Arthroplasty of the shoulder

Although the first shoulder arthroplasty was implanted in 1893 by the French surgeon Jules-Émile Péan, the development of the procedure came in the 1950s when Neer described the results using a vitallium prosthesis to treat comminuted fractures of the head of the humerus. About 20 years later, and with the addition of a glenoid component, he described a total shoulder replacement (TSR) for the treatment of osteoarthritis (OA).

Since then, there has been a progressive improvement, culminating in the concept of anatomical reconstruction of the proximal humerus in the early 1990s when the size and design of the humeral component were reconsidered. Other surgeons have used surface-replacement implants with good results. Unconstrained prosthetic arthroplasty of the shoulder is now used widely to treat glenohumeral OA, rheumatoid arthritis, and osteonecrosis, with good and reproducible results.

The outcome after the use of unconstrained prostheses in complex fractures of the proximal humerus and in arthritis resulting from a tear of the cuff has been less predictable. Although good relief from pain has usually been obtained, most patients had a limited range of movement, leading to difficulties with the activities of daily living. These poor results led to the development of specific implants for these difficult problems, a low-profile prosthesis for fractures and a semiconstrained reversed-geometry design for arthritis resulting from a tear of the cuff.

The anatomical basis of design of the humeral component

Neer believed that implants with a design which mimicked the normal anatomy would provide the best function and durability. However, the original Neer prosthesis was only available in a limited range of sizes. Fluoroscopic studies showed that the ability to reproduce the normal kinematics of the glenohumeral joint with such an implant was limited. In the early 1990s modular, or second-generation prostheses were developed (Biomet, Cofield, Global) to try to match the wide variation observed in the dimensions of the head and the diameter of the medullary canal. Unfortunately, their concept and design did not achieve Neer’s aim of mimicking the normal anatomy and two major problems were encountered. First, the prosthetic head was often malpositioned in both the vertical and the horizontal planes. This was because of their relatively fixed geometry. Most were un cemented and because they were press-fit, the position of the stem dictated that of the head, leading in some instances to displacement of the centre of rotation outside its normal position. Secondly, the head was frequently oversized. Heads usually came in differing depths but of the same diameter, leading the surgeon to implant excessively large prostheses. Studies have shown that there is a linear relationship between depth and diameter, such that only one depth goes with one diameter, except for heads larger than 50 mm in diameter. Another reason for oversizing was the gap between the osteotomy and the prosthetic head. Pearl and Kurutz, in a three-dimensional analysis, noted that even when this gap was eliminated and optimal prosthetic version was achieved, there was still a displacement of the centre of rotation greater than 5 mm.

Despite their modularity, second-generation prostheses did not allow replication of the proximal humeral anatomy and even created new problems not seen with the Neer prosthesis. Too large a head prejudices the biomechanics by over-tensioning the joint, thereby limiting mobility and possibly increasing wear of the glenoid cartilage with a hemiarthroplasty or wear of the polyethylene if the glenoid is resurfaced. The associated excessive tension in the rotator cuff may lead either to early rupture of the repair of subscapularis and possible anterior instability, or later stretching or tearing of supraspinatus, causing pain and loss of active elevation. Inaccurate reproduc-
tion of the geometry of the proximal humerus may induce abnormal function of the abductor muscles and change the lever arms about the glenohumeral joint. Nyffeler et al have shown that if the centre of the head lies too superiorly, subscapularis and infraspinatus are converted from abductors into adductors, substantially increasing the load on supraspinatus in elevation and abduction. Alteration of the bony anatomy by changing humeral retroversion may lead to eccentric loading at the periphery of the glenoid, which may increase glenoid wear with subsequent loosening.1,17 This may explain the rapid deterioration of the clinical results in some patients with second-generation arthroplasties.18

Boileau and Walch,4,19 and others,5 have shown that the shape of the proximal humerus is more complex than has been described previously (Fig. 1). Roberts et al5 and Wallace et al20 observed that the articular surface of the head was offset posteriorly compared with the proximal medullary axis. If a prosthesis is to reproduce normal anatomy its head must also be offset. We found that the articular surface was also medially offset in relation to the proximal medullary axis and that the head was variably orientated in the vertical and horizontal planes.4 Therefore it must be possible to offset the head posteriorly and medially and to vary its inclination and retroversion (Fig. 2).

