Complications of Total Shoulder Arthroplasty

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CURRENT CONCEPTS REVIEW
COMPLICATIONS OF TOTAL SHOULDER ARTHROPLASTY

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➤ Total shoulder arthroplasty can be associated with a multitude of complications, the most common of which include prosthetic loosening, glenohumeral instability, periprosthetic fracture, rotator cuff tears, infection, neural injury, and deltoid muscle dysfunction.

➤ Glenoid component loosening has continued to be an unresolved problem. Recent advances in glenoid component design and fixation and alternatives such as biologic resurfacing with meniscal allograft tissue have demonstrated satisfactory short to mid-term results.

➤ The reverse shoulder prosthesis has shown promising short-term results for the treatment of glenohumeral arthritis and massive rotator cuff tears and as a salvage procedure following failure of unconstrained total shoulder arthroplasty.

Total shoulder arthroplasty, originally used by Péan in 1893 to treat tuberculous arthritis[1] and subsequently modernized by Neer et al. in the 1950s for the treatment of three and four-part proximal humeral fractures[2], has demonstrated clinical efficacy when used for the treatment of primary and secondary degenerative conditions of the shoulder. The overall number of shoulder replacements has increased in parallel to the total number of total joint arthroplasties. Approximately 7000 total shoulder replacements were performed annually in the United States from 1996 through 2002. This represents a 40% increase compared with the 5000 arthroplasties per year performed from 1990 through 1992[3-11]. Despite the increase in the annual volume of shoulder arthroplasties, data have suggested that nearly three-fourths of the operations are performed by surgeons who do two or fewer procedures a year[12,13]. The favorability of the clinical outcomes of total shoulder arthroplasty as well as the decision to proceed with a total shoulder replacement instead of a hemiarthroplasty have been shown to depend on surgeon experience and hospital volume[12-16]. Patient readmission rates, complication rates, and lengths of hospital stays have all been shown to be lower when the procedures are done by high-volume surgeons and in high-volume hospitals[12-16].

As with other total joint procedures, total shoulder arthroplasty can be associated with a multitude of complications, the most common of which include prosthetic loosening, glenohumeral instability, periprosthetic fracture, rotator cuff tears, infection, neural injury, and deltoid muscle dysfunction. Rates of complications associated with total shoulder arthroplasty are highly variable (0% to 62%)[11,17], with mean complication rates ranging from 10% to 16%[11,17,18].

We retrospectively reviewed all articles published from 1996 to 2005, retrieved from the MEDLINE and OVID databases, that had direct references to "shoulder," "arthroplasty," and "replacement." Complication events were totaled and stratified according to the type of complication. The overall percentage of complications, the percentages of the different types of complications, and the prevalence of each type of complication as a percentage of all complications were calculated for comparison with the findings of our previous analysis, reported in 1996[11]. Our present analysis revealed 414 complication events in association with 2810 total shoulder replacements (a rate of 14.7%)[19-57]. That finding is in line with previous observations by one of us (M.A.W.) and colleagues[18], who reported 204 complications in association with 1459 shoulder arthroplasties (a rate of 14%), and by Chin et al.[58], who reported fifty-three complications in association with 431 shoulder arthroplasties (a rate of 12%). In our 1996 analysis, we reviewed forty-one series, which included a total of 1858 total shoulder arthroplasties, that had been reported on between 1975 and 1995[11]. The mean duration of follow-up in those series was 3.5 years. Our current report on the complications of total shoulder arthroplasty, as identified in the systematic review of the literature pertaining to total shoulder arthroplasty from 1996 to 2005, included thirty-nine clinical studies (involving 2810 total shoulder replacements) with a minimum duration of follow-up of two years. The average duration of follow-up was five years or more in sixteen of those studies (involving 665 shoulders)[24,26,29,35,38,41-43,45-49,52,54,57] compared with five studies in our previous analysis. Moreover, three studies (involving 190 shoulders)[26,28,50] in the present analysis, compared with none in our previous report[11], included a

duration of follow-up of ten years or more.

Despite the increase in the volume of total shoulder arthroplasties, the overall prevalence of complications revealed by our present analysis is in line with those in previous reports[11,18,59]. The reasons why arthroplasties fail are multifactorial. Previously reported revision rates ranged from 6% to 7%[59], whereas the present evaluation indicated a broad range of 5% to 42% for both constrained and unconstrained implants[19,20,22,25,28,37-40,43,45,47,49,50,53-55]. A sufficient duration of follow-up is critical in an assessment of the clinical outcomes of total shoulder replacements, as failures may become evident at the time of mid-term (five to ten-year) and long-term (greater than ten-year) evaluations. The purpose of this review is threefold: to assess whether the average duration of follow-up in studies of total shoulder replacements has increased, to determine whether the frequency or types of complications have changed, and to determine whether survivorship has changed with longer follow-up.

Constrained Total Shoulder Arthroplasty

Since the 1970s, constrained and semiconstrained shoulder prostheses, such as the so-called reverse ball-and-socket design, have been employed as an interim solution to the vexing problem of glenohumeral arthrosis associated with glenohumeral instability secondary to a functionally ineffective or an anatomically deficient rotator cuff[11,18-24,59]. In 1983, Neer et al. initially coined the term "cuff tear arthropathy" to describe the development, in certain shoulders with a chronic massive rotator cuff tear, of restricted shoulder motion with proximal humeral migration, "femoralization" (erosion of the greater tuberosity) of the humeral head, and "acetabularization" of the coracoacromial arch[60,61]. The outcomes of treatment of this form of arthritis are highly variable, which has led to a biomechanical classification of cuff tear arthropathy based on the degree of superior migration of the humeral head center of rotation and the amount of instability of the center of rotation[60]. Fixed-fulcrum and so-called reverse ball-and-socket prostheses were designed to replace the arthritic joint and to restore stability in shoulders with decentered and unstable glenohumeral axes of rotation[60]. Our initial review called into question the efficacy of the implantation of this device as a salvage procedure because of a high complication rate (range, 8% [six of seventy-one shoulders] to 100% [twenty-six of twenty-six shoulders]) and a high revision rate (range, 4% [three of seventy-one shoulders] to 54% [thirteen of twenty-four shoulders])[11]. Particularly concerning was the high rate of complications noted in the early postoperative period, with half of the reported studies including a duration of follow-up of less than one year[11].

