique to determine the integrity of the rotator cuff and residual cartilage in the painful shoulder arthroplasty. Ultrasound (US) offers a dynamic non-invasive method to assess the rotator cuff without distortion from the metal implants; a few reports have shown it to be particularly useful in evaluating the integrity of the subscapularis after TSA [8].

Additional Tests

The possibility of infection should be considered in every revision shoulder arthroplasty, even in the absence of clinical symptoms and signs of infection, because indolent infection is prevalent. There are additional tests that may yield useful information in the workup of a failed shoulder arthroplasty; in particular blood investigations including white blood cell count, C-reactive protein and erythrocyte sedimentation rate can provide an indicator of any infective process.

If there is any concern regarding an underlying infection, then samples should be acquired

for microbiological culture either by sterile joint aspiration or arthroscopic biopsy, although false positive rates are high [9]. All microbiology specimens should be subjected to extended cultures and enrichment medium regimes as advised by a microbiologist to ensure the successful identification of any low-virulence organisms, such as *Propionibacterium acnes*.

Indications for Revision

There are a number of reasons why patients may require revision shoulder arthroplasty. In a review of 47 studies with non-constrained shoulder implants that were implanted for degenerative or inflammatory conditions and had at least 2 years follow-up, complications occurred in 906 out of 4,010 shoulders (22.6 %) [10]. Surgical revision was needed in 11.2 % of cases, with at least one of the implant components being changed in 7.9 % of cases. Most complications were on the glenoid side: either bone wear in cases of hemiarthroplasty (20.6 %) or loosening in cases of total arthroplasty (14.3 %). The cause of failure is important for treatment strategies but also in predicting prognosis following revision surgery. Dines et al. [11] reviewed 78 shoulders that underwent revision shoulder arthroplasty; they found that those undergoing revision for osseous or component-related problems achieved better results than those performed for soft tissue deficiency.

Suboptimal Prosthesis Positioning

Neer first recognised that poor component positioning was a cause for failure and suboptimal outcome following shoulder arthroplasty [12]. Humeral malpositioning and alterations of the centre of rotation of the glenohumeral joint have been found to be the most common surgical errors in one of the largest series of failed shoulder arthroplasties [13]. The single most common technical error in failed shoulder arthroplasty is overly superior placement of the humeral component in relation to the greater tuberosity [13]. Anatomic reconstruction of the proximal humerus with regard to the glenohumeral centre of rotation and the relationship of the articular surface to the rotator cuff insertion have been shown to improve range of motion and shoulder function and provide indirect evidence of decreased glenoid loading and wear [14, 15]. In particular glenohumeral offset and the positioning of the humeral articular surface just superior to the greater tuberosity appear to be key in maintaining optimal shoulder function [16, 17]. There is a strong association between component malposition and postoperative superior humeral migration (Fig. 10.1), glenoid loosening and excessive glenoid wear [18–20].

Glenoid Failure

The single largest point of long-term failure in shoulder arthroplasty is due to failure of the glenoid, either due to erosion in hemiarthroplasty (HA) (Fig. 10.2) or excessive wear or loosening of glenoid component [17–20]. The prevalence of glenoid erosion has been estimated to approach 100 % [21] with symptomatic glenoid erosion being most common after HA performed for arthritic conditions as opposed to arthroplasty for proximal humeral fracture [13]. Resurfacing of the glenoid has demonstrated improvements in patient-reported outcome measures [22, 23]; however there is no long-term comparative data on these groups of patients. Failure of the glenoid component following TSA is considered to be the most common reason for revision of shoulder arthroplasty [18–20, 24].

The diagnosis of a loose glenoid component relies on identifying progressive radiological lucency surrounding the glenoid component in the presence of pain. Lucent lines associated with the glenoid component following TSA are commonly reported, especially with the progression of time [25]. Torchia et al. [1] reported results at 5–17 years postoperatively and showed that early development of lucencies around the glenoid component on radiographs correlated to the development of subsequent symptomatic glenoid loosening. This particular series demonstrated

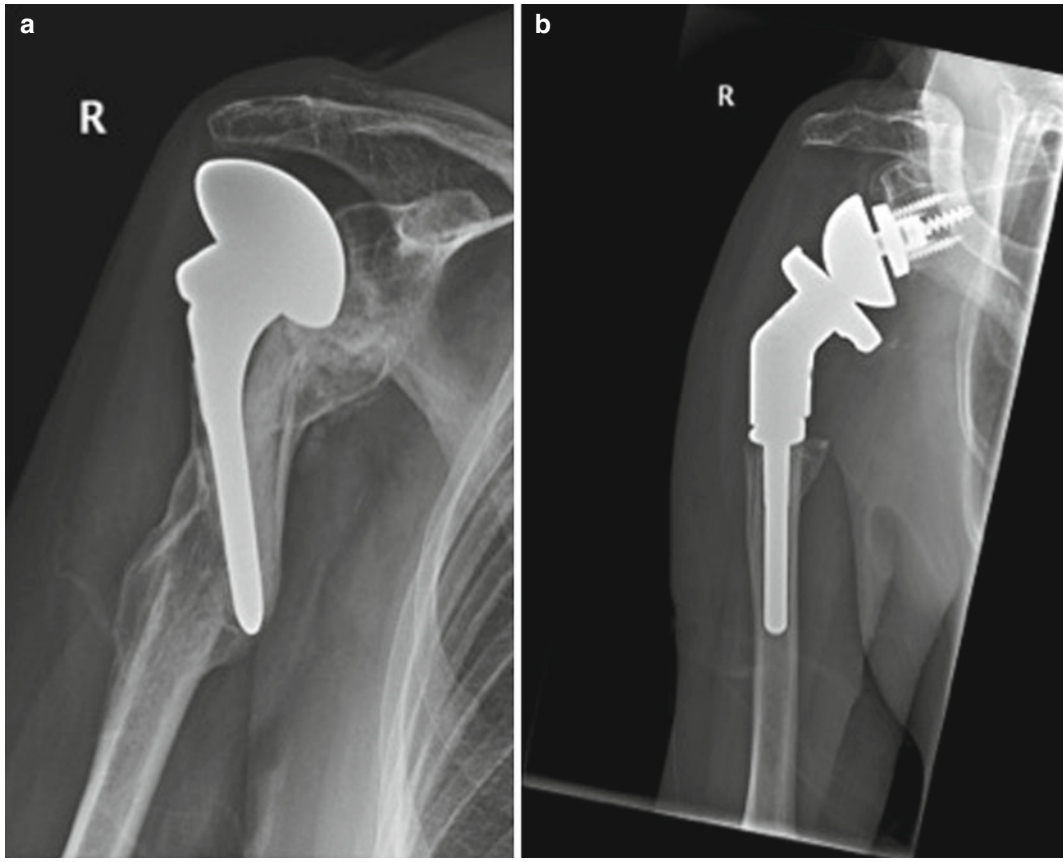


Fig. 10.1 (**a**) Failed hemiarthroplasty with stem perforation, (**b**) Successful revision with a modular reverse geometry prosthesis treated with a modular reverse geometry prosthesis

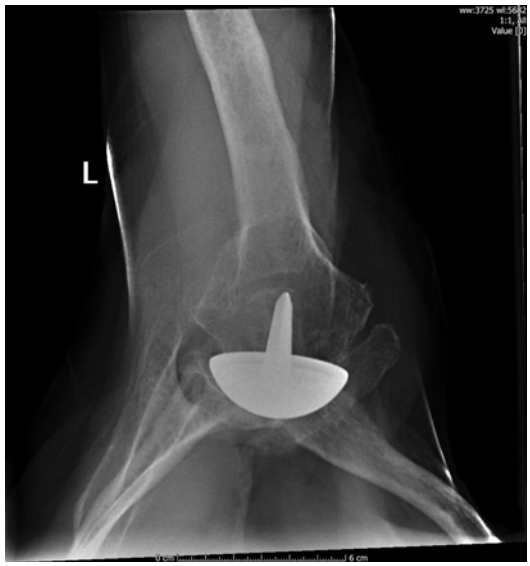


Fig. 10.2 Severe native glenoid wear post resurfacing hemiarthroplasty

that at 12 years following surgery, 84 % of patients had radiographic evidence of peri-glenoid lucencies in the implant bone interface [26]. Nagels et al. [27] defined radiological loosening as the observation of a progressive lucency around the glenoid component of 2 mm or more, spanning the whole cement-bone interface or an apparent shift in the position of the component. Deutsch et al. [28] attempted to further classify the presence of radiological loosening by setting out the following four features: circumferential radiolucent line of at least 2 mm around the glenoid component, progression of radiolucent lines on serial radiographs, presence of cement fragmentation and gross component migration.

It is important to note that lucent lines around a glenoid component on plain radiographs do not necessarily imply glenoid loosening [29]. The rate of clinical failure and revision

TSA due to a loose glenoid is lower than the rate of postoperative radiographic lucent lines and no definite causal relationship has been established.

The aetiology of glenoid loosening is multifactorial, including aseptic osteolysis, rotator cuff insufficiency and the so-called rocking horse phenomenon and infection. It is postulated that eccentric loading of the glenoid by the humeral head subjects the glenoid component to torque, ultimately generating tensile stress at either the bone-implant or bone-cement-implant interface, with the end result of loosening. The degree of eccentric loading has been found to be maximal in a superior-inferior direction, which presumably explains the rates of glenoid loosening observed in patients with non-functional rotator cuffs [25]. It has also been shown that glenoid components implanted in a central position demonstrate superior resistance to mechanical failure in comparison to those glenoid components implanted superiorly or inferiorly inclined or retroverted positions [30].

Humeral Failure

Component loosening is much less common on the humeral side compared to that of the glenoid [31]. In a large study of 1,584 shoulder arthroplasties, the revision rate, for any cause, of the humeral component was 8 % at 10 years [31]. Humeral loosening may be due to aseptic osteolysis but must raise the suspicion of infection. Risk factors for humeral revision include younger age, male gender, replacement due to posttraumatic arthritis and the use of a metal-backed glenoid component [31].

Instability

Shoulder subluxation or dislocation is a well-recognised complication of anatomic TSA; nearly 30 % of all complications associated with anatomic TSA relate to glenohumeral instability [6]. The overall rate of instability after TSA is 4.9 % of which 20 % of cases are posterior. Sanchez-Sotelo et al. [32] reported on 33 shoulders with anterior (Fig. 10.3) or posterior instability (Fig. 10.4). Based upon radiographic, clinical, and intraoperative findings, the authors attributed instability to abnormal soft tissue tension in 21 shoulders, component malpositioning in 1 shoulder and a combination of factors in 11 cases. Excessive posterior capsular laxity was implicated in 10 of the 14 shoulders with posterior instability, 1 of which also had excessive anterior capsular tightness.

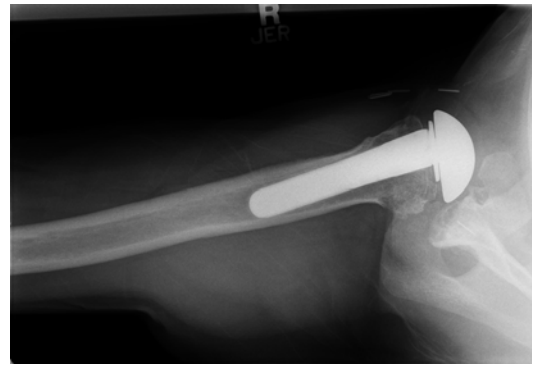


Fig. 10.3 Anterior instability post TSA

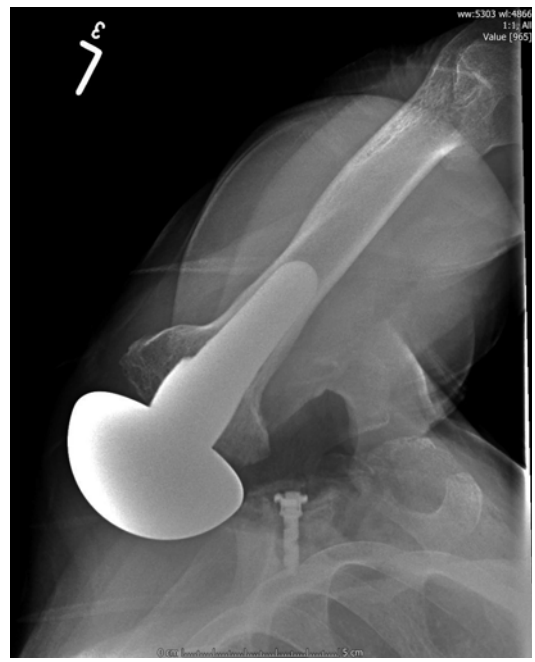


Fig. 10.4 Posterior instability following TSA

The most common cause for anterior instability is attributed to rupture of the subscapularis. However, posterior instability is most likely multifactorial in nature including excessive humeral retroversion, glenoid retroversion and failure to balance the soft tissues. Moeckel et al. [8] reported on three cases of posterior instability and found that retroversion of the glenoid and humeral component in combination with a tight subscapularis were causative factors.

Rotator Cuff

In the context of unconstrained shoulder arthroplasty, rotator cuff deficiency can occur intraoperatively or postoperatively. Risk factors for intraoperative injury include excessive retroversion of the humeral saw cut, which may damage the supraspinatus and infraspinatus [30] and excessive humeral head resection. Chronic failure of the rotator cuff after HA or TSA manifests as pain, lack of function and superior migration of the humeral head. This radiographic finding has been reported in up to 46 % of TSA procedures [5]. Whilst the true incidence of revision for rotator cuff failure is not well documented, there are an increasing number of reports of revision to RSA for this problem [33].

Infection

Infection is a rare (1 %) but devastating complication following shoulder arthroplasty [18]. Risk factors for infection include diabetes, infection at a distant site, revision surgery, previous local radiotherapy, inflammatory arthropathies, immunosuppression, advanced age and malnutrition [18, 34]. Infection must be a consideration in the evaluation of any patient with postoperative shoulder pain, especially in the context of radiographic evidence of loosening [34]. A detailed discussion related to the infected shoulder arthroplasty is covered in a separate chapter.

Surgical Techniques and Considerations

Prior to commencing surgery, previous operative reports should be accessed to confirm the index surgical approach, operative findings and type of implant that was used. The surgeon should be familiar with the implant that is being revised and have available any necessary instruments to assist removal.

Surgical Exposure

The patient is set up in the beach-chair position following general anaesthesia and an interscalene nerve block. Perform an examination under anaesthesia to determine degree of flexion, abduction, and external and internal rotation. Restriction in motion can direct the surgeon to the releases required.

Previous incisions are incorporated if possible although there should be a low threshold for a new incision in the optimal position away from the axilla to minimise contamination. The deltopectoral approach is generally recommended for use during revision cases, given it is extensile, to provide access to almost the entire humeral shaft distally. This is particularly relevant in cases where removal of a well-fixed humeral component is necessary. An anteromedial approach to the shoulder with detachment of the anterior deltoid from its clavicular and anterior acromial origins has been described as a method of enhancing exposure for difficult cases [35]. The surgeon should be aware that the cephalic vein can often no longer be relied upon as a landmark in revision surgery and that the delta-pectoral interval may be difficult to find due to scarring. It is best to start the dissection proximally adjacent to the most medial aspect of the deltoid origin from the clavicle. The superior 1–2 cm of pectoralis major insertion should be released to facilitate exposure.

There will frequently be dense adhesions on the deep surface of deltoid and lateral border of the conjoint tendon. Both surgical planes will need to be carefully developed, affording

significant care for the axillary and musculocutaneous nerves. First release the adhesions on the lateral aspect of the conjoint tendon by starting on the lateral aspect of the coracoid and working distally, and subsequently develop the planes on the anterior and superior aspects of subscapularis. Develop the subcoracoid space, and retract the conjoint tendon medially taking care not to injure the musculocutaneous nerve [36] and brachial plexus [37].

Next release the subacromial and subdeltoid spaces with a combination of sharp and blunt dissection. Flexion and internal rotation of the arm further exposes this tissue plane and allows proximal dissection up into the subacromial space. After the rotator cuff is identified, scar tissue is excised. To complete and confirm the subdeltoid release, use an index finger to sweep superiorly, posteriorly, laterally and finally anteriorly. At this point the deltoid should be fully separated and mobile from the rotator cuff and the underlying proximal humerus down to the level of the deltoid insertion; this will allow easy insertion of retractors to expose the subscapularis and rotator interval.

Protection of the axillary nerve is necessary throughout the procedure; it is found at the inferior border of the subscapularis in the subcoracoid space although identification may be difficult in cases of severe scarring. The "tug test" [38] can be useful to facilitate identification of the axillary nerve; this is performed by placing a finger from one hand on the nerve as it passes inferior to subscapularis and a finger from the other hand under the deltoid on the anterior branch of the nerve. The application of gentle pressure from one end will allow the transmission to be felt in the other end confirming the location of the nerve as well as demonstrating undersurface release of the deltoid. The long head of biceps should be examined and if diseased or scarred within the joint, then a tenotomy or tenodesis are performed.

After complete extra-articular mobilisation, the rotator interval is identified and opened. The coracoacromial ligament overhangs the rotator interval and therefore excision may improve exposure. The method of subscapularis release is determined by the degree of limitation of external rotation and the quality and thickness of the tendon. Typically, each centimetre increase of subscapularis length increases external rotation by approximately 20° [39]. The surgical options include a standard subscapularis tenotomy with capsular releases (for ER greater than 40°), subscapularis release directly from its bony insertion with subsequent medial reattachment (for ER between 20 and 40°) and a Z-lengthening of the tendon (for ER less than 20°).

The simplest and most familiar technique is a subscapularis tenotomy with circumferential release to increase tendon excursion and lateral advancement. A vertical incision is made by the use of a scalpel or electrocautery through the tendinous portion of the subscapularis 1 cm medial to its insertion on the lesser tuberosity to allow for direct tissue repair. Attention is paid to ligate or cauterise the anterior humeral circumflex artery as it crosses the inferior aspect of the tendon, and the arm should be placed in external rotation and adduction to further protect the axillary nerve. Simple traction sutures are then placed in the edge of the subscapularis tendon along the line of the tenotomy to facilitate mobilisation. Once the subscapularis has been divided, a circumferential release can be performed to maximise the muscle-tendon unit excursion. This release involves freeing its superior margin from the coracoid (coracohumeral ligament), the posterior surface from the anterior capsule and scapular neck, the inferior border from the axillary nerve and circumflex vessels and the anterior surface from the conjoined tendon [40].

The second option for the subscapularis is to dissect the tendon directly from its insertion on the lesser tuberosity with a more medial reattachment to effectively lengthen the muscle-tendon unit (subscapularis "peel") The subscapularis and capsule are dissected off the humerus as a single unit after which a circumferential release is performed as described above. Once the intra-articular release is completed, the subscapularis tendon is reattached to the humerus via transosseous sutures or anchors.

Third, for tendons of sufficient quality and thickness, a subscapularis Z-plasty to lengthen

the subscapularis is an option, although this is contraindicated if the tendon is thin and atrophic. Subscapularis Z-plasty was originally described for internal rotation contractures after surgery for recurrent anterior instability [41, 42]. A modification of this technique was described by Green and Norris [43] in the setting of shoulder arthroplasty for glenohumeral arthritis after anterior instability repair. Essentially the technique involves carefully dividing the anterior half of the subscapularis tendon at the margin of the lesser tuberosity, leaving the posterior half of the tendon attached. The anterior half of the tendon is then dissected medially to the level of the anterior glenoid, and the anterior capsule is divided at this level to create two tissue flaps. The lateral aspect of the anterior flap is sutured to the medial edge of the posterior flap to effectively lengthen the subscapularis. Nicholson et al. [44] have described a coronal Z-lengthening for internal rotation contractures in the setting of shoulder arthroplasty using the plane between the subscapularis and capsule which are then sutured to each other, creating an overlapping slide instead of an end to end repair. It is important to be aware that there are significant concerns regarding subscapularis Z-plasty, namely, that the repair is weak and that failure will lead to shoulder instability and that internal rotation strength is diminished. As a result of these issues, many authors have moved away from performing subscapularis Z-plasty.

The proximal humerus can now be dislocated anteriorly giving access to the humeral head; when doing so, care should be taken as to not use excessive external rotation force that can lead to an iatrogenic fracture or rotator cuff tear.

Humeral Component Revision

In most revision cases, the humeral component will need to be removed. Furthermore, in the majority of cases, the humeral stem is well fixed either with cement or bone on-growth. For this reason removal can be a challenging procedure that requires experience and appropriate instrumentation to minimise the risk of fracture and humeral bone defects. Occasionally the humeral stem can be retained if the implant is modular and only the glenoid requires revision. The most common reason is when revising a HA to a TSA or a TSA with a loose glenoid. There are also modern platform systems now available that allow conversion of an anatomic shoulder to a reverse without exchange of the humeral component.

In the first instance, scar tissue surrounding the neck of the prosthesis is removed. If the implant is modular, then the head is removed using a tuning fork. The proximal bone-implant or cement-implant interface is disrupted with the use of fine high-speed burrs and narrow osteotomes to facilitate implant removal (Fig. 10.5). Some implants have a connector for the stem with a slap-hammer adapter that will facilitate stem removal. If this is not the case, then a square-tipped impactor placed under the

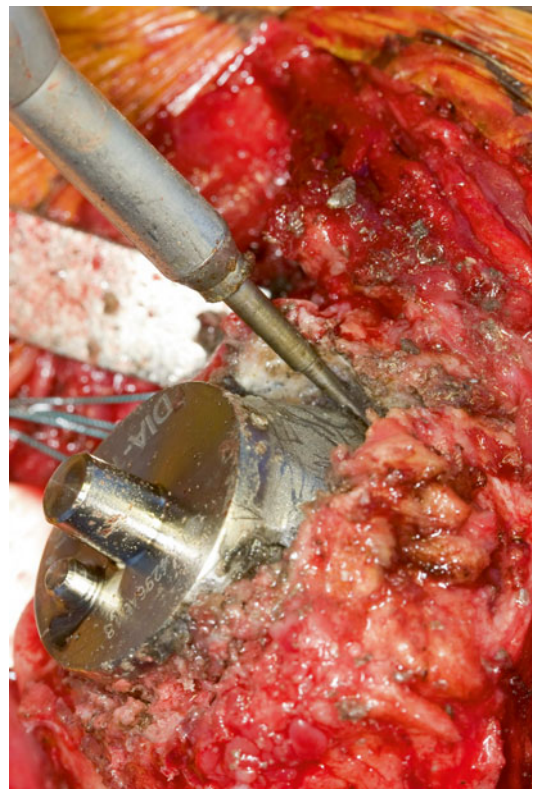


Fig. 10.5 Use of high-speed burr to facilitated component removal

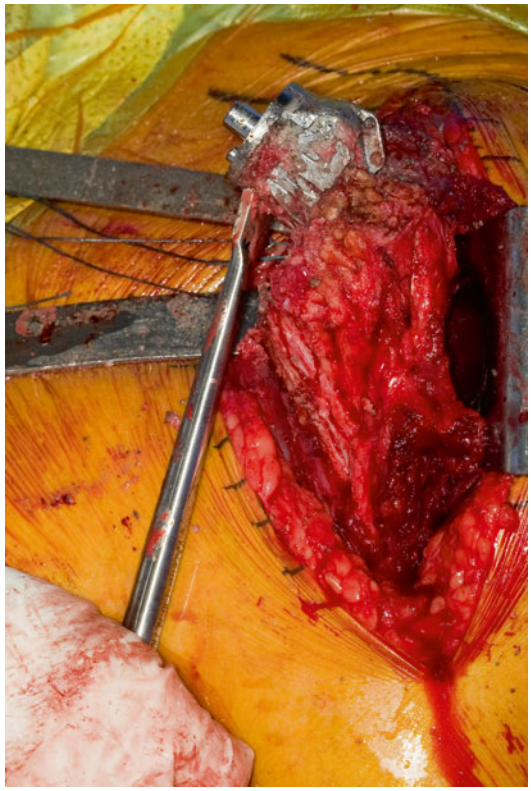


Fig. 10.6 Utilisation of impactor to facilitate humeral component removal

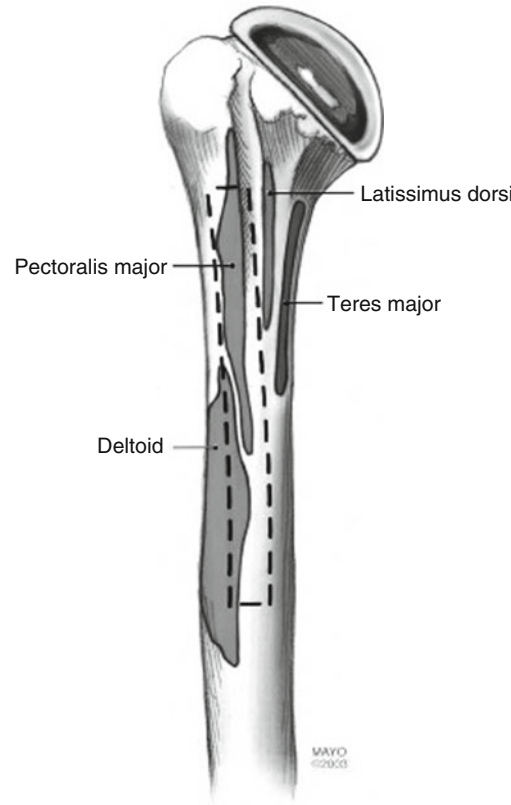


Fig. 10.7 Anterior humeral window [31]

infero-medial aspect of the neck is struck with a mallet to try to extract the implant (Fig. 10.6). In the situation where this does not work, and the humeral component remains well fixed further distally, then an anterior longitudinal humeral osteotomy can be used to gain access to the remaining humeral implant in a safe and controlled manner [13]. Sperling and Cofield have also described the application of a number of different humeral cortical "windows" to facilitate the removal of a well-fixed humeral stem [31]. They describe anterior humeral windows (Fig. 10.7) and advocate the use of a proximal medial humeral window (Fig. 10.8) when revising a humeral component with only proximal coating and a smooth distal stem. In contrast for fully textured components, or those with a well-fixed cement mantle, they recommend an anterior cortical window, which can be subsequently bypassed by a longer humeral revision stem. Good rates of union were achieved through either suture or wire cerclage fixation of the windows and a stable construct achieved using a cemented revision stem [31]. Pre-drilling in the line of the proposed osteotomy is a useful technique to avoid unwanted distal fracture propagation, and cerclage wires can be positioned prior to revision stem insertion for osteotomy fixation. The use of distal humeral windows has also been described for gaining access to the stem tip and distal cement mantle [12]. Ultrasonic devices may aid cement removal, but we would advocate caution to the potential risk of thermal injury to the radial nerve. Efforts to remove all cement in its entirety are only necessary in the case of revision for infection; in the absence of infection, a cement-in-cement revision can be performed.

Larger proximal bony deficiencies pose an additional challenge to the revision surgeon. Reconstructive options include the use of an allograft-prosthetic composite, a modular revision

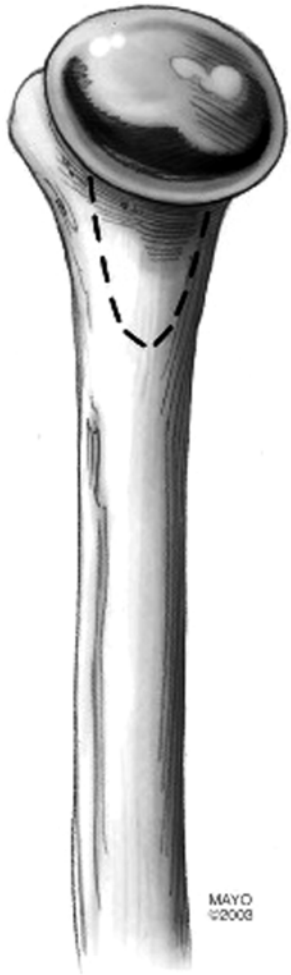


Fig. 10.8 Medial humeral window [31]

component system or custom tumour-type prostheses. Chacon et al. [45] reported high rates of bone incorporation with the use of APC combined with a reverse implant. The use of newer modular proximal humeral prostheses is an attractive option as it allows the resection level to be determined at the time of surgery and intraoperative flexibility via extensive component modularity (Fig. 10.1).

Glenoid Component Revision

Addressing the glenoid component is also very challenging during revision shoulder arthroplasty. The mode of failure and glenoid bone stock should be assessed prior to surgery. Large glenoid bony deficiencies frequently compromise implant fixation in a revision setting and sometimes may preclude glenoid component placement altogether [29]. In the case of an isolated loose glenoid component in a patient who is too frail to undergo major revision surgery, arthroscopic extraction of the loose component has been described with good postoperative results in a small series of patients [46].