These findings led to modifications in the design of the prosthesis and in the surgical technique. Identifying the true anatomical neck became the critical step. This was achieved by careful removal of the crown of osteophytes around the head. The anatomical neck could be visualised even in the presence of severe erosion of the head. Better understanding of the anatomical relationships within the normal glenohumeral joint has resulted in improvements in design of unconstrained prostheses so that the three-dimensional geometry of the proximal humerus can be recreated. The Aequalis prosthesis (Tornier Inc., St. Ismier, France) adopted these criteria and became the first third-generation shoulder replacement. The principle of correct positioning of the prosthetic head to mimic an individual’s anatomy is described as ‘adaptability’, and clinical results using this implant have been published to validate this view.21,22 Subsequent research with other third-generation implants, both modular and adaptable, has confirmed the importance
of recreating the unique nuances of each patient’s anatomy.1,6,16,23-28

Part of the principle of design in the third-generation implants is matching the depth of the head to its diameter, but is this important? We now know that displacement of the joint surface leads to altered kinematics and decreases glenohumeral movement, causing translation of the head of the humerus.24,27-30 Selecting the appropriate size of head is important since biomechanical experiments have shown that a change in the centre of rotation of 5 mm to 10 mm results in significant reduction of the lever arms of the deltoid and rotator-cuff muscles during abduction. Harryman et al.23 have shown that an increase in the depth of the head by only 5 mm decreases the range of glenohumeral movement by 20° to 30°. Decreasing the depth by 5 mm reduces the glenohumeral excursion by 24°-27 Using an oversized head component results in a substantial reduction of joint laxity and severe limitation of flexion, abduction and external and internal rotation.

What other aspects of the anatomy of the proximal humerus need to be considered in trying to design an anatomical prosthesis? If the individual neck-shaft angle is not respected, the length of the abductor muscles may be altered resulting in abnormal function.15 Therefore, the implant must offer this option in order to restore the lever arms of the deltoid and supraspinatus. Our study5 has shown that the provision of four stem-neck angles (125°, 130°, 135° and 140°) encompasses more than 95% of patients.

By resecting the humeral head at the anatomical neck and using an implant which can be constructed to match the retroversion, inclination and medial and posterior offset with an identical depth of head, the individual lever arms of the rotator cuff muscles are restored. This ‘anatomical reconstruction’ of the joint results in normal kinematics and kinetics. Third-generation systems can recreate structure and geometry which matches the normal anatomy to a greater extent than those of the second-generation.16 Now, 50 years later, Neer’s principles are being realised (Fig. 3).

Stemless humeral resurfacing prosthesis

Surface replacement of the humeral head was developed to treat patients with avascular necrosis, OA and rheumatoid arthritis. The major advantages over stemmed implants were the minimal removal of bone, facilitating revision surgery, and the avoidance of stress risers, thus eliminating the potential risk of fracture of the humerus. It also accurately recreated the anatomy with respect to offset, retroversion and inclination. Copeland developed a cementless surface replacement featuring a press-fit component positioned over the reamed humeral head and stabilised by a grooved peg (Biomet Merck, United Kingdom). The Mark-2 Copeland shoulder design has been used since 1990 and the results of 103 shoulder arthroplasties were described in 2001.8,9 The originators demonstrated results equivalent to those of conventional stemmed prostheses with a revision rate of 7.7% at ten years. Some subsidence of the humeral component was found in five shoulders and the incidence of lucencies less than 1 mm wide around it, was 30%. To improve bony ingrowth, a hydroxyapatite (HA) coating was added to the inferior aspect of the implant and the peg (Mark 3). Rydholm and Sjögen developed a cemented surface replacement and published their results in 1993. Again, the initial clinical results were good, but they reported a rate of loosening of 25% at a mean of 4.2 years after surgery.

Glenoid resurfacing prosthesis

The first glenoid component was introduced by Neer11 in 1972 to treat the wear of the glenoid associated with OA. This device was all-polyethylene and oval-shaped, with a curved back and a triangular keel designed for cementation. Although good clinical results are reported in TSR, a major concern is the presence and progression of radiolucent lines at the cement-bone interface. Their frequency varies between 30% and 96%, and increases with the length of follow-up.7,32-36 Fortunately, this common finding does not correlate with the requirement for revision surgery, which remains low.7,37 In a long-term study, Torchia et al.36 found that 87% of implants had survived for 15 years, with five- and ten-year rates of 98% and 93%, respectively. However, other studies have reported a direct relationship between the presence of radiolucent lines and the development of radiological or clinical loosening.31,34,39,40 It is our experience that glenoid radiolucent lines and loosening are associated with poor results with recurrent pain and progressive loss of active elevation.21,41

In an attempt to solve this problem and to achieve optimal long-term results, there have been many changes in the design of the glenoid component and in techniques of fix-
What surface geometry? The genesis of lucent lines is poorly understood and there have been many modifications to the original design. Surface geometry was thought to be an important factor in creating stability and, in most systems, the original oval shape has been changed to a more anatomical pear-shape. Clinically, this appears to have had little impact on the development of lucent lines. There is no evidence that a pear-shaped glenoid is superior to an oval one.