There has been renewed interest in the use of the reverse total shoulder arthroplasty for the treatment of such conditions as rotator cuff arthropathy and severe proximal humeral fractures with tuberosity malposition or nonunion as well as for the revision of failed total shoulder arthroplasties. Five studies[19-23] (involving 261 shoulders) with an overall average duration of follow-up of 3.1 years demonstrated improvements, following this procedure, in shoulder motion such as forward flexion and
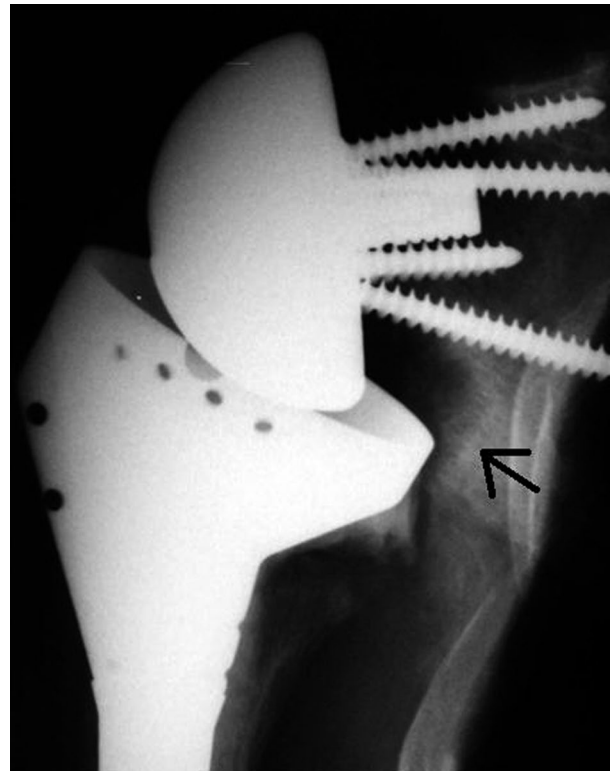

Fig. 1-A

Figs. 1-A through 1-E Complications of reverse total shoulder arthroplasty. **Fig. 1-A** Scapular notching (impingement) at the interface between the humeral component and the glenoid neck.

abduction and in pain relief as measured with the Constant score[62] (a patient-derived outcome measurement). Despite these encouraging short-term results, the complication rates were high (mean, 24.4%; range, 6.25% to 50%). Our analysis of the current literature regarding the reverse shoulder prosthesis revealed the most common complications, in order of frequency, to be scapular notching (Fig. 1-A), hematoma formation, glenoid dissociation such as baseplate failure or aseptic loosening (Figs. 1-B and 1-C), glenohumeral dislocation (Fig. 1-D), acromial and/or scapular spine fracture, infection, loosening or dissociation of the humeral component (Fig. 1-E), and nerve injury[19-24]. In parallel with these findings, the revision rates in the studies by Frankle et al.[19], Werner et al.[22], and Sirveaux et al.[23] were 12% (eight of sixty-six shoulders), 33% (nineteen of fifty-eight shoulders), and 4% (three of eighty shoulders), respectively. Notably, all shoulders with loosening or failure of the glenoid component were revised to either a hemiarthroplasty (three of the fifty-eight shoulders in the study by Werner et al. and two of the sixty-six shoulders in the study by Frankle et al.) or a second reverse shoulder prosthesis (six of the sixty-six shoulders in the study by Frankle et al.). In their study of seventy-seven patients (eighty shoulders), Sirveaux et al. found a 29.8% survival rate at eight years postoperatively, suggesting a high probability of failure with mid-term and long-term follow-up. It remains our belief that the enthusiasm for this particular implant should be tempered by the findings in
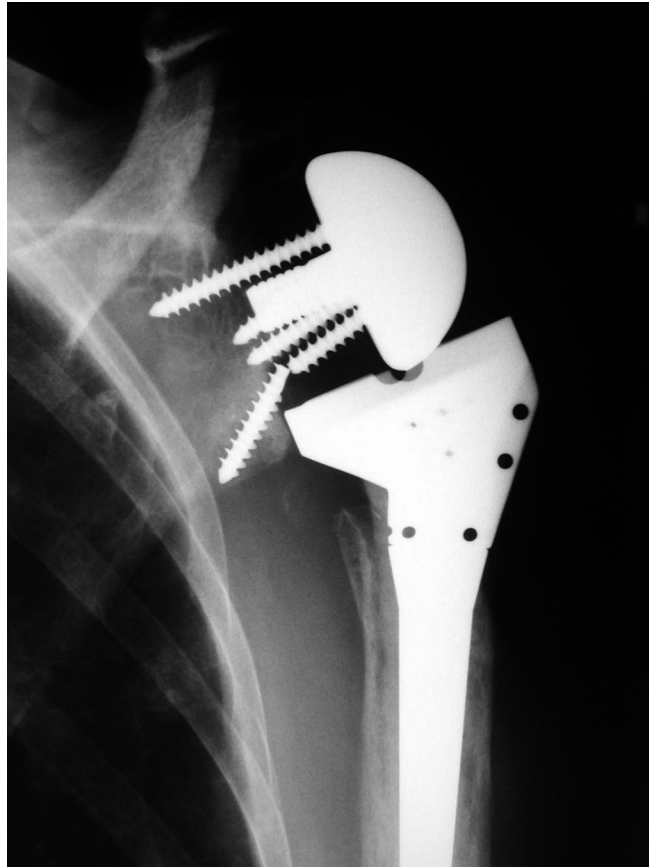
Fig. 1-B   Fig. 1-C

Failure of the glenoid baseplate with evidence of gross loosening and screw breakage.

future clinical evaluations with longer follow-up. There should be stringent indications for the utilization of the reverse prosthesis, and we agree with previous authors that the implant should be reserved for elderly patients with shoulder arthropathy and clinical pseudoparalysis who have sufficient bone stock for implantation of a glenoid component.

Unconstrained Total Shoulder Arthroplasty

Unconstrained total shoulder arthroplasty has proven to be highly successful for the treatment of primary and secondary degenerative conditions of the shoulder. Previous analyses of short to mid-term studies (with durations of follow-up of less than five years) have demonstrated good and excellent results[11]. When compared with constrained and semiconstrained shoulder arthroplasties, unconstrained shoulder arthroplasty has fewer complications with respect to aseptic loosening, instability, infection, and periprosthetic fractures[11]. The traditional definitions of complications and failure related to total shoulder arthroplasty have evolved over the last decade. In their report on the characteristics of unsatisfactory shoulder arthroplasties, Hasan et al. expanded the definition of failure to include patient dissatisfaction with the procedure[63]. Moreover, they were the first to describe stiffness as the leading cause of failure, which they noted in 104 (74%) of 141 shoulders.

In our present analysis, we evaluated thirty-three studies on unconstrained total shoulder arthroplasty (in a total of 2540 shoulders) with a minimum duration of follow-up of two years[25-57]; the average duration of follow-up was 5.3 years compared with four years in our previous analysis[11]. A majority of the studies indicated that overall patient satisfaction was excellent, good, or satisfactory after unconstrained total shoulder arthroplasty[27-30,32,34,39,42,46,47,49,54]. Kalandiak and the senior authors of the present paper (M.A.W. and C.A.R. Jr.) previously categorized complications with failure into three broad categories: those involving soft tissue (instability, stiffness, tuberosity malunion or nonunion, and rotator cuff tears), those involving the glenoid component, and those involving the humeral component[59]. They reiterated that most causes of failure are multifactorial. Utilizing the same three broad groups in our analysis, we found that the most common complications, in order of frequency, were component loosening, instability, periprosthetic fracture, rotator cuff tears, neural injury, infection, and deltoid muscle dysfunction[25-57] (Table I). In contrast to the findings in our previous analysis[11], periprosthetic fractures were more frequent (forty-six of 414 events) than postoperative rotator cuff tears (thirty-two events)[25-57]. In a multicenter evaluation of total shoulder arthroplasty and rotator cuff disease, Edwards et al. found that most complications involving component loosening,