After the humeral side has been addressed, the glenoid is exposed for revision. In the case of a failed HA with minimal bone loss, the glenoid can be replaced in the standard fashion. For an all polyethylene glenoid that is well fixed, the component can be cut into equal segments with a sagittal saw (Fig. 10.9). This allows piecemeal removal (Fig. 10.10) whilst minimising damage to the underlying glenoid bone stock. The central peg or keel can then be extracted using a rongeur, and the remaining cement mantle can be removed using osteotomes or a high-speed burr. Removal of metal-backed components can be associated with increased glenoid bone loss, so this should be done cautiously in a manner that preserves as much glenoid bone as possible. After removal of the glenoid, gentle reaming of the glenoid surface is performed to remove any fibrous tissue and to expose healthy subchondral bone.

The glenoid should now be carefully inspected to assess the location and extent of bone loss and the feasibility of reimplantation. Defects have been classified as central, peripheral and combined, which in turn can be mild, moderate or severe (Fig. 10.11). Deficiencies are classified as mild if they involve less than a third of the glenoid rim or surface, moderate if they involve between one- and two-thirds and severe if they involve greater than two-thirds. Mild and moderate deficiencies may be suitable for single-stage reimplantation with or without bone grafting whilst severe defects may preclude reimplantation. Superior outcomes have been observed when bone grafting and glenoid implantation are compared to cases where bone grafting alone is performed [47]. Cheung et al. [48] performed revision in 68 shoulders for glenoid loosening. In 33 patients, new glenoid implantation was possible at the time of the revision procedure, and

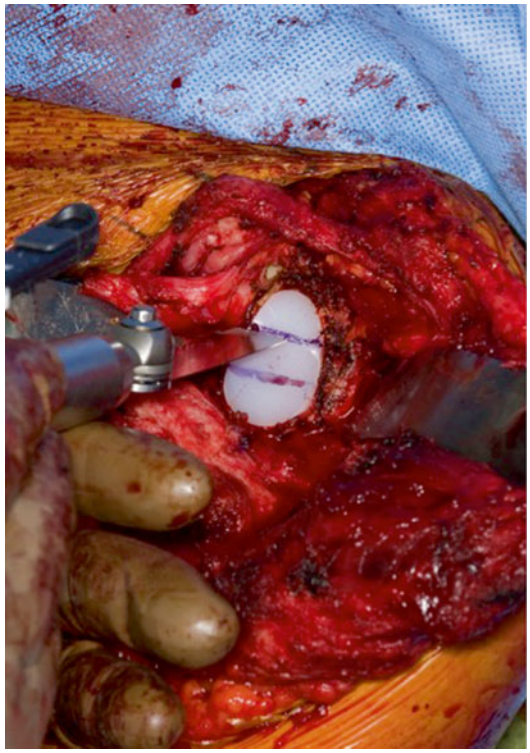


Fig. 10.9 Use of sagittal saw to remove polyethylene glenoid

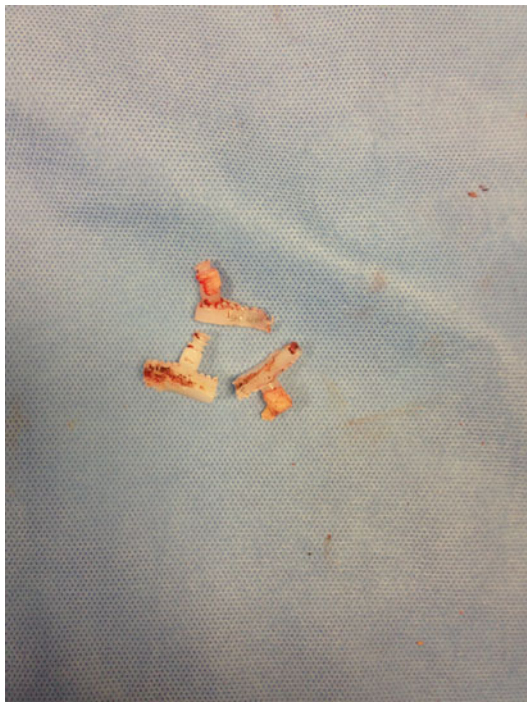


Fig. 10.10 Piecemeal removal of glenoid pegs

the remaining patients were revised to HA with glenoid bone grafting. Benefits of glenoid reimplantation were increased in forward elevation and greater patient satisfaction. The rate of revision-free survival at 5 years was not significantly different between the two groups. Overall, the results suggested that a new glenoid component should be implanted if structurally feasible.

Severe central or combined deficiencies may preclude a new component being implanted. In this situation, bone grafting using either cancellous or corticocancellous bone should be performed to restore glenoid bone stock and facilitate potential future glenoid revision. Selective second-stage glenoid component implantation is considered only in those patients who continue to report pain once the first-stage graft has fully consolidated [21, 47] Phipatanakul and Norris [21] reported on 24 patients undergoing revision TSA with removal of the glenoid component and bone grafting. Eighteen patients had adequate pain relief after the initial procedure, and four patients achieved good pain relief after a second-stage glenoid implantation for persistent pain. Graft subsidence was reported in 10 out of 20 cases (50%) although it did not preclude placement of a new glenoid component during the second-stage revision. Overall, the investigators found bone grafting of the glenoid beneficial in terms of pain relief as well as enabling delayed glenoid implantation. However, range of motion did not improve significantly and graft subsidence rate was concerning.

The two available techniques for bone grafting of a glenoid defect are corticocancellous impaction grafting or the use of a structural cortical bone graft. The type of defect, and whether it is contained or un-contained, will determine the appropriateness of the use of these available techniques. Central contained glenoid defects are typically managed with cancellous bone graft, whilst peripheral and combined defects are addressed with a combination of cancellous and structural bone graft. In cases with an isolated central glenoid deficiency, Neyton et al. [49] have described a technique using a central bicortical graft with the cortical aspect of the graft positioned laterally, with further cancellous graft packed peripherally and medially behind the cortical graft. In cases

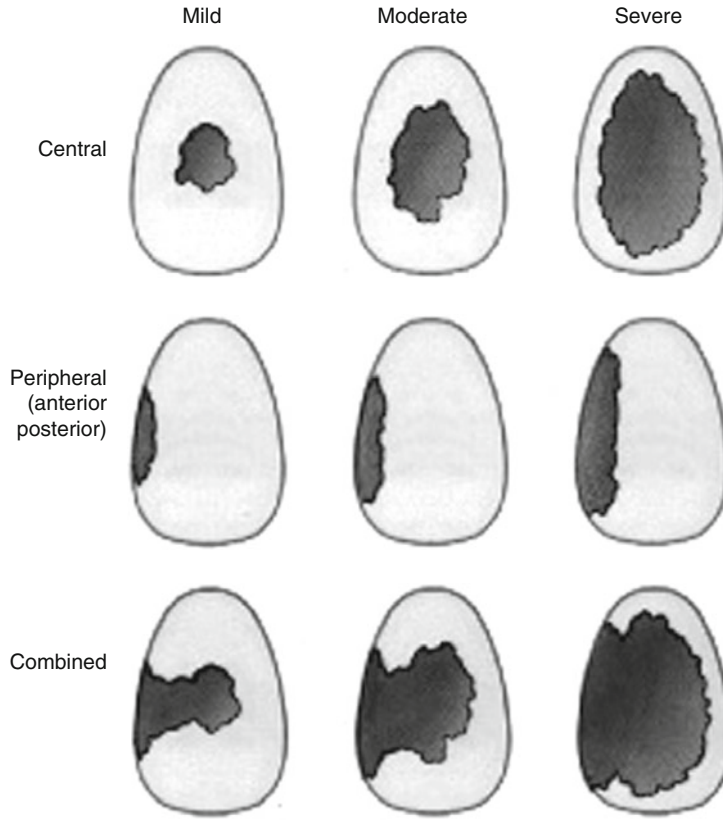


Fig. 10.11 Classification of glenoid bone defects [47]

with a peripheral deficiency, the same group describes the use of a bicortical graft secured with two cortical screws and then further cancellous graft being packed into the now "contained" residual defect. The biggest problem with impaction grafting alone is the risk of subsidence. Cancellous allograft either in morcellized or structural form has been associated with resorption and medialization of the humeral head [50]. When using structural grafts that are fixed with screws, placement should be planned to avoid interference with the glenoid component fixation. Although initial results were encouraging with the use of bulk allografts, longer-term follow-up has revealed evidence of graft resorption on radiographs [34].

Management of Instability

Anterior instability most commonly arises from failure of subscapularis, which is the main restraint to anterior glenohumeral translation. Mobilisation and repair of a ruptured subscapularis following shoulder arthroplasty patient is entirely dependent on the chronicity of the tendon failure. Early intervention implies easier mobilisation of the torn tendon from the anterior glenoid neck and possible direct repair. However, the subscapularis typically retracts quickly after rupture making adequate mobilisation and repair impossible. Pectoralis major transfer has been described to augment deficient anterior structures although results in the setting of TSA are associated with high failure rates [51]. More recently more predictable results have been achieved with conversion to reverse shoulder arthroplasty [52].

Surgical management of posterior instability after shoulder arthroplasty has traditionally involved improving component position and soft tissue balance including release of tight anterior structures and plication of the lax posterior capsule [53, 54]. When considering shoulder arthroplasty revision for posterior instability, the surgeon should have a thorough understanding of

the factors that predispose to the problem to optimise the chance of a successful outcome. Few studies have reported on the results after revision for posterior instability after shoulder arthroplasty. Furthermore, due to the limited number of patients, these reports have combined anterior and posterior instability cases making the results more difficult to evaluate. Moeckel et al.[8] reported on 7 cases of anterior instability and 3 cases of posterior instability in a series of 236 total shoulder arthroplasties. Revision surgery restored stability in all seven of the anteriorly unstable shoulders, whereas of the three with posterior instability, only two were stable at follow-up. The final patient failed two revisions and eventually underwent component removal. In a multicentre study performed by Ahrens et al. [55] consisting of 29 patients with posterior instability, revision surgery was successful in only 53 % of cases. In the Mayo Clinic [32] series of revision procedures for instability, 8 of the 14 shoulders with posterior instability underwent posterior capsule plication. However, 7 of the 14 patients required additional revision surgery in an attempt to restore stability. The authors concluded that surgical treatment of instability after shoulder arthroplasty is associated with a moderately high failure rate. The results of these studies suggest that the surgical treatment of posterior instability after shoulder arthroplasty with unconstrained anatomic components is associated with a significant failure rate, particularly when soft tissue procedures alone are performed. On this basis, RSA has emerged as an attractive revision alternative.

Abdel et al. [52] published results on 33 unstable anatomic shoulder arthroplasties that were revised to a reverse design of which two patients had posterior instability. Outcomes evaluated included visual analogue scores (VAS) for pain, range of motion, shoulder stability and Neer rating. The mean age of the patients at the time of revision surgery was 71 years. They were followed for a mean of 42 months (range, 25–71 months) or until revision surgery (one patient) or death (two patients). The average time from the index arthroplasty to revision was 26 months. Pain scores improved significantly as did mean active forward elevation from 40 to 97°, whereas there was no difference in internal or external rotation. At last follow-up 31 shoulders (94 %) were stable, the remaining two patients experienced dislocations, one at 2.5 weeks postoperatively and the other at 3 months postoperatively. According to the Neer rating system, there were 13 excellent, 10 satisfactory and 10 unsatisfactory results. The authors concluded that revision to a reverse prosthesis reliably restores shoulder stability with improved pain and active elevation although the overall results are inferior to the outcome with RSA in cuff-tear arthropathy. Whilst there is currently no literature available directly comparing the results of revision for instability using anatomic versus reverse techniques, these studies suggest that revision to RSA more predictably restores shoulder stability with better clinical outcomes compared to revision using anatomic components. It should be remembered that this is a complex patient group and that complication and revision rates remain high.

Revision to Reverse Shoulder Arthroplasty

Rotator cuff dysfunction (involving either the anterior or superior cuff) is a common cause of failed anatomic shoulder arthroplasty. This is associated with significant pain and loss of function. Revision surgeries using anatomic prosthesis designs are often disappointing. For this reason reverse shoulder arthroplasty (RSA) has emerged as an attractive revision alternative in dealing with a failed HA or TSA with cuff deficiency with or without bone loss [56]. RSA provides increased stability due to greater constraint and conformity enhanced by the increased tension within the deltoid muscle, which generates greater compressive forces across the glenohumeral joint.

Once the glenoid component has been removed, the glenoid should be carefully inspected to assess the location and extent of bone loss. Glenoid bone defects must be addressed to obtain secure fixation of the reverse baseplate, and larger defects may require structural bone grafts or may

even preclude implantation of a component. The guide pin is positioned in the appropriate location, and reaming is kept to a minimum to maintain subchondral bone and allow seating of the baseplate. The baseplate is now secured in place in a standard fashion with a combination of central and peripheral screws. The glenosphere is inserted using the largest available diameter to enhance stability and lessen the chance of dislocation. The humerus is brought into the wound, taking care not to get caught on the glenosphere in doing so, a trial liner is inserted on the trial humeral component and the shoulder reduced and the stability and tension assessed. The trials are now removed and the definitive implants inserted.

Walker et al. [57] performed a retrospective case series of 24 patients with failed TSA who were treated with conversion to RSA. Indications for conversion to RSA included failure of TSA from glenohumeral instability in 19, mechanical failure of the humeral or glenoid component in 10 and infection in 2. American Shoulder and Elbow Surgeons score improved from 38.5 preoperatively to 67.5. Fourteen patients rated their outcome as excellent, 3 as good, 3 as satisfactory and 2 as unsatisfactory. The overall complication rate was 22.7 %. The authors concluded that RSA is an effective treatment for failed TSA by decreasing pain and improving shoulder function although RSA in the revision setting is associated with a higher complication rate.

Patel et al. [15] considered the outcomes of 31 patients with a failed anatomic arthroplasty that were revised to a RSA; their results showed statistically significant improvement in all outcome measures. Improved function and pain relief were reliably achieved with 82.2 % or patients reporting a satisfactory, good or excellent outcome; the greatest improvement was noted in revision of failed TSA [15]. The authors concluded that RSA is a reliable salvage option for a challenging clinical problem. Kelly et al. [16] also found a significant improvement in function and pain when using RSA as a revision tool, although a complication rate of 50 % was observed in those requiring concomitant tri-cortical glenoid bone grafting; 80 % of these patients remained either satisfied or very satisfied with their outcome.

Melis et al. [58] specifically considered the outcome of RSA used to address aseptic glenoid loosening in 37 patients, 78 % requiring an associated structural bone graft in combination with glenosphere insertion. In three cases early glenoid component loosening was observed due to the use of baseplate with an insufficiently long central peg to provide adequate primary fixation to native glenoid bone. Two of these cases required revision to a "long-pegged" baseplate, going on to demonstrate successful radiological graft incorporation, and one was converted to a HA. Given the encouraging rates of graft incorporation that have been seen with RSA prostheses, some surgeons prefer to use RSA and bone grafting as a revision tool to address a glenoid bony deficiency even in the setting of an intact rotator cuff.

Conclusion

Revision shoulder arthroplasty is challenging for the patient and surgeon. Successful management of the failed shoulder arthroplasty starts with a thorough assessment of the patient, adequate imaging studies and exclusion of infection. The mode of failure must be clearly identified to direct the subsequent treatment strategy. Patients should be counselled carefully with regard to expected outcomes and potential complications. The surgeon should be clearly aware of the technical challenges presented by the exposure, removal of humeral and glenoid components and reimplantation. Soft tissue and bone deficiencies may preclude revision to a further anatomic implant, which has led to the expanding role of RSA in the revision setting.

References

1. Torchia ME, Cofield RH, Settergren CR. Total shoulder arthroplasty with the Neer prosthesis: long-term results. J Should Elb Surg. 1997;6:495–505.
2. Havelin L. The norwegian joint registry. Bulletin hospital of joint diseases (NY). 1999;58:139–47.
3. Chen A, Bain E, Horan M, Hawkins R. Determinants of patient satisfaction with outcome after shoulder arthroplasty. J Should Elb Surg. 2007;16:25–30.

4. Neer C, Kirby R. Revision of humeral head and total shoulder arthroplasties. Clin Orthop Relat Res. 1982;170:189–95.
5. Scalise JJ, Codsi M, Bryan J, Iannotti JP. The three-dimensional glenoid vault model can estimate normal glenoid version in osteoarthritis. J Should Elb Surg. 2008;17:487–91.
6. Chin PY, Sperling JW, Cofield RH, Schleck C. Complications of total shoulder arthroplasty: are they fewer or different? J Shoulder Elbow Surg. 2006;15(1):19–22.
7. Sperling JW, Potter HG, Craig EV, Flatow E, Warren RF. Magnetic resonance imaging of painful shoulder arthroplasty. J Shoulder Elbow Surg. 2002;11(4):315–21.
8. Moeckel BH, Altchek DW, Warren RF, Wickiewicz TL, Dines DM. Instability of the shoulder after arthroplasty. J Bone Joint Surg Am. 1993;75(4):492–7.
9. Updegrove GF, Armstrong AD, Kim HM. Preoperative and intraoperative infection workup in apparently aseptic revision shoulder arthroplasty. J Shoulder Elbow Surg. 2015;24(3):491–500.
10. Boileau P, Pennington SD, Alami G. Proximal humeral fractures in younger patients: fixation techniques and arthroplasty. J Shoulder Elbow Surg. 2011;20(2 Suppl):S47–60.
11. Dines JS, Fealy S, Strauss EJ, Allen A, Craig EV, Warren RF, et al. Outcomes analysis of revision total shoulder replacement. J Bone Joint Surg Am. 2006;88(7):1494–500.
12. Plausinis D, Kwon Y, Zuckerman J. Complications of humeral head replacement for proximal humeral fractures. Instr Course Lect. 2005;54:371–80.
13. Neer C. Replacement arthroplasty for gleno-humeral osteoarthritis. J Bone Joint Surg (Am). 1974;56:1–13.
14. Stechel A, Fuhrmann U, Irlenbusch L, Rott O, Irlenbusch U. Reversed shoulder arthroplasty in cuff tear arthritis, fracture sequelae and revision arthroplasty. Acta Orthop. 2010;81(3):367–72.
15. Patel D, Young B, Onyekwelu I, Zuckerman J, Kwon Y. Reverse total shoulder arthroplasty for failed shoulder arthroplasty. J Should Elb Surg. 2012;21:1478–83.
16. Kelly 2nd JD, Zhao J, Hobgood ER, Norris TR. Clinical results of revision shoulder arthroplasty using the reverse prosthesis. J Should Elbow Surg. 2012;21:1516–25.
17. Wirth M, Jr CR. Complications of shoulder arthroplasty. Clin Orthop Relat Res. 1994;307:47–69.
18. Jerosch J, Schneppenheim M. Management of infected shoulder replacement. Arch Orthop Trauma Surg. 2003;123:209–14.
19. Klatte TO, Junghans K, Al-Khateeb H, Rueger JM, Gehrke T, Kendoff D, et al. Single-stage revision for peri-prosthetic shoulder infection: outcomes and results. Bone Joint J. 2013;95-B:391–5.
20. Cabo J, Euba G, Saborido A, González-Panisello M, Domínguez MA, Agulló JL, et al. Clinical outcome and microbiological findings using antibiotic-loaded spacers in two-stage revision of prosthetic joint infections. J Infect. 2011;63:23–31.
21. Phipatanakul W, Norris T. Treatment of glenoid loosening and bone loss due to osteolysis with glenoid bone grafting. J Should Elb Surg. 2006;15:84.
22. Muh SJ, Streit J, Lenarz CJ, McCrum C, Warner JP, Shishani Y, et al. Resection arthroplasty for failed shoulder arthroplasty. J Should Elb Surg. 2013;22:247–52.
23. Phipatanakul WP, Bowen J, Jobe C. Removal of well fixed flanged humeral prostheses may require humeral expansion. J Should Elb Surg. 2009;18:724–7.
24. Cil A, Veillette C, Sanchez-Sotelo J, Sperling JW, Schleck CD, Cofield RH. Survivorship of the humeral component in shoulder arthroplasty. J Should Elb Surg. 2010;19:143–50.
25. Strauss E, Roche C, Flurin P-H, Wright T, Zuckman J. The glenoid in shoulder arthroplasty. J Should Elb Surg. 2009;18:819–33.
26. Owens CJ, Sperling J, Cofield R. Utility & complications of long-stem humeral components in revision shoulder arthroplasty. J Should Elb Surg. 2013;22:e7–12.
27. Nagels J, Valstar E, Stokdijk M, Rozing PM. Patterns of loosening of the glenoid component. J Bone Joint Surg (Br). 2002;84:83–7.
28. Deutsch A, Abboud J, Kelly J, Mody M, Norris T, Ramsey ML. Clinical results of revision shoulder arthroplasty for glenoid component loosening. J Should Elb Surg. 2007;16:706–16.
29. Namdari S, Goel D, Romanowski J, Glaser D, Warner JJP. Principles of glenoid component design and strategies for managing glenoid bone loss in revision shoulder arthroplasty in the absence of infection and rotator cuff tear. J Should Elb Surg. 2011;20:1016–24.
30. Hopkins A, Hansen U, Amis A, Emery R. The effects of glenoid component alignment variations on cement mantle stresses in total shoulder arthroplasty. J Should Elb Surg. 2004;13:668–75.
31. Sperling JW, Cofield RH. Humeral windows in revision shoulder arthroplasty. J Should Elb Surg. 2005;14(3):258–63.
32. Sanchez-Sotelo J, Sperling JW, Rowland CM, Cofield RH. Instability after shoulder arthroplasty: results of surgical treatment. J Bone Joint Surg Am. 2003;85-A(4):622–31.
33. Sperling J, Cofield R, Rowland C. Neer hemiarthroplasty and Neer total shoulder arthroplasty in patients fifty years old or less. Long-term results. J Bone Joint Surg (Am). 1998;80:464–73.
34. RA FML, editor. Glenoid component failure treated with a bulk allograft for revision total surgery. Presented at American Shoulder & Elbow Surgeons 18th Annual Meeting, 24th–27th Oct 2001; Napa.
35. Foruria AM, Oh LS, Sperling JW, Cofield RH. Anteromedial approach for shoulder arthroplasty: current indications, complications, and results. J Shoulder Elbow Surg. 2010;19(5):734–8.
36. Flatow EL, Bigliani LU, April EW. An anatomic study of the musculocutaneous nerve and its relationship to the coracoid process. Clin Orthop Relat Res. 1989;244:166–71.

37. McFarland EG, Caicedo JC, Guitterez MI, Sherbondy PS, Kim TK. The anatomic relationship of the brachial plexus and axillary artery to the glenoid. Implications for anterior shoulder surgery. Am J Sports Med. 2001;29(6):729–33.
38. Flatow EL, Bigliani LU. Tips of the trade. Locating and protecting the axillary nerve in shoulder surgery: the tug test. Orthop Rev. 1992;21(4):503–5.
39. Cuomo F, Checroun A. Avoiding pitfalls and complications in total shoulder arthroplasty. Orthop Clin North Am. 1998;29(3):507–18.
40. Yung SW, Lazarus MD, Harryman 2nd DT. Practical guidelines to safe surgery about the subscapularis. J Should Elb Surg/Am Should Elb Surg [et al]. 1996;5(6):467–70.
41. Hawkins RJ, Angelo RL. Glenohumeral osteoarthrosis. A late complication of the Putti-Platt repair. J Bone Joint Surg Am. 1990;72(8):1193–7.
42. MacDonald PB, Hawkins RJ, Fowler PJ, Miniaci A. Release of the subscapularis for internal rotation contracture and pain after anterior repair for recurrent anterior dislocation of the shoulder. J Bone Joint Surg Am. 1992;74(5):734–7.
43. Green A, Norris TR. Shoulder arthroplasty for advanced glenohumeral arthritis after anterior instability repair. J Shoulder Elbow Surg. 2001;10(6):539–45.
44. Nicholson GP, Twigg S, Blatz B, Sturonas-Brown B, Wilson J. Subscapularis lengthening in shoulder arthroplasty. J Should Elb Surg/Am Should Elb Surg [et al]. 2010;19(3):427–33.
45. Chacon A, Virani N, Shannon R, Levy JC, Pupello D, Frankle M. Revision arthroplasty with use of a reverse shoulder prosthesis-allograft composite. J Bone Joint Surg Am. 2009;91(1):119–27.
46. O'Driscoll SW, Petrie RS, Torchia ME. Arthroscopic removal of the glenoid component for failed total shoulder arthroplasty. A report of five cases. J Bone Joint Surg Am. 2005;87(4):858–63.
47. Antuna S, Sperling J, Cofield R, Rowland C. Glenoid revision surgery after total shoulder arthroplasty. J Should Elb Surg. 2001;10(3):217–24.
48. Cheung EV, Sperling JW, Cofield RH. Revision shoulder arthroplasty for glenoid component loosening. J Shoulder Elbow Surg. 2008;17(3):371–5.
49. Neyton L, Walch G, Nove-Josserand L, Edwards TB. Glenoid cortico-cancellous bone grafting after glenoid component removal in the treatment of glenoid loosening. J Should Elb Surg. 2007;15:173–9.
50. Neyton L, Favard L, Mole D, Walch G. Aseptic glenoid loosening or failure in total shoulder arthroplasty: revision with glenoid reimplantation. J Should Elb Surg. 2012;3:342–349.
51. Elhassan B, Ozbaydar M, Massimini D, Diller D, Higgins L, Warner JJ. Transfer of pectoralis major for the treatment of irreparable tears of subscapularis: does it work? J Bone Joint Surg. 2008;90(8):1059–65.
52. Abdel MP, Hattrup SJ, Sperling JW, Cofield RH, Kreofsky CR, Sanchez-Sotelo J. Revision of an unstable hemiarthroplasty or anatomical total shoulder replacement using a reverse design prosthesis. Bone Joint J. 2013;95-B(5):668–72.
53. Wirth MA, Rockwood Jr CA. Complications of total shoulder-replacement arthroplasty. J Bone Joint Surg Am. 1996;78(4):603–16.
54. Namba RS, Thornhill TS. Posterior capsulorrhaphy in total shoulder arthroplasty. A case report. Clin Orthop Relat Res. 1995;313:135–9.
55. Ahrens P, Boileau P, Walch G. Posterior instability after unconstrained shoulder arthroplasty in: 2000 shoulder prostheses…two to ten year follow up. Montpellier: Sauramps Medical; 2001.
56. Flury MP, Frey P, Goldhahn J, Schwyzer HK, Simmen BR. Reverse shoulder arthroplasty as a salvage procedure for failed conventional shoulder replacement due to cuff failure – midterm results. Int Orthop. 2011;35(1):53–60.
57. Walker M, Willis MP, Brooks JP, Pupello D, Mulieri PJ, Frankle MA. The use of the reverse shoulder arthroplasty for treatment of failed total shoulder arthroplasty. J Shoulder Elbow Surg. 2012;21(4):514–22.
58. Melis B, Bonnevialle N, Neyton L, Levigne C, Favard L, Walcg G, Boileau P. Glenoid loosening and failure in anatomical total shoulder arthroplasty: is revision with a reverse shoulder arthroplasty a reliable option? J Should Elb Surg. 2012;21(3):342–9.

Hemiarthroplasty for the Treatment of Proximal Humerus Fractures

11

Jia-Wei Kevin Ko and Charles L. Getz

Introduction

The majority of proximal humerus fractures encountered can be managed without surgical intervention [1]. However, more severe fractures, including three- and four-part proximal humeral fractures, may account for approximately 5 % of those seen [2]. In these types of fractures, surgical intervention may be considered in order to optimize patient function and pain relief.

Since the contributions of Dr. Neer, fractures that were not amenable to fixation routinely underwent proximal humeral replacement arthroplasty [1]. More recently, advancements in techniques of osteosynthesis and the development of reverse shoulder arthroplasty have narrowed the indications for anatomical prosthetic replacement. Nonetheless, hemiarthroplasty still has a role in the treatment of displaced proximal humeral fractures. Successful utilization of shoulder hemiarthroplasty for the treatment of fractures relies on a keen understanding of anatomy, careful patient evaluation, surgical planning, and meticulous surgical technique, as well as minimization of complications.

J.-W.K. Ko, MD
Department of Orthopedics, Orthopedic Physician Associates at Swedish Orthopedic Institute, Seattle, WA, USA
e-mail: jiawei.ko@gmail.com

C.L. Getz, MD (✉)
Department of Orthopedics, Shoulder/Elbow Division, Rothman Institute at Thomas Jefferson University, Philadelphia, PA, USA
e-mail: charlie.getz@rothmaninstitute.com

Classification

Proximal humeral fractures were initially described by Codman [3]. His classification system was based on the anatomical position of the fracture relative to the major proximal humeral segments as divided by physeal lines. These major fragments included the humeral head, the greater tuberosity, the lesser tuberosity, and the surgical neck. Neer modified this classification to add fracture displacement and angulation to the definition of a fracture "part," in what is now the most universally recognized classification system used today [4] (Fig. 11.1).

