Surgical management of shoulder arthritis

Jonathan P Evans
Paul Guyver

Abstract

Shoulder arthritis is a painful and functionally limiting condition. Importantly, the overarching diagnosis of shoulder arthritis encompasses a cascade of pathologies affecting the bony and soft tissue structures of the shoulder. Although many surgical and non-surgical management options are available, effective utilization of these treatments is dependent upon careful diagnosis and consideration of the complex anatomy of the glenohumeral joint. This review considers what is known about this increasingly common condition and the spectrum of treatments available.

Keywords Glenohumeral arthritis; reverse total shoulder; rotator cuff arthropathy; shoulder arthritis; shoulder replacement

Introduction

The glenohumeral joint of the shoulder is the most mobile joint in the body. The superlative mobility of this joint allows us to direct the position of our hands in space which is essential in enabling good upper limb function. Shoulder arthritis is the gradual, progressive mechanical and biochemical breakdown of articular cartilage and other joint tissues including the bone and joint capsule of the glenohumeral joint. It compromises the mobility of the joint, and in combination with the consequential pain of the pathological milieu, is a condition that can dramatically reduce a patient's quality of life. Treatments for shoulder arthritis range from physiotherapy and joint injections to highly complex and invasive joint replacement surgeries, ultimately all of these interventions are directed at the amelioration of symptoms and a restoration of patient function. Critically, the success of each intervention is dependent upon careful patient selection and a thorough understanding of the anatomical considerations, indications and limitations of each approach. This narrative review aims to outline the various treatment strategies in shoulder arthritis, with a selected emphasis on shoulder arthroplasty.

Epidemiology

The population prevalence of self-reported shoulder pain is estimated to be between 16% and 26%, and is the third most common cause of musculoskeletal presentation to a general practitioner.[1] The exact incidence and natural history of glenohumeral arthritis are unknown, although primary shoulder osteoarthritis (OA) is believed to be the underlying cause in 2%–5% of those presenting to primary care with shoulder pain. In the UK, 8.7 million people are affected by osteoarthritis and this number projected to rise with increasing life expectancy. It is therefore projected that presentations of primary shoulder osteoarthritis will consequently increase.

Although other causes of chondral damage, such as post-traumatic, chronic shoulder instability, avascular necrosis and inflammatory arthropathy, are included in the wide spectrum of glenohumeral arthrosis, joint replacement registries demonstrate that the predominant burden of arthritic disease on surgical management is from osteoarthritis (OA) and rotator cuff tear arthropathy (RCTA). Within the major joint replacement registries, OA was reported as the primary diagnosis in between 34% and 72% of cases and RCTA in 4%–21%.[2] There has also been a rapid expansion of both the number of shoulder replacements available and the number of arthroplasty procedures performed. In the UK, 4197 primary shoulder arthroplasties were recorded in 2013 on the National Joint Registry, rising to 5944 in 2016.[3] In the USA the demand for shoulder arthroplasty is projected to increase by 755.4% by 2030.[4] Synthesis of patient demographics from the major shoulder registries reveals a female preponderance and an average age of 70 yrs when shoulder arthroplasty is performed.[2]

Anatomical considerations

The glenohumeral joint, commonly referred to as the shoulder joint, is a 'ball and socket' type synovial joint. The articulation occurs between the large convex humeral head and more diminutive concave glenoid. It is this size mismatch that affords the glenohumeral joint such a wide arc of mobility, but this large functional range of motion is at the expense of joint stability. The relative instability of the bony structures is compensated by the surrounding soft tissues which are categorized as static (glenohumeral ligaments, coracohumeral ligament and glenoid labrum) and dynamic (rotator cuff muscles, long head of biceps and periscapular musculature). It is the dynamic stabilizers that are the most relevant in the context of shoulder arthroplasty.

