Total Wrist Arthroplasty

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Abstract

Although arthroplasty is a well-established procedure for many joints, its use in the wrist is less common, and the indications are less well defined. The standard procedure for the painful arthritic wrist remains radiocarpal arthrodesis. However, as technology and surgical procedures improve, wrist arthroplasty is being used more frequently. The authors provide a brief history of total wrist arthroplasty and review the arthroplasties most commonly used in the United States. Results with total wrist implants, the complications related to arthroplasty, technical aspects of the procedure, and salvage options are also discussed.

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Pain, deformity, and impaired function caused by wrist arthritis have proved to be very difficult problems to solve. With improvements in medical treatments and surgical procedures, restoration and maintenance of hand function have become more attainable. Wrist fusion has been the standard treatment for the painful wrist, but limited arthrodesis, partial resection with or without interpositional materials, and total wrist arthroplasty are now options for treating the painful arthritic wrist. In this article we will review the history and current literature on total wrist arthroplasty with the premise that a pain-free and mobile wrist is more functional than a fused wrist.

Indications

The indications for total wrist arthroplasty have not been clearly defined. The ideal patient for a total wrist arthroplasty has painful bilateral wrist disease and, despite arthritis, relatively good wrist alignment and motion. The vast majority of patients have generalized arthritis, mainly rheumatoid, which affects other joints in the same extremity, making it difficult to position the hand in space. A wrist arthroplasty can help the patient compensate for the lack of motion in other joints and thus better preserve function.

Contraindications to total wrist arthroplasty include a lack of neurologic or motor function, previous serious local infection, poor bone stock, chronic severe volar or ulnar subluxation, and a need for weight bearing through the joint, as with use of a cane or walker. It is imperative to establish the integrity of the extensor carpi radialis brevis and longus preoperatively.[1] Relative contraindications include flail nonfunctional digits with swan-neck deformity, failed arthroplasty of the metacarpal or interphalangeal joints, and lupus erythematosus (which predisposes to joint laxity).

Functional Requirements of the Wrist

Several authors have tried to define the wrist motion required for activities of daily living. Brumfield and Champoux[2] reported that the functional range of motion was 10 degrees of flexion to 35 degrees of extension; they did not measure radial and ulnar deviation. Palmer et al[3] calculated that 5 degrees of flexion, 30 degrees of extension, 10 degrees of radial deviation, and 15 degrees of ulnar deviation describe the minimum range of motion needed in the two essential planes of wrist motion. In a later study, Ryu et al[4] found the minimal required range of motion to be 60 degrees of extension, 54 degrees of flexion, 17 degrees of radial deviation, and 40 degrees of ulnar deviation. They also described a "reasonable" range of motion needed to accomplish most of the activities required of their study patients as

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being 40 degrees of extension and flexion, 10 degrees of radial deviation, and 30 degrees of ulnar deviation. The disparities between these studies may be attributable to different methods of measuring wrist motion as well as different views on the requirements for activities of daily living. However, the authors agree that the most important motion is extension with ulnar deviation for power grip. This amount of motion can be achieved with wrist replacement. Newer prostheses are designed to allow 60 degrees of extension, 40 degrees of flexion, and 20 degrees of radial and ulnar deviation.