Other less commonly utilized classifications include the AO classification system and the Hertel classification. The AO classification system is based on the universal classification principles used to classify articular fractures throughout all long bones [5]. A-type fractures include extra-articular unifocal fractures; B-type fractures include extra-articular bifocal fractures; lastly, C-type fractures include articular fractures. The Hertel classification system was essentially a modification of other anatomical classification systems but also furthered the concept that fracture pattern could predict humeral head ischemia at the time of fracture fixation [6]. In his series, the amount of metaphyseal head extension (<8 mm) and the

© Springer International Publishing Switzerland 2016
A.D. Armstrong, A.M. Murthi (eds.), *Anatomic Shoulder Arthroplasty*,
DOI 10.1007/978-3-319-29164-2_11

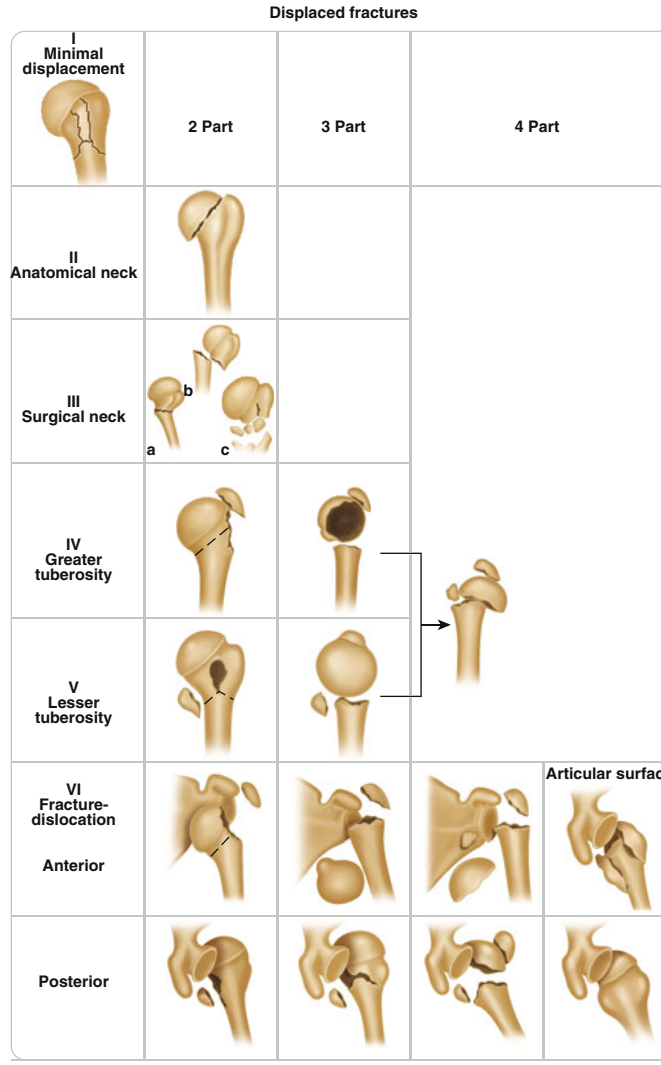


Fig. 11.1 Neer classification system for proximal humerus fracture (Neer [4])

integrity of the medial hinge (displacement >2 mm) were most predictive of ischemia (Fig. 11.2).

Anatomical Considerations

Vital to any attempt at reconstruction of the proximal humerus is a thorough knowledge of its anatomy and its range of variability. As noted above, there are four major segments to the proximal humerus, which represent the division between each of the ossification centers of the proximal humerus during skeletal growth. These include the humeral head, the greater tuberosity, the lesser tuberosity, and the surgical neck. These segments represent the major fracture lines and fracture fragments that should be identified and controlled in all cases.

The humeral head is retroverted in relation to the trans-epicondylar axis of the distal humerus. Studies have demonstrated substantial variability in the amount of retroversion that exists in the proximal humerus, but on average the humeral head exists around 19° of retroversion [7, 8]. When taking into account the valgus carrying angle of the elbow, this corresponds to about 30° of retroversion with respect to the axis of the ulna, which can be a more easily identifiable intraoperatively. Historically, the bicipital groove has been utilized as a point of reference for humeral head retroversion. In an anatomical study based on computed tomography scans, Boileau et al. noted that the central axis of the humeral head exists 7 mm (95 % CI 6.1–7.9 mm) posterior to the posterior margin of the bicipital groove [9]. This distance may have

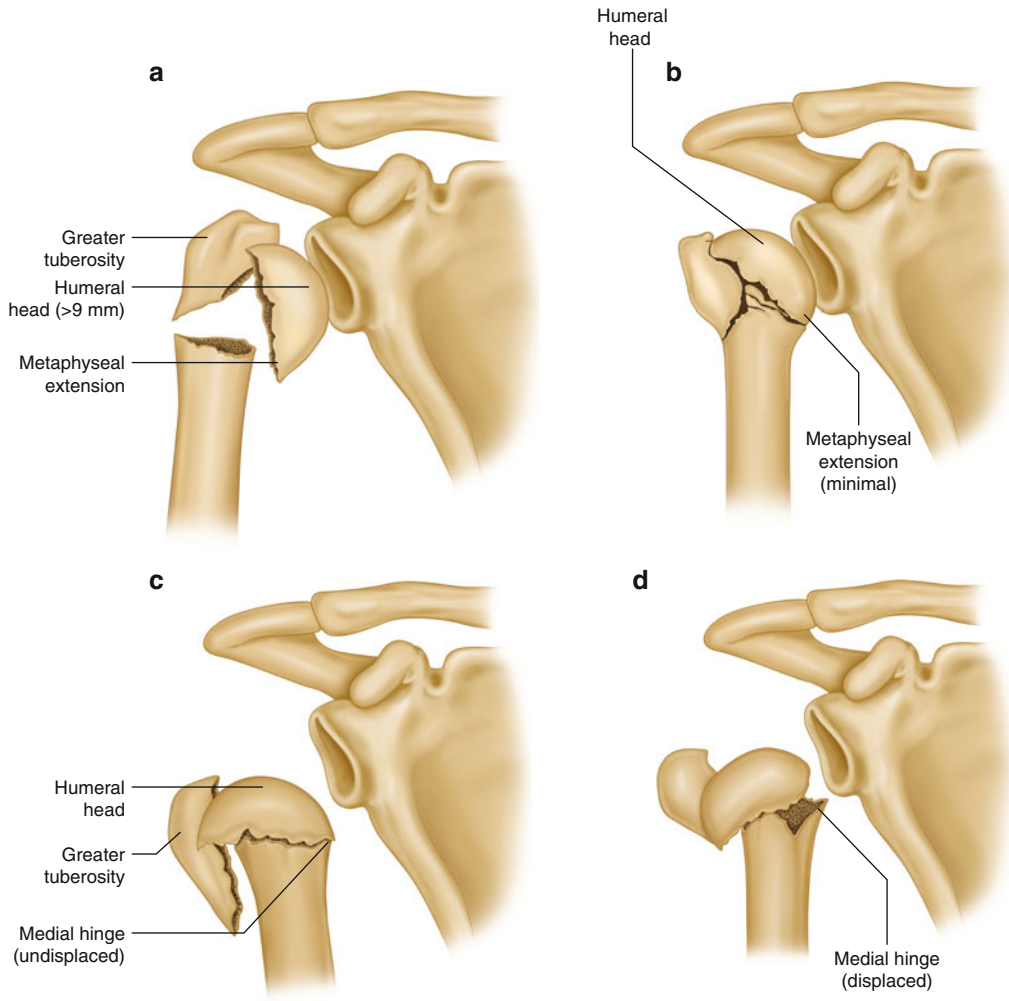


Fig. 11.2 Hertel's predictors of humeral head ischemia: (1) metaphyseal head extension <8 mm and (2) displacement of the medial hinge >2 mm. (**b**) and (**d**) demonstrates predictors of humeral head ischemia, (**a**) and (**c**) demonstrates predictors of preserved humeral head perfusion (Hertel et al. [34])

less variability than humeral head retroversion making it a more reliable landmark. However, limitations in the utility of the bicipital groove were also demonstrated in a prior study by Balg et al. who noted that there was substantial variation between patients and between the proximal to distal portions of the bicipital groove as the anatomy of the groove is more s-shaped rather than being straight [10]. The neck-shaft angle also exists within a range of variability. Several studies investigating this topic demonstrate that the mean neck-shaft exists between 130 and 135° [8, 11, 12].

Another important anatomical consideration is the blood supply to the proximal humerus. Traditionally, the majority of the blood supply was thought to occur through the anterior humeral circumflex artery and its concomitant arcuate branch. This belief was based upon a classic study by Brooks et al. who also noted that this branch was disrupted in most four-part proximal humeral fractures [13]. However, more recent studies have questioned the true dominance of the anterior humeral circumflex and suggested an increased role of the posterior humeral circumflex artery [14, 15]. As mentioned above, Hertel et al. noted some radiographic predictors for humeral head vascularity. They found that metaphyseal extension of the fracture line greater than 8 mm into the metaphysis and preservation of the medial hinge were predictive of preserved vascularity [6]. While preservation of the blood supply is thought to be an important determinant between fixation and arthroplasty options of

treatment for proximal humeral fractures, it is now recognized that reperfusion of the humeral head is possible even if blood supply to the humeral head is disrupted initially [16]. Therefore, it is likely that patient-related factors such as age, activity level, and bone quality may be more important determinants of treatment compared to the maintenance of humeral head blood supply alone.

The attachments and relationships of the soft tissue structures of the proximal humerus are useful to understand the deforming forces on each of the fracture fragments and also as anatomical landmarks for reconstruction. The greater tuberosity serves as the attachment site of the supraspinatus, infraspinatus, and teres minor tendons. This tends to pull this fragment posterosuperiorly in the shoulder and can lead to varus deformity through the fracture. The subscapularis attaches to the lesser tuberosity and tends to displace this fragment medially. The pectoralis major can also act as a deforming force pulling the shaft more medially. The pectoralis major tendon insertion is also an important landmark for judging or recreating humeral head height, particularly in instances in which extensive comminution may obscure normal bony landmarks. On average, the top of the humeral head is 5.6 cm superior to the pectoralis major insertion on the humeral shaft [17].

Indications for Surgery

Determining a plan for surgery depends upon both fracture characteristics and patient characteristics. While both have an effect on determining treatment options independently, they must be considered in conjunction to determine optimal treatment for a particular patient.

Proximal humeral fracture characteristics that favor treatment with hemiarthroplasty include four-part and some three-part fractures. Increased fracture displacement, comminution, and head dislocation all suggest a higher likelihood of compromised vascular supply, which may impede healing or lead to avascular necrosis. Likewise, head-splitting fractures pose a challenge to fixation and to vascularity, which may make replacement options more favorable.

However, there are many other aspects to consider other than the technical difficulty of osteosynthesis or the vascularity or the humeral head, especially when we now recognize that many fractures which initially compromised humeral head blood supply may undergo reperfusion [16]. It is also important to consider the age of the patient, their functional expectations, and implant survivorship. Therefore, we generally hesitate considering replacement options in active patients less than 60 years old. Likewise, in older patients (>70 years old) who are of low functional demand and diminished ability to participate in rehabilitation, reverse shoulder arthroplasty may be a more viable option. The bone quality of a patient may preclude satisfactory bone purchase for fixation techniques, and in these instances, prosthetic options will likely provide more reliable outcomes. Lastly, the status of the rotator cuff is an important factor to consider. While a deficient rotator cuff does not absolutely preclude fixation or hemiarthroplasty options, more reliable function may be achieved with reverse shoulder arthroplasty. There are no absolute indications for hemiarthroplasty over other treatment options; however, the optimal scenario is a displaced four-part proximal humerus fracture in an older but moderately active patient with diminished bone quality (but good tuberosity bone) and an intact rotator cuff.

Absolute contraindications to placement of a hemiarthroplasty for fracture are few but include severe neurologic compromise of the extremity or patients with an active infection of the shoulder.

Alternatives to Hemiarthroplasty

Several alternatives exist to hemiarthroplasty for the treatment of displaced three- and four-part proximal humeral fractures. Many of these may represent more viable options in certain patients with characteristics as described above. Multiple techniques of osseous fixation with various degrees of invasiveness have been described. Each of these can be effective in appropriately selected patients but are generally favored in the

younger and more active patients. Reverse shoulder arthroplasty is becoming a more popular treatment option and may yield more predictable results in lower-demand elderly patients. Lastly, nonoperative treatment may be the best course of treatment for most low-demand patients in which comorbid conditions render their surgical risk to be too high.

Preoperative Evaluation

Physical examination of a patient with a proximal humerus fracture is often limited given the pain associated with the fracture. Examination focuses on neurovascular status and ensuring there are no associated injuries. There are reports of axillary artery injury following proximal humerus fractures. Therefore a thorough examination of distal pulses and a high index of suspicion are required, particularly in displaced four-part fractures or fracture dislocations [18]. Likewise, the axillary nerve can also be at risk along with other nerves emanating from the brachial plexus. Subtle nerve injuries are likely more common than is generally thought with reports that they may exist in up to 67% of fractures [19]. However, it is rare that formal nerve exploration is required, as most are from neuropraxia and resolve without specific intervention.

All proximal humeral fractures should also be evaluated with plain radiographs. This typically includes a trauma series of the shoulder, which includes an AP view, scapular Y view, and an axillary view (Fig. 11.3). If the axillary view is too difficult to obtain due to patient discomfort, a Velpeau view can be obtained in its place. Evaluation of radiographs should focus on identifying the major fracture fragments and developing an operative plan. Studies have demonstrated that there is only moderate inter- and intraobserver agreement when classifying fractures using plain radiographs [20]. A computed tomography (CT) scan can be obtained if further evaluation of the fracture is required. Typically, this is utilized if there is uncertainty in identifying the fracture fragments or determining treatment. Additionally, requesting three-dimensional reconstructions can further improve conceptualization of the fracture and the development of a surgical plan. However, it should be noted that CT scans do little to improve the inter- and intraobserver reliability of fracture classification over plain radiographs alone [21, 22].

Surgical Technique

Our preferred position for surgery is the beach chair position with the patient's head elevated to approximately 45°. Although it may not need to be utilized, positioning should allow adequate fluoroscopic examination intraoperatively if

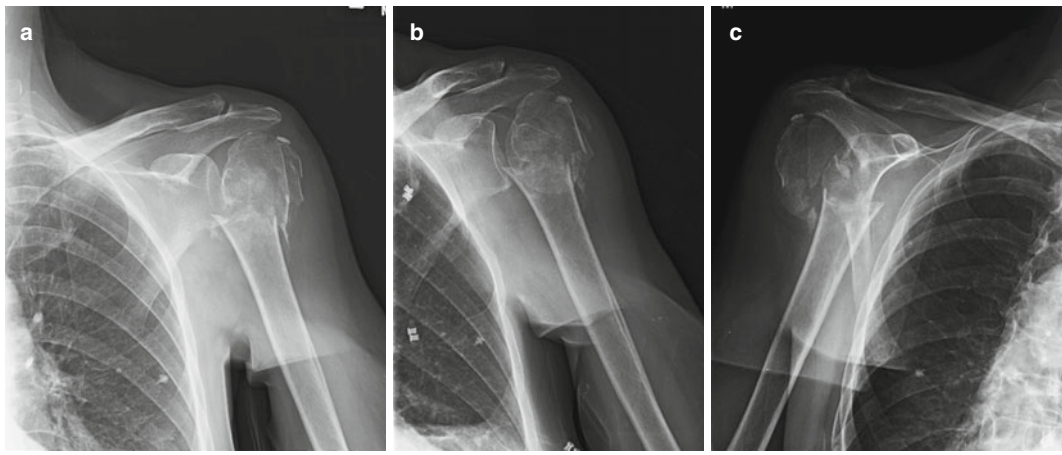


Fig. 11.3 (**a**) AP, (**b**) Grashey and Scapular-Y, (**c**) views of a patient with a displaced proximal humerus fracture

needed. Also, the use of a mechanical arm positioner can be helpful to free the hands of surgical assistants (Fig. 11.4).

A standard deltopectoral approach is typically employed. Unlike a deltopectoral approach for a standard arthroplasty, the upper border of the pectoralis major insertion is preserved if possible. This allows this landmark to be utilized for judging the height of the humeral stem. If the pectoralis insertion needs to be partially released for exposure, the location of the upper border should be clearly marked for later reference. Additionally, the coracoacromial ligament should be maintained if at all possible. This maintains the integrity of the coracoacromial arch and some resistance to superior escape if secondary cuff failure is encountered in the future.

Identification of the bicipital groove and biceps tendon is critical to establishing orientation in the shoulder during fracture cases. This is often more challenging than in uninjured shoulders due to the presence of fracture hematoma and local soft tissue edema. In these instances, identification of the biceps tendon more distally can be more reliable as the insertion of the pectoralis tendon is just lateral to the biceps tendon. Unroofing of the bicipital sheath will lead to the rotator interval, which can be released as part of identification and control of the major fracture fragments. The fracture line which separates the lesser tuberosity fragment from the greater tuberosity fragment typically lies about 1 cm posterior to the bicipital groove in the senior author's experience. Therefore, care must be taken to keep the most anterior fibers of the supraspinatus attached to the most anterior portion of the greater tuberosity during exposure. This often requires osteotomizing the bicipital groove so the entire great tuberosity and supraspinatus can be reconstructed. Once the lesser tuberosity and greater tuberosity fragments are identified and segregated, they should be tagged with a suture for later manipulation (Fig. 11.5a). The biceps tendon can be tenodesed to the pectoralis tendon insertion with resection of the intra-articular portion so that it is out of the way and does not impede fracture visualization or reduction. Some surgeons prefer to keep the biceps intact to help judge soft tissue tension. With the greater and lesser tuberosity fragments identified and retracted, the humeral head fragment should be easily identifiable through the rotator interval and removed. This fragment is retained on the surgical field to guide sizing of the prosthetic humeral head. The glenoid should be inspected for any associated injuries, in particular glenoid rim fractures, that were not appreciated before.

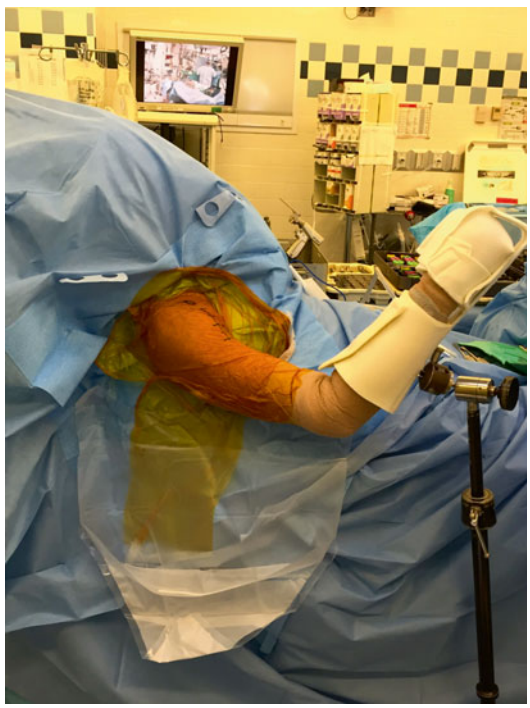


Fig. 11.4 This figure demonstrates the typical beach chair positioning with a mechanical arm positioner

Next, the humeral shaft is delivered from the wound in preparation for arthroplasty implantation. The details of humeral preparation depend on the specific implant system utilized. However, focus should be placed on recreating humeral head height and version. Depending on the amount of comminution and metaphyseal bone loss, the retained fragments may or may not be helpful for judging these parameters. Therefore, the anatomical landmarks described above are used, namely, the relation of the pectoralis major insertion to humeral head height and the relation of the bicipital groove to the central axis of the humeral head keeping in mind the variability and limitations of each of these landmarks. Attention to proper sizing is important, especially avoiding

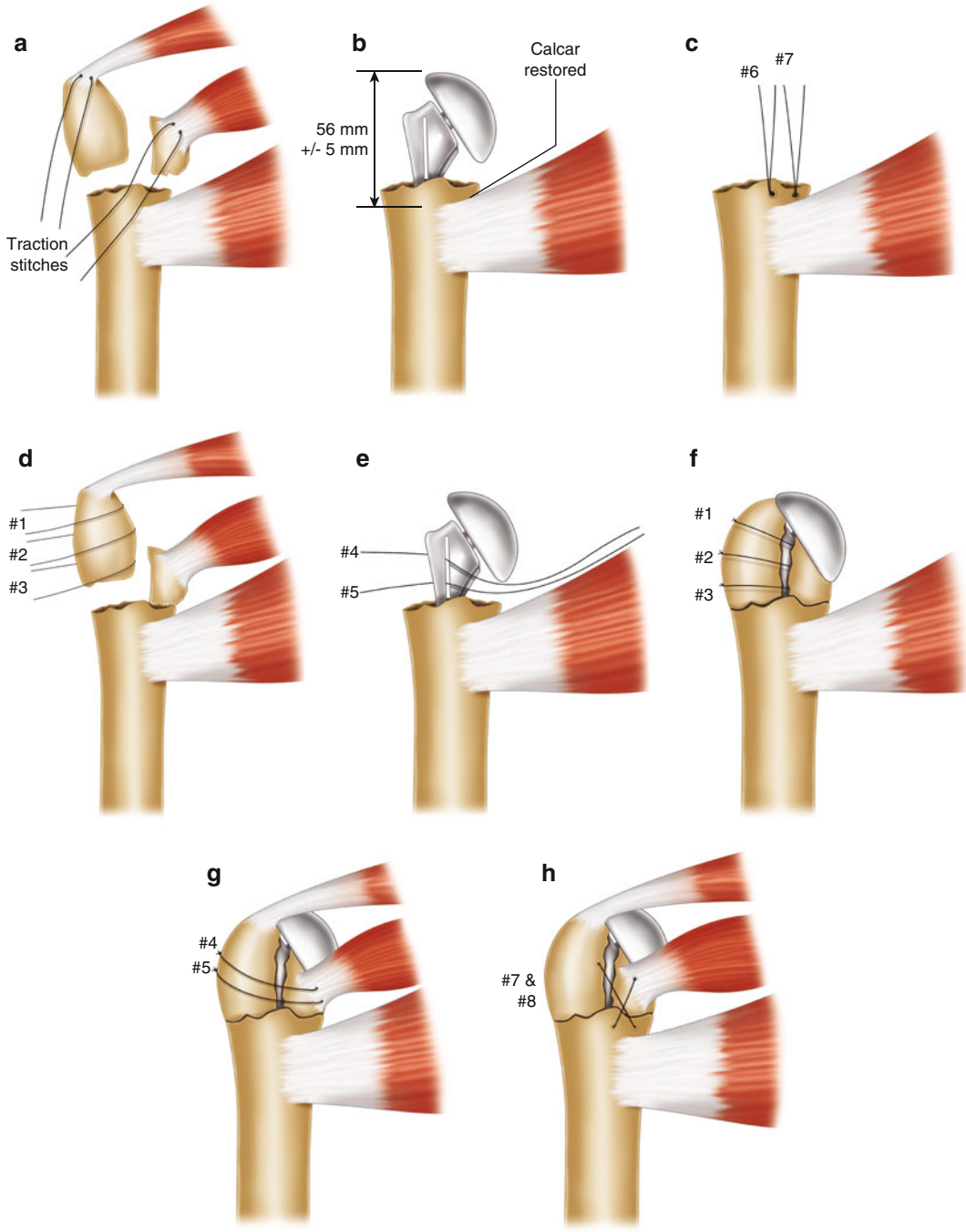


Fig. 11.5 (**a**–**h**) Identification and tagging of the greater tuberosity and lesser tuberosity fracture fragments and suture configuration used to anatomically reduce and secure the tuberosities

overstuffing the joint with too large of a humeral head, as this can place undue tension of the rotator cuff and tuberosity repair. It is our preference to error on undersizing the head if there is any question regarding sizing of the humeral head implant. Another common pitfall to avoid is

implant insertion with too much retroversion, as this can result in uniformly poor function [23].

Trialing of the components is vital to ensure that anatomy has been restored. Also, it can give an indication of whether or not the tuberosities can be adequately reduced and if there is enough stability for cementless fixation. Fluoroscopy can be utilized at this point if desired to assess implant placement and recreation of the "gothic arch" [24] (Fig. 11.6). The senior author finds fluoroscopy essential for assessing proper tuberosity positioning. Once satisfactory component positioning and sizing has been attained, it is often helpful to mark specific relationships between the trial implant and the humeral shaft so that they can be precisely recreated during implantation of the final components. Preparation of the humeral shaft for suture fixation of the tuberosities with drill holes and suture shuttling should also be performed prior to implantation of the final components. Both cemented and cementless fixation can be utilized depending on the amount of stability the humeral component has and whether or not this allows for secure restoration of humeral head height and version.

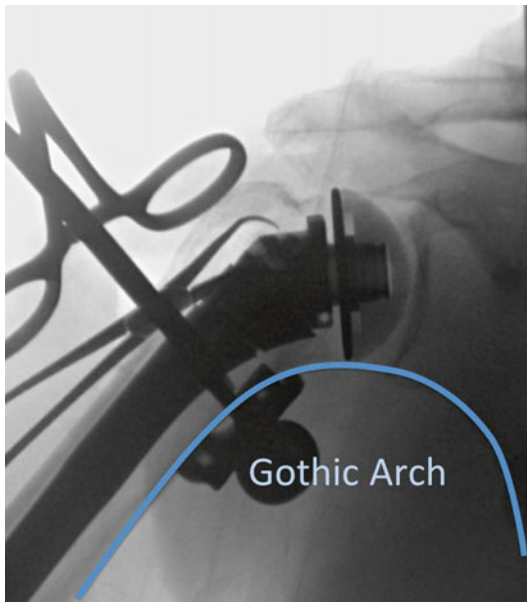


Fig. 11.6 Fluoroscopic image demonstrating recreation of the "gothic arch" of the shoulder

Once the final implant is in place, secure tuberosity fixation must be obtained and is the most critical portion effecting the outcome of this procedure [23]. While many techniques and suture configurations are possible, several principles should be adhered to. Heavy nonabsorbable suture is generally utilized. Horizontally oriented sutures secure the greater and lesser tuberosity back to one another. Looping these sutures through or around the implant can help to reduce the tuberosities to the implant and prevent migration. Frankle et al. demonstrated that a medial cerclage stitch which incorporates both tuberosities provided the best biomechanical configuration to minimize interfragmentary displacement and strain [25]. Vertically oriented sutures help to secure the tuberosities back to the shaft. Several drill holes in the shaft placed in front of and behind the bicipital grove should be placed and sutures shuttled prior to implantation of the final prosthesis. All sutures are generally placed in a mattress fashion if possible although simple sutures can often be used as a cerclage around the implant and tuberosities as described above (Fig. 11.5b–h). Bone graft from the excised humeral head can be used to fill in any remaining space between the tuberosities and the implant left from metaphyseal comminution or bone loss. Lastly, closure of the rotator interval can add additional security between the lesser and greater tuberosity fragments and can help to seal in any bone grafting. At this point, some surgeons may elect to use fluoroscopy again to confirm tuberosity reduction prior to final tensioning and tying of the sutures.

Considerations of Prosthetic Design

While implant design cannot overcome poor surgical technique or principles, many major implant companies now have developed fracture-specific stems which may offer improved ability to anatomically reduce the tuberosities and to fixate them securely. While each specific implant has its own proprietary design features, they all generally have similar design goals. Most fracture-specific stems are less bulky in the metaphyseal region so that less of the existing tuberosity bone will have

to be removed to anatomically reduce the tuberosities to the implant. Additionally, many possess a coating to promote bony ingrowth of the tuberosities to the implant. These implants also have strategically placed holes in the fins or collar that can be used to secure tuberosity sutures (Fig. 11.7).

It is now also becoming increasingly popular to utilize "platform" stems, which allow conversion of the prosthesis to a reverse shoulder arthroplasty without needing to remove the entire stem. This feature can be attractive because if the outcome following a hemiarthroplasty is suboptimal, conversion to a reverse shoulder arthroplasty is often the salvage procedure of choice. This is particularly beneficial if the prosthesis needs to be cemented since the challenges of cement removal can be appreciated by any surgeon who has undertaken revision surgery. Overall, however, the clinical benefits of each of these design features have yet to be established, despite the seemingly sound logic behind their application.

Postoperative Care and Rehabilitation

The operative arm is maintained in a sling for 2 weeks except for gentle pendulums and intermittent elbow, wrist, and hand movement. In an effort to promote anatomical tuberosity healing, only passive range of motion is permitted until 6 weeks following surgery. The limits of motion should be dictated at the time of surgery depending on the security of fixation of other factors such as the patient's bone and tendon quality. This must also be balanced with the patient's rehabilitation potential and propensity for stiffness. Active-assisted range of motion is generally initiated by 6 weeks with progressive strengthening at 12 weeks. Sequential radiographs of the shoulder should be taken at each postoperative visit to assess the adequacy of tuberosity healing and any subsequent migration or malposition.