The rotator cuff is composed of four muscles, the supraspinatus, infraspinatus, subscapularis and teres minor. All have their origin from the scapular and surround the humeral head where they insert on its superior and lateral aspect. They act both as a group of prime movers and synergistically to compress the humeral head into the glenoid, thereby stabilizing and centring the humeral head throughout its range of motion. The larger deltoid muscle which sits over the rotator cuff exerts a predominantly superior force upon the humeral head when it contracts. The rotator cuff, therefore, acts as a fulcrum, maintaining the centre of rotation, whereas the deltoid abducts and elevates the arm (Figure 1a). Consequently, in the absence of a functioning rotator cuff, the joint is relatively unstable and an anatomically positioned deltoid is unable to move the arm and forces the humeral head into the under the surface of the acromium (Figure 1b). This has a large bearing on the choice of arthroplasty, as a total shoulder replacement or hemiarthroplasty that aims to restore the anatomy of the shoulder will be unstable, a reverse shoulder replacement is able to compensate for the absence of a functioning rotator cuff by positioning the deltoid in

Jonathan P Evans ***BSc MSc MBChB MRCS*** *is an Orthopaedic Registrar at the Department of Trauma and Orthopaedics, Plymouth Hospitals NHS Trust, Plymouth, UK. Conflicts of interest: none declared.*

Paul Guyver ***MBBS FRCS(Tr&Orth)*** *is a Consultant Trauma and Orthopaedic Surgeon at Plymouth Hospitals NHS Trust, Plymouth, UK. Conflicts of interest: none declared.*

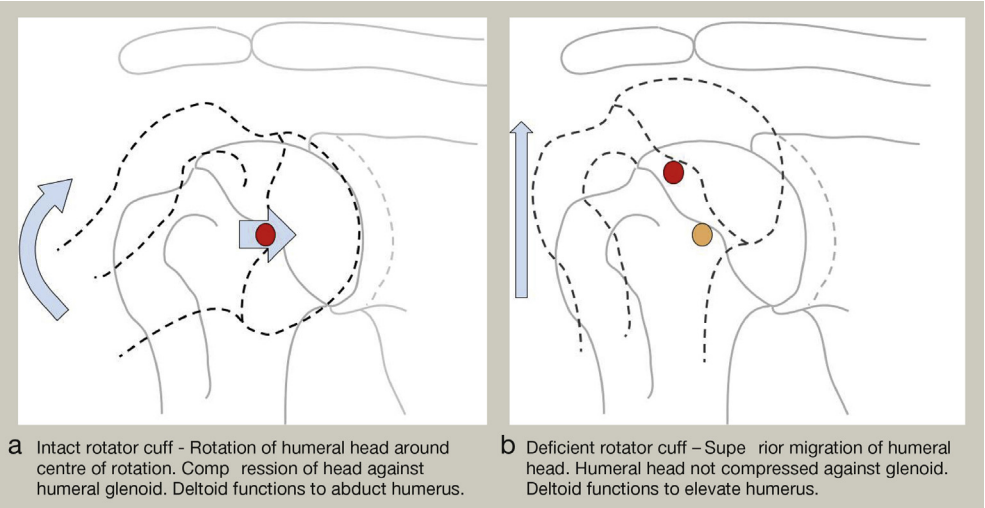

Figure 1 Schematic of normal shoulder position when deltoid functions to abduct humerus (**a**) and in rotator cuff deficiency (**b**).

a mechanically advantageous position and constraining the centre of rotation (Figure 2d).

It is also important to note that unlike the weight-bearing joints such as the hip and knee, where the pain of arthritis is secondary to cartilage destruction, the shoulder is more often affected by coexisting abnormalities of periarticular soft tissues. Where osteoarthritis results in narrowing of the glenohumeral joint due to degeneration of the articular cartilage and subchondral bone, the supporting rotator cuff musculature is normally intact. This differentiates it from RCTA, where the cuff deficient humeral head is displaced superiorly against the undersurface of the acromium producing a distinct wear pattern.

Clinical presentation and diagnosis

The shoulder is often affected by the complex integration of multiple potential pain generators surrounding the glenohumeral joint. Arthrosis of the shoulder is not a typical cause of shoulder pain, and is often a diagnosis of exclusion as symptoms can often be vague and non-specific. The classical presenting symptoms are of progressive, activity-related pain that is deep in the joint, which tends to localize posteriorly. In reality, the diagnosis of glenohumeral arthritis is made through careful and thorough history, examination and use of adjunct imaging. The British Elbow and Shoulder Society (BESS) best practice patient pathway recommends sequential assessment of red flags (recent trauma, any mass or swelling, evidence of infection) followed by clinical screening for evidence of instability or acromioclavicular joint disease prior to the localization of glenohumeral joint pathology. A reduction in external rotation should be assessed, if present a radiograph should be conducted to assess the pathological findings associated with glenohumeral arthritis (joint space narrowing, osteophytes and subchondral sclerosis) (Figure 3), from frozen shoulder (radiographically normal joint). Two radiograph views of the shoulder are always taken (anterioposterior and axillary lateral), with the axillary view providing the best image to assess joint space narrowing, and in rare cases a locked posterior dislocation. The associated presence of rotator cuff weakness and/or radiographic evidence of high riding humeral head (<7 mm of acroimohumeral distance) and wear on the undersurface of the acromion is suggestive of rotator cuff arthropathy.