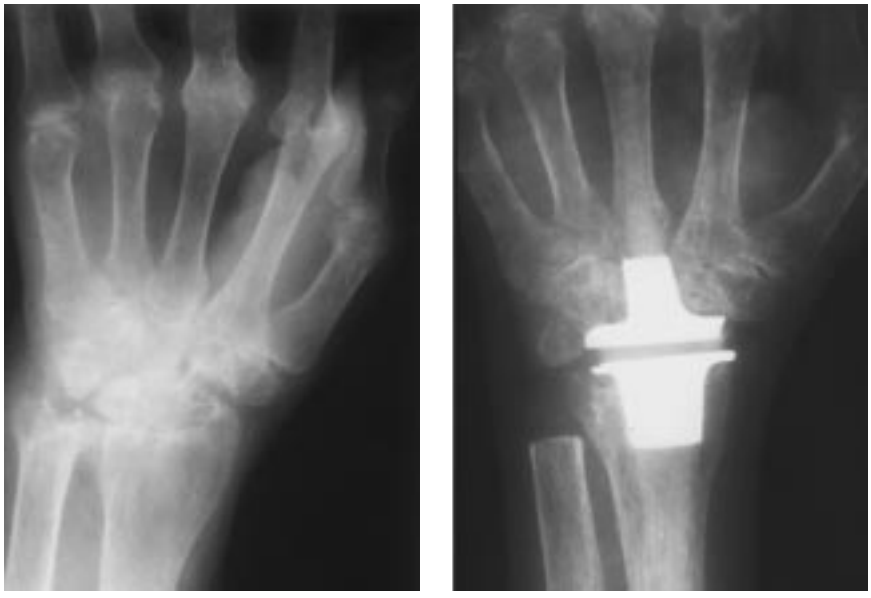

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Fig. 1 **A,** Radiograph of wrist affected by severe rheumatoid arthritis with carpal collapse and radiocarpal disease. **B,** Film obtained after replacement of wrist joint with a Swanson silicone implant and titanium grommets.

History

Themistocles Gluck performed the first total wrist arthroplasty in 1890, using an ivory prosthesis in a wrist joint affected by tuberculosis.[5] His results with multiple joint replacements in septic joints were adequate in the short term, but the repairs eventually failed due to the underlying pathologic condition. It was his first attempts, however, that gave others the initiative to proceed in developing joint replacement prostheses.

Swanson placed a silicone spacer in a finger joint in 1940 and then developed a similar but larger double-stemmed, flexible-hinge silicone implant for the radiocarpal joint in 1967.[6] This implant is barrel-shaped in the midsection and slightly flattened on the dorsal and volar surfaces and is available in five sizes. One end of the implant is placed in the medullary canal of the radius; the other is placed through the capitate and into the third metacarpal canal. This prosthesis is essentially a spacer around which scar tissue conforms, giving soft-tissue stability to the joint (Fig. 1). Success rates decline markedly over the life of this implant to 50% pain relief at 5 years; implant fracture rates as high as 52% and revision rates of 26% to 36% have been reported.[7-9] Because of the high complication rate, the indications for use of this implant are very limited.[10]

Metal-and-Plastic Designs

Meuli[11] and Volz[12] each developed metal-and-plastic wrist arthroplasty devices for cement fixation in the early 1970s after their dissatisfaction with the Swanson prosthesis. Both original designs had metal components for insertion in the second and third metacarpals as well as the distal radius. The metal-and-plastic design provided for more extensive reconstruction of the carpus by reconstitution of the carpal-metacarpal height ratio.[12] Metallic prostheses also allow release of contracted soft tissues and early motion due to the inherent stability of the arthroplasty.

The first Meuli wrist arthroplasty was introduced in Berne, Switzerland, in 1972 as an articulated nonhinged ball-and-trunnion design.[11] The design was meant to imitate the center of wrist motion, which is located in the center of the capitate with a ball-and-socket joint. The reoperation rate for the first 26 Meuli arthroplasties was 35%, with problems related to soft-tissue imbalance and centering cited. Actuarial analysis showed a 75% revision rate for the first 3 years. After experience was gained, the reoperation rate dropped to 20%. In patients with distal component loosening, there was progressive volar displacement of the cup component, which led to increased dorsiflexion. The dorsiflexed position produces wear of the flexor tendons against the prosthesis, causing both tendon rupture and carpal tunnel syndrome. Design changes did not decrease the incidence of loosening or tendon imbalance problems.[13] At present,

we believe there are no indications for use of this prosthesis.