Fig. 11.7 This figure demonstrates several examples of fracture-specific stems which include a less bulky metaphyseal region, fins which permit suture passage, and proximal ingrowth coating

Results of Hemiarthroplasty for Fracture

Hemiarthroplasty performed for displaced three- and four-part proximal humeral fractures typically provides good pain relief and adequate waist level function. However, its ability to restore range of motion and overhead function is inconsistent. In a systematic review of the literature including over 800 hemiarthroplasties, Kontakis et al. demonstrated an average forward elevation of 105.7°, abduction of 92.4°, and external rotation of 30.4° [26]. Additionally, careful evaluation of many postoperative patients will demonstrate that the majority of these patients gain much of their motion through scapular compensation rather than through the glenohumeral joint.

In another study with some of the longest follow-up, Antuna et al. reported on 57 hemiarthroplasties with a minimum of 5 years follow-up [27]. Satisfactory outcomes using the Neer rating system were achieved in only 47 % of cases, and only 58 % of patients achieved a minimum of 90° of active forward elevation. This highlights some of the challenges in performing a hemiarthroplasty for this particular patient population. In general, a patient can expect good pain relief but inconsistent ability in restoring preoperative function.

As noted above, the functional results following hemiarthroplasty are intimately tied to healing of the tuberosities. If anatomical healing of the tuberosities can be achieved, then good results can be obtained. However, if the tuberosities resorb or become malunited, poor results are inevitable. In many respects, the outcome following this surgery is an "all or nothing" phenomenon hinging on the tuberosities. This was illustrated in a recent study by Cuff et al. looking at the treatment of displaced proximal humerus fractures treated with hemiarthroplasty or reverse shoulder arthroplasty [28]. In this study, patients who had a hemiarthroplasty and adequately healed their tuberosities achieved an average of 131° of elevation, while those who did not only achieved 52°.

Complications

Tuberosity Malunion/Nonunion and Rotator Cuff Dysfunction

Tuberosity malunion, nonunion, or resorption remains the most significant contributor to poor patient function following hemiarthroplasty (Fig. 11.8). Boileau et al. reported on a series of 66 patients in which tuberosity malpositioning occurred in 50 % of the patients and was associated with worse functional outcome [23]. While initial malposition of the tuberosities was understandably associated with poor final positioning, there were also 15 patients in which the tuberosities migrated from their initial postoperative position. This again demonstrates the importance of anatomical reduction of the tuberosities but also creating a secure enough construct to keep them in place until healing occurs. Even with good reduction and security of the tuberosities, healing is not guaranteed. Tuberosity nonunion or resorption has been described with regularity. In the series reported by Antuna et al., they reported tuberosity nonunion or resorption in

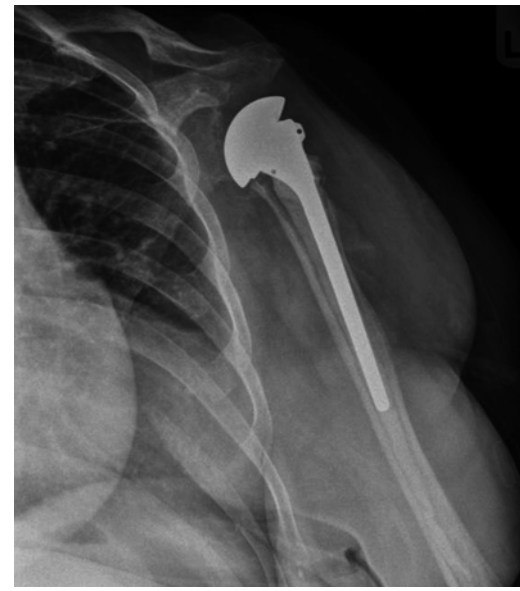


Fig. 11.8 Radiograph demonstrating resorbed tuberosities following a hemiarthroplasty performed for a proximal humeral fracture

29 % of their patients that were available for radiographic follow-up [27].

Cuff dysfunction following hemiarthroplasty is intimately tied to tuberosity malposition or nonunion. This was clearly demonstrated in a study by Greiner et al. in which they correlated fatty infiltration of the supraspinatus and infraspinatus muscle to malposition of the greater tuberosity and fatty infiltration of the subscapularis to lesser tuberosity malposition [29]. Glenohumeral subluxation can also be quite common, particularly in the superior direction indicating an incompetent posterosuperior rotator cuff function [27]. In the largest systematic review in the literature, proximal migration of the humeral head was noted in 6.8 % of all cases [26]. Cuff dysfunction can occur independent of tuberosity malunion and can stem from age-related cuff wear or failure to recreate anatomical humeral head height or version. Overall, however, this is likely a less significant contributor to long-term cuff dysfunction compared to issues with tuberosity malposition and healing.

The management of lingering issues involving the tuberosities and rotator cuff can be difficult and should be tailored to individual symptoms and functional goals. Revision tuberosity fixation can be attempted if there is early migration; however, delayed treatment can require osteotomies to mobilize the tuberosities, and resorption can make revision fixation difficult to achieve. Many cases therefore require conversion to a reverse total shoulder arthroplasty.

Neurologic Injury

Nerve injuries are underappreciated sequelae of proximal humerus fractures. This may stem from the difficulty in thoroughly assessing neurologic function in an elderly patient with an acutely painful fracture or the subtle nature of many of these nerve injuries. However, nerve injuries detectable by electromyographic testing have been reported to exist in up to 67 % of patients related to the initial trauma, as was noted above [19]. Neurologic injury can also occur during surgical intervention, particularly with the distortion in anatomy that can occur with fractures. However, this is much less commonly reported in the literature.

The axillary nerve is the most commonly reported nerve injury, owing to its close anatomical location to the surgical field [30]. The musculocutaneous nerve and other brachial plexopathies are also possible and typically result from excessive traction during surgery. Thankfully, the majority of injuries are typically transient in nature and resolve without any specific intervention.

Heterotopic Ossification

Heterotopic ossification has been reported to occur in approximately 8.8 % of hemiarthroplasties performed in the fracture setting [26]. The propensity for developing heterotopic ossification may be related to several patient-related factors such as having the condition ankylosing spondylitis or diffuse idiopathic skeletal hyperostosis. It may also be related to the energy of the initial injury or delays in treatment [31, 32]. Most cases of heterotopic ossification result in only Brooker grade 1 or 2 heterotopic ossification, and the majority of these cases do not result in any significant loss of motion or function. Therefore, routine prophylaxis against heterotopic ossification is generally not undertaken. More extensive Brooker grade 3 or 4 heterotopic ossification is a more rare occurrence but can serve as enough of an impediment to motion and function to warrant excision once the heterotopic ossification has matured.

Glenoid Wear

Progressive wear of an un-resurfaced glenoid is a concern for any hemiarthroplasty of the shoulder (Fig. 11.9). In practice, however, it is seldom necessary to revise a hemiarthroplasty for fracture purely due to glenoid wear. The rate of reoperation for glenoid wear was reported to be 4.2 % in one series in the literature [33]. The relatively low rate of symptomatic glenoid wear is likely related to the

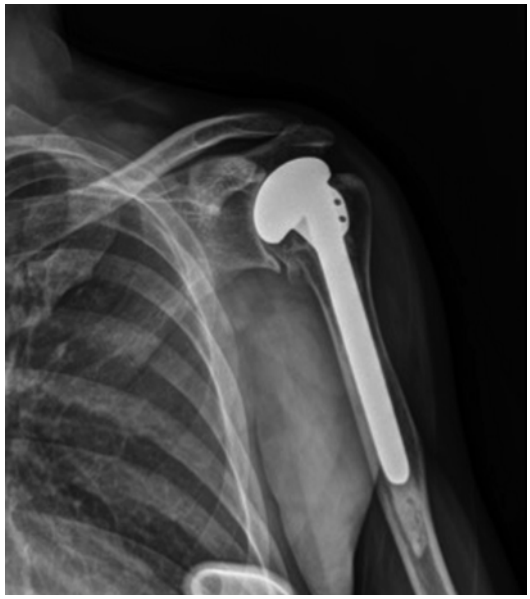


Fig. 11.9 Radiograph demonstrating progressive glenoid wear following hemiarthroplasty

low functional demands of the patient population who sustain these fractures. In the instance that glenoid wear is thought to be the major contributor to the patient's dysfunction, insertion of a glenoid component can be considered. However, in many instances, conversion to a reverse total shoulder arthroplasty may offer a more reliable result.

Infection

Infections are relatively uncommon with rates of superficial and deep infections reported to be 1.6% and 0.6%, respectively, in a systematic review involving 771 hemiarthroplasties for fracture [26]. The relatively low rate of reported infection in this patient population may come as a surprise to some given the relatively poor quality of the soft tissues and multiple medical comorbidities that a more elderly patient population can have. Superficial infections typically respond to antibiotic treatment with or without surgical debridement. Deeper infections may require implant removal if complete infection eradication is the goal and is often associated with significant morbidity and mortality.

Conclusions

Shoulder hemiarthroplasty for the treatment of fractures involving the proximal humerus is a technically challenging procedure with narrowing indications. However, in patients where fixation options are suboptimal but they are of an age or activity level precluding them from being a good candidate for a reverse total shoulder, a role for this procedure still exists. Recreation of anatomy with secure tuberosity fixation is vital to avoiding the most common causes of poor functional results. If major pitfalls can be avoided, satisfactory function and durable pain relief can be achieved.

References

1. Neer 2nd CS. Displaced proximal humeral fractures. II. Treatment of three-part and four-part displacement. J Bone Joint Surg Am. 1970;52(6):1090–103.
2. Bhandari M, Matthys G, McKee MD, Evidence-Based Orthopaedic Trauma Working G. Four part fractures of the proximal humerus. J Orthop Trauma. 2004;18(2):126–7.
3. Codman E. The shoulder: rupture of the supraspinatus tendon and other lesions in or about the subacromial bursa. Boston: Private Publication; 1934.
4. Neer 2nd CS. Displaced proximal humeral fractures. I. Classification and evaluation. J Bone Joint Surg Am. 1970;52(6):1077–89.
5. Muller ME, Nazarian S, Koch P, Schatzker J. The comprehensive classification for fractures of long bones. Berlin: Springer; 1990.
6. Hertel R, Hempfing A, Stiehler M, Leunig M. Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. J Should Elb Surg/Am Should Elb Surg. 2004;13(4):427–33. doi:10.1016/S1058274604000795.
7. Hernigou P, Duparc F, Hernigou A. Determining humeral retroversion with computed tomography. J Bone Joint Surg Am. 2002;84-A(10):1753–62.
8. Robertson DD, Yuan J, Bigliani LU, Flatow EL, Yamaguchi K. Three-dimensional analysis of the proximal part of the humerus: relevance to arthroplasty. J Bone Joint Surg Am. 2000;82-A(11):1594–602.
9. Boileau P, Bicknell RT, Mazzoleni N, Walch G, Urien JP. CT scan method accurately assesses humeral head retroversion. Clin Orthop Relat Res. 2008;466(3):661–9. doi:10.1007/s11999-007-0089-z. PubMed PMID: 18264854, PubMed Central PMCID: PMC2505224.
10. Balg F, Boulianne M, Boileau P. Bicipital groove orientation: considerations for the retroversion of a prosthesis in fractures of the proximal humerus. J Should

Elb Surg/Am Should Elb Surg. 2006;15(2):195–8. doi:10.1016/j.jse.2005.08.014.
11. Boileau P, Walch G. The three-dimensional geometry of the proximal humerus. Implications for surgical technique and prosthetic design. J Bone Joint Surg. 1997;79(5):857–65.
12. Iannotti JP, Gabriel JP, Schneck SL, Evans BG, Misra S. The normal glenohumeral relationships. An anatomical study of one hundred and forty shoulders. J Bone Joint Surg Am. 1992;74(4):491–500.
13. Brooks CH, Revell WJ, Heatley FW. Vascularity of the humeral head after proximal humeral fractures. An anatomical cadaver study. J Bone Joint Surg. 1993;75(1):132–6.
14. Duparc F, Muller JM, Freger P. Arterial blood supply of the proximal humeral epiphysis. Surg Radiol Anat SRA. 2001;23(3):185–90.
15. Hettrich CM, Boraiah S, Dyke JP, Neviaser A, Helfet DL, Lorich DG. Quantitative assessment of the vascularity of the proximal part of the humerus. J Bone Joint Surg Am. 2010;92(4):943–8. doi:10.2106/JBJS.H.01144.
16. Bastian JD, Hertel R. Initial post-fracture humeral head ischemia does not predict development of necrosis. J Should Elb Surg/Am Should Elb Surg. 2008;17(1):2–8. doi:10.1016/j.jse.2007.03.026.
17. Murachovsky J, Ikemoto RY, Nascimento LG, Fujiki EN, Milani C, Warner JJ. Pectoralis major tendon reference (PMT): a new method for accurate restoration of humeral length with hemiarthroplasty for fracture. J Should Elb Surg/Am Should Elb Surg. 2006;15(6):675–8. doi:10.1016/j.jse.2005.12.011.
18. Lim EV, Day LJ. Thrombosis of the axillary artery complicating proximal humeral fractures. A report of three cases. J Bone Joint Surg Am. 1987;69(5):778–80.
19. Visser CP, Coene LN, Brand R, Tavy DL. Nerve lesions in proximal humeral fractures. J Should Elb Surg/Am Should Elb Surg. 2001;10(5):421–7. doi:10.1067/mse.2001.118002.
20. Sidor ML, Zuckerman JD, Lyon T, Koval K, Cuomo F, Schoenberg N. The Neer classification system for proximal humeral fractures. An assessment of interobserver reliability and intraobserver reproducibility. J Bone Joint Surg Am. 1993;75(12):1745–50.
21. Sjoden GO, Movin T, Guntner P, Aspelin P, Ahrengart L, Ersmark H, et al. Poor reproducibility of classification of proximal humeral fractures. Additional CT of minor value. Acta Orthop Scand. 1997;68(3):239–42.
22. Bernstein J, Adler LM, Blank JE, Dalsey RM, Williams GR, Iannotti JP. Evaluation of the Neer system of classification of proximal humeral fractures with computerized tomographic scans and plain radiographs. J Bone Joint Surg Am. 1996;78(9):1371–5.
23. Boileau P, Krishnan SG, Tinsi L, Walch G, Coste JS, Mole D. Tuberosity malposition and migration: reasons for poor outcomes after hemiarthroplasty for displaced fractures of the proximal humerus. J Should Elb Surg/Am Should Elb Surg. 2002;11(5):401–12.
24. Krishnan SG, Bennion PW, Reineck JR, Burkhead WZ. Hemiarthroplasty for proximal humeral fracture: restoration of the Gothic arch. Orthop Clin North Am. 2008;39(4):441–50. doi:10.1016/j.ocl.2008.05.004, vi.
25. Frankle MA, Ondrovic LE, Markee BA, Harris ML, Lee 3rd WE. Stability of tuberosity reattachment in proximal humeral hemiarthroplasty. J Should Elb Surg/Am Should Elb Surg. 2002;11(5):413–20.
26. Kontakis G, Koutras C, Tosounidis T, Giannoudis P. Early management of proximal humeral fractures with hemiarthroplasty: a systematic review. J Bone Joint Surg. 2008;90(11):1407–13. doi:10.1302/0301-620X.90B11.21070.
27. Antuna SA, Sperling JW, Cofield RH. Shoulder hemiarthroplasty for acute fractures of the proximal humerus: a minimum five-year follow-up. J Should Elb Surg/Am Should Elb Surg. 2008;17(2):202–9. doi:10.1016/j.jse.2007.06.025.
28. Cuff DJ, Pupello DR. Comparison of hemiarthroplasty and reverse shoulder arthroplasty for the treatment of proximal humeral fractures in elderly patients. J Bone Joint Surg Am. 2013;95(22):2050–5. doi:10.2106/JBJS.L.01637.
29. Greiner SH, Diederichs G, Kroning I, Scheibel M, Perka C. Tuberosity position correlates with fatty infiltration of the rotator cuff after hemiarthroplasty for proximal humeral fractures. J Should Elb Surg/Am Should Elb Surg. 2009;18(3):431–6. doi:10.1016/j.jse.2008.10.007.
30. Plausinis D, Kwon YW, Zuckerman JD. Complications of humeral head replacement for proximal humeral fractures. Instr Course Lect. 2005;54:371–80.
31. Neer 2nd CS, McIlveen SJ. Humeral head replacement with reconstruction of the tuberosities and the cuff in 4-fragment displaced fractures. Current results and technics. Rev Chir Orthop Reparatrice Appar Mot. 1988;74 Suppl 2:31–40.
32. Brown TD, Bigliani LU. Complications with humeral head replacement. Orthop Clin North Am. 2000;31(1):77–90.
33. Mighell MA, Kolm GP, Collinge CA, Frankle MA. Outcomes of hemiarthroplasty for fractures of the proximal humerus. J Should Elb Surg/Am Should Elb Surg. 2003;12(6):569–77. doi:10.1016/S1058274603002131.
34. Hertel, et al. Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. JSES. 2004;13:427–33.

12 Complications: Infection, Subscapularis Insufficiency, Periprosthetic Fracture, and Instability

Jonah Hebert-Davies and Leesa M. Galatz

Infection

Infections after shoulder arthroplasty are relatively rare but nevertheless have considerable impact on outcomes. Periprosthetic infections in the shoulder differ vastly from those of other joints in that the most common pathogen is *Propionibacterium acnes*, a difficult organism to isolate. Treatment is often based on a high index of suspicion. Incidence has been reported from 0.4 % to 4 % [1–3], although the real incidence may be higher. Infection is associated with component loosening and pain. Although diagnostic techniques have improved, accurate diagnosis can still prove challenging. Treatment options are based on multiple factors including pathogen, associated bone loss, and patient-specific details.

Propionibacterium acnes is the most commonly described pathogen, and *Staphylococcus aureus* and coagulase-negative *Staphylococcus* are the next most common. A variety of other organisms have been identified [1, 2]. *P. acnes* is a gram-positive bacillus commonly found in the axilla in great abundance [4]. Given that it is a normal skin flora and has low virulence, its role in infection is poorly understood.

J. Hebert-Davies, MD, FRCSC
Department of Orthopedic Surgery,
Hopital du Sacre-Coeur de Montreal,
5400 W Gouin Blvd, Montreal H4J 1C5, QC, Canada
e-mail: jonahdavies@gmail.com

L.M. Galatz, MD (✉)
Department of Orthopaedics Surgery,
Mount Sinai Health System, New York, NY, USA
e-mail: leesa.galatz@mountsinai.org

Diagnosis

Unexplained or new onset of pain after shoulder arthroplasty should immediately raise suspicion of infection. Acute systemic symptoms such as fever or sepsis are rare on presentation but can occur in immunocompromised patients (rheumatoid arthritis, sickle cell anemia). Patients with any progressive lucency or bone loss on serial X-rays should be screened for infection. Both *P. acnes* and coagulase-negative *Staphylococcus* have relatively low virulence. Definitive diagnosis can be difficult and cultures usually require extended incubation time of tissue samples (up to 21 days) [4]. Adjuvant means of diagnosis have been developed with varying levels of success. The gold standard for diagnosis remains positive cultures from open biopsy of multiple tissue samples. The difficulty with revision surgery is that infection must be excluded before proceeding. A reliable diagnosis allows the surgeon to plan for a one-stage versus a two-stage revision surgery [5].

Typical preoperative workup should include biological markers such as C-reactive protein (CRP), sedimentation rate (ESR), and white blood cell count (WBC). These markers often lead to false-negative results, with normal or only

© Springer International Publishing Switzerland 2016

A.D. Armstrong, A.M. Murthi (eds.), *Anatomic Shoulder Arthroplasty*,
DOI 10.1007/978-3-319-29164-2_12

slightly elevated values despite active infection [6]. Fluoroscopic joint fluid aspiration has been proposed by certain authors; however these have had typically low sensitivity (12.5 %) [7]. A newer method has recently been described using arthroscopy to obtain tissue biopsies. Dilisio et al. compared results from these biopsies to cultures obtained during the subsequent open revision procedure. They found a 100 % sensitivity/specificity/negative and positive predictive value [8]. This was in contrast to fluoroscopically obtained aspirates, which had a sensitivity of only 16 %. They concluded that arthroscopic biopsy in the setting of a presumed or possibly infected shoulder arthroplasty is a reliable means of confirming diagnosis and identifying the causative agent [8]. Villacis et al. recently looked at interleukin-6 (IL-6) as a diagnostic marker for infection. They obtained serum values for all patients undergoing revision surgery and considered a positive intraoperative culture as a diagnosis of infection. Overall sensitivity and specificity were 14 % and 95 % respectively [9]. They concluded that serum IL-6 levels were not an effective method of diagnosis of shoulder arthroplasty infection. Following this, another group looked at using synovial fluid IL-6 as a marker of infection. Sensitivity and specificity were 87 % and 90 %, respectively, and both preoperative and intraoperative measurements correlated to each other. They suggested that preoperative fluoroscopic-guided aspiration with IL-6 measurement could be a useful adjunct for diagnosing infection [10].

Consistent intraoperative diagnosis of latent infection is very useful for surgical decision-making during revision surgery. Unfortunately, gram stain is rarely contributory in this setting, and culture results may take up to 21 days for *P. acnes* to become positive. Frozen section has been used with arthroplasty in other joints with varying success [11, 12]. Grosso et al. looked at the sensitivity of frozen section for diagnosis of infection in revision shoulder arthroplasty [13]. Using standard guidelines of five polymorphonuclear leukocytes per high-powered field in five fields as a positive result, they found a 50 % sensitivity and 100 % specificity for *P. acnes* infection. They then modified the criteria to be a sum of ten polymorphonuclear leukocytes in five fields. With the new criteria, the sensitivity rose to 72 %, while the specificity remained at 100 %. The authors recommended lowering the threshold for a positive screening in order to increase the yield of frozen section.

Risk Factors

The preponderance of *P. acnes* infection in the shoulder can be in part attributed to the numerous sebaceous glands and hair follicles of the axilla in close proximity to the surgical incision. Patients developing infection generally have identifiable risk factors in up to 50 % of the time [2, 6]. Specific risk factors include diabetes, systemic lupus erythematosus, rheumatoid arthritis, previous surgical procedures, and remote infection. Other risk factors include chemotherapy, corticosteroid therapy or intra-articular steroid injections, coagulopathy, renal failure, fluid and electrolyte disorders, and a diagnosis other than primary osteoarthritis (cuff tear arthropathy, acute proximal humerus fracture or nonunion, avascular necrosis) [2, 6, 14]. Smucny et al. looked at inpatient development of infection and found a direct correlation with length of stay. The risk of a surgical site infection (SSI) increased by 14 % per additional day of hospitalization [14]. Morris et al. looked at risk factors associated with infection after reverse shoulder arthroplasty (RSA) specifically. They found that previous failed arthroplasty and younger age were the only two independent risk factors for infection [15]. According to their findings, patients above the age of 65 were less likely to develop infections after RSA.

Prevention

Preventing SSIs should be a priority because treatment is often complicated and can require multiple interventions. Matsen et al. attempted to locate the areas of the surgical site most likely to find *Propionibacterium* in patients undergoing revision. They found positive cultures in an

unprepared epidermal layer in 16/18 men and 7/12 women. Initial and final dermal cultures were obtained prior to antibiotic prophylaxis and were positive in 11/20 for the men and none of the women. They concluded that surgical preparation did not completely eliminate dermal *P. acnes*, and it persists in sebaceous glands in significant quantities (10^5 or greater.) [16]. Deep cultures were positive in 12/20 cultures for the male patients and only 1 of the females, and this was correlated with the dermal cultures [17]. They concluded that males were more likely to have *Propionibacterium* present in their wound than females, and this is despite adequate skin preparation. Lee et al. confirmed these results finding that 70 % of patients undergoing TSA had a positive epidermal culture for *P. acnes* immediately following skin preparation with chlorhexidine prep.

Other studies have evaluated for the presence of *P. acnes* in primary surgeries. Levy et al. obtained intra-articular cultures during primary TSA in patients who had not had prior shoulder surgery. They found positive cultures in 23/55 (42 %) patients [18]. All patients were treated with 4 weeks of oral antibiotics and no patient developed infective signs. The authors hypothesized that low-grade infection with *P. acnes* may even play a role in the development of OA; however this has not been substantiated [19]. Matsen et al. examined patients undergoing TSA for primary osteoarthritis without a history of infection. Cultures were obtained after receiving intravenous antibiotic prophylaxis and were positive in three out of ten patients (7/50 specimens) [20]. The authors concluded that even with adequate skin prep and appropriate antibiotic prophylaxis, *P. acnes* is very commonly found in the surgical site. The relevance of its presence is difficult to interpret, but presence may be a risk for infection.

Antibiotic prophylaxis usually involves a first-generation cephalosporin (cefazolin) and has been shown effective at reducing the overall infection rate [21]. Despite this success, several authors believe an alternative prophylaxis regimen should be used to specifically address the *Propionibacterium* problem [20]. Finally, the use of antibiotic-loaded cement in total shoulder arthroplasty has been supported by at least one study. Nowinski et al. retrospectively compared two cohorts of total shoulder arthroplasties: one using antibiotic cement and the other with normal cement. These two groups were well matched, and they found a 3 % higher infection rate in the group using normal cement [3].

Treatment

Treatment for infected joint arthroplasty is debatable and there is a lack of consensus among shoulder surgeons. Treatment with antibiotics and retention of the prosthesis, for eradication or chronic suppression, has very high failure rate, up to 60–75 % [22]. This should be reserved for patients that are either medically unfit for surgery or refuse to undergo revision. Resection arthroplasty is another therapeutic option that should be kept as a last resort. A review of patients after resection arthroplasty demonstrated a successful elimination of infection and reasonable pain relief (a mean reduction of 4.3 points on the VAS scale); a majority (13/17) of patients had no or very limited functional ability in the affected shoulder [23]. Therefore, resection is an option in end-stage cases.

The mainstay of treatment for prosthetic joint infection includes either single- or two-stage revision arthroplasty combined with prolonged intravenous antibiotic therapy. Single-stage revision has the advantages of lower cost, decreased morbidity, and potentially better outcomes. The drawbacks include a theoretically higher reinfection rate and the need for subsequent surgery. Several studies have reported good outcomes with single-stage revision without a higher than expected risk of reinfection [22, 24, 25]. Another recent study demonstrated a 94 % infection-free survivorship at a mean of 4.7 years following single-stage revision [26]. The protocol used by the surgeons included intraoperative tissue samples to confirm infection, thorough debridement and irrigation of the surgical field, reimplantation with antibiotic-loaded cement, and postoperative IV antibiotics for an average of 10.6 days [26].

Two-stage revision arthroplasty is the preferred method for treating prosthetic joint infections of the shoulder for most surgeons. The protocol consists of explantation with aggressive debridement and antibiotic spacer placement and prolonged IV antibiotic treatment. A tissue biopsy and/or joint aspirate culture with evaluation of inflammatory blood markers (CRP, ESR, WBC) follows IV antibiotic treatment, and second-stage reimplantation takes place when confident that there is elimination of infection. There is limited data on results of this protocol, likely due to the relatively low incidence rate of infections in shoulder arthroplasty. Coste et al. reported on ten patients treated with two-stage revision. Their cohort had a 20-point increase in the mean constant [27] score; however there was persistent infection in four patients (40 %) with one patient undergoing a second revision [22]. Strickland et al. reported on 19 shoulders undergoing staged treatment, with 7 shoulders (37 %) having persistent infection [28]. They also reported 14 complications and concluded that while staged revision offered a better chance at infection eradication, it was associated with significant morbidity and low functional outcome results [28]. Sabesan et al. evaluated two-stage revision using reverse arthroplasty in 17 patients. They had one persistent infection (6 %) and 35 % complication rate, including five reoperations for instability [29]. Cleary, this is a challenging clinical problem without a definitive and predictable solution. Figure 12.1 demonstrates a protocol for treating suspected or confirmed prosthetic joint infections of the shoulder.