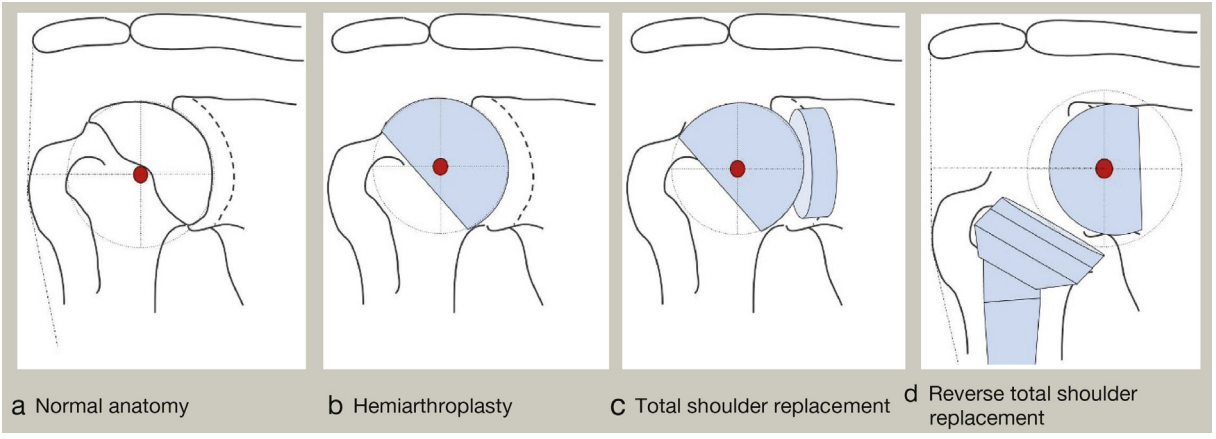

Figure 2 Schematic of normal shoulder and the three main categories of glenohumeral prosthesis. Note the centre of rotation in b and c remains in the anatomical position, in d the Grammont principles are applied, the centre of rotation is medialized and the humerus is lowered increasing the deltoid tension.

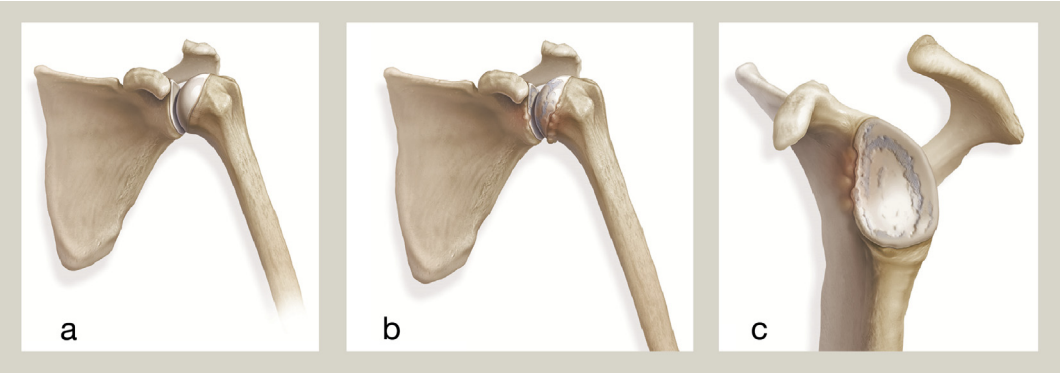

Figure 3 A normal glenohumeral joint (**a**) and the typical morphological changes found in osteoarthritis (**b + c**): joint space narrowing, chondral wear and osteophytes.

Magnetic resonance imaging (MRI) and ultrasound may be used in equivocal cases where the integrity of the rotator cuff is uncertain. Computed tomography may be used if there is concern regarding bone stock and eccentric wear, particularly of the glenoid. Moderate to severe glenohumeral arthritis can be associated with an erosive change to the posterior half of the glenoid. The concordant glenoid retroversion needs to be recognized, as failure to correct this when performing a total shoulder replacement predisposes the joint to instability, posterior subluxation and glenoid component loosening.