What material? The original Neer\textsuperscript{11} glenoid component was made of polyethylene, which was 2.5 mm thick. This is still the material of choice. There is a trend toward the use of thicker polyethylene, but the optimal thickness has yet to be determined. In the 1980s, a new polyethylene, Hylamer (DePuy, Warsaw, Indiana), was introduced with the anticipated advantage of improving wear characteristics. This material was stiffer and more brittle than polyethylene and resulted in a number of catastrophic failures leading rapidly to its abandonment.\textsuperscript{18,42} In 1984 Neer introduced a metal-backed component with 2.5 mm of polyethylene, but again there is no evidence that this provided better fixation with cement. In the near future, other bearing surfaces will be tested in the shoulder using information derived from the promising advances of metal-on-metal and ceramic-on-ceramic arthroplasty of the hip.

Keel or pegs? The next development was the use of pegs instead of a keel.\textsuperscript{43} The proposed benefits were a more uniform distribution of stress to the bone, as modelled by finite-element analysis,\textsuperscript{13,44} and the minimal removal of bone, which might offer better possibilities of success if revision was required. Some components have three pegs while others have four or five. There has been no scientific analysis which has shown that one configuration offers advantages over another in terms of loosening or failure.\textsuperscript{43,45} The incidence of lucent lines and loosening around the pegged component is often underestimated because of the oblique orientation of the glenoid fossa.\textsuperscript{46,47} The shape of the keel itself is important, with a triangular configuration offering no primary fixation while a trapezoidal design does.\textsuperscript{48}

Convex or flat back? We carried out a radiological study to determine if convex implants had a lower incidence and progression of radiolucencies.\textsuperscript{49} The series consisted of 66 shoulder arthroplasties for primary OA, divided into two groups based on the type of glenoid component. One comprised 35 shoulders with a cemented, flat-back polyethylene component and the other 31 shoulders with a cemented convex-back, polyethylene component. Both groups were statistically comparable and homogenous with regard to pre-operative variables. An independent observer evaluated the radiographs, which were produced using a standardised fluoroscopic technique in which the x-ray beam was perpendicular to the plane of the implant-bone interface. The keeled, convex-back glenoid component outperformed the flat-back version on the immediate post-operative radiographs and this superiority was maintained at two years. These results confirm those of biomechanical studies.\textsuperscript{48,50}

What is the optimal mismatch between the glenoid and the humeral components? In shoulder arthroplasty, mismatch is defined as the difference in the radius of curvature of the head and the glenoid component.\textsuperscript{51} Until recently, no recommendations for mismatch had been scientifically substantiated. In a clinical study, we evaluated the effect of mismatch on radiolucencies around the glenoid and found a statistically significant linear relationship.\textsuperscript{52} Based on these results, radial mismatch appears to be optimised at greater than 5.5 mm. Long-term studies of arthroplasty of the hip and knee have shown that major problems arise due to particular polyethylene wear debris causing a macrophage response and osteolysis leading to loosening. The shoulder is not a captive joint with a fixed centre of rotation. The range of movement of the humeral head articulating with the glenoid is much greater and so translational and shear forces are much higher.

Cemented or uncemented glenoid? Cofield\textsuperscript{53} pioneered an early uncemented TSR in 1986 (Cofield Total Shoulder System; Smith & Nephew, Memphis, Tennessee), which spawned other uncemented systems, such as the Biomodular Shoulder (Biomet Inc., Warsaw, Indiana) and the 3M Modular Shoulder (3M Health Care, Rotherham, United Kingdom). We performed a prospective, randomised study which suggested that cementless, metal-backed components were inferior to cemented, polyethylene implants with respect to functional results and fixation.\textsuperscript{41} The high rate of loosening associated with accelerated wear of polyethylene led us to abandon the use of metal-backed glenoid components. The rapid wear of the polyethylene with this type of component can be related to at least four factors: 1) insufficient thickness of the polyethylene; 2) excessive thickness of the glenoid component; 3) rigidity due to the metal back; and 4) recurrence of posterior humeral subluxation despite re-orientation of the glenoid and balancing of the soft tissue (Fig. 4). Dissociation of the polyethylene from the metal base plate has been reported by us and others.\textsuperscript{20,41,53-55}

Can we improve the technique of fixation of the glenoid? Brems\textsuperscript{55} showed that surgical technique was a critical variable since lucent lines were seen on radiographs taken in the recovery room in up to 70% of patients. Before the advent of component-specific reamers, the glenoid was prepared with a high-speed burr and sculpted by eye and experience. Collins et al\textsuperscript{56} demonstrated in vitro that physiologically eccentric loads could be minimised by proper reaming which ensured improved conformity between the glenoid component and bone. They also showed that mechanical reaming was superior to manual preparation. Improvements in instrumentation, including glenoid reamers, now ensure better congruity and conformity between the back of the implant and the host bone. Perhaps the most important
advances in glenoid fixation came from understanding the importance of meticulous implant-to-bone conformity and perfect alignment of the glenoid component.  