instability, fractures, and rotator cuff tears (sixty-six of the ninety complications) became evident after the initial course of treatment (after three weeks)[34]. In a study of 320 shoulders (267 patients), Deshmukh et al. summarized the complications with respect to the time of occurrence and reported that, on the average, component loosening was found at 7.7 ± 4.8 years; infections, at 12.1 ± 2.9 years; dislocations, at 2.1 ± 3.6 years; and periprosthetic fractures, at 5.8 ± 4.7 years[25]. In a study in which thirty-six shoulders were treated with total shoulder arthroplasty, Sperling et al.[28] reported two postoperative infections requiring revision surgery at ten and thirteen years postoperatively, removal of the glenoid component from one shoulder at eleven months because of aseptic loosening, and loosening of the glenoid and humeral components in two shoulders at ten and fourteen years. Reinforcing the need for longer-term follow-up, Torchia et al.[50], in their study of 113 total shoulder arthroplasties, reported that the time to revision was seven months to 10.4 years for component loosening, 11.4 to 13.5 years for infection, 6.4 years for a fracture, and 10.4 years for a rotator cuff tear. With our finding that complications, particularly component loosening and instability, present later in the postoperative course, we believe that accurate and detailed longer-term follow-up is necessary to clearly elucidate the shortcomings of total shoulder arthroplasty.

Component Loosening

Loosening of the glenoid and humeral components is a common event, accounting for 39% (161) of the 414 reported complications in our present analysis[25-57]. With the inclusion of more studies with mid-term to long-term follow-up (five to ten years) in the present analysis, this represents a 10% increase in the overall incidence compared with that in our initial review[11]. A majority (83% [134]) of the 161 cases of loosening involved failure of fixation of the glenoid component[11,25-57].

Loosening of the Glenoid Component

Radiolucencies at the cement-bone interface of the glenoid component continue to be problematic, with a reported prevalence ranging from 0% to 100%[64-71]. In our review of studies in which the average duration of follow-up was ten years or more[26,28,50], we found that authors had reported glenoid radiolucent lines in nearly 80% (117) of 148 shoulders and had noted radiographic evidence of loosening (migration, tilt, or a shift of the component or a complete radiolucent line of >1.5 mm in thickness[57]) in fifty (34%) of the 148 shoulders (Figs. 2-A and 2-B). At an average of 13.4 years, only eleven (7%) of the 148 shoulders had required revision surgery specifically because of the glenoid loosening. Summation of data from reports with less than ten years of follow-up proved difficult because of the wide variability

Fig. 1-D

Fig. 1-E

Fig. 1-D Scapular "Y" lateral radiograph showing an anterior glenohumeral dislocation. **Fig. 1-E** Humeral component dissociation with separation of the diaphyseal and epiphyseal sections.
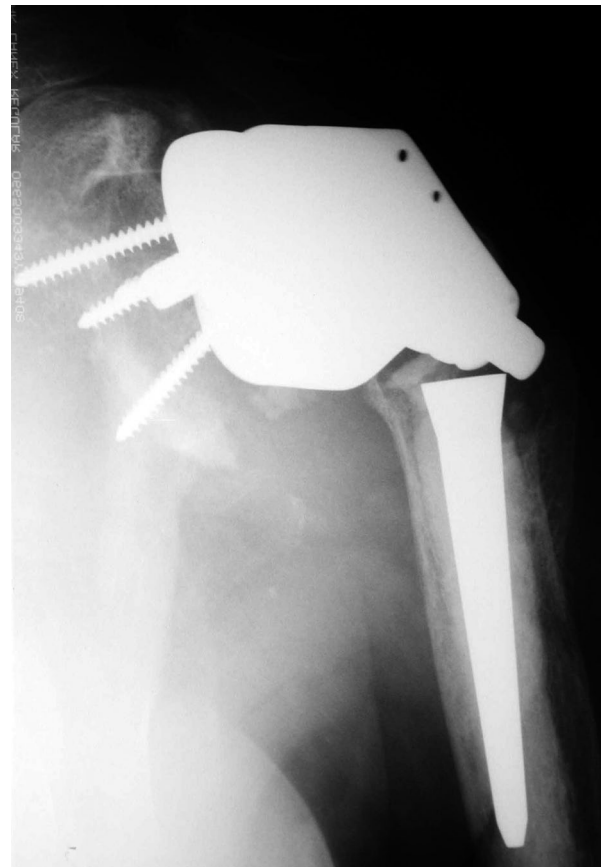
TABLE I Complications Following Unconstrained Total Shoulder Arthroplasties in Studies Reported from 1996 to 2005*			
Complication	No. of Shoulders	Percentage of All Complications	Percentage of All Shoulders
Component loosening	161	39	6.3
Glenoid	134	32	5.3
Humerus	27	6.5	1.1
Instability	124	30	4.9
Superior	77	19	3.0
Posterior	25	6	1.0
Anterior	22	5	0.9
Periprosthetic fracture	46	11	1.8
Intraoperative	27	6.5	1.1
Postoperative	19	4.6	0.7
Rotator cuff tear	32	7.7	1.3
Neural injury	20	4.8	0.8
Infection	19	4.6	0.7
Deltoid detachment	2	0.5	0.08
*Thirty-three series including a total of 2540 shoulders.			

in (or lack of) reporting of glenoid radiolucent lines, rates of glenoid loosening, and number of revisions due to compromise of the glenoid component. However, specific reports with less than ten years of follow-up demonstrated a broad range of rates of glenoid radiolucent lines of 15% to 84%[32,34,35,41,52,56,57].

Alternative techniques to diminish the rate of radiolucent lines in the immediate postoperative period and to improve long-term glenoid stability have included preservation of the subchondral plate, concentric glenoid reaming[72], optimal biomaterial selection and design, glenohumeral prosthetic mismatch[73,74], and metal-backed implants[11,36,56,57,75]. More recent studies have suggested that improved glenoid component design (pegged rather than keeled), cement techniques (pressurization rather than manual packing), and instrumentation all play a vital role in enhancing initial fixation, which may reduce the incidence of early loosening of non-metal-backed glenoid components[65,66,76]. A previous in vivo study by the senior ones of us (M.A.W. and C.A.R. Jr.) and colleagues demonstrated that use of pegged (rather than keeled) glenoid components produced superior mean fixation strength in weight-bearing canine models initially (at zero months) and at short-term (three and six-month) postoperative time intervals[66]. In an evaluation of pegged glenoid components implanted in 289 shoulders of patients with primary osteoarthritis, Lazarus et al. reported significant improvements in radiolucency scores and component seating when compared with those for thirty-nine shoulders treated with a keeled glenoid component (p < 0.05)[65]. However, only one of the thirty-nine shoulders with a keeled component and nineteen of the 289 with a pegged component lacked radiolucent lines on initial postoperative anteroposterior and axillary lateral radiographs. A recent prospective, randomized clinical trial involving radiographic comparison of pegged and keeled glenoid components with excellent interobserver reliability revealed a significantly larger percentage of radiolucent lines around the keeled components (39%; nine of twenty-three shoulders) than around the pegged components (5%; one of twenty shoulders) (p < 0.05)[76]. The authors of that study suggested that the surgeon should balance the increased technical difficulty of placing pegged components with the potential long-term benefits of fewer radiolucent lines and less glenoid loosening[50,76].