Non-arthroplasty management

The initial aim in patients presenting with shoulder arthritis is symptom control using non-surgical methods. Current treatment options to control pain and optimize range of motion include oral analgesics, non-steroidal anti-inflammatory drugs (NSAIDs), intraarticular injections (corticosteroids and hyaluronic acid), physical therapy and acupuncture.[5] Of these therapies it should be noted that the use of NSAIDs can be contraindicated owing to gastrointestinal and renal side effects and cardiac toxicity, especially in the elderly and intraarticular injections only provide temporary relief. Exercise and physical therapy may provide benefits as they do in other shoulder conditions, but their true efficacy in osteoarthritis is unknown.[5]

Surgical options where arthroplasty is not desirable, for example, in the younger patient, include arthroscopic debridement, microfracture and osteochondral grafting. Although it is unknown if arthroscopic debridement can alter the natural history of arthritis, the goal of the procedure is to improve the intraarticular environment through the removal of loose and irreparable fragments. Although there may be a role in early management of glenohumeral arthritis, the relief is usually transient. In patients with small focal areas of arthritis and an intact subchondral plate, microfracture, where an awl is used to create small fractures through the subchondral plate, may be used. The clot of blood within these fractures carries mesenchymal stem cells which have the ability to transform into fibrocartilage. The results from this technique are often extrapolated from the treatment of the knee, and studies of long-term effectiveness in the shoulder are not currently available. Osteochondral grafting uses autograft or allograft material to restore a full-thickness cartilage deficiency where the subchondral plate is compromised. Autologous osteochondral grafting (mosaicplasty), where single or multiple small cylindrical osteochondral grafts that are harvested from a donor site (commonly the knee), has been utilized in the shoulder. This technique carries the theoretic advantage of transplanting articular hyaline cartilage rather than fibrocartilage substitution, but again only limited short-term data in shoulder populations is available.

Although evidence on the effectiveness of non-arthroplasty treatment of shoulder arthritis is limited, it is only once these measures have become ineffective that arthroplasty should be considered.

Shoulder arthroplasty – an evolution in design

Although shoulder arthroplasty is one of the most successful and widely used approaches for the management of end-stage glenohumeral arthritis,[2,6] its use has only been commonly accepted within the last 20 years. The design evolution and consequential adoption by surgeons across the world only emerged as a result of relatively recent discoveries in anatomical morphology and an appreciation of the shoulders complex mechanical environment.

The first reported shoulder replacement was implanted by Péan in 1893, in a 37-year-old patient with tuberculous arthritis. It consisted of an iridescent platinum tube, a hardened rubber ball coated with paraffin, and two metal loops that attached the ball to the scapula and the tube to the ball. Although it functioned well for 2 years it was ultimately removed due to infection. Following this pioneering work, there was a substantial hiatus before the work of Charles S Neer II began to popularize the technique in the 1980s. Neer believed that the best outcomes would be gained when the implant mimicked the patients' normal anatomy. In 1953 he implanted a hemiarthroplasty (HA) (replacement of the proximal humerus) and then in 1974 a total shoulder replacement (TSR) (resurfacing of the glenoid and replacement of the proximal humerus).[7] However, the prosthesis was only available in two sizes and the resultant mismatch between implant size and the patient's native shoulder resulted in high rates of loosening (>50%) and poor shoulder kinematics. The pursuit of an implant that recreated 'normal anatomy' was then applied to the first modular designs in the early 1990s (Biomet, Cofield and Global models), which attempted to match the wide variations in the dimensions of the humeral head and diameter of the medullary canal. Though an improvement, these second-generation prostheses did not truly mimic the complex three-dimensional anatomy of the proximal humerus. The work of Boileau and Walch[8] revealed that the shape of the proximal

humerus was much more complicated than previously described. This then led to the development of third-generation prostheses where additional variable neck angles and eccentric heads recreated the tridimensional bony anatomy. Current fourth-generation humeral implants follow these design principles and further improve the flexibility of the construct by applying an interchangeable platform based system which allows conversation from the anatomic construct (TSR or HA) to a reverse shoulder replacement without having to revise the stem.