**Can we improve the cementing technique?** Better cementing techniques have also been advocated, with Neer et al.\(^{35}\) being the first to emphasise their importance. Norris and Lachiewicz\(^ {18}\) showed that modern cementing techniques may help to decrease the development of lucent lines. The technique of preparation of the glenoid by compaction has shown a decrease in the rate of lucent lines.\(^ {58}\) Rather than removing cancellous bone, as originally proposed by Neer, this technique uses a special instrument to compact the bone, thereby providing a more solid base for the keel. The aim is to obtain the smallest layer of cement around the glenoid component.

All of these measures play an important role in improving the longevity of the glenoid component. Despite changes in design over three decades, there has been little improvement in the incidence of lucent lines. The most important advances have arisen from developments in surgical technique, with mechanical reaming and cancellous bone compaction being recommended.\(^ {59}\) There remains, however, no consensus as to the design of the ideal glenoid component. The all-polyethylene, cemented, curved-back design remains the best choice and an optimal mismatch between the humeral and glenoid components decreases the risk of lucent lines and loosening.\(^ {49}\)

**Hemiarthroplasty or total shoulder replacement?**

Debate over the place of TSR as opposed to hemiarthroplasty occurs mainly in the treatment of primary OA. Although some surgeons, led by Wirth and Rockwood,\(^ {38}\) claim that a glenoid component is rarely required, it is becoming more evident that for OA, TSR gives superior results to HA in mid-term follow-up studies.\(^ {60-67}\) In a recent large, multi-centre study, Edwards et al.\(^ {62}\) showed that in OA, TSR was superior in terms of relief from pain, active range of movement, activity scores and patient satisfaction, and had comparable complication rates.

There are a small number of randomised clinical trials which have compared TSR with HA for the treatment of OA and all report more favourable outcomes with the addition of a glenoid component.\(^ {60-65}\) Gartsman et al.\(^ {63}\) prospectively analysed a series of 51 shoulders with primary OA and observed that the TSR group had statistically better relief from pain and internal rotation than those with HA. Three patients in the HA group had early recurrence of pain and loss of movement which correlated with erosion of the glenoid, and thus required revision to insert a glenoid component. In a randomised study by Sandow et al.,\(^ {65}\) in which the randomisation occurred only after exposure of the glenoid, HA was shown to be inferior to TSR. Although many of the outcomes were comparable early on, the TSR group had less pain. Several patients in the HA group had pain secondary to glenoid erosion and required revision to implant a glenoid component. Due to the higher early revision rate in the HA group, the study was discontinued. Lo et al.\(^ {64}\) also noted superior relief from pain in TSR when compared with HA in 42 patients with OA. Again, there was a small but noteworthy percentage of patients with HA who required early conversion to TSR because of glenoid wear and pain. A meta-analysis by Lo et al.\(^ {64}\) also showed that TSR was superior to HA for consistent relief from pain, active range of movement and patient satisfaction. In summary, TSR offers better short- and mid-term results, but has the risk of long-term problems with the glenoid component.

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**Figure 4** – a) CT scan and b) photograph after retrieval of the implant showing that accelerated wear of the polyethylene is a risk after resurfacing of the glenoid with a metal-backed component. Posterior wear of the polyethylene is visible.
It is becoming more apparent that the results of HA for OA gradually deteriorate, mainly due to secondary erosion of the glenoid (Fig. 5). Cofield et al. review 35 patients who had undergone HA for OA with a mean follow-up of ten years; 51% had unsatisfactory results due to pain secondary to progressive erosion of the glenoid, 36% of whom had a conversion to TSR with good clinical results. Until recently, HA had been a recommended option in patients with OA and a concentric glenoid. In their initial study Levine et al. showed that HA with a concentric glenoid gave satisfactory results in 86% of their patients. However, at a later review the rate of satisfaction had decreased to 67% at 7.9 years. The potential advantages of TSR over HA in terms of relief from pain and improvement in function have also been demonstrated after the sequelae of fracture, the advanced stages of avascular necrosis and rheumatoid arthritis. In a recent retrospective study, Trail and Nuttall did not find any statistical difference in the outcome after HA and TSR in patients with rheumatoid arthritis. They noted some progressive proximal and medial migration of the humeral component in the patients with HA, four whom had revision to TSR for persistent pain. None of the glenoid components needed to be revised. They concluded that the disadvantages of possible loosening of the glenoid component in TSR must be weighed against the possibility of medial migration in HA.