Polyethylene Compared with Metal-Backed Glenoid Implants
Persistent concern regarding aseptic loosening of the glenoid component has led to additional innovations, including the use of metal-backed implants; preliminary results from our initial analysis suggested that such components were associated with lower rates of radiolucent lines and radiographic evidence of loosening[11]. However, early enthusiasm for these implants has been tempered by mid-term follow-up results, with substantial issues related to progression of radiolucent lines, severe osteolysis, polyethylene-metal tray dissociation, glenoid tray fracture, and screw breakage[36,56,57]. Wallace et al. initially reported no significant differences between glenoid metal-backed and cemented polyethylene components with regard to pain, range of motion, shoulder function, or general health at an average of five years postoperatively[56]. There was a total of fourteen complications (fourteen of eighty-six shoulders), with eight requiring revision. Only two of the eight revisions were due to polyethylene-metal tray dissociation. Additionally, radiolucent lines were observed in thirteen (41%) of thirty-two shoulders treated with a cemented glenoid component in comparison with six (23%) of twenty-six shoulders treated with a metal-backed glenoid component[56].

More recent reports by Boileau et al.[36] and Martin et al.[57] have called into question the long-term durability of cementless glenoid implants, with failures specifically related to progres-
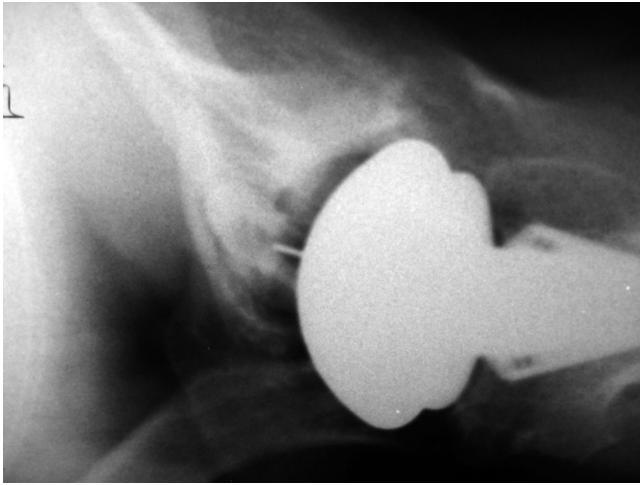
Fig. 2-A

Fig. 2-B

Fig. 2-A Axillary radiograph of a circumferential glenoid radiolucent line in a sixty-three-year-old patient with a total shoulder prosthesis and a six-month history of persistent shoulder pain. **Fig. 2-B** Gross specimen of the explanted keeled glenoid component, showing macroscopic structural damage and polyethylene wear.

sive radiolucent lines, osteolysis, tray fracture, and screw breakage. At an average of thirty-eight months (minimum, three years) postoperatively, Boileau et al. reported a significantly greater prevalence of periprosthetic radiolucent lines in association with metal-backed glenoid components (p = 0.01), with four (20%) of twenty shoulders demonstrating radiographic evidence of loosening requiring revision. Martin et al. also reported radiolucent lines around the glenoid component and/or screws, in fifty-three (38%) of 140 shoulders. At a mean 7.5 years, fifty-five (39%) of the 140 shoulders were slightly to severely painful, with sixteen (11%) of the 140 requiring revision secondary to glenoid failure[57].

The mid-term (five to ten-year) results associated with uncemented, metal-backed glenoid components have proven to be unsatisfactory, particularly with regard to a higher rate of clinical and radiographic failures than had been previously reported. Longer-term follow-up may amplify issues related to polyethylene wear, aseptic loosening, and screw breakage[75].

Prosthetic Mismatch
In a review of the effect of prosthetic mismatch in 319 shoulders treated with a single type of total shoulder prosthesis and followed for a mean of 53.5 months (range, twenty-four to 110 months), Walch et al. observed a lower (better) radiolucency score in association with mismatches between the glenoid and humeral head diameters of >5.5 mm (ceiling, 10 mm)[73]. The authors cautioned that the upper limit of mismatch had not been conclusively determined and that greater prosthetic mismatches could lead to increased joint translation, accelerated polyethylene wear, or fracture.

*Hemiarthroplasty Compared with
Total Shoulder Arthroplasty*
Hemiarthroplasty has historically been favored over total shoulder arthroplasty for the management of specific shoulder

conditions with inadequate glenoid bone stock, irreparable rotator cuff tears associated with fixed upward displacement of the humeral head, glenohumeral arthrosis in patients less than fifty years of age, proximal humeral fractures in elderly patients, and humeral head osteonecrosis with an intact glenoid cartilaginous surface[77]. With persistent concerns regarding the survival of the glenoid component, previous authors have questioned the indications for glenoid resurfacing, prompting surgeons to favor hemiarthroplasty for patients with glenohumeral arthritis[67,77-80]. In 1974, Neer reported the results of hemiarthroplasty in forty-seven patients at an average of six years[81]. Twenty-eight of these patients were treated for primary osteoarthritis, and they exhibited good pain relief. Twelve patients who were followed radiographically for ten years had no radiographic evidence of degenerative progression of the glenoid. In that report, Neer concluded that there was minimal impetus to proceed with glenoid resurfacing given the possibility of increased complications. However, in 1982 and 1990, Neer et al. reported favorable results in forty patients who had undergone total shoulder arthroplasty for the treatment of osteoarthritis, with thirty-six demonstrating an excellent result[82,83]. They modified their initial recommendation by advising surgeons to proceed with hemiarthroplasty in the specific situations of substantial glenoid osseous deficiency or a preserved glenoid fossa with congruence. A recent review of the literature has similarly reinforced the principle of total shoulder arthroplasty providing predictable pain relief and functional improvement for patients with glenohumeral osteoarthritis and an intact rotator cuff[84].

Additional clinical outcome studies and meta-analyses have indicated that, overall, total shoulder arthroplasty provides better results than hemiarthroplasty with regard to pain relief, motion, and level of activity[34,51,84,85]. In a multicenter trial, Edwards et al. found a 94% rate of good or excellent results after 601 total shoulder arthroplasties and an 86% rate of good

or excellent results after eighty-nine hemiarthroplasties followed for at least two years[34]. The total shoulder arthroplasties, in comparison with the humeral head replacements, resulted in significantly positive differences ($p < 0.05$) with regard to average Constant scores (70 compared with 64 points), active forward flexion (145° compared with 130°), and active external rotation (42° compared with 36°).