The reverse total shoulder replacement (RTSR), where the glenoid is replaced with a ball (glenosphere) and the cup is inserted into the humerus, was devised in response to the situation where the normal anatomy cannot be restored. Again, this anatomical conundrum was identified by Neer; he observed that in patient's where the rotator cuff muscles of the shoulder were deficient, an HA or TSR humeral component would not stay centred, resulting in defunctioning of the prime shoulder movers and greater implant stresses.[9] The RSR aims to improve function by adding stability, having the weight-bearing surface convex and supported part concave, moving the centre of rotation medially and humerus distally to improve the lever arm of the deltoid muscle, thus compensating for the absence of a functioning rotator cuff. Many of the early developments in RSR technology struggled to adequately address implant stability and range of motion leading to high failure rate. It is thanks to the work of Paul Grammont in the 1980s who developed and refined these RSR concepts that continue to underpin all of the present day implant designs[9] (Figure 2d).

Replacement of the glenoid surface, thereby creating a total joint replacement in combination with a humeral head prosthesis, was again pioneered by Neer. The first glenoid component was introduced in 1972 to treat osteoarthritis. This prosthesis was all-polyethylene and although it performed well, concern regarding the presence and progression of radiolucencies around the back side of the implant have prompted many alterations in the design and fixation techniques. The surface geometry of the glenoid is of particular importance and it was recognized by Neer and others that an increased radius of curvature of the glenoid component compared to the humeral head is required to allow translation of the humeral head during movement, the consequence of which is a reduction in edge loading, localized wear and loosening. Though the original designs for the glenoid component were all-polyethylene, a desire for cementless fixation and ease of revision saw the development of metal-backed implant designs. The first metal-backed implant was introduced by Neer in 1984, and continued design modifications continued into the 2010s; however, recent reports of high failure rates in metal-backed glenoids, have resulted in all-polyethylene implants being used much more frequently.

Modern prosthesis types

Modern shoulder arthroplasty apply these anatomic and reverse shoulder concepts, using prostheses that replace the humeral head with or without an associated replacement of the glenoid surface. There are three broad categories of shoulder arthroplasty: hemiarthroplasty using a stem, metaphyseal bearing or humeral head resurfacing; anatomic total shoulder replacement; and reverse total shoulder replacement. All arthroplasty categories pursue the same dual objective of relieving the pain due to degeneration and restoring shoulder function (Figures 2 and 3).

Shoulder arthroplasty is performed under general anaesthetic or regional anaesthetic supplemented with sedation. The most commonly applied regional anaesthetic technique is an interscalene block. The most accepted surgical approach is deltopectoral with some surgeons favouring the Mackenzie lateral approach. As with other major arthroplasty surgeries, shoulder replacement carries a significant complication risk. The overall complication rate in both TSR and RTSA has been estimated to be 15%.[10]

Hemiarthroplasty

Design

Replacement of the humeral head can be conducted using either a stemmed, stemless (metaphyseal bearing) or a cap-like prosthesis (resurfacing). All of these prosthesis types apply the anatomical principles outlined by Neer, with the resultant construct being described as unconstrained as it does not improve upon the pre-existing anatomical stabilizers. The humeral component consists of a smooth spherical metal articular surface which is fixed into place using numerous methods. Stemmed implants use either a press-fit or cement-fixation technique in the medullary canal of the humerus, stemless prostheses use a press-fit design or fixation using central cage screws securing the prosthesis to the humeral metaphysis and resurfacings press fit onto a preshaped (reamed) humeral head.

Indication and outcome

The choice between humeral head replacement and total shoulder arthroplasty in shoulder arthritis is controversial. Though humeral head replacements have been found to improve patients symptoms in primary osteoarthritis, meta-analyses of trial data have found total shoulder arthroplasty to provide significantly greater pain relief, gain in forward elevation and external rotation, patient satisfaction and lower revision rates.[11] The use of hemiarthroplasty may be indicated when the humeral joint surface is degenerate but the glenoid is intact and there is sufficient glenoid arc to stabilize the humeral head, when there is insufficient bone to support a glenoid component, if there is fixed upward displacement of the humeral head (as found in rotator cuff tear arthritis) and a RTSR is not possible, and when heavy demands would be placed on the joint, such as a manual occupation, sport or lower extremity paresis. There are some important advantages of hemiarthroplasty over TSR; it is less technically complex surgery, operating time and blood loss are reduced and the cost is less and these elements may be factored into the decision-making process. However, in the modern applications of hemiarthroplasty, its use is now becoming increasingly limited to unreconstructable proximal humeral fractures rather than the management of arthritis. In younger, active patients, hemiarthroplasty has been applied with biological resurfacing of the glenoid using allograft and autograft materials, however there is no long-term data supporting this method.