Are there any indications for HA? It is generally viewed as the procedure of choice in three circumstances: 1) when the glenoid is intact, as in fractures of the proximal humerus and in the early stages of avascular necrosis; 2) when a glenoid component cannot be inserted for technical reasons such as glenoid dysplasia and when bone grafting of the posterior glenoid is not technically feasible, or in severe end-stage rheumatoid arthritis where there is bone loss and concentric retraction of the soft tissues; 3) when the risk of glenoid wear and loosening is high, such as in young, active patients with OA. In this group, HA will avoid later problems with polyethylene. In arthritis due to tear of the cuff when the latter is absent, a reverse prosthesis may be indicated.

Copeland stated that even when HA was indicated, the glenoid should be not be ignored. He recommended drilling the articular surface to encourage secondary formation of fibrocartilage. Biological resurfacing, as proposed by Burkhed, is another potential option for patients in whom a glenoid component cannot be used. More recently, Yamaguchi, Ball and Galatz has suggested interposing a meniscus onto the glenoid surface. However, there have been no studies that show any additional clinical benefit for soft-tissue interposition glenoplasty.

Prognostic factors with unconstrained prostheses
A number of factors have been found to affect the outcome of unconstrained shoulder arthroplasty for OA. The rotator cuff. In most patients with primary OA of the shoulder, the tendons of the rotator cuff are intact. Neer stated that tears were found in less than 10% of patients with OA and those which did occur were usually small. In a multicentre study of 766 cases of primary OA, 7% had a partial and 7% a full-thickness tear of supraspinatus. These tears did not have any significant effect on the outcome. Furthermore, it has been shown that repairing a tear of supraspinatus when performing a shoulder replacement for OA does not change the functional results. These small degenerative tears can be ignored. Concomitant acromioplasty, which is not recommended, does not change the functional outcome.

The tendon of the long head of biceps. This tendon is abnormal in at least 30% of patients with primary OA, showing delamination, pre-ruption or hypertrophy. Biceps tenodesis offers better relief from pain, and we routinely perform this procedure as part of TSR.

Fatty infiltration of muscle. The degree of fatty infiltration of the cuff muscles has a direct impact on the functional outcome. Severe fatty infiltration of infraspinatus (Gouttailler stage 3 or 4) is associated with decreased functional results in OA. In our series, these patients had a mean Constant score of only 54 points with mean active elevation of 104°, as opposed to 72 points and 147° when infraspinatus was normal (stage 1).

The glenoid. Deformation of the glenoid in OA has been classified and shown to have an effect on the surgical out-
Functional results are significantly lower in a dysplastic glenoid with only active elevation to 130° in a type-C configuration, and the rate of complications is significantly higher with a bioconcave shape (18 with a type-B). We recommend CT to assess the morphology of the glenoid in all patients undergoing TSR (Fig. 6). In most cases an axillary radiograph is inadequate to assess true wear and retroversion of the glenoid. It is important to know the version in relation to the long axis of the scapula and the depth of the remaining glenoid vault in order to properly plan the insertion of the component (Fig. 7).

Pathology. The results of unconstrained shoulder arthroplasty vary according to the underlying pathology. Figure 8 shows the results of unconstrained arthroplasty in a multicentre study of 1852 primary procedures carried out over a period of ten years.

Surgical technique. The results of unconstrained arthroplasty of the shoulder depend on the quality of the anatomical reconstruction. Recent reports have suggested that inferior results may be due to malpositioning of the component or the use of non-anatomical prostheses. Malpositioning of the head as a result of poor design can lead to tendinopathy of the rotator cuff, superior migration of the head of the humerus and loosening of the glenoid component. By using a prosthesis which does not offer any posterior offset, the centre of rotation is moved anteriorly, altering the lever arms of the internal and external rotators. If the posterior surface of the osteotomy is left uncovered there is a potential for loosening of the glenoid component. Inaccurate version may result in glenohumeral instability, subcoracoid or subacromial impingement, excessive polyethylene wear and aseptic loosening.

Complications of unconstrained prostheses

The complications which occurred in the 1842 primary Aequalis prostheses with a minimum follow-up of two years are shown in Table I. Degenerative or inflammatory arthropathies accounted for 1542 cases and 300 were undertaken for proximal fractures of the humerus. Table I
Neer77 showed that no surgeon in either the USA or Europe has been able to reproduce the results obtained by Neer when using his prosthesis or a similar system (Tables IV and V). Technical faults. These include poor or incomplete repair of the subscapularis tendon, malposition of the prosthesis usually leaving the humeral component proud, with resultant pain or tear of the rotator cuff and excess anteversion or retroversion of either the humeral or glenoid components. Errors in rehabilitation. Overaggressive rehabilitation may lead to reflex sympathetic dystrophy and stiffness or to rupture of subscapularis and anterior instability.