To our knowledge, Gartsman et al. performed the only randomized, prospective study comparing total shoulder arthroplasty with hemiarthroplasty in patients with osteoarthritis and an intact rotator cuff[51]. Fifty-one patients with congruent glenoid wear were randomized to be treated with either total shoulder arthroplasty (twenty-seven shoulders) or hemiarthroplasty (twenty-four shoulders) and were evaluated at a mean of thirty-five months (range, twenty-four to seventy-four months) postoperatively. The authors found significant improvements ($p < 0.05$) with regard to pain relief and internal rotation in the patients treated with total shoulder arthroplasty, compared with those treated with hemiarthroplasty, and found additional trends suggesting better strength, function, and satisfaction scores. The authors reported increases in the cost (mean, $1177), operative time (thirty-five minutes), and blood loss (150 mL) associated with the total shoulder arthroplasties but no revisions of those procedures. Three shoulders that had been treated with a hemiarthroplasty were revised to a total shoulder arthroplasty secondary to increased pain and radiographic evidence of increased glenoid wear; the mean cost of the revisions was $15,998.

A recent multicenter clinical trial that was performed to evaluate the influence of preoperative factors on the outcome of total shoulder arthroplasty showed that glenoid erosion, humeral head subluxation, and a substantial preoperative loss of the passive range of motion had detrimental effects on outcome[86]. Repairable full-thickness tears of the rotator cuff isolated to the supraspinatus tendon did not affect the outcome. Active forward flexion and external rotation were better in nineteen shoulders that had undergone total shoulder arthroplasty than they were in ten shoulders that had undergone hemiarthroplasty. The authors recommended the use of a glenoid component in shoulders with glenoid erosion and in those with a small, repairable tear of the supraspinatus and co-existent glenoid arthritis.

The results of conversion of a hemiarthroplasty to a total shoulder arthroplasty have proven to be less predictable than those of primary total shoulder arthroplasty. Sperling and Cofield[87] reported poor results in a study of eighteen patients who had undergone such a conversion. According to the criteria described by Neer et al.[83], seven of the eighteen patients demonstrated an unsatisfactory result secondary to a limited range of motion. Carroll et al.[88] reported similarly unsatisfactory results (in seven of fifteen patients), suggesting that revision total shoulder arthroplasty following a failed hemiarthroplasty produces inferior outcomes and inconsistent pain relief when compared with primary total shoulder arthroplasty.

In order to minimize the long-term complications of polyethylene wear, proponents of hemiarthroplasty in younger patients (less than fifty-five to sixty years of age) with osteoarthritis have explored biologic glenoid resurfacing with interposition of a capsular, fascial, or meniscal allograft[89-92]. In 1995, Burkhead and Hutton[89] reported their experience with biologic resurfacing in fourteen patients with glenohumeral arthritis. Of the fourteen patients, six—three in whom the glenoid had been resurfaced with an anterior capsular graft and three in whom it had been resurfaced with autogenous fascia lata—were followed for a minimum of two years. All six patients exhibited painless gains in forward elevation (57°), external rotation (45°), and internal rotation (six spinal segments).

In 2001, Ball et al. reported positive results of meniscal allograft interposition arthroplasty in six patients[90]. At an average of two years postoperatively, four of the six patients reported only slight or no pain. Moreover, all patients demonstrated substantial improvements in shoulder motion, without radiographic evidence of glenoid erosion. In 2003, Nowinski and Burkhead presented promising mid-term to long-term results of biologic glenoid resurfacing with fascia lata or Achilles tendon allograft in twenty-six shoulders (twenty-four patients)[91]. At five to thirteen years postoperatively, 81% of the patients demonstrated a satisfactory or excellent result. The authors suggested that this procedure may be a viable choice for the treatment of glenohumeral arthrosis in younger patients who wish to remain active, with the future option of a conversion to a total shoulder arthroplasty. Recently, one of us (M.A.W.)[92] reported on six consecutive patients (average age, forty-four years; range, thirty-one to fifty-three years) who had undergone hemiarthroplasty and glenoid resurfacing with meniscal allograft and were followed for an average of twenty-three months. Objective measures (forward elevation and external rotation) and subjective measures (a visual analog scale and the Simple Shoulder Test) all demonstrated substantial improvements, with radiographs indicating improved joint space. These findings reaffirm the viability of this technique in the treatment of glenohumeral arthrosis in young, active patients.

Loosening of the Humeral Component

Despite an overall prevalence of 1% (twenty-seven of 2540 shoulders), nearly 7% (twenty-seven) of the 414 complications identified in our analysis consisted of aseptic loosening of the humeral component[25-57]. Although humeral radiolucent lines are uncommon, recent reports have indicated a higher frequency with use of press-fit humeral stems[93,94]. Maynou et al. reported radiolucent lines about the humeral component in twenty of forty shoulders[93]. All eleven press-fit humeral stems in that cohort were associated with some degree of radiolucency, and there was clear radiographic evidence of loosening of two of those stems. No revisions were necessary, and glenoid resurfacing did not correlate with the presence of radiolucent lines or humeral component loosening. In their study of sixty-two primary ingrowth total shoulder prostheses, Sperling et al. defined "at risk" humeral components as those with radiographic evidence of subsidence, tilt, or 2-mm lucent lines around the implant (in modified Gruen zones 1 through 8)[95]. At an average of 4.6 years postoperatively, the authors reported incomplete radi-

olucent lines adjacent to eleven (18%) of the sixty-two humeral implants, and six of the eleven were judged to be "at risk." Of the six "at risk" humeral components, only one required revision because of symptomatic loosening.

Matsen et al. found radiolucent lines in seventy-seven (61%) of 127 shoulders, with the majority (seventy-five) occurring at the distal stem tip[94]. The humeral head replacements and the total shoulder arthroplasties had similar rates of radiolucent lines (59% [twenty of thirty-four] and 61% [fifty-seven of ninety-three, respectively]). None of the shoulders demonstrated subsidence or a shift in the position of the humeral component at an average of three years postoperatively.

Sanchez-Sotelo et al. reported that, of forty-three cemented humeral implants followed for an average of 6.6 years, only one was at risk, despite evidence of radiolucent lines in sixteen shoulders[96]. In contradistinction to the report by Matsen et al.[94], the overall prevalence, extent, and thickness of humeral radiolucent lines were significantly higher in association with total shoulder arthroplasties than they were in association with hemiarthroplasties (p < 0.05)[96]. Humeral component survival may be affected by the mode of fixation (press-fit compared with cemented) and the biologic response to wear particles. Changes at the periprosthetic humeral interface in the presence of a glenoid component raise concern about osteolysis and the potential for symptomatic loosening, requiring close long-term follow-up and possibly revision surgery[93-97].

Instability Following Total Shoulder Arthroplasty

Stability of the glenohumeral joint is provided by an interplay of mechanisms that promote a range of motion and purposeful function. Loads of increasing severity are offset initially by joint surface anatomy, joint volume, atmospheric pressure, and joint fluid cohesion/adhesion. Moderate loads are counteracted by the deltoid muscle and rotator cuff, while larger loads are counterbalanced by capsulolabral structures and bone structure[11,17]. Total shoulder arthroplasty can alter these complex interactions, making soft-tissue tensioning and component positioning critical in the prevention of postoperative instability. Our previous and present analyses indicated that glenohumeral instability is the second leading cause of complications associated with total shoulder arthroplasty, with a reported prevalence of 4% (124 of 3081 shoulders) and accounting for 30% of all complications (124 of 414)[11,25-57].