Humeral head resurfacing was introduced as a means of preserving the humeral bone stock in young, active patients with osteoarthritis that has failed non-operative management. It too

carries the advantage of shorter operating times as well as a low prevalence of periprosthetic fracture and preservation of native bony anatomy (humeral head version, posterior head translation and head-shaft angle) as an osteotomy is not required. Stemless designs are used as partial joint replacements in the same cohort as resurfacings and carry similar advantages. With both of these designs the ability to retain bone stock, preservation of the native and non-pathological glenoid, while keeping the possibility of simple conversion to TSR in the future appears to be a beneficial situation, particularly in patients under the age of 50, however, this premise is yet to be clearly evidenced based.

Total shoulder replacement

Design

A total shoulder replacement can be constructed through the combination of a stemmed, stemless (metaphyseal bearing) or resurfacing humeral component, all with a spherical metal articular surface, and a polyethelene glenoid component. The humeral component can be fixed in place using either a press-fit or cement, the glenoid component is most commonly cemented into position.

In accordance with Neer's principles of anatomic restoration, regardless of the construct that is utilized, satisfactory outcome is reliant on orientation and fixation of the components and soft tissue balancing. In the context of arthritis, it is important to note that pathological abnormalities may include humeral head and glenoid osteophytes, posterior glenoid wear, posterior capsular stretching and anterior capsular contracture, all of which will need to be addressed to gain optimal functioning. Modern implants provide variable neck angles and eccentric heads to allow recreation of the native bony anatomy. It is also vital the implant is properly sized, a change in the centre of rotation of 5 mm decreases the range of motion by 20–30 degrees,[12] an oversized humeral component results in a substantial reduction in joint laxity and severe limitation of flexion, abduction and external rotation. If the procedure and rehabilitation are done properly, results can be just as good as those after the more common arthroplasties of the knee and the hip. The durability of modern total shoulder replacement is as good as or better than that of other joint replacements. Results of long-term follow-up in several series have reported revision rates for all causes averaging less than 10%, with glenoid component loosening averaging only 4.3%.[13]

Indication and outcome

Total shoulder arthroplasty is now the main surgical treatment for primary shoulder osteoarthritis.[5] It is also indicated in inflammatory arthritis, post-traumatic arthritis and failed hemiarthroplasty. The mean age of implantation is 67 years, though advanced age is not a contraindication and TSR can be considered in those aged over 85 years if warranted by the intensity of the pain.[14]

TSR is an unconstrained prostheses, and in accordance with Neer's anatomical principles, implantation requires an intact rotator cuff as the resultant anatomic joint in reliant on the native soft tissue structures to centre the joint, which has a significant impact on the mobility and longevity. TSR also requires adequate glenoid bone stock for implantation. In primary osteoarthritis, the results of TSR are often favourable in comparison to inflammatory arthritis as the rotator cuff is normally of good quality and the bone stock is generally preserved.

As previously mentioned, considerable debate exists within the literature regarding the choice between total shoulder arthroplasty or hemiarthroplasty. Well-designed studies which determine which implant provides the most benefit in specific types of pathology are still required. However, of the major randomized studies, meta-analyses and registry data analyses, TSR appears to provide a pain and global health benefit over that achieved in hemiarthroplasty,[15] though this data cannot necessarily be extrapolated to specific patient groups (e.g. specific pathology type, disease state or patient demographics). However, current evidence does not clearly demonstrate a functional or quality-of-life benefit of TSR over hemiarthroplasty,[15] and outcome of revision surgery between TSR and hemiarthroplasty is currently unknown.

Reverse shoulder replacement

Design

The RTSR quite simply reverses the geometry of the glenohumeral joint, turning the ball into a socket and the socket into a ball. The components consist of a glenoid baseplate which is fixed to the bony glenoid, normally using screws, onto which a hemisphere (known as the glenosphere) is attached. The humeral component consists of a metal stem which is cemented or press-fit, the proximal end of which allows the placement of a polyethylene-lined socket.

This design utilizes the Grammont principles, whereby the centre of rotation is medialized and humerus distalized, the weight-bearing surface is convex and the supported element concave.[9] The application of these principles allows restoration of deltoid tension, which lengthens the moment arm. When the deltoid contracts, the proximal humerus levers around the glenosphere without the requirement of an intact rotator cuff to stabilize the centre of rotation.