New advances in prostheses for fractures

Since Neer reported his results in 1970,27 prosthetic replacement has been a well-accepted method of treatment for selected three- and four-part fractures of the proximal humerus (Table III). The functional results, however, remain poor, unpredictable and worse than those obtained in patients with OA. A critical review of the literature shows that no surgeon in either the USA or Europe has been able to reproduce the results obtained by Neer when using his prosthesis or a similar system (Tables IV and V).

The main complication causing poor results is loss of fixation of the greater tuberosity.65-78-81 Several factors can lead to this including malpositioning of the component, inadequate positioning of the tuberosity and the absence of bone grafting, inadequate fixation of the tuberosity, misjudgement of an ‘anatomical reduction’ and overaggressive rehabilitation.

In order to achieve better and more predictable results, techniques have recently been introduced which improve osteosynthesis of the tuberosity, including the use of a modified prosthetic design and instrumentation which allow a more anatomical reconstruction.59

Malpositioning of the prosthesis. Excessive height and/or retroversion of the humeral component may result from ‘eye-balling’ its final position in the medullary canal because of the disruption of normal anatomical landmarks. Careful pre-operative planning and the use of a fracture jig to control length and retroversion can help to prevent this.59 New instruments have been designed to stabilise the component and to achieve more accurate positioning in both height and retroversion. Before surgery, a full-length radiograph of the contralateral humerus should be obtained with scaled markers. The length should be measured from the epicondylar axis to the top of the head. Using

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<th>Table I. Incidence (%) of complications in a multicentre series of 1842 unconstrained prostheses</th>
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<tr>
<td>Nonunion, malunion of the tuberosities (160/300)       53</td>
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<tr>
<td>Glenoid problems with metal-backed component (48/354)    13.6</td>
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<tr>
<td>Glenoid loosening with polyethylene cemented component (81/705) 11.5</td>
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<tr>
<td>Glenoid erosions (hemiarthroplasty) (24/770)             3.1</td>
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<tr>
<td>Secondary rotator-cuff pathology (71/1542)              4.6</td>
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<tr>
<td>Anterior and posterior instabilities (58/1842)           3.1</td>
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<tr>
<td>Stiffness (30/1842)                                     1.6</td>
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<tr>
<td>Neurological complications (30/1842)                    1.6</td>
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<tr>
<td>Loosening of a cemented humeral component (28/1803)     1.5</td>
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<tr>
<td>Intra-operative fracture of the humerus (26/1842)       1.4</td>
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<tr>
<td>Infection (22/1842)                                     1.2</td>
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<td>Post-operative fractures of the humerus (17/1842)       0.9</td>
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<th>Table II. Incidence (%) of revision surgery in a multicentre series of 1842 unconstrained prostheses</th>
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<tr>
<td>Glenoid problems with metal-backed component (26/354)    7.3</td>
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<tr>
<td>Nonunion and malunion of the tuberosities (13/300)       4.3</td>
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<td>Glenoid erosions after hemiarthroplasty (19/770)          2.5</td>
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<tr>
<td>Anterior or posterior instability (27/1842)              1.5</td>
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<tr>
<td>Glenoid loosening of polyethylene cemented component (9/705) 1.3</td>
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<tr>
<td>Secondary rotator-cuff pathology (20/1842)               1.3</td>
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<tr>
<td>Infection (16/1842)                                     0.9</td>
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<tr>
<td>Post-operative fracture of the humerus (11/1803)         0.6</td>
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<tr>
<td>Stiffness (10/1842)                                     0.5</td>
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<tr>
<td>Loosening of a cemented stem (6/1842)                   0.3</td>
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<tr>
<td>Intra-operative fracture (1/1842)                       0.05</td>
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<td>Neurological complications                              0.0</td>
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<tr>
<th>Table III. Neer’s series of hemiarthroplasty for displaced three- and four-part fractures</th>
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<tbody>
<tr>
<td>Number of cases</td>
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<td>Neer77</td>
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a fracture jig intra-operatively allows this distance to be recreated and controls retroversion.

**Excessive bulkiness of the prosthetic neck.** The design of the neck of a standard prosthesis prevents anatomical reduction of the greater tuberosity and often requires the excavation of valuable cancellous bone. It only allows a small interface between the greater tuberosity and the shaft, which is the critical zone for achieving union of the tuberosity (Fig. 9). Standard components do not make provision for adequate bone grafting. Modifications in design have overcome these problems, providing better and more predictable results (Fig. 10). In a recent large multicentre investigation of HA for fracture of the proximal humerus,
we found that using a specially designed prosthesis resulted in a twofold reduction in migration of the tuberosity and in nonunion or malunion.\(^7\)

**Inadequate fixation of the tuberosity.** Biomechanical studies have shown that the addition of cerclage sutures to the construct improves stability, especially if the reduction is anatomical.\(^7\)\(^2\),\(^8\)\(^3\) Having a smooth medial border on the metaphysis of the humeral component is crucial, since a slightly rough surface can result in breakage of cerclage sutures. This principle also holds for fixation through the rough prothetic holes of many humeral components. Fixation through the holes in the fins of the component is unnecessary as long as there is a means of placing multiple cerclage sutures medially.