Periprosthetic Fracture

Periprosthetic humerus fractures are rare with an incidence of 0.6–3 % of all shoulder arthroplasties. The majority of these fractures involve the

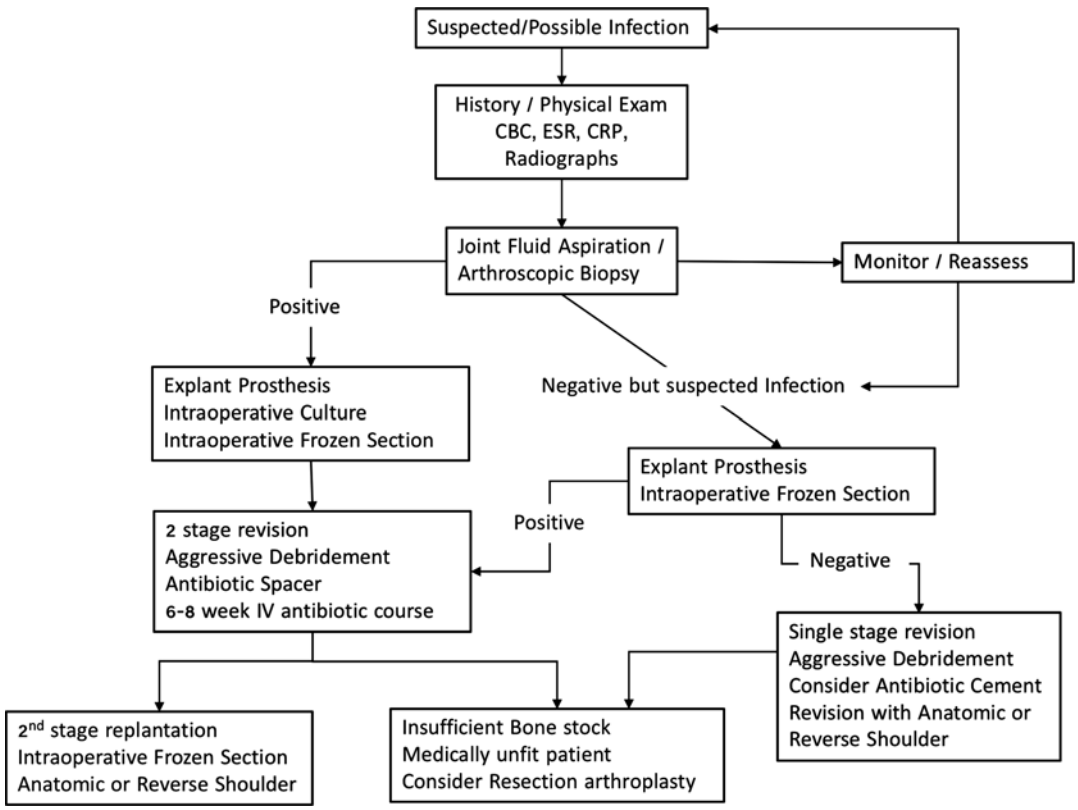


Fig. 12.1 Treatment algorithm for suspected/confirmed shoulder arthroplasty infection

humerus. Glenoid periprosthetic fractures are rare and most often occur in metal-backed implants (such as reverse shoulder arthroplasty baseplates). A vast majority of humeral fractures occur intraoperatively secondary to technical errors. Technical errors include poor patient positioning and inadequate surgical exposure. This results in excessive traction and rotation and can encourage cortical breach due to increased leveraging on bone and soft tissues. Oversized implants also cause fractures [30]. Patient age and sex, osteopenia, and rheumatoid arthritis are risk factors for periprosthetic fractures [30]. In one series, 85 % of fractures occurred in women with an average age of 71 years [31]. Others also found that RA was present in 55–100 % of patients with postoperative humerus fractures [32, 33].

Nonunions for periprosthetic fractures occur in higher frequency compared to other humerus fractures [32]. Several factors are thought to play a role, including relative stress shielding, increased force transmission, and potential distraction caused by an oversized stem [32]. Delayed healing is similarly seen in patients with RA, female sex, and osteopenia.

Prevention

Prevention of periprosthetic fractures is key because treatment options are often difficult. Adequate patient positioning helps reduce forced manipulation of the shoulder during component preparation, especially during canal reaming. Fully releasing all soft tissue adhesions in both the subacromial and subdeltoid spaces will decrease the torsional forces through the humeral shaft during manipulation. Finally, inferior capsular release and rotator interval release help achieve excellent glenoid exposure and protect the humerus from retractors and excessive external rotation.

Technical errors during reaming also lead to fractures. Initial reaming should be started lateral to the center of rotation and posterior to the biceps groove. This helps to avoid varus placement of the reamer and lateral cortical breaching. Reaming should be collinear to remain within the confines of the cortical bone and avoid cortical notching. Several other techniques during reaming (using hand-controlled reamers, limiting reaming to the earliest cortical chatter, using slightly undersized trials and implants) can help minimize stress through the humeral cortex. A press-fit stem also increases the relative risk for a fracture to 2.9 compared to a cemented component [34]. Reverse arthroplasty stems have a flared proximal component that can increase stress risers through the metaphysis during implantation. Postoperatively, patients who have had notching or canal transgression, a varus-positioned stem, an ipsilateral total elbow arthroplasty, or a loose stem are all at an increased risk for future fracture.

Fracture Classification

Fractures about a humeral implant are classified according to location. Wright and Cofield described three types of fractures: type A is centered near the tip of the stem and extends proximally, type B is centered around the tip, and type C is located distal to the stem [33]. Campbell and Iannotti described a similar classification system based on location. Type I fracture involves the tuberosities, type II is in the metaphyseal region, type III is located around the tip of the stem, and type IV is distal to the tip in the diaphysis [35]. Osteopenia is an important risk factor for periprosthetic fractures. It is classified according to ratio of the cortical thickness compared to the width of the humeral diaphysis. A ratio >50 % indicated normal bone, 25–50 % indicated mild osteopenia, and <25 % indicated severe osteopenia. Based on this definition, osteopenia has been reported to be present in 75 % of the periprosthetic humeral shaft fractures [35, 36].

Treatment

Factors to consider include the location, stability of the fragments, stability of the prosthesis, and bone quality. Fracture treatment is dictated according to

fracture type and characteristics. Nonoperative management is preferred for minimally displaced, stable fractures in patients with body habitus amenable to bracing. Surgical treatment is recommended for patients with grossly unstable fractures, with loose stems, or with displaced fractures that have failed nonsurgical treatment [36].

Intraoperative fractures, as a rule, should be addressed at the time of surgery. If discovered, tuberosity fractures should be repaired with cerclage fixation using heavy nonabsorbable suture or wire. Fractures involving the humeral shaft can be bypassed with a longer stem and supplemented with cerclage wires, strut allografts, or plate fixation as needed.

Treatment of fractures occurring postoperatively depends on implant stability. In general, loose implants should be revised. Fractures involving the tuberosities can be treated conservatively when they are not displaced or minimally displaced. Displaced fractures can be treated similarly to those found intraoperatively. Proximal fractures are treated with a long-stemmed prosthesis that bypasses the fracture by two or three cortical widths [30, 35]. Stems may be cemented or press fitted and supplemented with wires and allograft without significant impact of healing rates [32]. Fractures around the distal aspect of the stem can be treated with revision using a longer implant, open reduction internal fixation (ORIF), or a combination of both (Fig. 12.2a–c). Hybrid fixation using a locking plate and cerclage wires can be used with a stable humeral stem. Very distal fractures are treated similarly to non-periprosthetic diaphyseal humerus fractures. In the absence of bone loss and stem loosening, fixation using standard or locking plates is used with or without supplemental wires (Fig. 12.3a–c).

Treatment of periprosthetic glenoid fractures is often more complex and is completely dependent on implant stability and bone stock. These fractures typically occur with reverse shoulder prostheses. Small fractures occurring intraoperatively can be ignored if sufficient stability of the baseplate is achieved. Otherwise, long-pegged implants with extra screw fixation are a good option to maintain a steady component. If a baseplate cannot be safely implanted, staged surgery is advisable with fracture fixation occurring in the first surgery. The second stage is used for reimplantation, with or without the use of supplemental bone graft.

Outcomes

Outcomes reporting for periprosthetic humeral fractures are reserved to case series and level IV evidence [30, 34, 35, 37, 38]. Kumar et al. reported on 16 postoperative fractures occurring at a median time of 49 months from initial surgery. All fractures healed; however, those treated operatively healed in a mean time of 278 days compared to 180 days for nonoperative treatment [30]. Although this may seem counterintuitive, it is due to the initial, unsuccessful nonoperative treatment in the surgical group that lasted a mean of 123 days. Another study reviewed 21 patients with periprosthetic humeral fractures and found average time to union was 2.3 months for fractures treated surgically compared to 3.5 months for those undergoing conservative treatment [35]. Athwal et al. reviewed a large series of 45 intraoperative fractures which included 20 tuberosity fractures, 16 humeral shafts, 6 metaphyseal, and 3 combined fractures [34]. All fractures united at an average of 17 weeks although subanalysis revealed displaced shaft fractures took significantly longer to heal (mean 22.5 weeks). Overall outcomes for patients sustaining fractures around a primary arthroplasty were found to have satisfactory to excellent outcome in 24/31 patients. Fractures occurring around a revised humeral component tended to have worse outcomes, although it is not known if this is due to the revision itself. Best outcomes were found in patients with non-displaced tuberosity fractures [34].

Recently, Andersen et al. reported on 36 patients with postoperative fractures treated with ORIF or revision surgery with or without fixation [37]. All fractures in the ORIF group healed at an average time of 6.8 months, compared to 7.7 months in the revision group. A majority of patients returned to pre-fracture ASES scores regardless of the treatment modality.

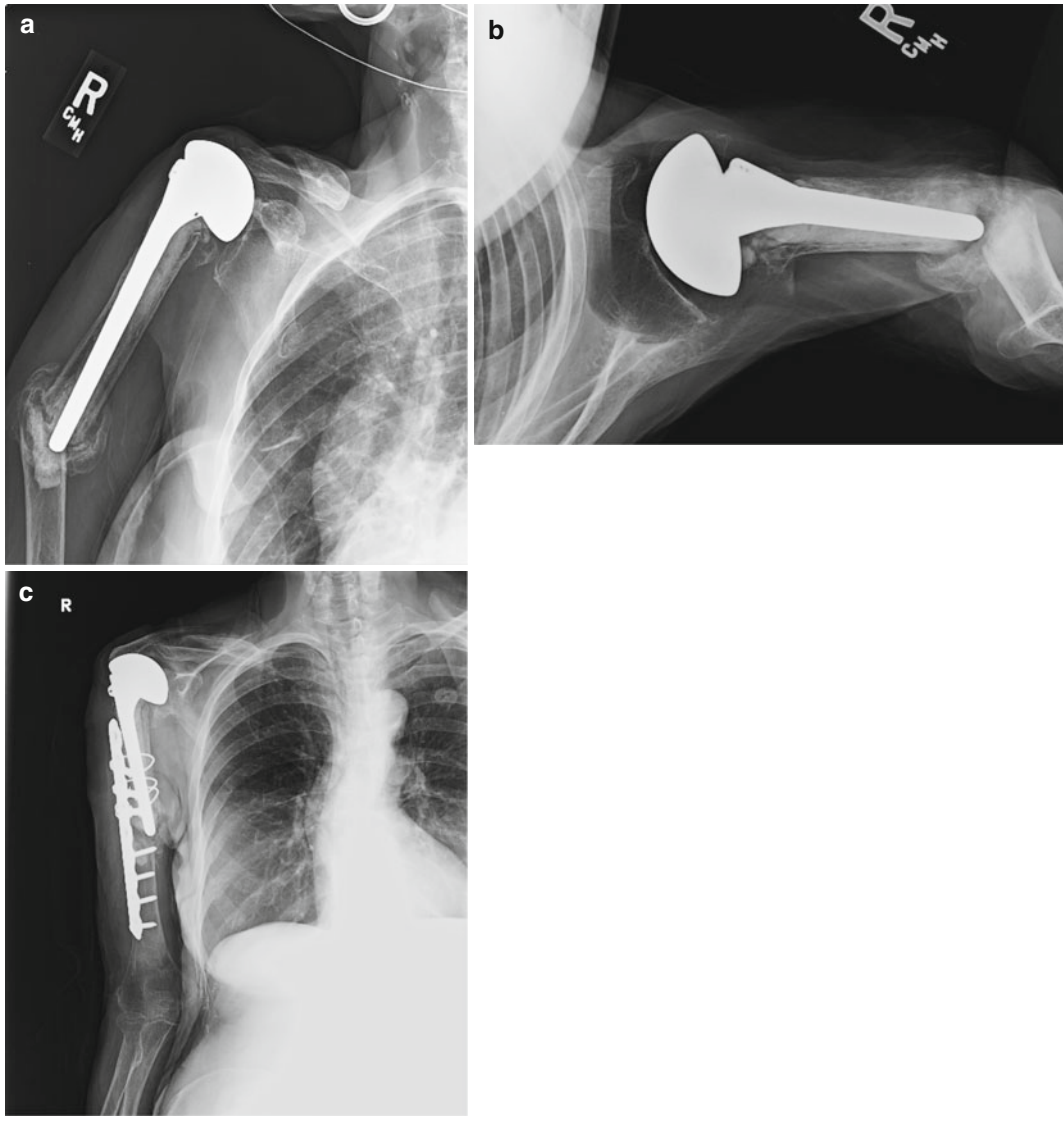


Fig. 12.2 (**a**, **b**) AP and axillary views of a Type III periprosthetic humeral fracture. (**c**) Postoperative x-ray showing treatment with open reduction and internal fixation using hybrid fixation with screws and cerclage wires

Periprosthetic humeral fractures are a rare and challenging clinical problem. Efforts should be made to prevent their occurrence by using proper operative techniques. Special care should be taken in patients with documented risk factors (osteopenia, RA, revision surgery, etc.) to avoid increasing stress on the humerus. Intraoperative fractures are treated based on location, fracture stability, and stem fixation. Postoperative fractures are treated similarly with the exception that nonsurgical management may be attempted in certain fracture patterns. Tuberosity fractures are addressed using suture or wire fixation. Unstable meta-diaphyseal fractures around a well-fixed stem are treated with plate and screw constructs with or without cerclage wires and cortical struts. Loose stems should be revised and made to bypass the fracture by at least two cortical widths. Fractures distal to the tip of the stem are treated like standard humeral shaft fractures with stable osteosynthesis that bypasses the stem sufficiently.

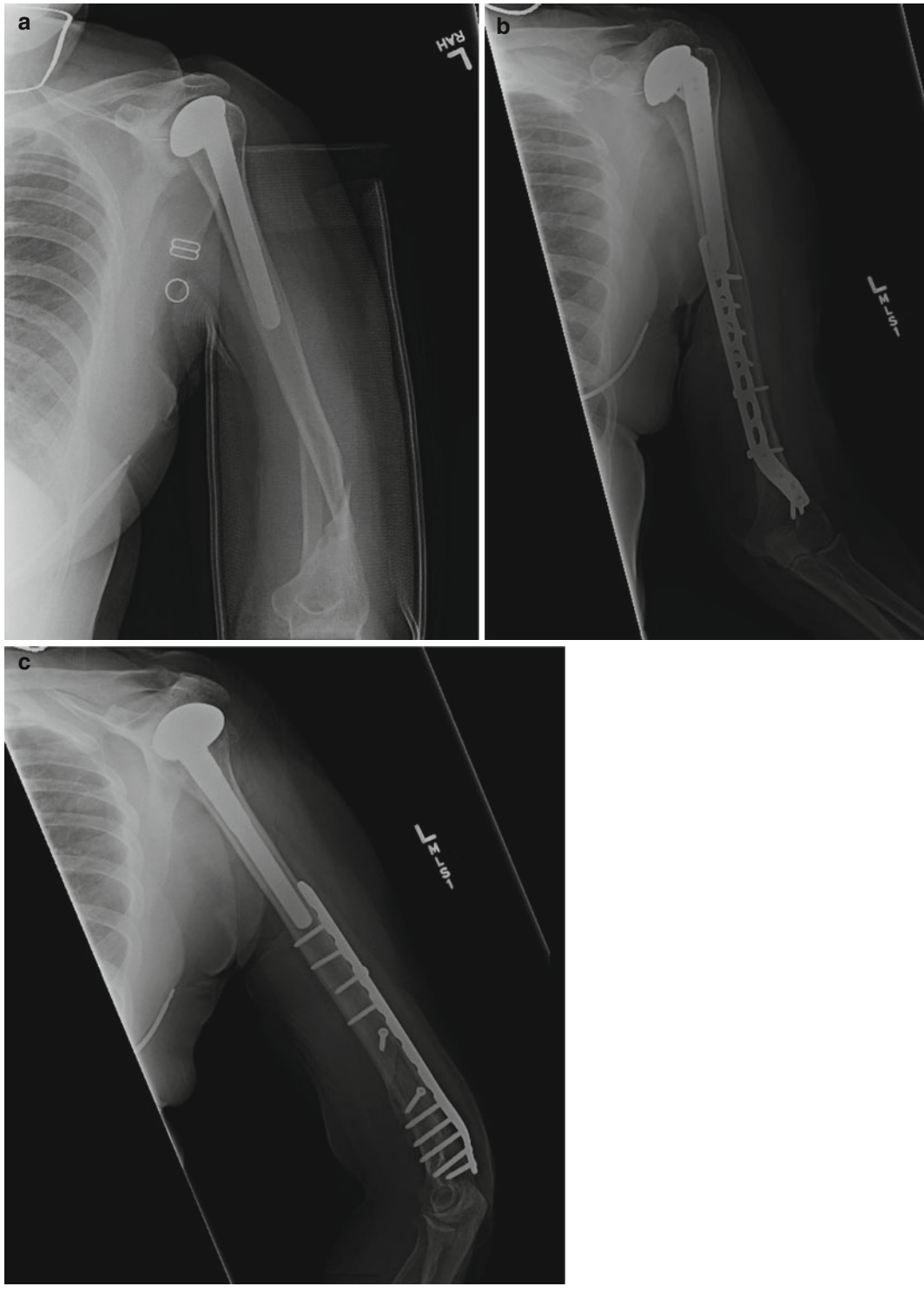


Fig. 12.3 (**a**) Preoperative X-ray for a Type IV periprosthetic fracture. (**b**, **c**) Postoperative x-rays showing open reduction and internal fixation

Shoulder Arthroplasty Instability

Instability after shoulder arthroplasty is a rare complication, occurring in about 5 % of all replacements [1, 39]. This rate has been reported to be much higher for reverse shoulder arthroplasty, up to 15–28 % [40, 41]; however this is likely due to initial learning curve reported in these early series. Instability is specific to the type of implant used. Instability following total shoulder arthroplasty is generally related to component malposition, component loosening, soft tissue deficiency, or a combination of all of these. Dislocation following reverse shoulder arthroplasty is related to component malposition, trauma, or component wear.

Instability following anatomic shoulder arthroplasty can be divided into anterior and posterior instability. Anterior instability is related to component anteversion, subscapular deficiency, or a combination of both [42, 43]. Revision for anterior instability does not usually result in renewed stability. Two large series reported that less than 50 % of patients regained stability following revision surgery [42, 44, 45]. Treatment options include component revision, subscapularis repair, pectoralis major transfer, soft tissue supplementation, and reverse shoulder arthroplasty [44, 46, 47]. Conversion to reverse shoulder arthroplasty was found to solve instability in 94 % of patients in one recent study [48].

Posterior instability is usually caused by soft tissue laxity (posterior capsule in chronically subluxated shoulders or biconcave glenoid) or excessive retroversion of components. Treatment consists of component revision, posterior capsular plication, postoperative immobilization, or revision to reverse shoulder arthroplasty. Soft tissue management and component revision resulted in 64 % of good outcomes in one study [44]. A recent series found that revision to reverse shoulder arthroplasty helped regain stability in 95 % of patients [49].

The reverse shoulder arthroplasty (RSA) is a semi-constrained implant with inherent stability provided by component shape. Postoperative instability has been reported as high as 68 %, but recent analyses estimate the incidence closer to 0–8 % [50, 51]. Component positioning has a definite impact on stability. A biomechanical study found that glenoid version had little to contribute to inherent stability, which is logical because the spherical nature of the implant should change very little with slight degrees of version change [52]. The position of the humeral component, however, greatly influences inherent stability in both the resting position and the 90° abducted position. With a neutral glenosphere, there was a 20 % increase in stability for each 10° of anteversion placed in the stem, starting at 20° of retroversion [52]. Gallo et al. reviewed the first 57 RSAs and found an overall instability rate of 15.8 %, all occurring within the first 6 months of the initial surgery [41]. They found component malposition or infection to be responsible of all cases. They concluded that the steep learning curve for reverse shoulder arthroplasty likely explains the high instability rate in this series. Another recent study reviewed all RSAs done at one institution and found a 2.9 % instability rate. The mean time to dislocation was 3.4 weeks postoperatively. All patients underwent initial attempt at closed reduction and was successful in 81 % of cases. Ultimately, 7 of 11 patients (64 %) needed revision surgery [51]. Another report describes similar success with initial treatment with closed reduction, resulting in a 62 % revision-free survival. Black et al. reported on six patients undergoing revision RSA for instability. They found only a 50 % retention rate, with two patients undergoing resection arthroplasty and a third remaining in fixed anterior dislocation [53].

Overall, instability following shoulder arthroplasty is a difficult problem to treat. Depending on the type of dislocation, initial closed reduction can be an effective treatment. Recurrent instability must be treated with revision surgery to address the cause (soft tissue deficiency, component malposition, infection.) For incurable instability in anatomic total shoulder arthroplasty, revision to reverse shoulder arthroplasty is a good salvage operation. Recurrent instability following revision reverse shoulder arthroplasty has a very poor prognosis and often leads to resection arthroplasty or hemiarthroplasty.

Subscapularis Insufficiency

Subscapularis rupture following total shoulder arthroplasty is a rare complication that can lead to pain, weakness, and instability [54]. Multiple risk factors have been described including revision operation, oversized head, subscapularis lengthening, and noncompliance with postoperative activity restrictions [54]. Also, patients with significant internal rotation contracture and insufficient release at the time of surgery are at high risk for subscapularis tear [54]. A recent biomechanical study found that a deficient subscapularis induced a compensatory decrease in force of the infraspinatus muscle. This force decrease was balanced by an increase of the supraspinatus and middle deltoid. Consequently, the deficient subscapularis induced upward migration of the humeral head with eccentric contact patterns and higher stress in the glenoid component [55]. Regardless of the method used to address the subscapularis when performing arthroplasty, function and strength of the tendon take roughly 24 months to recover [56]. Even at 2 years, only 15 % of patients return to normal function of the subscapularis [56]. Although there is no difference in functional outcomes between a subscapularis peel, tenotomy, and lesser tuberosity osteotomy [57], one advantage of the osteotomy is the ability to see failure on X-ray (Fig. 12.4). Ives et al. found that patients with a symptomatic TSA had a 51 % prevalence of subscapularis tear on ultrasound compared to 9 % in individuals with an asymptomatic TSA [58]. Ideal treatment consists of early repair with or without supplementation of a pectoralis major transfer [54, 59]. Ultimately, although patients undergoing tendon repair, with or without tendon transfer, regain most function, their objective outcomes are decreased [54].

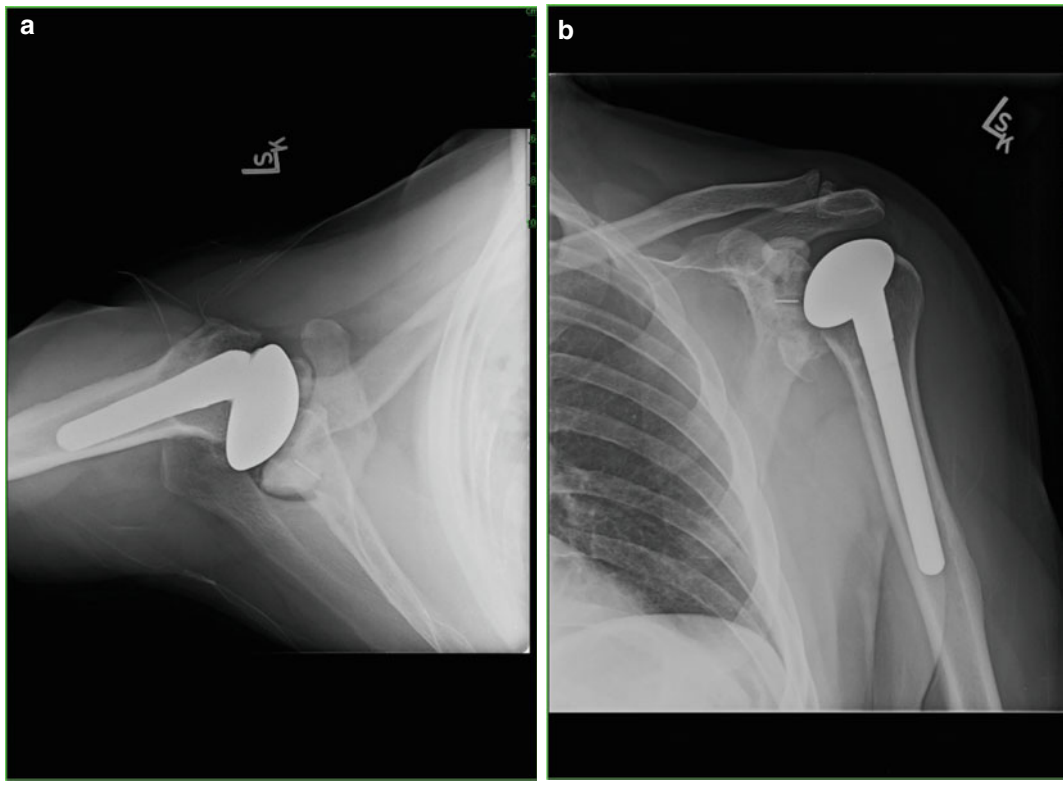


Fig. 12.4 Axillary (**a**) and AP (**b**) x-ray views of a left shoulder in a patient with early failure of a lesser tuberosity osteotomy. The tuberosity has migrated medially and inferiorly

Conclusion

Shoulder arthroplasty provides dramatic improvements in functional outcome for patients suffering from osteoarthritis. Complications of shoulder arthroplasty are rare; however, they can severely impact these outcomes. Ideally, surgeons would take every necessary precaution to avoid these complications. Unfortunately, even when all precautions are taken, some complications will undoubtedly occur. In these cases, a systematic approach to both diagnosis and treatment, as outlined in this chapter, is necessary to ensure the best possible outcomes.