A recognized association with the medialization of the centre of rotation is scapular notching. This results from impingement of the medial side of the humeral prosthesis with the scapular neck during adduction. The significance of this finding is unclear but has led to the development of lateralized offset designs which sacrifice base plate stability for an increased range of motion and reduced notching. Clear long-term data on the outcome of medial and lateralized designs are not currently available. Overall survivorship data for the RTSR is also limited, however, the New Zealand arthroplasty register shows a 93% survivorship at 13 years.[9]

Where the TSR utilizes a radial mismatch between the humeral head and the socket, thereby allowing some translation, the components of RTSR have the same radius of curvature. This results in a concentric arc of motion and the most recent designs have large convex components which allow a large range of movement with improved stability.[6] Though these glenoid components utilize metal-backed uncemented designs, which in TSR have shown high failure rates, the glenoid complication rate in RTSA is very low. This is felt to be a consequence of low initial shear forces at the glenoid, which are rapidly replaced by compression loading due to the prosthesis geometry.

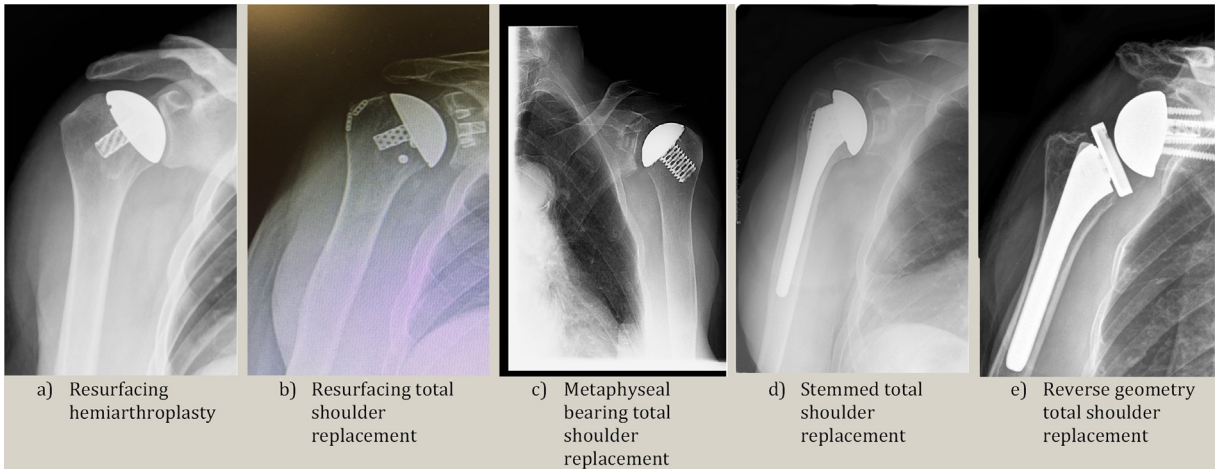

Figure 4 Radiographs depicting the main categories of shoulder replacement: surface replacement (**a**), total shoulder replacement (**b, c, d**) and reverse total shoulder replacement (**e**).

Indication and outcome

RTSA is indicated in rotator cuff arthropathy, rotator cuff-deficient shoulders with pseudoparalysis with no arthrits, acute proximal humeral fractures or fracture sequalae and revision of total shoulder replacements or hemiarthroplasties with cuff failure. It has also been advocated for use in shoulders where the rotator cuff is intact but there is severe glenoid bone loss.

Where the RTSR compensates for an absent rotator cuff, the deltoid function must be assured preoperatively in all portions of the muscle. Though the use of RTSR is increasing in lower age ranges, it should be used with caution in patients under 65 years of age as the long-term outcomes are uncertain.[9]

Patients who undergo RTSA for arthropathy often have limited shoulder function as a consequence of their index pathology. The outcomes of surgery should, therefore, be viewed within this context. Overall patient satisfaction with RTSA has not been found to correlate well with standard patient-reported outcome measures, which may reflect a different spectrum of patient expectations that those traditionally collected. Although RTSA can provide good forward elevation and abduction, driven through the deltoid muscle, the rotational range of motion that would have been produced by subscapularis, teres minor and infraspinatus, may not be restored which may hamper activities of daily living. If this is suspected due to preoperative massive rotator cuff tears, a latissimus dorsi transfer can be considered to provide external rotation power.