**Misjudgement of an ‘anatomical reduction’.** Even with excellent pre-operative planning and an advanced jig system for placement of the component, it is possible to misjudge the position of the tuberosities after the initial fixation. The reduction is often found to be excellent at the time of surgery but is seen to be unsatisfactory on the post-operative radiographs. We recommend that an intra-operative anteroposterior radiograph be obtained before final fixation of the tuberosity in order to check its position.

**Overaggressive rehabilitation.** Excessive early passive and active movement may result in failure of union of the tuberosity. In a recent study, it was shown that patients who have been mobilised according to the concept of early passive movement had double the risk of migration of the tuberosity (27%) compared with those who had been immobilised for a longer period (14%). We recommend that the arm be immobilised in a position of neutral rotation for four to six weeks until union of the tuberosity occurs.

**The reverse prosthesis: an old concept revisited**

The combination of a massive tear of the rotator cuff and arthritis of the glenohumeral joint may lead to a painful, pseudoparalytic shoulder. In this situation an unconstrained shoulder prosthesis can only offer limited functional results (Table VI).

Similarly, the results of the bipolar prosthesis have been disappointing\(^7\)\(^0\) and previous designs of constrained implants using a ball and socket or reverse ball and socket have failed.\(^7\)\(^4\)-\(^8\)\(^8\) The main reason for failure was that the centre of rotation remained lateral to the scapula, resulting in limitation of movement and excessive torque on the glenoid component, with subsequent early loosening.\(^8\)\(^9\)

The Delta reverse prosthesis (DePuy Inc, United Kingdom) designed by Grammont et al\(^1\)\(^0\) introduced two major innovations, namely a large glenoid hemisphere with no neck and a small humeral component inclined almost horizontally and covering less than half of the hemisphere. This

\(\text{Table VI. Published series for hemiarthroplasty in cuff-deficient shoulders}\)

<table>
<thead>
<tr>
<th>Authors</th>
<th>Number of patients</th>
<th>Follow-up in yrs (range)</th>
<th>Persistent post-operative pain scale (%)</th>
<th>Active elevation (˚)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pollock et al(^1)(^0)(^3)</td>
<td>19</td>
<td>3 (1 to 9)</td>
<td>2 (10.5)</td>
<td>Pre-operative</td>
</tr>
<tr>
<td>Arntz et al(^1)(^0)(^4)</td>
<td>18</td>
<td>3 (2 to 10)</td>
<td>7 (39)</td>
<td>60</td>
</tr>
<tr>
<td>Williams and Rockwood(^1)(^0) (^5)</td>
<td>21</td>
<td>4 (2 to 7)</td>
<td>3 (14)</td>
<td>70</td>
</tr>
<tr>
<td>Field et al(^1)(^0)(^6)</td>
<td>16</td>
<td>3 (2 to 5)</td>
<td>3 (19)</td>
<td>60</td>
</tr>
<tr>
<td>Zuckerman et al(^1)(^0)(^7)</td>
<td>15</td>
<td>2 (1 to 15)</td>
<td>8 (53)</td>
<td>69</td>
</tr>
<tr>
<td>Favard et al(^1)(^0)(^8)</td>
<td>60</td>
<td>4 (2 to 10)</td>
<td>NA*</td>
<td>57</td>
</tr>
<tr>
<td>Sanchez-Sotello et al(^1)(^0)(^9)</td>
<td>33</td>
<td>5 (2 to 11)</td>
<td>9 (27)</td>
<td>72</td>
</tr>
</tbody>
</table>

* NA, not available
design medialises the centre of rotation, stabilises the articulation and minimises torque on the glenoid component (Fig. 11). It recruits more fibres of the anterior and posterior deltoid to act as abductors. The design also lowers the humerus relative to the acromion, thus restoring, and even increasing, deltoid tension. Thus, the reverse prosthesis creates a new biomechanical environment in which the deltoid muscle can function despite the lack of muscles of the rotator cuff.

Clinical experience lives up to the biomechanical concept with restoration of active elevation over 90° in patients with a cuff-deficient shoulder. Active external rotation, however, is often limited, particularly when teres minor is not functioning. Internal rotation is also rarely restored because of the design limitations of the prosthesis. The published series of Delta prostheses are small, but show promising early results (Table VII).