In 1973, Volz developed an articulated nonhinged prosthesis that functions as a dorsopalmar tracking device[12] (Fig. 2). No rotational motion is allowed with this device. There have been fewer complications with the Volz prosthesis than with the Meuli prosthesis, due in part to the more stable design. The incidence of loosening has also been smaller, but tendon balance continues to be a problem. In one series,[14] the incidence of imbalance was 22%, the complication rate was 29%, and the revision rate was 12%.[14] There have been several dislocations of this prosthesis, which have been attributed to inadequate release of the volar capsule.[12]

Figgie and Ranawat designed a trispherical wrist arthroplasty in 1977.[15] It is a plastic-bearing semiconstrained total wrist replacement with an axle mechanism (Fig. 3). The axle prevents dislocation but takes no load during normal activities. The distal component has an ultra-high-molecular-weight polyethylene (UHMWPE) liner, which articulates with a radial sphere. The implant is intended to be cemented into the third metacarpal with an offset stem for the second metacarpal and a short stem placed into the scaphoid to prevent rotation. The radial component has a 12-degree palmar tilt. The ball-and-socket joint allows 90 degrees of flexion and 80 degrees of extension with 15 degrees of ulnar and radial deviation in vitro. The implant is designed to provide a slightly mobile instant center of rotation that allows for axis shifts during flexion and extension to balance the moment arms of the ulnar and radial tendons. This semiconstrained design theoretically allows the soft tissues to relieve some of the stresses on the component and thus increase durability.

The only published data on the wrist prosthesis to date are those of Figgie et al.[15] In 1988 they reported on 38 cemented implants inserted because of class III or class IV rheumatoid arthritis, with an average follow-up of 5 years. Pain relief was satisfactory in 35 wrists. All 38 implants were stable, and the rate of overall good or excellent results was 88%. The average arc of motion was 68 degrees. There were two revisions, one for pain and one for loosening. Radiographs showed nonprogressive radiolucent lines in the bone around 9 implants; in three instances, components were noted to have perforated the metacarpal and migrated, but the wrist remained painless.