Anterior Instability

Anterior and superior instability accounted for 80% (ninety-nine) of the 124 cases of instability[25-57] (Figs. 3-A and 3-B). The etiology of anterior instability is likely multifactorial and involves a combination of soft-tissue tensioning and component positioning. Anterior instability is usually associated with humeral component malrotation, anterior glenoid deficiency, anterior deltoid muscle dysfunction, and failure of the subscapularis tendon and anterior aspect of the capsule[11,17,98,99]. In the experience of the senior ones of us (M.A.W. and C.A.R. Jr.), anterior instability secondary to subscapularis rupture has generally been a function of operative technique, tissue quality, inappropriate physical therapy, or the use of oversized components[11,17]. Moeckel et al. retrospectively reviewed ten cases of instability (seven anterior and three posterior) in a study of 236 shoulders[100]. All seven anteriorly dislocated shoulders demonstrated a tear of the subscapularis tendon at the time of revision. Four of the seven shoulders were treated with repeat mobilization and repair of the subscapularis, whereas the remaining three required reconstruction with an Achilles tendon allograft as a static stabilizer. Clinical and radiographic follow-up at two years showed no evidence of anterior subluxation or frank dislocation.

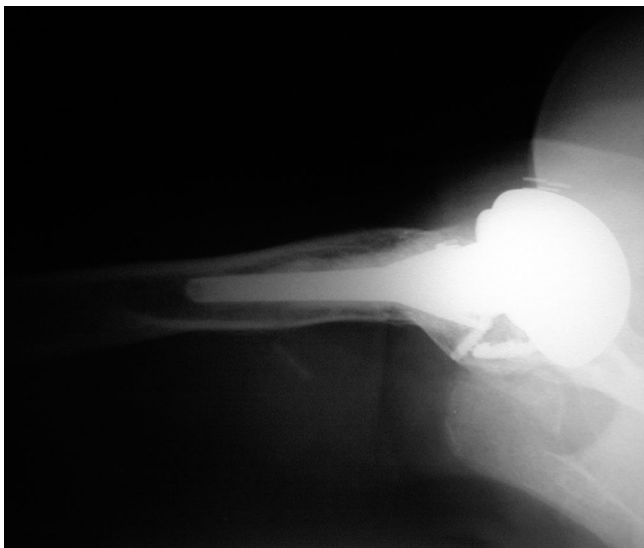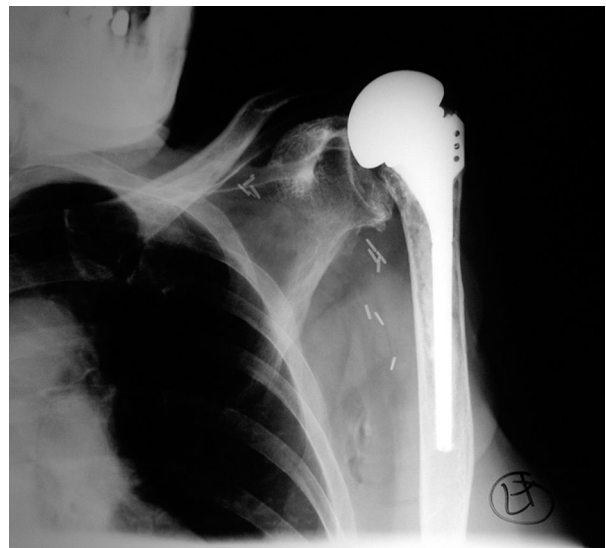More recently, Sanchez-Sotelo et al. reported their clini-

Fig. 3-A

Fig. 3-B

Figs. 3-A and 3-B Axillary lateral and anteroposterior radiographs showing combined anterior subluxation of the glenohumeral joint and superior escape of the humeral head due to rotator cuff dysfunction and compromise of the coracoacromial arch.

cal experience with thirty-three shoulders with instability, which was anterior in nineteen and posterior in fourteen[53]. On the basis of radiographic, clinical, and intraoperative findings, the authors attributed the instability to abnormal capsular tension and/or rotator cuff dysfunction in twenty-one shoulders, component malpositioning in one shoulder, and a combination of elements in eleven. Revision surgery restored stability in only nine of the thirty-three shoulders, with the rate of failure being higher for the shoulders with anterior instability than for those with posterior instability. The authors reported that the results of revision surgery for instability were marginal, with failure rates exceeding 50%.

Matsoukis et al. reported the results of shoulder arthroplasty for the treatment of arthritis in fifty-five shoulders with a history of anterior dislocation[55]. At a mean of forty-five months (range, twenty-four to eighty-seven months) postoperatively, general improvements in the mean Constant score (from 30.8 points preoperatively to 65.8 points postoperatively), active forward flexion (from 82.1° to 138.9°), and active external rotation (4.0° to 38.6°) were noted. Four patients demonstrated dynamic anterior glenohumeral instability. One underwent revision of the humeral stem to increase retroversion, with subsequent resolution of the instability. Some authors have suggested that asymmetric glenoid reaming be used in patients with arthritis due to recurrent dislocation to reduce the likelihood of anteversion of the glenoid component and subsequent anterior instability[99].

Superior Instability

Superior instability has been reported in association with deficiency of the rotator cuff or coracoacromial arch and has been particularly evident in patients treated with shoulder arthroplasty for cuff tear arthropathy[69,81,101-103]. Reports by Boyd et al. indicated that the amount of proximal migration and the presence of a torn rotator cuff were positively correlated with poor preoperative function[69,81]. In a shoulder with superior instability of a total shoulder prosthesis, the force-couple imbalance between the rotator cuff and the deltoid can lead to eccentric loading forces on the glenoid component, causing accelerated wear and eventual loosening. Patients with glenohumeral arthritis and massive rotator cuff tears may maintain an acceptable degree of pain-free shoulder function and a satisfactory range of motion if there is an intact deltoid and a stable center of rotation. The more common picture entails substantial pain and functional deficits as well as a destabilized center of rotation[60]. Previous failed treatments and an in-depth analysis of cuff tear arthropathy led to the development of the Seebauer classification, which divided shoulders into four groups based on the degree of superior migration from the center of rotation (ranging from minimal migration to anterior-superior escape) and the degree of instability of the center of rotation of the shoulder[60]. We previously advocated the use of humeral head arthroplasty with preservation of the coracoacromial ligament followed by an appropriate physician-directed therapy program for patients with superior instability[11]. We additionally advocated component removal with glenoid bone-grafting for patients with a

symptomatically loose glenoid component following a total shoulder arthroplasty. In a study of sixty-six shoulders with cuff tear arthropathy treated with an extended humeral prosthesis, Visotsky et al. reported substantial improvements in the average external rotation (from 8° preoperatively to 30° postoperatively), average forward flexion (from 56° to 116°), average visual analog score (from 9.3 to 1.9), and the average American Shoulder and Elbow Surgeons (ASES) score (from 29 to 79 points)[60]. On the basis of the concept of so-called limited-goals surgery, the authors promoted hemiarthroplasty as a form of treatment for patients with superior migration and limited stability; however, they alternatively suggested that the reverse shoulder prosthesis may be used for shoulders that demonstrate anterior-superior escape due to glenohumeral instability and a deficiency in the coracoacromial arch[60]. The reverse shoulder prosthesis has more recently been utilized in patients in whom a total shoulder arthroplasty has failed secondary to rotator cuff dysfunction with or without a symptomatically loose glenoid component. The previously enumerated results[19-23] indicate that this procedure is a viable option as a salvage procedure in patients with superior instability.