References

1. Cofield RH, Edgerton BC. Total shoulder arthroplasty: complications and revision surgery. Instr Course Lect. 1990;39:449–62.
2. Sperling JW, Kozak TK, Hanssen AD, Cofield RH. Infection after shoulder arthroplasty. Clin Orthop Relat Res. 2001;382:206–16.
3. Nowinski RJ, Gillespie RJ, Shishani Y, Cohen B, Walch G, Gobezie R. Antibiotic-loaded bone cement reduces deep infection rates for primary reverse total shoulder arthroplasty: a retrospective, cohort study of 501 shoulders. J Shoulder Elbow Surg. 2012;21(3):324–8.
4. Saltzman MD, Marecek GS, Edwards SL, Kalainov DM. Infection after shoulder surgery. J Am Acad Orthop Surg. 2011;19(4):208–18.
5. Franceschini V, Chillemi C. Periprosthetic shoulder infection. Open Orthop J. 2013;7(1):243–9.
6. Topolski MS, Chin PYK, Sperling JW, Cofield RH. Revision shoulder arthroplasty with positive intraoperative cultures: the value of preoperative studies and intraoperative histology. J Shoulder Elbow Surg. 2006;15(4):402–6.
7. Schneeberger AG, Gilbart MK, Sheikh R, Gerber C, Ruef C. Non-purulent low-grade infection as cause of pain following shoulder surgery: preliminary results. Chir Organi Mov. 2009;93(Suppl 1(S1)):S71–7. Springer Milan.
8. Dilisio MF, Miller LR, Warner JJP, Higgins LD. Arthroscopic tissue culture for the evaluation of periprosthetic shoulder infection. J Bone Joint Surg J Bone Joint Surg Inc. 2014;96(23):1952–8.
9. Villacis D, Merriman JA, Yalamanchili R, Omid R, Itamura J, Rick Hatch GF. Serum interleukin-6 as a marker of periprosthetic shoulder infection. J Bone Joint Surg Am. 2014;96(1):41–5.
10. Frangiamore SJ, Saleh A, Farias Kovac M, Grosso MJ, Zhang X, Bauer TW, et al. Synovial fluid interleukin-6 as a predictor of periprosthetic shoulder infection. J Bone Joint Surg. 2015;97(1):63–70.
11. Wong Y-C, Lee Q-J, Wai Y-L, Ng W-F. Intraoperative frozen section for detecting active infection in failed hip and knee arthroplasties. J Arthroplast. 2005;20(8):1015–20.
12. Lonner JH, Desai P, Dicesare PE, Steiner G, Zuckerman JD. The reliability of analysis of intraoperative frozen sections for identifying active infection during revision hip or knee arthroplasty. J Bone Joint Surg. 1996;78(10):1553–8.
13. Grosso MJ, Frangiamore SJ, Ricchetti ET, Bauer TW, Iannotti JP. Sensitivity of frozen section histology for identifying Propionibacterium acnes infections in revision shoulder arthroplasty. J Bone Joint Surg. 2014;96(6):442–7. PubMed – NCBI.
14. Smucny M, Menendez ME, Ring D, Feeley BT, Zhang AL. Inpatient surgical site infection after shoulder arthroplasty. J Shoulder Elbow Surg. 2015;24(5):747–53.
15. Morris BJ, O'Connor DP, Torres D, Elkousy HA, Gartsman GM, Edwards TB. Risk factors for periprosthetic infection after reverse shoulder arthroplasty. J Shoulder Elbow Surg. 2015;24(2):161–6.
16. Leeming JP, Holland KT, Cunliffe WJ. The microbial ecology of pilosebaceous units isolated from human skin. J Gen Microbiol. 1984;130(4):803–7.
17. Matsen FA, Butler-Wu S, Carofino BC, Jette JL, Bertelsen A, Bumgarner R. Origin of propionibacterium in surgical wounds and evidence-based approach for culturing propionibacterium from surgical sites. J Bone Joint Surg Am. 2013;95(23):e1811–7.
18. Levy O, Iyer S, Atoun E, Peter N, Hous N, Cash D, et al. Propionibacterium acnes: an underestimated etiology in the pathogenesis of osteoarthritis? J Shoulder Elbow Surg. 2013;22(4):505–11.
19. Mook WR, Klement MR, Green CL, Hazen KC, Garrigues GE. The incidence of propionibacterium acnes in open shoulder surgery: a controlled diagnostic study. J Bone Joint Surg. 2015;97(12):957–63. PubMed – NCBI.
20. Matsen III FA, Russ SM, Bertelsen A, Butler-Wu S, Pottinger PS. Propionibacterium can be isolated from deep cultures obtained at primary arthroplasty despite intravenous antimicrobial prophylaxis. J Shoulder Elbow Surg. 2015;24(6):844–7. PubMed – NCBI.
21. Randelli P, Castagna A, Cabitza F, Cabitza P, Arrigoni P, Denti M. Infectious and thromboembolic complications of arthroscopic shoulder surgery. J Shoulder Elbow Surg. 2010;19(1):97–101.
22. Coste JS, Reig S, Trojani C, Berg M, Walch G, Boileau P. The management of infection in arthroplasty of the shoulder. J Bone Joint Surg Br. 2004;86(1):65–9.
23. Rispoli DM, Sperling JW, Athwal GS, Schleck CD, Cofield RH. Pain relief and functional results after resection arthroplasty of the shoulder. J Bone Joint Surg Br. 2007;89(9):1184–7.
24. Cuff DJ, Virani NA, Levy J, Frankle MA, Derasari A, Hines B, et al. The treatment of deep shoulder infection and glenohumeral instability with debridement,

reverse shoulder arthroplasty and postoperative antibiotics. J Bone Joint Surg Br. 2008;90(3):336–42.
25. Ince A, Seemann K, Frommelt L, Katzer A, Loehr JF. One-stage exchange shoulder arthroplasty for peri-prosthetic infection. J Bone Joint Surg Br. 2005;87(6):814–8.
26. Klatte TO, Junghans K, Al-Khateeb H, Rueger JM, Gehrke T, Kendoff D, et al. Single-stage revision for peri-prosthetic shoulder infection: outcomes and results. Bone Joint J. 2013;95-B(3):391–5.
27. Constant CR, Murley AG. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res LWW. 1987;214:160–4.
28. Strickland JP, Sperling JW, Cofield RH. The results of two-stage re-implantation for infected shoulder replacement. J Bone Joint Surg Br. 2008;90(4):460–5.
29. Sabesan VJ, Ho JC, Kovacevic D, Iannotti JP. Two-stage reimplantation for treating prosthetic shoulder infections. Clin Orthop Relat Res. 2011;469(9):2538–43.
30. Kumar S, Sperling JW, Haidukewych GH, Cofield RH. Periprosthetic humeral fractures after shoulder arthroplasty. J Bone Joint Surg Am J Bone Joint Surg Inc. 2004;86(4):680–9.
31. Krakauer JD, Cofield RH. Periprosthetic fractures in total shoulder replacement. Oper Tech Orthop. 1994;4(4):243–52.
32. Boyd AD, Thornhill TS, Barnes CL. Fractures adjacent to humeral prostheses. J Bone Joint Surg Br. 1992;74(10):1498–504.
33. Wright TW, Cofield RH. Humeral fractures after shoulder arthroplasty. J Bone Joint Surg Br. 1995;77(9):1340–6.
34. Athwal GS. Periprosthetic humeral fractures during shoulder arthroplasty. J Bone Joint Surg Br. 2009;91(3):594.
35. Campbell JT, Moore RS, Iannotti JP, Norris TR, Williams GR. Periprosthetic humeral fractures: mechanisms of fracture and treatment options. J Shoulder Elbow Surg. 1998;7(4):406–13.
36. Steinmann SP, Cheung EV. Treatment of periprosthetic humerus fractures associated with shoulder arthroplasty. J Am Acad Orthop Surg. 2008;16(4):199–207.
37. Andersen JR, Williams CD, Cain R, Mighell M, Frankle M. Surgically treated humeral shaft fractures following shoulder arthroplasty. J Bone Joint Surg J Bone Joint Surg Inc. 2013;95(1):9–18.
38. Singh JA, Sperling JW, Schleck C, Harmsen WS, Cofield RH. Periprosthetic infections after total shoulder arthroplasty: a 33-year perspective. J Shoulder Elbow Surg. 2012;21(11):1534–41. PubMed – NCBI.
39. Streubel PN, Simone JP, Sperling JW, Cofield R. Thirty and ninety-day reoperation rates after shoulder arthroplasty. J Bone Joint Surg Am. 2014;96(3):e17.
40. Trappey GJ, O'Connor DP, Edwards TB. What are the instability and infection rates after reverse shoulder arthroplasty? Clin Orthop Relat Res. 2010;469(9):2505–11. PubMed – NCBI.
41. Gallo RA, Gamradt SC, Mattern CJ, Cordasco FA, Craig EV, Dines DM, et al. Instability after reverse total shoulder replacement. J Shoulder Elbow Surg. 2011;20(4):584–90.
42. Sperling JW, Hawkins RJ, Walch G, Zuckerman JD. Complications in total shoulder arthroplasty. J Bone Joint Surg Am. 2013;95(6):563–69.
43. Wirth MA, Rockwood CA. Complications of total shoulder-replacement arthroplasty. J Bone Joint Surg. 1996;78(4):603–16.
44. Sanchez-Sotelo J, Sperling JW, Rowland CM, Cofield RH. Instability after shoulder arthroplasty: results of surgical treatment. J Bone Joint Surg. 2003;85-A(4):622–31.
45. Moeckel BH, Altchek DW, Warren RF, Wickiewicz TL, Dines DM. Instability of the shoulder after arthroplasty. J Bone Joint Surg. 1993;75(4):492–7.
46. Gee AO, Angeline ME, Dines JS, Dines DM. Shoulder instability after total shoulder arthroplasty: a case of arthroscopic repair. HSS J. 2014;10(1):88–91.
47. Endres NK, Warner JJP. Anterior instability after total shoulder replacement: salvage with modified Latarjet procedure. A report of 2 cases. J Shoulder Elbow Surg. 2010;19(2):e1–5. PubMed – NCBI.
48. Abdel MP, Hattrup SJ, Sperling JW, Cofield RH, Kreofsky CR, Sanchez-Sotelo J. Revision of an unstable hemiarthroplasty or anatomical total shoulder replacement using a reverse design prosthesis. Bone Joint J. 2013;95-B(5):668–72.
49. Walker M, Willis MP, Brooks JP, Pupello D, Mulieri PJ, Frankle MA. The use of the reverse shoulder arthroplasty for treatment of failed total shoulder arthroplasty. J Shoulder Elbow Surg. 2012;21(4):514–22.
50. Wall B, Nové-Josserand L, O'Connor DP, Edwards TB, Walch G. Reverse total shoulder arthroplasty: a review of results according to etiology. J Bone Joint Surg. 2007;89(7):1476–85.
51. Chalmers PN, Rahman Z, Romeo AA, Nicholson GP. Early dislocation after reverse total shoulder arthroplasty. J Shoulder Elbow Surg. 2014;23(5):737–44.
52. Favre P, Sussmann PS, Gerber C. The effect of component positioning on intrinsic stability of the reverse shoulder arthroplasty. J Shoulder Elbow Surg. 2010;19(4):550–6.
53. Black EM, Roberts SM, Siegel E, Yannopoulos P, Higgins LD, Warner JJP. Failure after reverse total shoulder arthroplasty: what is the success of component revision? J Shoulder Elbow Surg. 2015;24(12):1908–14.
54. Miller BS, Joseph TA, Noonan TJ, Horan MP, Hawkins RJ. Rupture of the subscapularis tendon after shoulder arthroplasty: diagnosis, treatment, and outcome. J Shoulder Elbow Surg. 2005;14(5):492–6.
55. Terrier A, Larrea X, Malfroy Camine V, Pioletti DP, Farron A. Importance of the subscapularis muscle after total shoulder arthroplasty. Clin Biomech (Bristol, Avon). 2013;28(2):146–50.

56. Lapner PLC, Wood KS, Zhang T, Athwal GS. The return of subscapularis strength after shoulder arthroplasty. J Shoulder Elbow Surg. 2015;24(2):223–8.
57. Lapner PLC, Sabri E, Rakhra K, Bell K, Athwal GS. Comparison of lesser tuberosity osteotomy to subscapularis peel in shoulder arthroplasty: a randomized controlled trial. J Bone Joint Surg Am. 2012;94(24):2239–46.
58. Ives EP, Nazarian LN, Parker L, Garrigues GE, Williams GR. Subscapularis tendon tears: a common sonographic finding in symptomatic postarthroplasty shoulders. J Clin Ultrasound. 2013;41(3):129–33.
59. Nelson GN, Namdari S, Galatz L, Keener JD. Pectoralis major tendon transfer for irreparable subscapularis tears. J Shoulder Elbow Surg. 2014;23(6):909–18.

Rehabilitation of Shoulder Arthroplasty

13

John J. Basti

Total shoulder arthroplasty is most frequently used to eliminate pain and restore function for an array of conditions that cause destruction of the articular surfaces of the glenohumeral joint and surrounding soft tissue [1–5]. Optimizing the patient response to these types of surgeries is multifactorial. A positive surgical experience combined with a well-designed postoperative rehabilitation program, including patient education, is key a component to a positive outcome. Several factors contribute to a successful outcome: the pathological condition of the joint, the quality of the bone and soft tissues, the status of the rotator cuff and deltoid, the overall condition of the patient, and their ability to perform, execute, and comply with the rehabilitation program [6, 7]. The team approach is advocated with ongoing communication between the surgeon, patient, and therapist as the rehabilitation program is developed and implemented at each phase of the progression. Rehabilitation of the shoulder can be challenging. The shoulder is a complex structure that has five articulations, i.e., the glenohumeral joint, the coracoacromial articulation, the acromioclavicular joint, the sternoclavicular joint, the only attachment to the axial skeleton, and the scapular thoracic articulation. With little bony stability at the glenohumeral joint, shoulder function for the upper extremity and hand placement is most reliant on the surrounding soft tissues, the capsule, ligaments, rotator cuff, deltoid, and periscapular muscles for static and dynamic stability. Attaining an optimal outcome, establishing normal motion, dynamic stability, and strength is the result of a well-performed surgery, an adaptive progressive system of rehabilitation directed by the surgeon, implemented and executed by the therapist in concert with a cooperative, engaged, and educated patient.

Shoulder rehabilitation for patients with symptoms following trauma or surgery is an essential component for a good recovery. A positive surgical outcome and team approach comprised of the surgeon, therapist, and patient with a well-designed and well-implemented rehabilitation program enhanced by ongoing communication lend itself to improved and hopefully optimal outcomes.

J.J. Basti, PT
Columbia Shoulder and Elbow Society,
Center for Shoulder, Elbow & Sports Medicine,
Columbia University Medical Center,
New York, NY, USA
e-mail: jb.ptra@gmail.com

Treatment Principles

Treatment principles are the cornerstone of a well-organized and appropriately administered rehabilitation program and are as follows:

One: Performing a thorough initial evaluation following the surgical procedure is the first step in

© Springer International Publishing Switzerland 2016

A.D. Armstrong, A.M. Murthi (eds.), *Anatomic Shoulder Arthroplasty*,
DOI 10.1007/978-3-319-29164-2_13

establishing trust in the patient/therapist professional relationship. Obtaining a history with subjective and objective measurements will convey the patient's general postoperative state, their pain level, and their level of understanding of what was done and what's expected, their physical impairments, and functional limitations which are critical points for developing a level of effective intervention.

Two: Control pain and swelling using appropriate analgesics and pain medication coordinated with exercise to limit pain, muscle guarding, and spasm. Application of heat/ice and other physical therapy modalities such as gentle mobilization and therapeutic massage are effective adjuncts to exercise. *Three*: The notion of early passive motion tailored to the surgical repair has been supported in the literature to establish motion and limit the effect of postsurgical soft tissue scarring and adhesions. Strengthening is better served when range of motion has been regained and reactivity has diminished. This is the first step in the rehabilitation process preparing the patient for active assistive and active motion as flexibility and healing progresses [6–8].

Four: The scapular plane has been defined as the plane of maximal elevation [8] (Fig. 13.1). This plane allows the humeral head to be centered on the glenoid and the capsule to be relaxed with appropriate tension on the surrounding ligaments and muscles. Moving the extremity in this plane is more comfortable postoperatively and maximizes functional elevation [7, 8].

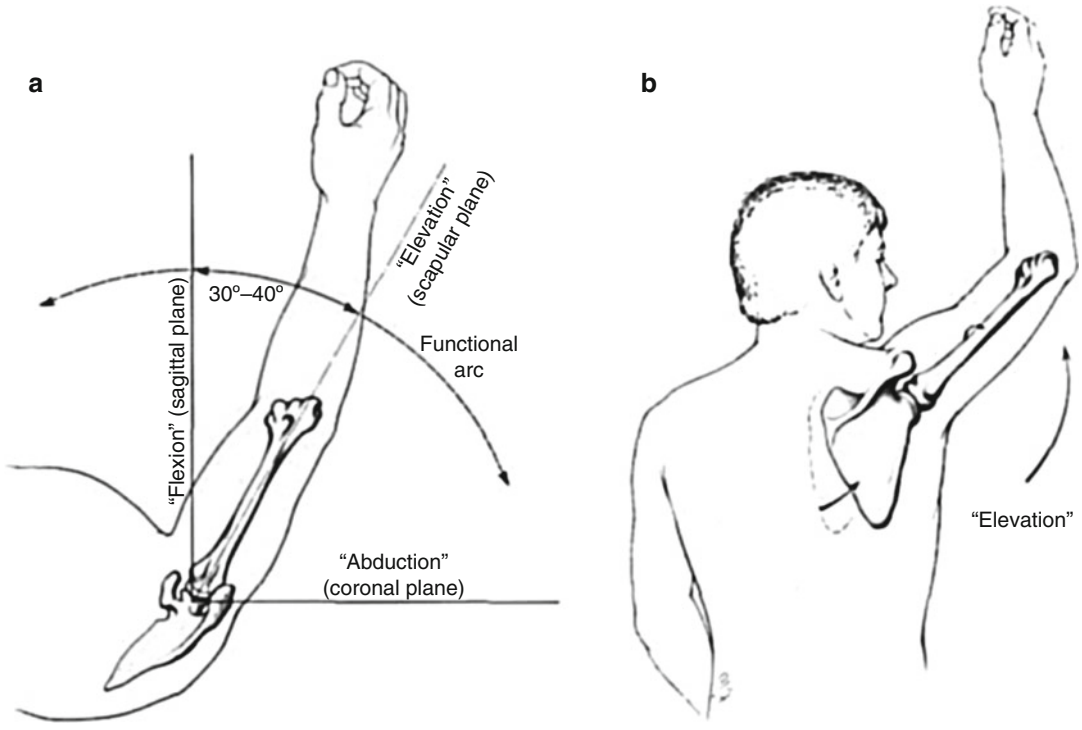


Fig. 13.1 Scapular plane. The plane of maximal elevation is centered on the scapular plane, rather than the coronal plane (abduction) or sagittal plane (flexion). Shoulder movements should be thought to be centered on this plane because (**a**) the capsule of the glenohumeral joint is most relaxed in the scapular plane, allowing the highest upward excision, with the greatest ease and freedom of movement, and (**b**) the glenohumeral joint is most often used in this plane. Movements here occur more naturally and with less effort. The body may be rotated to cause the arm to be raised in the scapular plane rather than the coronal plane. The concept is stressed in the postoperative exercise program (From Neer [12], by permission of WB Saunders)

Five: Proximal and distal joints should be incorporated into the program. Elbow, wrist, and hand motion facilitates improved circulation and reduces edema and stiffness. Attention to proximal musculature provides dynamic stability to the scapula; thus the glenohumeral joint is addressed later in the program, while glenohumeral motion is established.

Six: With patients who have stiffness, the rehabilitation program focuses on range of motion, stretching, and flexibility exercise. With patients who have good flexibility but weakness, the program focuses on strengthening.

Seven: Patient education, compliance, and participation in a home program are some of the most important aspects of the postoperative program. Patients should be given written instruction with the home program providing a clear understanding of the exercise. Review of the use of pain medication and appropriate use of heat and ice should be explained. Lying or sleeping flat in the supine position is rarely tolerated. Positioning for comfort should be demonstrated (a recliner, when possible, with a pillow under the arm in a neutral position (scapular plane) semi-reclined for the shoulder to be above the heart, relative to gravity, facilitating circulation and edema control) with instruction to family and friends.

Eight: Having a good understanding of the surgical procedure, the soft tissue reconstruction and the understanding of early protection of certain structures direct the therapist, tailoring the exercise program to the patient. The exercise program incorporates a progression of passive, active assistive range of motion, gentle isometrics, and active exercise, which initiates strengthening, followed by advanced stretching and progressive resistive exercise [9–13].

Shoulder Arthroplasty and Considerations in Rehabilitation

The indications for shoulder arthroplasty have been well established.

Osteoarthritis is the most common indication for shoulder arthroplasty [2, 7, 14–16]. These patients generally present with significant pain and globally restricted motion, especially external rotation. Rehabilitation focuses on range of motion and flexibility first and then strengthening since these patients usually develop good strength. The soft tissues in this process are preserved but retracted and stiff. Rotator cuff tears occur in only 5–10 % having little effect on outcome since they are usually small 1 cm tears [5, 17]. Rheumatoid arthritis and other inflammatory conditions account for approximately 30 % of all total shoulder replacements. More care must be given to the soft tissues during surgery and rehabilitation secondary to the progressive chronic inflammatory nature of this systemic disease. Rotator cuff tears are significantly higher in these patients and can occur up to 50 % with an average of 25 % occurrence [18]. Rehabilitation is focused on preventing stiffness with gentle range of motion with the limits determined at the time of surgery protecting the rotator cuff repair. In addition, other joint involvements are considered and may necessitate altering and modifying exercises. These patients usually develop good mobility but are slower gaining strength.

Arthritis of instability falls into two categories, patients who have chronic recurrent dislocation and/or subluxation and those who have had a previous surgical procedure for instability [14]. The patients who have had prior instability surgery tend to be at a younger age with a higher incidence found in the male population [5]. One or more traumatic dislocations can put the individual at risk of developing osteoarthritis of the glenohumeral joint [14, 19]. Stability at the glenohumeral joint is dependent on the balance of the soft tissue envelope surrounding the glenohumeral joint. Patients with instability who undergo surgical stabilization procedures, if not done properly, develop the risk of articular cartilage damage which can result in shoulder arthroplasty. In instances where staples and screws and other hardware are used, migration and malposition can result in additional cartilage damage [20]. In other instances, over-tightening the soft tissues in an attempt to restore stability to either side of the glenohumeral joint for anterior instability or missed multidirectional instability can result in

displacement of the humeral head to the nonoperated (unaddressed) side; this results in a chronically subluxed humeral head away from the surgically repaired side with the consequence of disabling pain, progressive cartilage wear, soft tissue contracture, bone loss, and loss of motion [14, 21].

Rehabilitation Program

The postoperative rehabilitation program is decided at the time of surgery. Usually the program is initiated on the same day as surgery; however, a modification during the surgical procedure may necessitate an alteration in the normal progression of postoperative rehabilitation and may be deferred. With the use of regional anesthesia, the patient is comfortable and can be moved without pain to the passive limits set in surgery. It is believed that early passive motion tailored to the surgical procedure is the cornerstone to a successful outcome, provided the bony repair and soft tissues are not overstressed and adequate pain control is achieved [3, 6–8, 14, 21]. Early passive motion is one of the most important aspects of the rehabilitation program. The application and assessment of intensity of exercise were defined by Mccann et al. [22]. Their electromyographic study of shoulder rehabilitation exercises forms the foundation of this present exercise program. They found that in the supine position, passive external rotation and forward flexion generated the least electrical activity of the rotator cuff and deltoid [22]. They found that there was less activity in the middle deltoid and supraspinatus muscles with the elbow bent versus straight during passive motion. Of course all motion was directed in the plane of the scapula and when compared to elevation with the elbow straight muscle activity was consistently less. It is therefore recommended that early passive motion in the plane of the scapula be performed with a bent elbow. They also felt that verbal cues to relax and to let the arm hang like a "rag doll" further reduced muscle activity [22]. Passive range of motion limits is usually set at 130° of forward elevation in the plane of the scapula and 30° of external rotation. Reverse total shoulder patients may be protected in a sling for 6 weeks or moved to 0° external rotation and 90° of forward elevation which is at the discretion of the surgeon. With the inter-scalene block in place eliminating pain, the patient sees how freely the extremity moves with the new replacement. As the block wears off, the patient begins to regain feeling; however, they are medicated to reduce the intensity of the postoperative pain. Patients are instructed to take their arm out of the sling and do elbow flexion and extension and wrist and hand motion frequently throughout the day. Patients are also instructed in pendulum exercises originally described by Codman (Fig. 13.2). The exercise was originally a momentum exercise. Swaying and rotation of the body implemented a momentum that provided passive painless motion at the glenohumeral joint with the patient bent forward. Teaching these exercises is sometimes a challenge; however, with the patients who have difficulty, teaching them to bend forward and

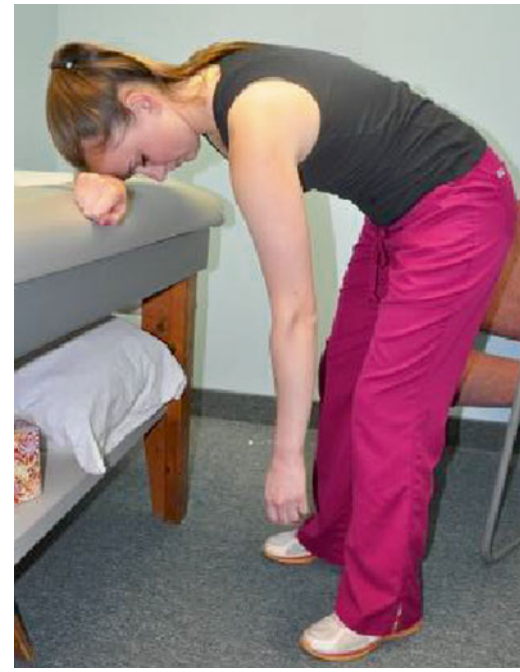


Fig. 13.2 Patient bends forward at the waist supporting the trunk with the uninvolved arm on top of a counter top or dresser. Relax your operated arm, letting it hang straight down. Gently begin to rock your body allowing momentum to move the extremity in small circles, clockwise and counterclockwise

place there opposite extremity on a table or countertop to stabilize their proximal musculature protecting their back facilitates the exercise adequately. Having the upper extremity hang in the dependent position exerts gentle traction with the weight of the extremity reducing the amount of pain, muscle spasm, and tightness at the shoulder complex, accomplishing the goal of the exercise. Gentle small circles clockwise with the thumb leading and palm forward and counter clockwise with thumb leading and palm facing back are gently initiated by the patient. In this case the pendulum is considered a relaxation exercise and a warm-up exercise and a good precursor to following exercises. Supine or semi-reclined passive external rotation in the plane of the scapula is then initiated by the therapist. The patient should be positioned with a pillow underneath the arm keeping it in neutral position avoiding extension with the elbow slightly away from the side (Fig. 13.3). Small circular motions are started with the upper extremity supported at the elbow and held at the wrist. Gentle external rotation is started to the limits of range designated at the time of surgery, usually 30°, or to a point where pain and stiffness are beginning. Forward elevation is accomplished in the same manner to a limit of 130° (Fig. 13.4). Slow easy motion with constant verbal cues to relax and let go is given during these exercises. This approach facilitates trust and cooperation enhancing the relaxation effect to accomplish the goals of treatment. Guarding and resistance with these exercises put the repair at risk whether it is tuberosity fixation, subscapularis repair, or rotator cuff repair. As the surgical procedure permits, usually days 2–3, supine active assistive external rotation with the stick (Fig. 13.5) is initiated followed by

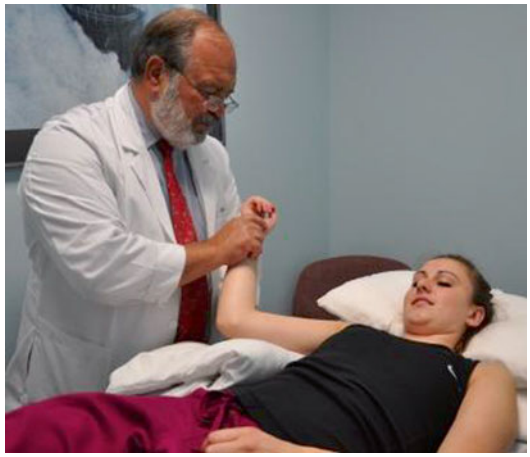


Fig. 13.3 Patient lies supine with pillow supporting elbow comfortably at the side in the plane of the scapular. The therapist supports the wrist and elbow. Passive external rotation is performed to set limits, usually 30°, accompanied by verbal ques to relax the arm

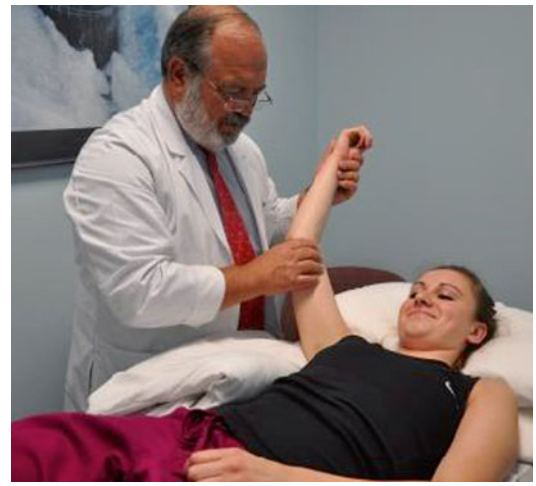


Fig. 13.4 Patient lies supine with pillow supporting elbow comfortably at the side in the scapular plane. The therapist supports the wrist and elbow. Passive forward flexion is performed to set limits, usually 130°, accompanied by verbal ques to relax the arm

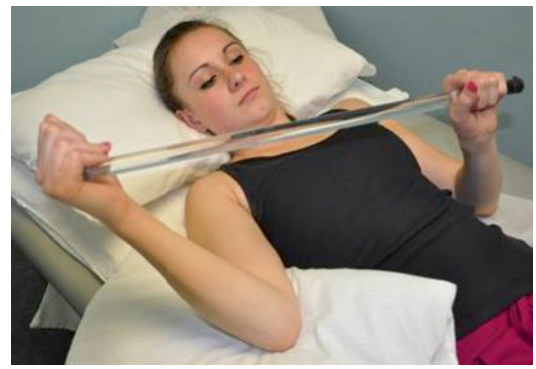


Fig. 13.5 Patient lies on their back with a pillow under the arm. Patient holds a stick with the involved end positioned into the palm. The good hand pushes the affected hand gently outward with the stick. Return to starting position

active assistive supine forward elevation (Fig. 13.6). Patients are instructed in range of motion exercises with the goals of maintaining and accomplishing 30° of external rotation and 130° of elevation. The supine position is preferred since this allows the individual to relax the trunk and cervical muscles and focus on the shoulder. If a physical condition precludes this position, semi-reclined or sitting positions are reverted too. The patients are instructed to proceed to the point of stiffness when performing their exercises and move into it a slight amount to create a gentle stretch and tension but not pain. A count of five to ten with a hold is recommended and then a return to the neutral position with one or two easy short arc oscillations to help with relaxation before repeating the exercise. The exercises are usually repeated for ten repetitions. In the performance of the pulley exercises, the pulley block is located over the shoulder of the operated side so that elevation performed by the opposite extremity elevates the affected extremity in the plane of the scapula (Fig. 13.7). Putting the pulley over the head will bring the upper extremity across the body putting undue stress on the posterior capsule and soft tissues. Patients usually experience pain and have reduced motion when early exercises are performed out of the plane of the scapula. Increased EMG activity of the deltoid and spinati muscles was noted with pulley exercises suggesting more active muscle contraction [22]. Therefore they are deferred with arthroplasty with rotator cuff repairs for fear of re-tear. In these cases pulleys are usually started at 6 weeks or when the surgeon deems that the repair is stable. Independent exercise while in the hospital is encouraged along with review of the exercises with the patient to ensure good execution and understanding of the exercises. Upon discharge the patients are cautioned about the development of a temperature greater

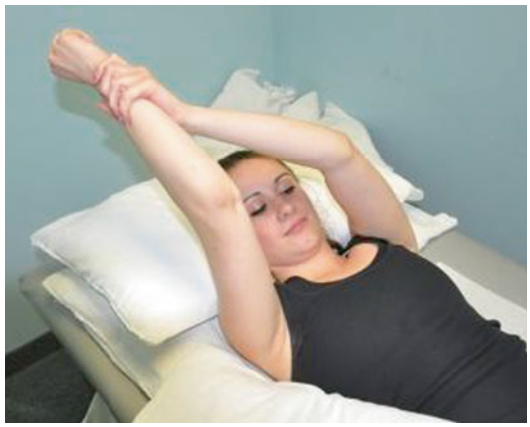


Fig. 13.6 Patient lies on their back with the pillow under the involved arm. With their good hand, they reach across and grasp the involved wrist. The patient smoothly pulls the arm upward above the head

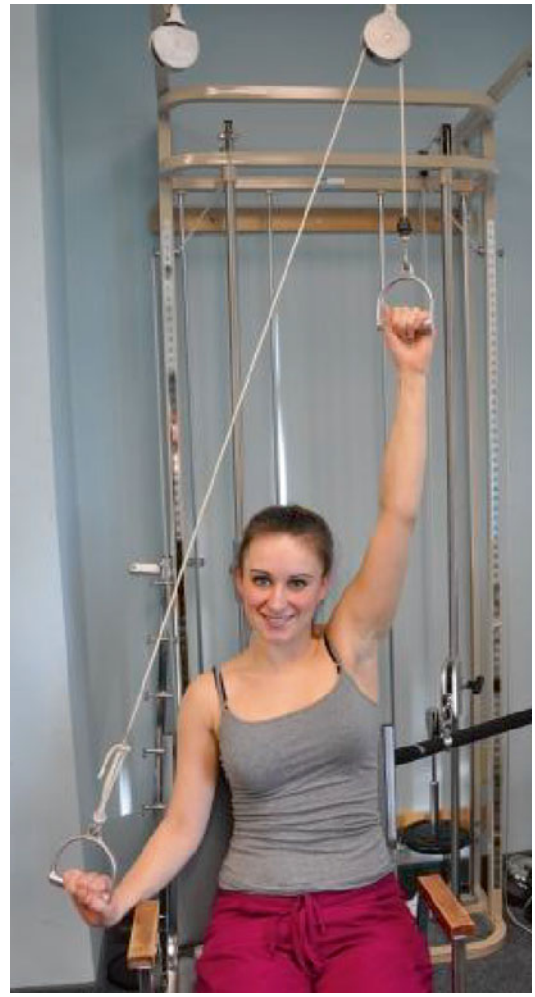


Fig. 13.7 Sit on a chair with the pulley block positioned over the operated shoulder. Patient relaxes the involved arm, while the good arm pulls the involved arm above the head. Gently lower to start position

than 101° Fahrenheit, the onset of severe pain not relieved by medication, intolerance to the pain medication, excessive bleeding from the surgical site, or any additional physical symptoms they may be experiencing.