Active elevation can be restored in patients with arthritis and an irreparable tear of the cuff after implantation of a reverse prosthesis, but rotation remains limited. The design appears to protect against early loosening of the glenoid component but impingement of the humeral component on the neck of the scapula can lead to notching and wear of polyethylene. This is a cause for some concern, especially as the notch often seems more extensive than can be explained by impingement alone.

**Table VII. Published series for Grammont reverse prosthesis**

<table>
<thead>
<tr>
<th>Author/s</th>
<th>Number</th>
<th>Pathology*</th>
<th>Follow-up (mths)</th>
<th>Active elevation (°)</th>
<th>Constant score</th>
<th>Re-operative (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grammont, Baulot and Chabernaud</td>
<td>16</td>
<td>CTA</td>
<td>27</td>
<td>Pre-operative 14</td>
<td>Post-operative 69</td>
<td>13</td>
</tr>
<tr>
<td>De Buttet et al</td>
<td>71</td>
<td>CTA</td>
<td>24</td>
<td>Pre-operative 19.4</td>
<td>Post-operative 59.5</td>
<td>4.2</td>
</tr>
<tr>
<td>De Wilde et al</td>
<td>5</td>
<td>Revision</td>
<td>30</td>
<td>‘fair’</td>
<td>14</td>
<td>62</td>
</tr>
<tr>
<td>Rittmeister and Kerschbaumer</td>
<td>8</td>
<td>RA</td>
<td>54</td>
<td>Pre-operative 17</td>
<td>Post-operative 63</td>
<td>37.5</td>
</tr>
<tr>
<td>Jacobs, Debeer and De Smet</td>
<td>7</td>
<td>CTA</td>
<td>16</td>
<td>Pre-operative 17.9</td>
<td>Post-operative 56.7</td>
<td>0</td>
</tr>
<tr>
<td>Sirveaux et al</td>
<td>80</td>
<td>CTA</td>
<td>44</td>
<td>Pre-operative 22.6</td>
<td>Post-operative 65.6</td>
<td>5.0</td>
</tr>
<tr>
<td>Valentti et al</td>
<td>39</td>
<td>CTA</td>
<td>84</td>
<td>Pre-operative 21</td>
<td>Post-operative 63</td>
<td>15</td>
</tr>
<tr>
<td>Boulahia et al</td>
<td>16</td>
<td>CTA and SF</td>
<td>35</td>
<td>Pre-operative 31</td>
<td>Post-operative 59</td>
<td>12.5</td>
</tr>
<tr>
<td>Delloye et al</td>
<td>5</td>
<td>Revision</td>
<td>81</td>
<td>Pre-operative NA</td>
<td>Post-operative 40</td>
<td>60</td>
</tr>
<tr>
<td>De Wilde et al</td>
<td>6</td>
<td>Tumours</td>
<td>12</td>
<td>Pre-operative NA</td>
<td>Post-operative NA</td>
<td>0</td>
</tr>
<tr>
<td>Boileau et al</td>
<td>45</td>
<td>CTA, SF revision</td>
<td>40</td>
<td>Pre-operative 17</td>
<td>Post-operative 59</td>
<td>13.0</td>
</tr>
</tbody>
</table>

* CTA, cuff-tear arthropathy; RA, rheumatoid arthritis; SF, sequela of fracture
† NA, not available
Prosthetic instability is a further problem which may be related to insufficient tension of the deltoid and medial impingement, but is also facilitated by medialisation of the humerus and the consequent slackening of the remaining muscles of the rotator cuff. Complications can also affect the humeral component as exemplified by subsidence of uncemented humeral components and late disassociation between the neck of the humerus and the stem.

Despite these concerns, the reverse prosthesis offers a real solution in several situations, such as arthritis due to tear of the cuff, severe fractures, revision surgery in a cuff-deficient shoulder, and tumour surgery when, previously, the options had been very limited (Fig. 12). The results are less predictable in revision surgery and in patients with rheumatoid arthritis. The results for this prosthesis have only been reported in older patients with limited levels of activity.

Therefore, one century after Péan’s shoulder arthroplasty and 50 years after Neer’s innovations, biomechanical research, developments in design, technical modifications, and clinical outcome studies have enabled surgeons to realise Neer’s aims of recreating the normal anatomy and, in the case of Grammont’s reverse shoulder arthroplasty, in producing an anatomical and biomechanical milieu which allows patients to function despite pathology which was once considered to be inoperable.

References
29. Ballmer FT, Sidles JA, Lippitt SB, Matsen FA 3rd. Cemented polyethylene versus uncemented metal-backed glenoid components in total shoulder arthroplasty: a prospec-
The effects of glenoid component prosthetic arthroplasties of the shoulder.