In 1990, Figgie et al[13] recalled 34 of the patients seen in 1988 (an aver-

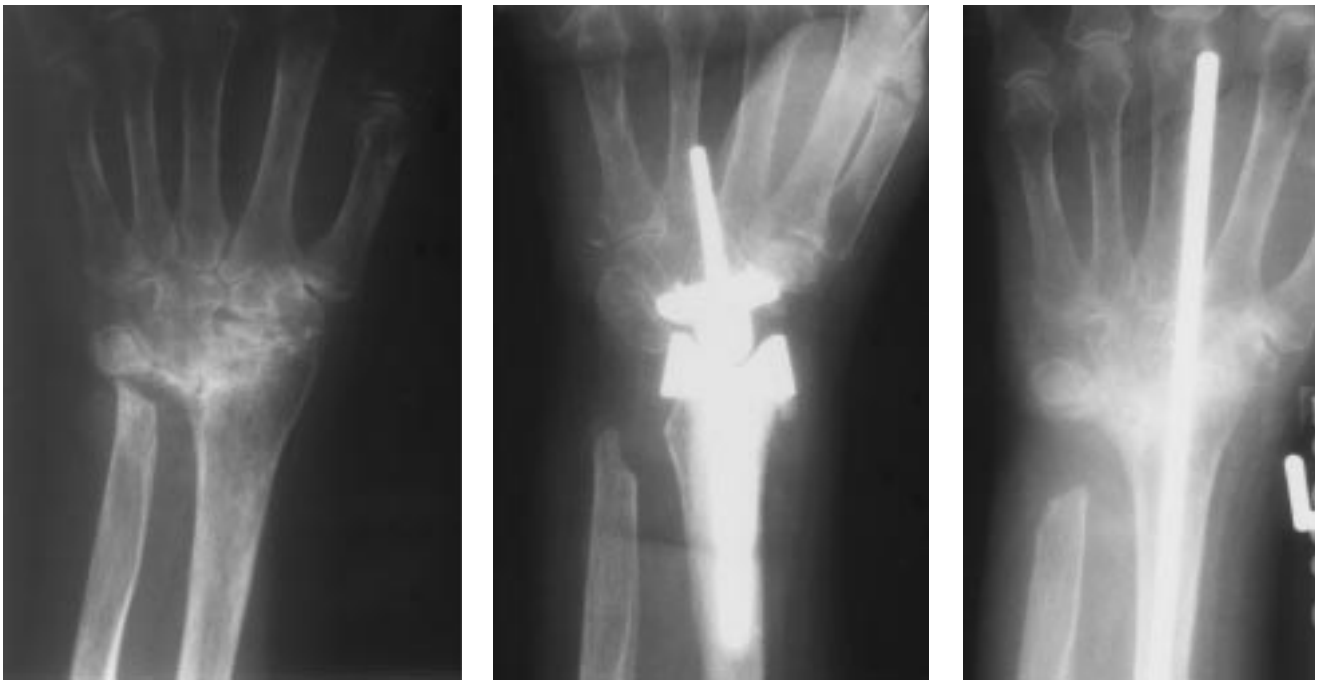

Fig. 2 **A,** Radiograph of wrist affected by degenerative rheumatoid arthritis. **B,** Film obtained after placement of a Volz II total wrist implant (Howmedica; Rutherford, NJ). Note that the distal implant is not secured in the metacarpal. **C,** Wrist fusion with local bone graft after failure and removal of the Volz prosthesis.

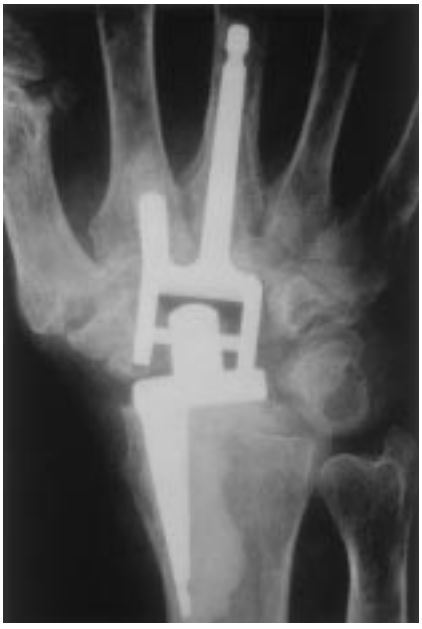

Fig. 3 Anteroposterior radiograph obtained after placement of a trispherical wrist arthroplasty device.

age follow-up of 9 years). Thirty wrists were pain-free, and 28 patients had good or excellent results. There had been no new revisions, but six wrists demonstrated postoperative tendon attrition and rupture. These patients had preoperative tendon ruptures. The authors concluded that the presence of intact extensor tendons before the operation is a prerequisite.

For optimal performance, the trispherical arthroplasty should be placed with the center of rotation at least 2 mm volar to the axis of the radial canal. There should also be restoration of the carpal height to between 40% to 60% of the length of the third metacarpal, and the extensor tendons should be intact. Figgie et al[13] have noted satisfactory reconstruction for patients with soft-tissue imbalance, metaphyseal bone loss, and carpal dislocation. The trispherical implant is also being redesigned for noncemented insertion.

A biaxial total wrist arthroplasty was designed by Beckenbaugh[16] to solve the problem of loosening associated with ball-and-socket designs. This implant was first used in 1982. It is a semiconstrained prosthesis with a transversely oriented axis designed to duplicate the axis of the normal wrist (Fig. 4). The stem has a porous coating to enhance cement fixation and to facilitate noncemented fixation.

Lirette and Kinnard[17] reported on 15 implants placed in wrists with stage III or stage IV rheumatoid arthritis. At a mean follow-up of 54 months, they found that the results in all patients were rated good or excellent with the Hospital for Special Surgery scoring system. However, radiolucent lines were seen around 4 of the prostheses, and there was one dislocation.

Cobb and Beckenbaugh[18] reported on 52 biaxial wrist arthroplasties performed from 1983 through 1988 and followed up for 5 years or until failure. The average range of motion was 36 degrees of dorsiflexion, 29 degrees of palmar flexion, 10 degrees of radial deviation, and 20 degrees of ulnar deviation. There were 11 failures, with loosening in 8 implants, and eight wrists underwent revision. The overall survival rate at 5 years was 82%.