Posterior Instability

In our analysis, we found twenty-five instances of posterior glenohumeral instability[25-57].

Posterior instability has previously been attributed to excessive component retroversion[11,98-100] but is probably multifactorial in nature. Posterior glenoid erosion and soft-tissue imbalance have been implicated in the development of posterior instability (Fig. 4). We previously reported our institutional experience with posterior instability in seven shoulders, four of which demonstrated humeral retroversion of >80° and four of which had substantial posterior glenoid erosion[11]. Methods employed for correction of the instability included restoration of normal retroversion of the humeral component, glenoid reaming to reestablish glenoid version, and posterior capsulorrhaphy[11]. Reports by Hill and Norris[49] and Namba and Thornhill[104] indicated similarly favorable results following augmentation of glenoid bone stock and soft-tissue imbrication for treatment of posterior instability.

Inferior Instability

Inferior instability most commonly results from failure to restore the humeral length when replacement is performed for a proximal humeral fracture or tumor[11,53]. Clinically, these patients lack the ability to raise the arm above the horizontal plane as a result of the inadequate humeral length and poor deltoid muscle tensioning[11].

Periprosthetic Fractures

The reported prevalence of periprosthetic humeral fractures in association with unconstrained total shoulder arthroplasty has been estimated to be between 1.5% to 3%[11,17,105]. The present analysis, which identified forty-six periprosthetic fractures in the review of 2540 unconstrained total shoulder arthroplasties (a rate of 1.8%), reaffirms this estimate[25-57].

Fig. 4

Axillary radiograph showing posterior subluxation of the humeral head component secondary to eccentric posterior glenoid wear.

Approximately 11% (forty-six) of the 414 complications in the current review were due to periprosthetic fractures[19-57], in comparison with 20% in our previous analysis[11]. In contradistinction, periprosthetic fractures (twelve intraoperative and one postoperative) accounted for nearly 25% of all complications in a recent report by Chin et al.[58]. Chin et al. could not explain why, despite an overall reduction in the complication rate over time (31% compared with 12%), there was a relative increase in fracture frequency. Although a majority of the fractures (twelve of thirteen) in that report occurred intraoperatively, our present review of total shoulder arthroplasties done from 1996 to 2005 demonstrated that 41% (nineteen) of forty-six periprosthetic fractures occurred postoperatively[25-57].

Intraoperative Fractures

Intraoperative fractures of the humerus or glenoid generally are the result of errors in surgical technique such as inadvertent reaming, overzealous impaction, or manipulation of the upper extremity during glenoid exposure[11,17]. Spiral fractures of the humerus are due to substantial torsional forces generated during external rotation of the shoulder. Without full extension of the arm off the side of the operating table, inappropriate placement of the prosthesis or reamer may result in cortical perforation. After humeral head resection, medial cortical perforation can occur if the initial reamer or trial stem is not eccentrically positioned in the superolateral aspect of the proximal part of the humerus[11,17]. The senior ones of us (M.A.W. and C.A.R. Jr.) have been satisfied with the utilization of cerclage wiring and a long-stemmed prosthesis to address intraoperative fractures. Simple cerclage wiring has been advocated for fractures proximal to the tip of the implant. Fractures that occur distal to the implant tip warrant a long-stemmed prosthesis inserted through a combined deltopectoral and anterolateral surgical approach to the humerus. The prosthesis should extend at least two humeral cortical diame-

ters beyond the most distal aspect of the fracture[11].

Intraoperative glenoid fractures may also occur during total shoulder arthroplasty. The stability of the glenoid component depends on the preparation of the glenoid surface, soft-tissue balancing, and the quality of the glenoid bone[11,17]. Scapular fractures in proximity to the glenoid may compromise component stability, leading to early symptomatic loosening. Intraoperative bone-grafting or a revision glenoid component with wedge reinforcement may be employed[11,17]. Glenoid resurfacing is not advocated when bone support is questionable. As a salvage step, the remaining intact glenoid can be sculpted with a hand burr or glenoid reamer to match the radius of curvature of the humeral head component[11,17].

Postoperative Fractures

The senior ones of us (M.A.W. and C.A.R. Jr.) have used an initial nonoperative approach for the management of postoperative periprosthetic fractures with the caveat that inaction should not lead to a delay in early functional rehabilitation. Nonoperative treatment involves the use of a functional brace, isometric exercises, and early motion[11,17]. Others have advocated initial operative intervention with open reduction and internal fixation followed by postoperative spica cast immobilization for a minimum of six weeks[106]. Kumar et al. reviewed their experience with nineteen postoperative periprosthetic humeral fractures (occurring in a population of 3091 patients) to specifically propose a treatment algorithm based on fracture classification[105]. The average time from the surgery to the fracture was forty-nine months. Of sixteen fractures with a complete set of radiographs, six healed uneventfully after an average of 180 days of nonoperative management, and the remaining ten required operative intervention (five immediately and five after an average delay of 123 days). The average time to union after the initial surgical intervention was 278 days. On the basis of their results, Kumar et al. proposed initial nonoperative management for fractures proximal to the stem tip and for fractures with acceptable alignment at the tip of a well-fixed humeral stem. Open reduction and internal fixation was encouraged for fractures at the stem tip that had not united by three months, while revision with a long stem was recommended for similar fractures associated with a loose humeral component. A trial of nonoperative management was also recommended for fractures distal to the stem if appropriate alignment could be maintained with an orthosis[105].

Rotator Cuff Tears

In the current analysis, postoperative tearing of the rotator cuff was the fourth most frequent complication of total shoulder arthroplasty, with a prevalence of 1.3% (thirty-two of 2540 shoulders)[25-57]. Ruptures of the subscapularis tendon accounted for a majority (seventeen; 53%) of the thirty-two events[25-57]. Factors that have been associated with postoperative tears of the subscapularis tendon include multiple operations, overstuffing of the joint, overly aggressive therapy involving external rotation during the early postoperative period, and tendon compromise by lengthening techniques[98,106,107]. Miller et al. reported symp-

tomatic rupture of the subscapularis tendon in seven (5.9%) of 119 patients who had been followed for an average of twenty-eight months (range, eighteen to fifty-five months)[107]. All seven ruptures were treated with operative repair of the tendon, with four requiring augmentation with a transfer of the pectoralis major, at two to fifty-three months after the shoulder arthroplasty. Our previous analysis did not reveal a clear association between rotator cuff tears and activity-altering pain[11]. However, Miller et al. reported lower ASES and patient satisfaction scores in association with subscapularis tears. Miller et al. encouraged early intervention with gentle mobilization in patients with a symptomatic subscapularis tear and recommended augmentation with a pectoralis major transfer during delayed repair.