Outpatient Rehabilitation

After a detailed history and physical exam, goals can be established and a progressive safe outpatient rehabilitation experience can be initiated. Establishing a good rapport with the patient and communicating with the surgeon are the first steps in this process. A postoperative report is very helpful and ensures proper care and supports early safe rehabilitation since the therapist is more aware of what was done at the time of surgery and reinforces the precautions followed during rehabilitation. Review of a home program, including the exercises being performed, the importance of coordinating pain medication with exercises, positioning for comfort, as well as any concerns or difficulty the patient may be experiencing, should be addressed, reviewed, and discussed. The exercise program is initiated and complemented with the use of heat/ice and electrical modalities, followed by gentle mobilization for accessory motion and therapeutic massage to reduce pain, muscle spasm, and stiffness in preparation for exercise.

Active assistive exercises continue for 6 weeks including pendulum, supine external rotation with the stick, active assistive forward flexion supine, and pulley exercises following total shoulder replacement with an intact rotator cuff (Table 13.1). Extension (Fig. 13.8) and internal rotation (Fig. 13.9) are avoided for 6 weeks since they put tension on the repaired subscapularis and arthroplasty with rotator cuff repair for risk of re-tear (Tables 13.2 and 13.3).

Isometric exercise can be initiated at 6–9 days submaximally. A gentle progression of external rotation, flexion, abduction, and extension (Fig. 13.10) is introduced. Internal rotation is deferred since isometrics significantly increase the amount of muscle activity of the subscapularis when evaluated by EMG [22]. Internal rotation resistance is avoided for 6 weeks. Patient's reactivity should be followed with appropriate adjustment of the exercise. Younger patients with

Table 13.1 TSR, intact RC sling 2–3 weeks, and then PRN

Time post-op	Exercise	Exercise program
1–2 days	EPM (early passive motion)	Supine ER to 30°
		Supine FF to 130°
		Elbow/wrist/hand ROM
		Pendulum
3 days	Active assistive	Pendulum
		ER w/stick (to 30°)
		FF (to 130°), pulleys
		No IR[a] no exit. w/stick[a]
6–9 days	Isometrics	ER (no IR), anterior
		Deltoid, posterior deltoid,
		Middle deltoid, multi-angle
Goals: control pain and swelling, protect the anterior capsule and subscapularis tendon repair, prevent adhesion formation, increase ROM (scapular plane), educate (importance of medication, ice heat application, compliance to the program, frequent gentle exercise, rest, positioning for comfort at home, family friend instruction), establish a well-understood home program, with a gradual introduction of exercises		
10 days	Active	Supine FF w/stick
		Supine Ff w/stick + weight (1–2 lb)
		Supine FF
		ER side lying
		Eccentric pulleys
		Standing press w/stick
		Eccentric standing press w/stick
		Prone Ext./Abd to midline
6 weeks	Advanced stretching	Follow exercise figures
	Resistive (scapular)	Follow exercise figures
Goals: control pain and swelling, increase active ROM, increase strength, develop neuromuscular control of the shoulder complex, increase proprioception, normalize response to dynamic challenges		

FF forward flexion, *ER* external rotation, *Abd* abduction, *w* with, *TSR* total shoulder replacement
[a]Ext. (extension) and IR (internal rotation): not performed until 6 weeks post-op

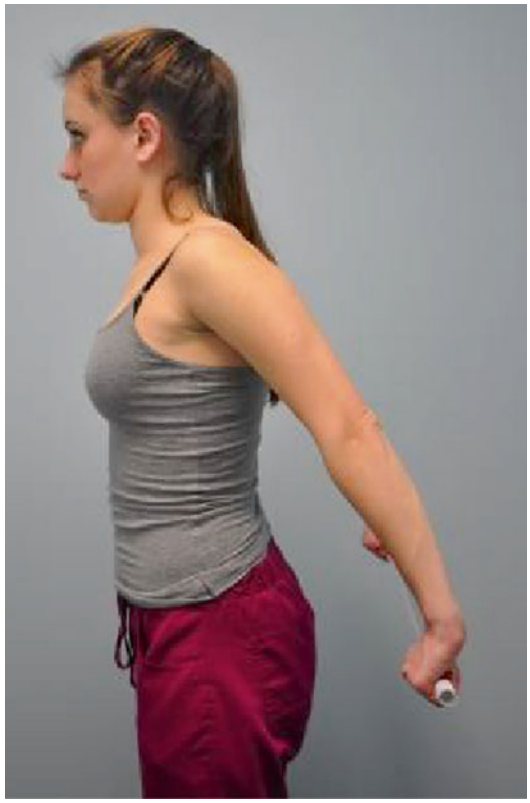


Fig. 13.8 Patient grasps stick behind back. Using your good arm to supply the power, push the stick backward and stretch

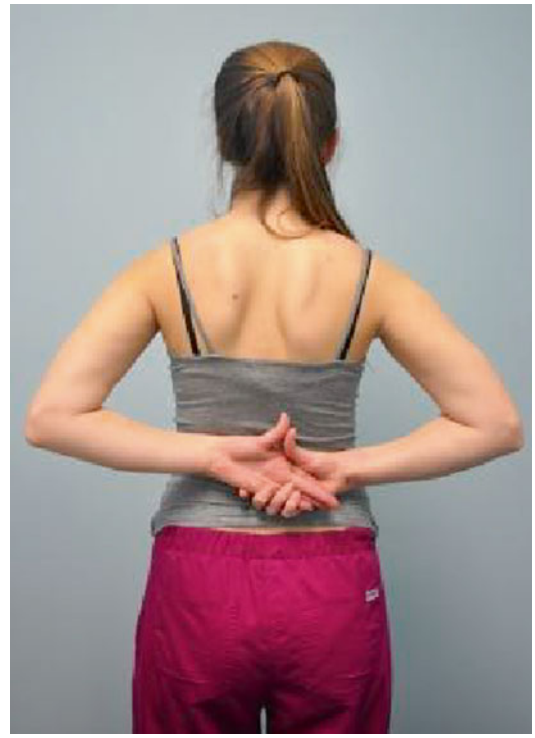


Fig. 13.9 Use your good hand to grasp the involved wrist. Let the good hand supply the power to slide up the middle of the back

good strength move quickly through this phase. Older patients with long-standing pathology may be slower to respond to this process. In patients with small to medium rotator cuff tears, isometrics are not initiated until 2–3 weeks. With the larger massive repairs, submaximal progressing to maximal isometrics is started at approximately 6–8 weeks.

Active Exercise (Early Strengthening)

Application of exercise is a procedure and soft tissue repair dependent. This phase of the exercise program is comprised of initial closed loop supine forward flexion using a stick. This allows the patient to actively use the deltoid and rotator cuff with reduced load in the supine position with the support and stability from the opposite extremity avoiding pain (Fig. 13.11). As the patient becomes more comfortable with that exercise, a 2 lb weight (Fig. 13.12) is added to improve strength in the supine position. The patient then progresses to active supine forward flexion with the extremity alone (Fig. 13.13). This can be initiated at 10 days after total shoulder replacement and humeral head replacement with an intact rotator cuff. Arthroplasty with rotator cuff tear due to the requirement of bone and soft tissue healing is begun at 4–6 weeks and as late as 8 weeks with massive rotator cuff tears. Side-lying external rotation is initiated in this phase with a bolster between the elbow and trunk to maintain the glenohumeral joint in the plane of the scapula (Fig. 13.14). The loading of the shoulder is then progressed to eccentric pulleys in the sitting position (Fig. 13.15). This helps the patient begin to reestablish neuromuscular control of the rotator cuff, deltoid, and periscapular muscles. This exercise is comfortable and protected under full control of the patient

Table 13.2 TSR, w/cuff involvement, medium repair approx. 2–3 cm

Time post-op	Exercise	Exercise program
1–2 days	EPM (early passive motion)	Supine ER to 30°
		Supine FF to 130°
		Elbow/wrist/hand ROM
		Pendulum
3 days	Active assistive	Pendulum
		ER w/stick (to 30°)
		FF (to 130°), pulleys
		No IR[a] no Ext. w/stick[a]
2–3 weeks	Isometrics	ER (no IR), anterior deltoid
		Posterior deltoid
		Middle deltoid, multi-angle
Goals: control pain and swelling, protect the anterior capsule and subscapularis tendon repair, prevent adhesion formation, increase ROM (scapular plane), educate (importance of medication, ice/heat application, compliance to the program, frequent gentle exercise, rest, positioning for comfort at home, family/friend instruction), establish a well-understood home program, with a gradual introduction of exercises		
3–4 weeks	Active	Supine FF w/stick
		Supine FF w/stick + weight (1–2 lb)
		Supine FF
		ER side lying
		Eccentric pulleys
		Standing press w/stick
		Eccentric standing press w/stick
		Prone Ext./Abd
6 weeks	Advanced stretching	Follow exercise figures
	Resistive (scapular)	Progress as tolerated
Goals: control pain and swelling, increase active ROM, increase strength, develop neuromuscular control of the shoulder complex, improve proprioception, normalize response to dynamic challenges		

Sling 2–3 weeks and then PRN
FF forward flexion, *ER* external rotation, *Abd* abduction, *w* with, *TSR* total shoulder replacement
[a]Ext. (extention) and IR (internal rotation) not performed until 6 weeks post-op

Table 13.3 TSR, w/cuff involvement large rotator cuff repair 3–5 cm massive repair >5 cm

Time post-op	Exercise	Exercise program
1–2 days	EPM (early passive motion)	Supine ER to 30°
		Supine FF to 130°
		Elbow/wrist/hand ROM
		Pendulum
6–8 weeks	Active assistive	Pendulum
		ER w/stick (to 30°)
		FF (to 130°), pulleys
		No IR[a] no Ext. w/stick[a]
6–8 weeks	Isometrics	ER (no IR), anterior
		Deltoid, posterior deltoid,
		Middle deltoid, multi-angle
Goals: control pain and swelling, protect the anterior capsule and subscapularis tendon repair, prevent adhesion formation, increase ROM (scapular plane), educate (importance of medication, ice/heat application, compliance to the program, frequent gentle exercise, rest, positioning for comfort at home, family/friend instruction), establish a well-understood home program, with a gradual introduction of exercise		
8 weeks	Active	Supine FF w/stick
		Supine FF w/stick + weight (1–2 lb)
		Supine FE
		ER side lying
		Eccentric pulleys
		Standing press w/stick
		Eccentric standing press w/stick
		Prone Ext./Abd
12 weeks	Advanced stretching	Follow exercise figures
	Resistive (scapular)	Progress as tolerated
Goals: control pain and swelling, increase active ROM, increase strength, develop neuromuscular control of the shoulder complex, improve proprioception, normalize response to dynamic challenges		

Sling 6–8 weeks
FF forward flexion, *ER* external rotation, *Abd* abduction, *w* with, *TSR* total shoulder replacement
[a]Ext. (extention)/IR (internal rotation and performed until 10–12 weeks post-op)

while the hand follows the dowel down to a resting position. Standing press with the stick (Fig. 13.16) is advanced to an eccentric exercise (Fig. 13.17) which incrementally further loads and challenges the shoulder. With this progression of exercises, the therapist should be mindful of altered mechanics such as a shoulder shrug indicating weakness

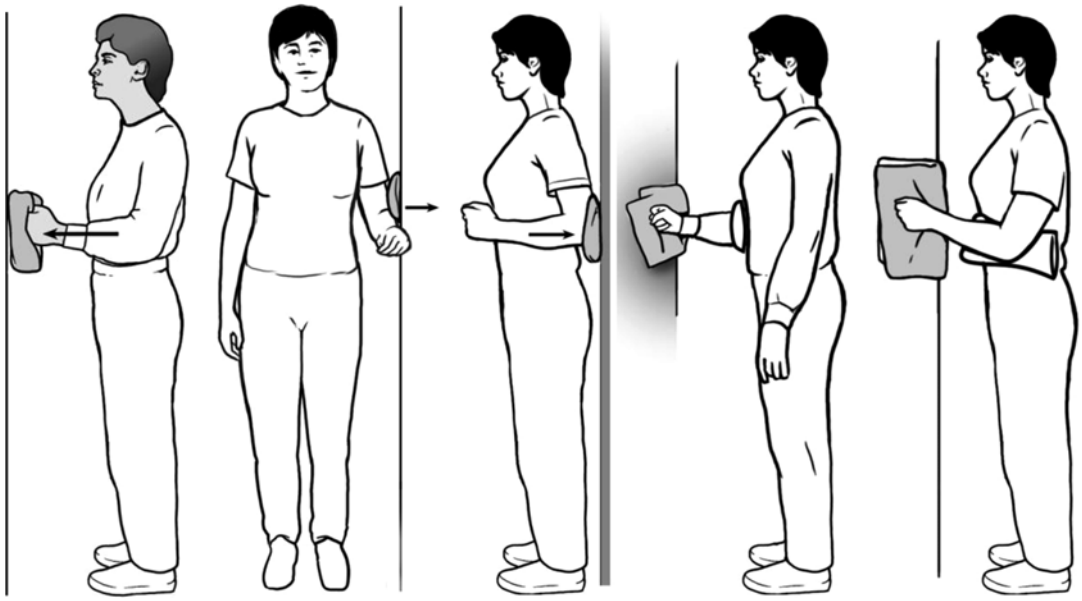


Fig. 13.10 Place towel between the extremity and door frame. Push into door frame first flexion, followed by abduct, extension, external rotation, and internal rotation. Hold for the count of five to ten submaximal contractions at first

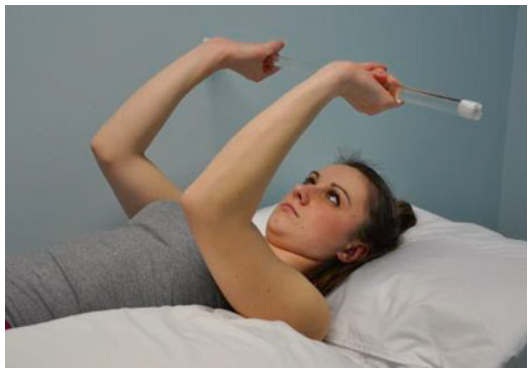


Fig. 13.11 Hold stick in both hands and raise over head with the assist of the nonoperated arm

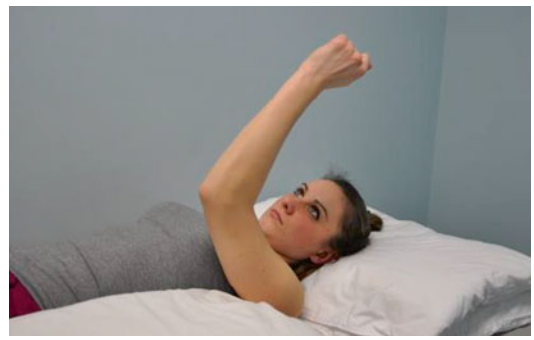


Fig. 13.13 The patient elevates in the supine position starting with a bent elbow at 90° and straightens arm as they reach up over head

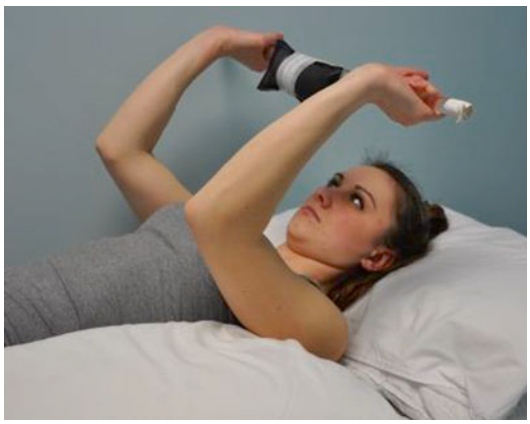


Fig. 13.12 Hold stick in both hands and raise overhead with a 1–2 lb weight

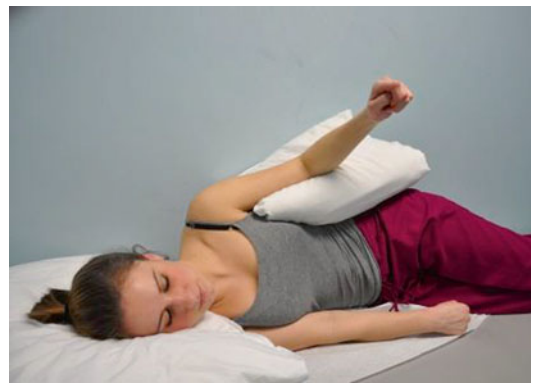


Fig. 13.14 With a bent elbow at 90° supported on a pillow, the patient slowly raises their hand away from the body

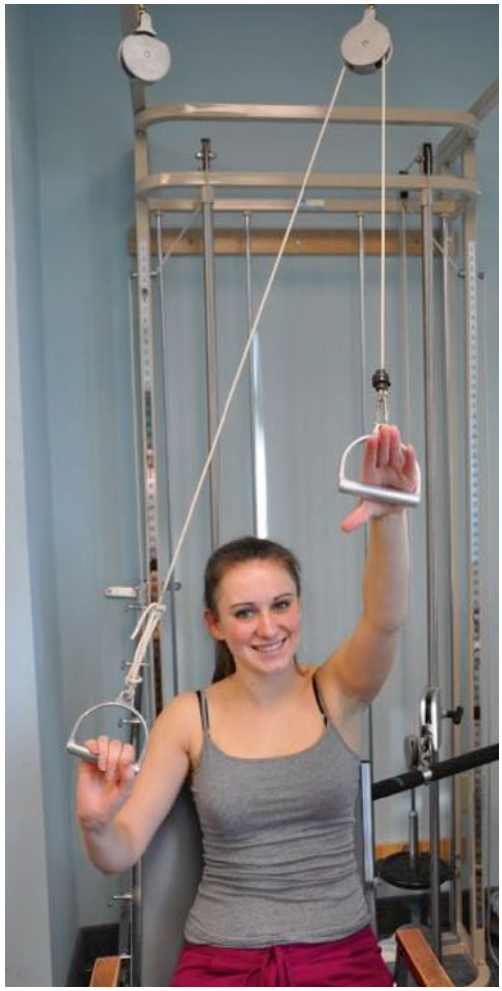


Fig. 13.15 Patient raises the involved arm as high as it can go with the pulley; open the hand and slowly follow the handle down to the starting position

and overloading of the rotator cuff and its inability to maintain the humeral head centered on the glenoid. The patient should return to the previous exercise and continue to strengthen until good mechanics are achieved before advancing. Failure to do this will result in impingement with riding up of the humeral head under the coracoacromial arch creating an inflammatory response of the underlying soft tissue. With a watchful attentive therapist, this pitfall can be avoided. Prone extension (Fig. 13.18) and abduction (Fig. 13.19) are then initiated to isolate the posterior structures during strengthening of the posterior cuff and periscapular muscles.

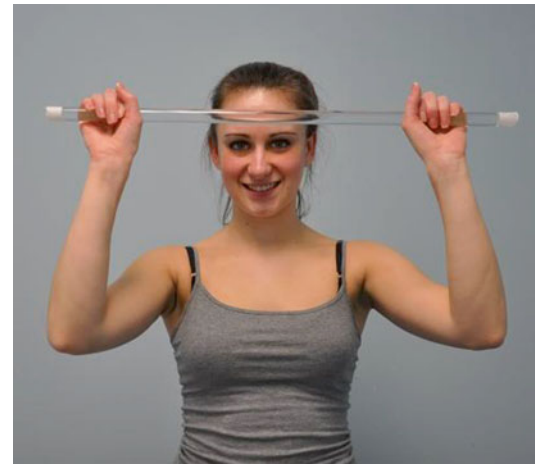


Fig. 13.16 Patient holds stick at chest level, raising the stick overhead keeping it level

Fig. 13.17 Patient holds stick at chest level, raising the stick overhead to maximum height, lifts the involved hand off the stick, and slowly follows the stick to starting position

Fig. 13.18 Lying prone the arm is extended to midline

Fig. 13.19 Lying prone the arm is abducted to midline palm down or thumb pointing up

Advanced Stretching Exercise

Stretching exercises become more aggressive as the healing progresses and the planar motion increases. Advanced stretching is not initiated until the sixth postoperative week since the intensity of the exercises directs stretching in combined planes of motion and toward maximum range and flexibility. With massive and large rotator cuff repairs and humeral fractures, advanced stretching is deferred until 12 weeks when healing is suitable to accept the stretching. At this point in the program if there is excessive stiffness, emphasis is placed on stretching with less attention paid to strengthening. Functional range of motion, above and below the horizontal, with full end range, with combined movement is the goal of the advanced stretching program. During stretching the patient is instructed to move to the point of stiffness, apply additional force slightly into the stiff range, and hold for the count of five to ten. This should be repeated for five to ten repetitions and can be adjusted according to the patient's tolerance and response to treatment. The one-arm wall stretch is started with the patient holding the wrist of the affected extremity and sliding it up the wall (Fig. 13.20). As the patient begins to reach up, the wrist is released and the patient stretches up and leans his axilla and arm into the wall. The goal of the exercises is to have the patient's axilla and arm flat against the wall. After 140° of forward elevation is comfortably obtained, combined flexion, external rotation, and abduction stretching can be initiated (Fig. 13.21). This position can be challenging for the patient with end range stiff-

Fig. 13.20 Patient places hand on a door, reaches up, and stretches to the top of the door, attempting to press their armpit onto the door

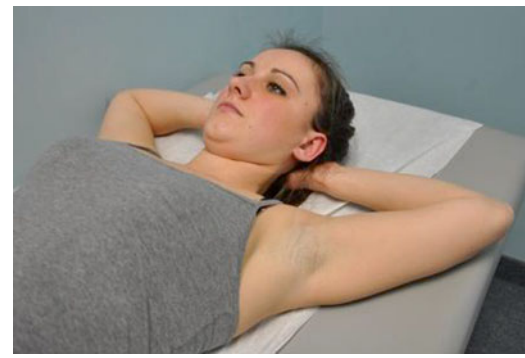


Fig. 13.21 Patient clasps their hands and raises them in one motion over their head placing them behind the head. They try to spread their elbows out to the side and touch the mat and then bring them together

ness. This stretch focuses on the inferior and anterior structures of the shoulder most especially at the glenohumeral joint. With these advanced stretching exercises, planar motion can be normal; however, there can be quite a bit of stiffness with combined rotational components which may result in soreness after performing these exercises. One should proceed in a gentle slow progression of intensity of stretching since patients can become sore with these exercises. The over-the-door hang (Fig. 13.22) is one of the more aggressive exercises using the weight of the patient, controlled by the patient, in the overhead stretch position. This is a hang-down exercise. Stretch is applied by the patient bending knees and relaxing the shoulders and arms and clasping the top of the door with their fingertips. A chin-up bar can also be used for this exercise. This stretch should be gradual and controlled. The standing 90/90 corner stretch (Fig. 13.23) continues to address combined motion and resulting stiffness. Patients may demonstrate good external rotation in the plane of the scapula; however, if they elevate to 90° and attempts to externally rotate, their shoulder adducts and external rotation is limited usually less than 90° in abduction. The patient is directed to walk toward the corner of a room, place his arms at 90° abduction approaching external rotation as far as he can and place his hands on the wall with his elbows and forearms, and lean into the corner of the wall. If the patient has limited external rotation, it may be difficult to assume this position so modification should be made. With younger patients, supine external rotation at 90° of abduction at 90° of elbow flexion may be initiated with a stick pushing the hand further into external rotation (Fig. 13.24). Advanced internal rotation stretch incorporates a towel or scarf (Fig. 13.25). This is especially effective for people to have difficulty

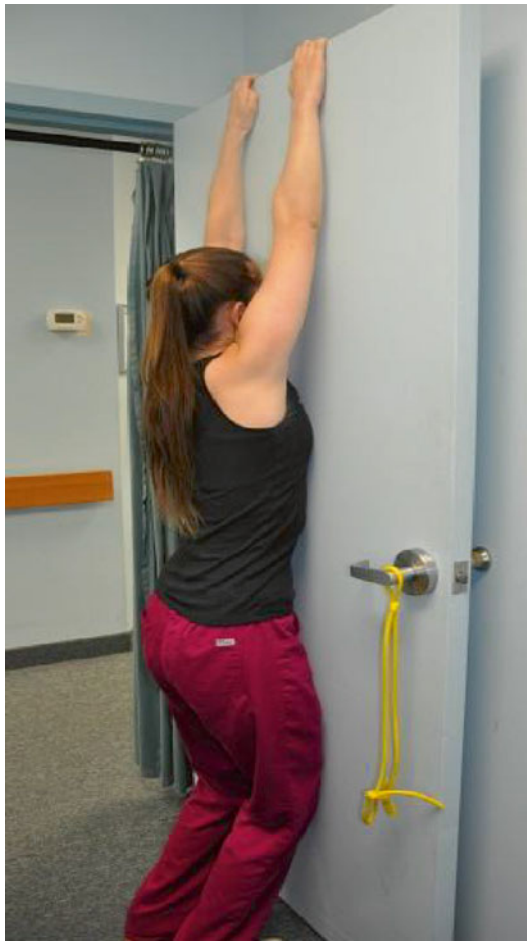


Fig. 13.22 Patient slides hands to the top of the door and grasps with their fingertips. Relaxing their shoulders and bend their knees, gently, to apply weight and stretch their shoulders