The Universal Total Wrist Implant (Kinetikos Medical; San Diego, Calif) was designed by Menon[19] and was introduced for clinical use in 1990 (Fig. 5). The distal component is flat with a prong that is cemented into the capitate and radial and ulnar screws that are placed through the prosthesis into the peripheral carpal bones. The distal component covers a broad area of the carpal osteotomy and allows carpal bone defects to be grafted. An intercarpal arthrodesis is carried out with the insertion of the prosthesis to support the carpal component. The radial component has an inclination similar to that of the natural radius (20 degrees). A UHMWPE insert is placed between the cemented titanium wrist components, creating a geometric mimic of the radioscapholunate articulation. The insertion technique requires less bone resection than is needed for other currently available prostheses, which theoretically allows easier revision.

Menon[19] reviewed the results with 37 implants inserted over a 9-year period and reported that 88% of the patients obtained pain relief. The most common complication was dislocation, which occurred in 5 implants. Two patients had loose radial components; both were noncemented components. A more recent design has a carpal component fixed by only three screws with no central stem; this design is not available for use in the United States.

Other prostheses have been developed in an attempt to improve on past design failures. However, the results have been poorly documented, and most implants failed early. Other implants are used mainly outside the United States and will not be discussed in this review except to mention their names. They include the Hamas precentered prosthesis developed in 1979,[20] which has been associated with migration; the Guepar wrist,[21] a non-metal-backed design that became available in 1983 and has demonstrated a very high failure rate; the CFV wrist,[22] which uses shims to create better in situ alignment; the LODA design; the Weber design from the Mayo Clinic; and the Giachino wrist from the University of Ottawa.

Technical Aspects

Carpal collapse, demonstrated by an increased metacarpal-carpal height ratio, contributes to de-

creased grip strength and decreased active extension at the metacarpophalangeal joint. This ratio is determined by comparing the length of the third metacarpal to the height of the carpus, as measured from the base of the third metacarpal to the articular surface of the distal radius. Carpal collapse may not be the sole reason for weakness in the patient with rheumatoid arthritis but should be corrected at the time of surgery by bone grafting if necessary to improve hand mechanics and to decrease the risk of prosthetic instability.

Centering the implant has proved to be the most difficult technical aspect of the operation, especially for the ball-in-socket design types. Youm et al[23] described the normal center of rotation of the wrist as being along the axis of the third metacarpal and through the proximal pole of the capitate. However, the center of rotation has subsequently been found to move with flexion and extension in an asymptotic plane. The prosthesis should be aligned distally with the third metacarpal and proximally with the ulnar border of the radius. Some of the newer designs have single or double offset stems to improve alignment and fixation, which has improved the ability to center the components; however, none of the wrist designs adequately recreates the mobile center of rotation. Without proper attention to the alignment of the prosthesis, the moment arms of the tendons will be altered, which can potentially cause wrist imbalance, resulting in deformity and instability.

Fixation has also proved to be problematic. The ball-and-socket joint was conceived as a nonconstrained device; however, if the mechanism becomes fixed, large forces are transmitted across the implant and the bone-implant interface, resulting in a loosening rate of up to 50% in the distal component. Mechanical studies have shown that under normal loads the materials of the prosthesis will not fail, but that with repetitive stress, bone resorption, subsidence, and loosening at the bone-cement interface will occur. As a general rule, the more constrained the design, the more likely the risk of loosening.