RTSR use is rapidly expanding, in the UK in 2013 1513 RTSA were registered on the National Joint Registry, rising to 3015 in 2017. This represented a proportional rise from 31.7% of all shoulder joint arthroplasties to 50.7%.[3] Even though clear long-term data is needed, RTSA is increasingly being accepted as a reliable option when there is no other viable alternative. However, the relatively high complication rate and lack of salvage options in revision RTSA highlight the need for judicious patient selection.

Figure 4 illustrates the radiographic appearances of the different categories of shoulder replacement.

Conclusion

Shoulder arthritis is a potentially debilitating condition that has a significant impact on quality of life. This review highlights that through careful clinical assessment and patient-specific application of the current armamentarium of medical and surgical treatments, great improvements in pain and function can be achieved. Although evidence from long-term follow-up studies is limited in contrast to that of hip and knee arthritis, great advances in have been made within the last 50 years, and the speed of innovation continues unabated. What must not be forgotten however is that at the root of all medical and surgical advances, as we have learned from Dr Neer, it is an understanding of the shoulder's complex anatomy that forms the foundation of all our of treatment decisions. ◆

REFERENCES

1 Mitchell C, Adebajo A, Hay E, Carr A. Shoulder pain: diagnosis and management in primary care. *BMJ Br Med J* 2005; **331:** 1124.
2 Bayona CEA, Somerson JS, Matsen FA. The utility of international shoulder joint replacement registries and databases: a comparative analytic review of two hundred and sixty one thousand, four hundred and eighty four cases. *Int Orthop*, 2017; 1–8.
3 National joint registry (NJR). 14th annual report, 2017.
4 Padegimas EM, Maltenfort M, Lazarus MD, Ramsey ML, Williams GR, Namdari S. Future patient demand for shoulder arthroplasty by younger patients: national projections. *Clin Orthop Relat Res* 2015; **473:** 1860–7.
5 Craig RS, Goodier H, Singh JA, Hopewell S, Rees JL. Shoulder replacement surgery for osteoarthritis and rotator cuff tear arthropathy. The Cochrane Library, 2017.
6 Deore VT, Griffiths E, Monga P. Shoulder arthroplasty—past, present and future. *J Arthros Joint Surg* 2018 Jan 1; **5:** 3–8.
7 Neer Ii CS, Watson KC, Stanton PJ. Recent experience in total shoulder replacement. *J Bone Joint Surg Ser A* 1982; **64:** 319–37.
8 Boileau P, Walch G. The three-dimensional geometry of the proximal humerus. *J Bone Joint Surg Ser B* 1997; **79:** 857–65.
9 Titchener AG, Tambe AA, Clark DI. Reverse shoulder arthroplasty. *Bone Joint 360* 2017; **6:** 2.
10 Bohsali KI, Wirth MA, Rockwood Jr CA. Complications of total shoulder arthroplasty. *JBJS* 2006; **88:** 2279–92.
11 Radnay CS, Setter KJ, Chambers L, Levine WN, Bigliani LU, Ahmad CS. Total shoulder replacement compared with humeral head replacement for the treatment of primary glenohumeral

osteoarthritis: a systematic review. *J Shoulder Elbow Surg* 2007; **16:** 396–402.

12 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. *JBJS* 1995; **77:** 555–63.

13 Labek G, Thaler M, Janda W, Agreiter M, Stöckl B. Revision rates after total joint replacement: cumulative results from world-wide joint register datasets. *J Bone Joint Surg Br* 2011; **93:** 293–7.

14 Walch G, Boileau P, Noël E. Shoulder arthroplasty: evolving techniques and indications. *Joint Bone Spine* 2010; **77:** 501–5.

15 Carroll RM, Izquierdo R, Vazquez M, Blaine TA, Levine WN, Bigliani LU. Conversion of painful hemiarthroplasty to total shoulder arthroplasty: long-term results. *J Shoulder Elbow Surg* 2004; **13:** 599–603.

Acknowledgement

The authors would like to acknowledge both Arthrex™ and Exactech Inc who kindly provided radiographs of their companies' shoulder prostheses seen in Figure 4 and Arthrex™ who kindly provided the illustrations used in Figure 3. All images are reproduced with explicit consent from the above companies and should not be other than in this journal.