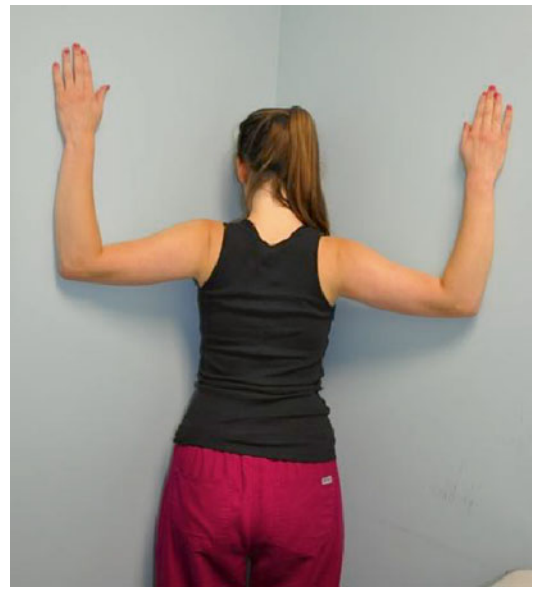


Fig. 13.23 With arms out to the side with elbow bent to 90°, the patient gently leans their body forward into the corner

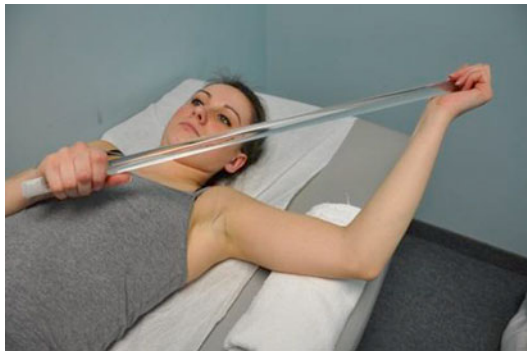


Fig. 13.24 Place a pillow under the elbow with the arm abducted to 90°. With the scapular stabilized against the mat, the patient bends the elbow to 90° and pushes the hand toward external rotation

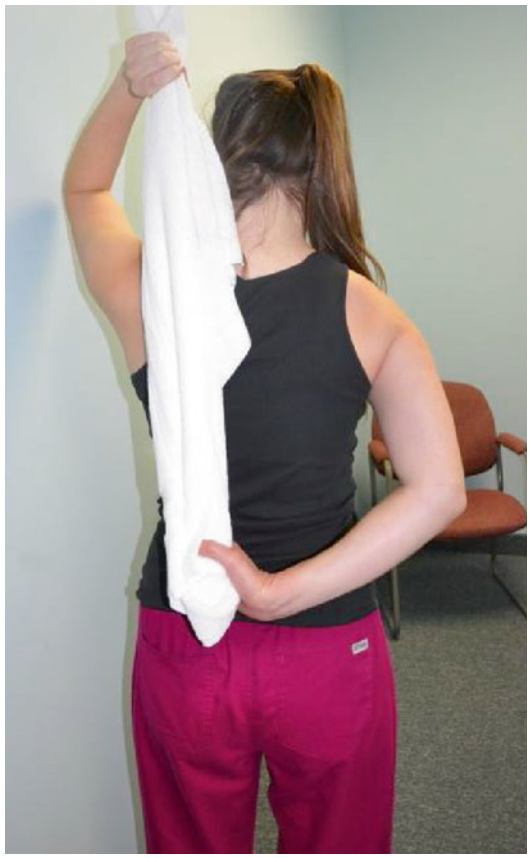


Fig. 13.25 The patient grasps a towel or old silk tie using their uninvolved arm to pull the involved arm up the center of the back

using their opposite hand behind the back. Standing with the hand on the counter is an alternative to this exercise (Fig. 13.26). If posterior

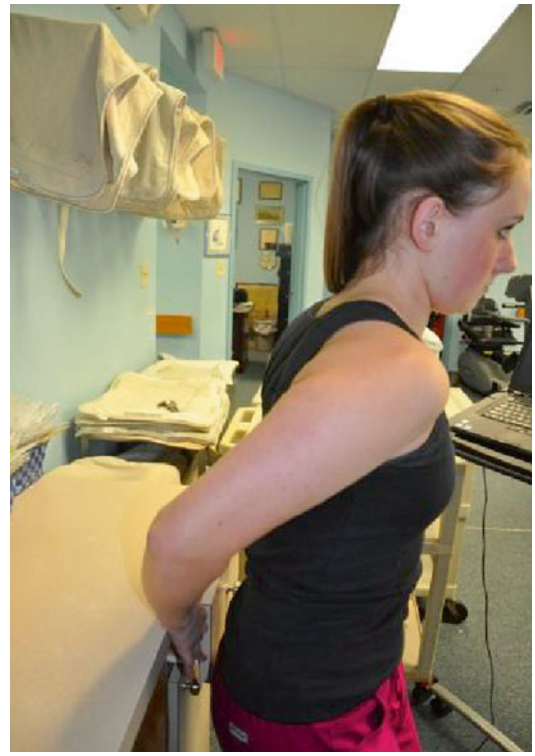


Fig. 13.26 The patient places the hand in the center of the back, leans into the counter top, and grasps it with their hand and bends at the knees

capsular tightness is present, the cross-body adduction stretch (Fig. 13.27) will help stretch the posterior aspect of the shoulder. If the scapula is very mobile, lying supine stabilizes the scapula toward the thorax and will help facilitate isolated posterior capsular stretching.

Resistive Exercise

At 6 weeks strengthening is also initiated since the soft tissues are intact and the subscapularis tendon repair is sufficiently healed. With large to massive rotator cuff repairs, resistance does not start until 12 weeks since the soft tissues require longer protection for adequate healing. Joint reaction force at the normal glenohumeral joint, while raising the arm in abduction, approximates body weight [23]. During resistive exercises, the amount of force generated at the glenohumeral joint should be considered. Overloading the joint with resistive exercises will alter arthro-kinematics

Fig. 13.27 Patient raises the involved arm to the horizontal position. With the other hand, they push their elbow toward the opposite shoulder

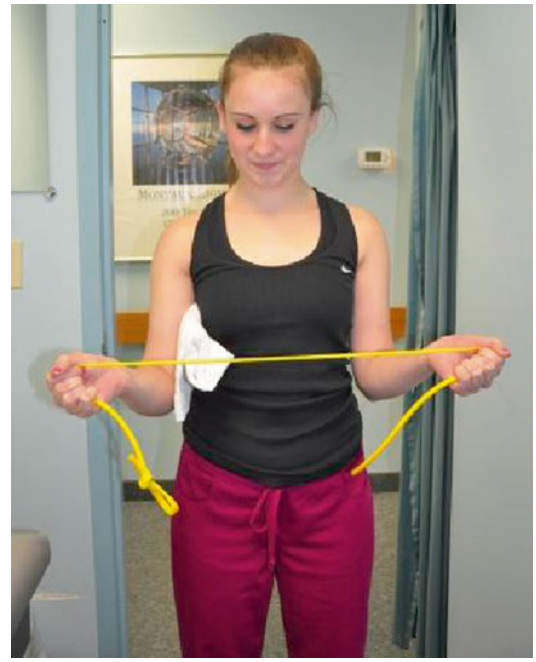


Fig. 13.28 Patient holds the elastic tubing in both hands with a towel placed between the involved elbow and the waist to maintain the scapular plane. With the elbow pressed to the towel, the patient pulls outward and slowly returns to the starting position

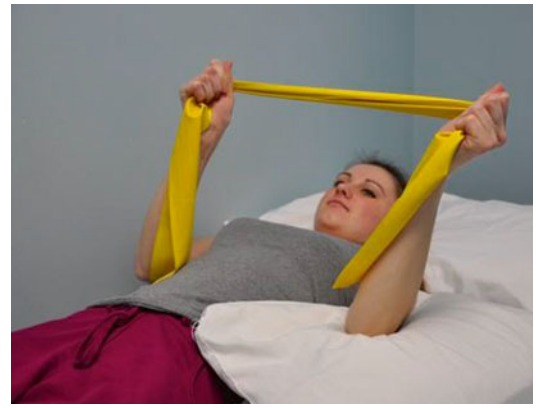


Fig. 13.29 To help avoid substitution, the patient is placed supine to stabilize the trunk and scapular with a towel or pillow under the arm to maintain the scapular plane. Holding the elastic band in both hands, the patient pulls outward and returns slowly with the elbow maintained at 90°

and should be avoided. Pain should also be avoided during strengthening. A progression of light to heavy elastic tubing is incrementally introduced as the patient begins to strengthen. As he becomes more comfortable with the resistive exercises, free weights are then introduced. The goal of this part of the exercise program is to strengthen with proper mechanics keeping the humeral head centered on the glenoid avoiding a shrug sign and riding up. If this occurs, or if there is pain, the resistance should be reduced. External rotation with resisted tubing initiates strengthening to the rotator cuff (Fig. 13.28). The patient should place a towel between his arm and trunk as demonstrated and externally rotate avoiding substitution. If substitution is unresolved, the supine position can be reverted too (Fig. 13.29). Resistive internal rotation is performed in the same position with controlled inward rotation to the belly press position followed by slow release with controlled eccentric rotation to the starting position (Fig. 13.30). This motion may be weak due to the direct effects of the surgery and contracture released. The subscapularis strength is pivotal in maintaining the stability of the shoulder. Strength may be slow to return since it is the only muscle released during the surgery [8, 18]. Resisted abduction and combined external rotation is a complex exercise. It involves combined strengthening and coordination directed at the periscapular muscles, deltoid infraspinatus, and teres minor

Fig. 13.30 The elastic tub is attached to the doorknob. With a bolster under the elbow, the patient takes a large step away from the door. Holding the elbow against the bolster, the patient internally rotates the hand toward the stomach and slowly allows it to return to the starting position

Fig. 13.31 While holding the elastic band with both hands with elbows maintained at 90°, the patient starts by pulling their hands apart outward and upward and at the same time lifting their elbows away from the body. It important to lead with the hands not the elbows

muscles for abduction and external rotation (Fig. 13.31). Weakness of either group results in upward rotation of the scapula and drifting of the hand and forearm inward. Placing an elastic band on a doorknob stepping back and pulling in straight back strengthens the posterior deltoid (Fig. 13.32). This exercise usually is not problematic. The uppercut or punch upward strengthens the rotator cuff and anterior deltoid (Fig. 13.33). A band is attached to the doorknob and the patient punches up to the horizontal. Riding up of the shoulder as well as pain should be monitored. If

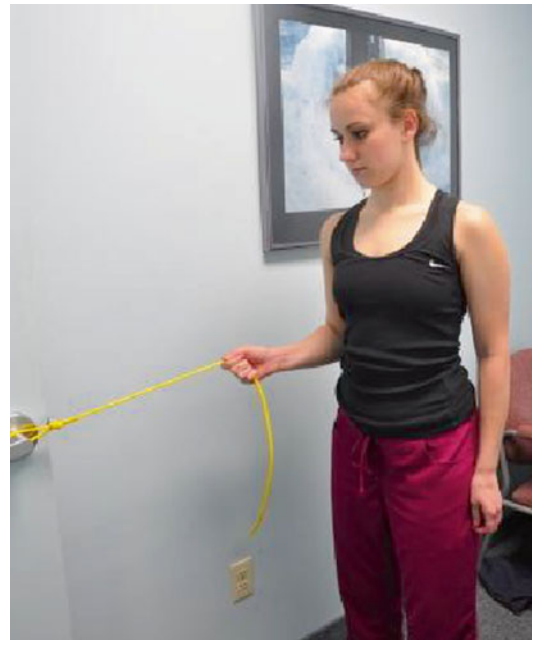


Fig. 13.32 The elastic tub is placed on the doorknob. Patient takes a large step back. Patient pulls straight back until the hand is at the waist and then returns to the starting position

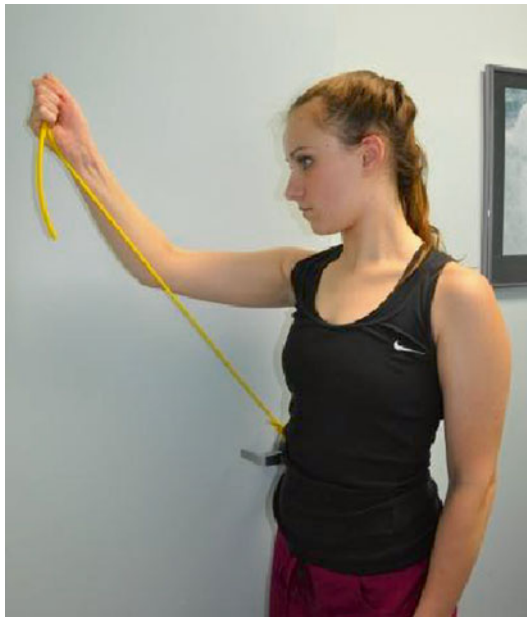


Fig. 13.33 The elastic band is attached to the doorknob. Standing with the shoulder next to the door and your elbow at the doorknob and waist, the patient performs an uppercut raising their hand above the head and shoulder motion approaching 90° and then slowly returns to the starting position

Fig. 13.34 Patient holds a bar or a stick beginning with a 1–2 lb weight and performs a standing press raising the bar as high as possible and then returns to the starting position

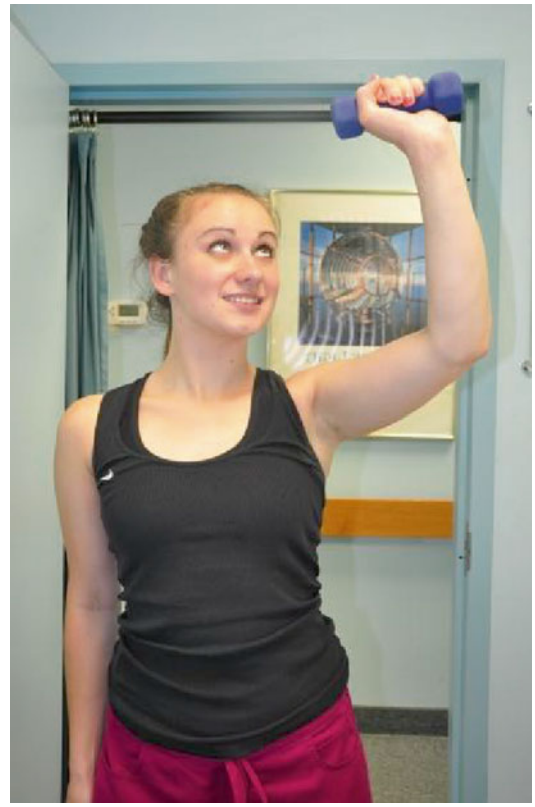


Fig. 13.35 Patient holds a weight 1–5 lb with palm out at shoulder level. Patient then presses weight upward until the arm is straight and then returns to the starting position

either is present, reduction in the amount of resistance is recommended. Standing press with the stick and a weight is the next exercise (Fig. 13.34). Symmetry should be evaluated. This exercise is then followed by the one-arm press without a weight and then adding a 1–2 lb weight (Fig. 13.35). Care should be taken to monitor and evaluate the quality of movement and kinematics as the therapist progresses the patient through these strengthening exercises. Improper exercise execution and/or overloading can result in painful inflamed soft tissues and rotator cuff. As range of motion and flexibility improve with gains in strength, the scapular and periscapular muscles are addressed. Setting of the scapula with an upward rotation movement maintaining the humeral head centered in the glenoid is necessary for proper overhead function. Abnormal scapular mechanics in this scenario is usually due to presurgical glenoid or glenohumeral pathology and stiffness. With range of motion and strength being restored at the glenohumeral joint, it is not uncommon to see normal scapulothoracic/humeral mechanics develop without focus on the periscapular muscles during early rehabilitation. However, if periscapular muscle dysfunction is present after

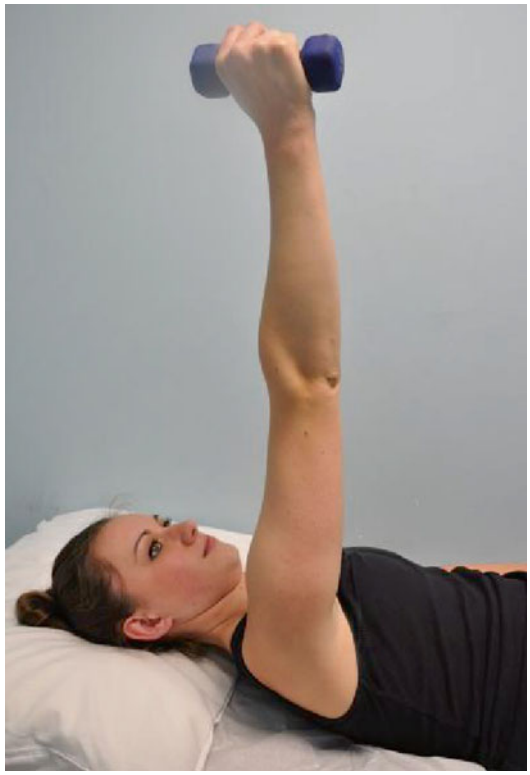


Fig. 13.36 Patient lies supine with a 1–5 lb weight in the hand with a straight arm at 90° shoulder flexion. With a locked elbow, the patient raises the shoulder reaching toward the ceiling and then slowly returning to the starting position

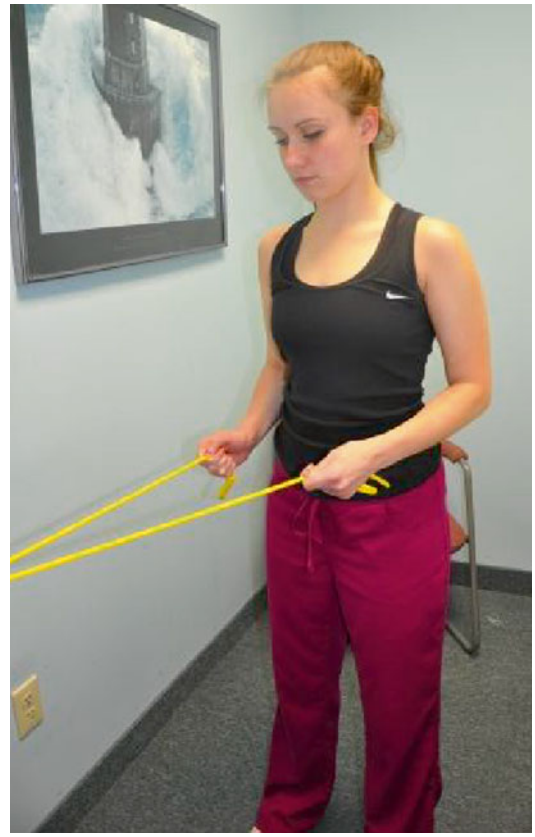


Fig. 13.37 Elastic bands are attached to the doorknob. Patient takes a large step back and, with bands in both hands, pulls back till elbows approach the waist at the point the patient pulls his scapular together and pinches their center back together

glenohumeral motion and strength are established, strengthening of these muscles will ensure continued proper function below and above the horizontal. Strengthening is started in the supine position with scapular protraction. The patient performs a reach up plus with the one or 2 lb weight or appropriate resistance (Fig. 13.36). The second exercise is scapular retraction using the elastic bands. The elastic band is attached to the door and held in two hands. The patient has his arms outstretched in front and isolates bringing their scapula together as the patient expands their chest up and out (Fig. 13.37). For younger patients, the quadruped push-up plus is effective in developing strength and control for proper mechanic at the scapular thoracic articulation (Fig. 13.38).

Fig. 13.38 Patient assumes the quadruped position. Patient locks their elbows and pushes the center of the back toward the ceiling and then returns to the starting position

Exercise Strategy for the Weak Shoulder

In some instances the attempt to repair and rehabilitate long-standing destruction of the biomechanical and neuromuscular components of the shoulder to regain shoulder function requires an altered strategy of rehabilitation to attain an optimal outcome. Patients with severe weakness following long-standing disease or following severe trauma involving muscular and neurovascular injury may not progress as expected in the recovery process. The primary goal of function above the horizontal may be slow to realize. Inability to raise the upper extremity in the erecting position above the horizontal due to weakness may require a modified rehabilitation approach to regain function. These patients can be challenging and require closer attention to techniques in strengthening exercises that will allow them to realize their full potential. The weak shoulder program focuses on supine exercise with the effects of gravity reduced on the weight of the extremity. The program is a progression from supine to the erecting sitting position moving from 0 to a 30° elevation of the trunk to a 60 and then 90° position which gradually increases the effect of gravity on the extremity as the patient approaches the critical range of 60–120° of shoulder elevation. The patient starts at a comfortable position supine where elevation can be accomplished, closed loop using a stick, with good mechanics (Fig. 13.39). Avoiding anterior superior translation of the numeral head with a shrug sign assures appropriate resistance. The rotator cuff in this position is not overloaded and performs its function of centralization and control as the deltoid powers through to elevate the extremity. Strengthening with progressive forms of resistance such as weights, elastic bands, and manual resistance imparted by the therapist is administered. The patient is advanced to the next level of

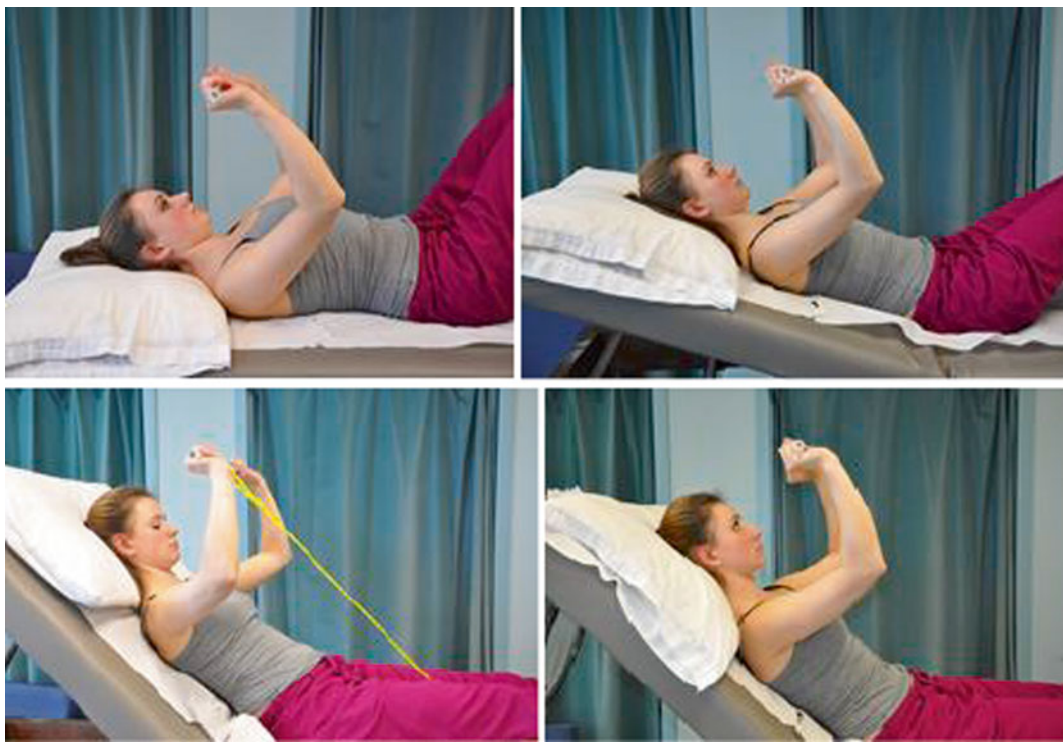


Fig. 13.39 Patient is progressed from supine to 30° to approximately 60° and finally to 90° (not pictured). The effect of gravity and the weight of the upper extremity approaching 60–120° of elevation is increased at each position

trunk elevation when a shrug sign is no longer apparent and motion is smooth and comfortable. Active elevation of the extremity with good mechanics is the goal. This process may be slow. Patients are advised to be patient and not to become frustrated since gains in strength may be protracted. Functional gains can be realized up to 1 year to 18 months and sometimes longer if there is an associated neurovascular injury or complications during surgery.

In conclusion, rehabilitation of shoulder arthroplasty requires an understanding of the pathology, complexity of the surgery, and postoperative management in order to accomplish the best possible outcome. The concept of early controlled range of motion has been presented with a logical progression of exercise and its application with respect to the surgical procedure, soft tissue reconstruction, healing, and exercise intensity. Certain potential complications have been addressed and should always be considered in the rehabilitation process. Team approach has been emphasized and its importance in the care of the patient maximizing recovery and outcome. The guidelines have been presented with a specific exercise program that has an ordered intensity of exercise. A modified strengthening program has been presented to manage those patients who present with significant weakness and have difficulty gaining forward elevation. The programs presented are flexible working modules that can be applied and adjusted to any shoulder patient, at any point in the rehabilitation process to attain an optimal outcome.

References

1. Crosby LA. Total shoulder arthroplasty: monograph series. Rosemont, Illinois: AAOS Instructional Course. 2000.
2. Fehringer EV, Kopjar B, Boorman RS, Churchill RS, Smith KL, Matsen III FA. Characterizing the functional improvement after total shoulder arthroplasty for osteoarthritis. J Bone Joint Surg Am. 2002;84-A(8):1349–53.
3. Arntz CT, Jackins S, Matsen III FA. Prosthetic replacement of the shoulder for the treatment of defects in the rotator cuff and the surface of the glenohumeral joint. J Bone Joint Surg. 1993;75- A(4):485–91. 2.
4. Cofield RH, Iannotti JP, Matsen FA III, Rockwood CA Jr. Shoulder arthroplasty: current techniques. AAOS Instructional Course Lecture No. 148. Rosemont, Illinois: American Academy of Orthopedic Surgery; 1998.
5. Shapiro J, Zuckerman J. Glenohumeral arthroplasty: indications and preoperative considerations. AAOS Instructional Course Lecture. Vol. 51. Rosemont, Illinois: American Academy of Orthopedic Surgery; 2002.
6. Basti JB, Dionysian E, Sherman PN, Bigliani LU. Management of proximal humeral fractures. J Hand Ther. 1994;7:111–20.
7. Bigliani LU, Flatow EL. Rehabilitation of shoulder arthroplasty. Should Arthroplasty. 2005;1:167–7.
8. Neer II CS. Shoulder reconstruction. Philadelphia: WB Saunders; 1990. p. 143–271.
9. Hughes M, Neer II CS. Glenohumeral joint replacement and postoperative rehabilitation. Phys Ther. 1995;55:8.
10. Brems JJ. Rehabilitation following total shoulder arthroplasty. Clin Orthop. 1994;307(10):70–85.
11. Brown DD, Friedman RJ. Postoperative rehabilitation following total shoulder arthroplasty. Total Should Arthroplast. 1998;29(3):535–47.
12. Boardman II ND, Cofield RH, Bengston KA, Little R, Jones MC, Rowland CM. Rehabilitation after total shoulder arthroplasty. J Arthroplasty. 2001;16(4): 483–6.
13. Brems J. Rehabilitation after total shoulder arthroplasty: current concepts. Semin Arthroplast. 2007;18:55–65.
14. Bigliani LU, Weinstein DM, Glasgow MT, Pollock RG, Flatow EL. Glenohumeral arthroplasty for arthritis after instability surgery. J Shoulder Elbow Surg. 1995;4(2):87–94.
15. Bryant D, Litchfield R, Sandow M, Gartsman G, Guyatt G, Kirkley A. A comparison of pain, strength, range of motion, and functional outcomes after hemiarthroplasty and total shoulder arthroplasty in patients with osteoarthritis of the shoulder. A systematic review and meta-analysis. J Bone Joint Surg. 2005;87(9):1947–56.
16. Iannotti J, Norris T. Influence of preoperative factors on the outcome of shoulder arthroplasty for glenohumeral osteoarthritis. J Bone Joint Surg. 2003;85(9):251–8.
17. Bradley ET, Aziz B, Jean-Francios K, Boileau P, Chantel N, Walch G. The influence of rotator cuff disease on the results of shoulder arthroplasty for primary osteoarthritis: results of a multi-center study. J Bone Joint Surg. 2002;84-A(12):2240–8.
18. Sanchez-Sotelo J. Shoulder arthroplasty: monograph series 45, AAOS 11–17. Rosemont, Illinois: American Academy of Orthopedic Surgery; 2012.
19. Matsoukis J, Tabib W, Guiffault P, Mandelbaum A, Walch G, Nemoz C, Edwards T. Shoulder arthroplasty in patients with a prior anterior shoulder dislocation. J Bone Joint Surg. 2003;85-A(8):1417–24.

20. Zuckerman JD, Matsen II FA. Complications about the glenohumeral joint related to the use of screws and staples. J Bone Joint Surg Am. 1984;66: 175–80.
21. Brems JJ. Arthritis of dislocation. Othop Clin N Am. 1998;29(3):453–66.
22. McCann PD, Wootten MS, Kadaba MP, Bigliani LU. A kinematic and electromyographic study of shoulder rehabilitation exercises: clinical orthop. Relat Res. 1993;288:179–88.
23. Poppen NK, Walker PS. Forces at the glenohumeral joint in abduction. Clin Orthop. 1978;135(9):165–70.

Index

© Springer International Publishing Switzerland 2016
A.D. Armstrong, A.M. Murthi (eds.), *Anatomic Shoulder Arthroplasty*,
DOI 10.1007/978-3-319-29164-2