Soft-tissue imbalance has continued to be a complication of total wrist arthroplasty. Tendon imbalance in arthroplasty is due to preoperative malpositioning of tendons and carpal collapse, with resultant soft-tissue contractures.[13] The imbalanced forces typically pull the wrist into flexion and ulnar deviation, leading to a fixed contracture, which is a contraindication to total wrist arthroplasty when the deformity is severe. Tendon imbalance combined with contracture of the

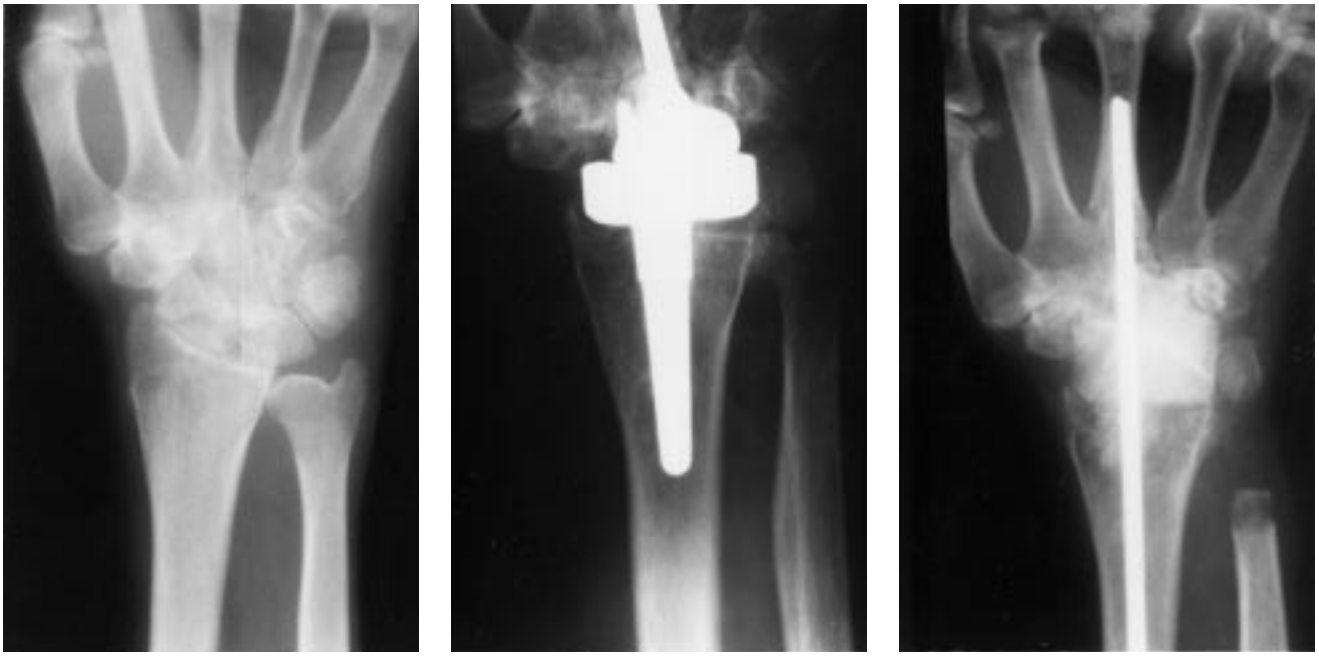

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Fig. 4 **A,** Radiograph of wrist affected by osteoarthritis. **B,** Film obtained after placement of a biaxial total wrist implant (Biax Total Wrist System; DePuy, Warsaw, Ind). **C,** Subsequent failure of the implant necessitated fusion of the wrist with allograft iliac-crest bone graft.