Neural Injuries

Unlike our previous analysis, the present review indicated similar prevalences of neural injury (twenty events) and infection (nineteen events). Twenty shoulders had an injury to the brachial plexus or the peripheral nerves. While most of the neural complications were related to the axillary nerve (thirteen shoulders), three involved the brachial plexus, one involved the radial nerve, and three were categorized as postoperative regional pain syndrome. Ten of the thirteen axillary nerve injuries resolved spontaneously over time without surgical intervention[19-57]. One patient sustained an intraoperative transection of the axillary nerve requiring transfer of the trapezius muscle to the proximal part of the humerus[50]. Two of the three brachial plexopathies resolved, whereas all of the cases of regional pain syndrome subsided after a course of intensive physiotherapy[50].

Infection

The overall prevalence of infection following total shoulder arthroplasty was 0.7% (nineteen of 2540)[25-57]. Although uncommon, infection after total shoulder arthroplasty remains a devastating complication. Most infections develop in the setting of immunosuppression secondary to host-related factors such as diabetes, rheumatoid arthritis, systemic lupus erythematosus, previous surgery, and remote sources of infection. Extrinsic causes of infection include chemotherapy, systemic corticosteroid therapy, and repeated intra-articular steroid injections[11,17]. Infections may be classified as acute (presenting less than three months after the arthroplasty), subacute (presenting at three months to one year), or late (presenting at more than one year)[108-110]. There are several options for treatment, including antibiotic suppression, irrigation and débridement with retention of the implant, one-stage exchange with antibiotic-impregnated cement fixation, staged reimplantation with antibiotic-impregnated cement spacers, resection arthroplasty, arthrodesis, and amputation[11,17,109-117].

The clinical presentation of periprosthetic infections has not changed substantially in the last decade. It is usually nonspecific, with pain being the most common presenting symptom. Laboratory tests such as measurements of the C-reactive protein level, erythrocyte sedimentation rate, and white blood-cell count are important indicators of infection[11,17,109,110]. In our 1996 report, the six patients with clinical signs of infection after total shoulder arthroplasty demonstrated an average white blood-cell count of 11,980/μL (11.98 × 10⁹/L) and an average erythrocyte sedimentation rate of 75 mm/hr[11,17]. In 2001, Sperling et al.[111] reported that a deep periprosthetic infection developed in twenty-six of 2512 shoulders at an average of 3.5 years after the arthroplasty. They reported the average preoperative leukocyte count to be 7.4×10^3 (3.8 to 15.6×10^3) with a mean erythrocyte sedimentation rate of 47 mm/hr (10 to 135 mm/hr). The most commonly isolated organisms were *Staphylococcus aureus* (thirteen shoulders), coagulase-negative Staphylococcus (nine shoulders), and *Propionibacterium acnes* (five shoulders). The authors divided thirty-two shoulders (with the addition of several referred to their institution) into four groups based on the treatment regimen: group I (twenty-one shoulders) was treated with resection arthroplasty; group II (six shoulders), with débridement and retention of the prosthesis; group III (two shoulders), with direct exchange; and group IV (three shoulders), with delayed reimplantation. Groups II and III demonstrated a high rate of recurrent infection of 50%, whereas group-IV patients remained without infection at the time of the latest follow-up. Intravenous antibiotic treatment averaged thirty-one days for twenty-six shoulders, with thirteen of them subsequently treated with oral antibiotics for an average of twenty-seven days. At the time of final follow-up, Sperling et al. concluded that two-stage reimplantation offers the best outcome with regard to eradication of infection, pain relief, and shoulder function.

Coste et al.[112] retrospectively reviewed the cases of forty-nine shoulders with a confirmed periprosthetic infection and determined that antibiotics or débridement alone were ineffective. The authors recommended immediate revision, with aggressive débridement, exchange of the prosthesis, and appropriate intravenous antibiotic therapy, in shoulders with acute infection.

The treatment algorithms for periprosthetic infections of the shoulder currently mirror those of protocols established for infections associated with hip and knee arthroplasties[109,110,118-122]. As is the case in the hip and knee, the soft-tissue sleeve in the shoulder must be maintained to minimize contractures. Some surgeons have advocated the use of antibiotic-impregnated cement spacers after implant removal due to infection. Several independent reports have indicated favorable outcomes after the use of anatomically designed polymethylmethacrylate spacers[113-117], allowing for delayed exchange[115-117] or permanent placement[113].

Deltoid Muscle Dysfunction

Deltoid muscle dysfunction secondary to axillary nerve injury or deltoid muscle detachment remains a devastating complication with poor outcomes following total shoulder arthroplasty. Catastrophic loss of shoulder function is the natural sequela of such a complication. Several exposures involving deltoid muscle detachment have been previously described for optimal intraoperative visualization during total shoulder replacements[11,17]. Neer and Kirby observed severe deltoid muscle dysfunction in 92% (thirty-four) of thirty-seven shoulders

that had been treated with a short deltopectoral approach and a superior approach with proximal deltoid muscle detachment[123]. Beginning in 1977, Neer and the most senior one of us (C.A.R. Jr.) have advocated the extended deltopectoral approach, which preserves the origin and insertion of the deltoid muscle but still allows excellent exposure for both humeral head and glenoid resurfacing[11,17].

With revision shoulder arthroplasty, deltoid muscle function becomes increasingly important, particularly in situations in which an anatomically or functionally absent rotator cuff precludes another unconstrained shoulder arthroplasty. With the loss of deltoid muscle function, even the reverse shoulder prosthesis ceases to be an option.

Future Considerations

With advances in implant design, refinement of operative technique and rehabilitation protocols, and utilization of validated patient-outcome-assessment tools, it has been possible to provide clinically appropriate surgical treatment for patients with symptomatic glenohumeral arthritis. The present analysis demonstrated a modest increase in the average duration of follow-up, indicating persistent issues related to failure of the glenoid implant. Despite the growing trend toward increased follow-up, more than ten years of continued evaluation was reported in only three of the thirty-nine series. Longer-term studies are critical for assessment of patient outcomes regarding pain relief, shoulder function, and quality-of-life issues.

Glenoid component loosening has continued to be an unresolved problem, as was substantiated by the increased percentage of complications at the time of mid-term to long-term follow-up. In the past, alternative implants such as cementless, metal-backed glenoid components have been utilized, but longer follow-up has demonstrated an increase in complication rates when compared with those associated with cemented glenoid components. Recent advances in the design and fixation of glenoid components (the use of pegged, cemented glenoid components) and alternative bearing surfaces such as meniscal allografts have demonstrated promising short to mid-term results. Again, only longer follow-up will confirm the efficacy of these newer implants.

The reverse shoulder prosthesis has shown promising short-term results for the treatment of glenohumeral arthritis and massive rotator cuff tears and as a salvage procedure following failed unconstrained total shoulder arthroplasty. Longer follow-up may identify additional problems with the semiconstrained implant design that are currently not apparent. There should be stringent indications for the utilization of the reverse shoulder prosthesis, which should be reserved for elderly patients (older than seventy years of age) with shoulder arthropathy and clinical pseudoparalysis who have sufficient bone stock for implantation of a glenoid component. Future randomized, blinded studies comparing hemiarthroplasty with reverse shoulder arthroplasty in the treatment of cuff tear arthropathy will further refine the treatment algorithm.

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