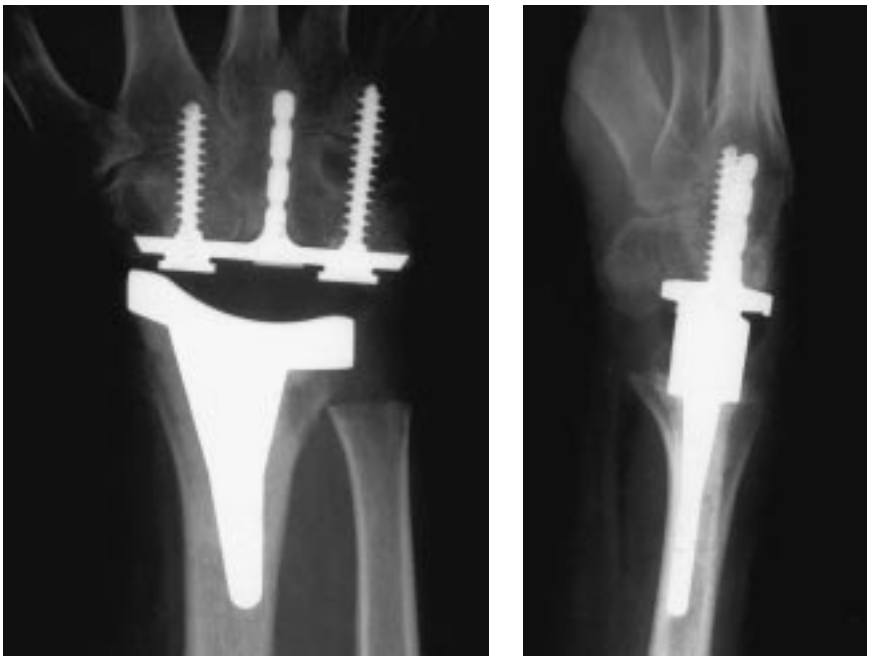

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Fig. 5 Anteroposterior **(A)** and lateral **(B)** radiographs obtained after placement of the Universal Total Wrist Implant.

volar wrist capsule leads to both early and late arthroplasty dislocation and static and dynamic instability with recurrence of fixed deformities. Capsular release and tendon lengthening to release fixed contractures and realign the wrist have not been effective in severe cases.

Tendon imbalance can be difficult to detect preoperatively, and electromyographic studies may be helpful in identifying functional activity in weak muscles around the wrist.[12] The flexors and extensors are not intrinsically equal in their potential motor power; therefore, centering the prosthesis to optimize lever arms can be extremely difficult. Ruptures of the extensor carpi radialis brevis and longus tendons are particularly problematic. Assessment of the resting position of the wrist during surgery with the forearm in pronation and supination will help identify the optimal soft-tissue balance.

Appropriate capsular releases will improve soft-tissue balance around the implant and improve the range of motion. However, severe fixed soft-tissue contractures have been almost impossible to overcome. Precise instrumentation for component placement in total wrist arthroplasty has not been developed; therefore, optimal implant positioning continues to be difficult to achieve.

Complications

Short-term complications in total wrist arthroplasty are usually the result of incorrect surgical technique (Fig. 2, B). Problems with bone abutment and instability should be dealt with at the time of surgery.[10] Long-term complications primarily reflect the progressive nature of the disease and the physical demands on implant durability and host tolerance. The most frequent late complications include ulnar deviation,[24] fracture of the device (with the Swanson arthroplasty), extensor tendon ruptures, ulnar nerve compression, and flexor tendon ruptures. Infection seldom occurs.

Salvage Procedures

Treatment of failed implants is now becoming more common. Revision of the prosthesis is an option if the bone stock is adequate. Soft-tissue reconstruction can be attempted for a dislocation if the prosthesis is well aligned. A resectional arthroplasty can be considered; however, the results are unpredictable.[25] In our experience, removal of the prosthesis and arthrodesis with a bulk iliac-crest bone graft or allograft (Fig. 4, C) to maintain length and tendon balance provides the most satisfactory results.

Rettig and Beckenbaugh[26] reported on the results with the biaxial prosthesis in 13 revision procedures for failed arthroplasty. At 31 months, 2 further revisions and one arthrodesis had been necessary. Eight patients reported no pain. The postoperative range of motion was functional, with the greatest motion in extension and ulnar deviation.

The biaxial component has been modified to a long-stem, multiprong distal component for revisions in patients with poor bone stock.[27] In a review of the results in 10 patients who received this modified prosthesis for revision at an average 3.8-year follow-up, there were two arthrodeses. The radiographs of 2 of the other 8 patients showed radiolucent lines; 6 patients were without pain, and 2 patients noted mild pain. This modified implant has shown better short-term outcomes in revision procedures than other devices.

Beer and Turner[28] reported their experience with wrist arthrodesis

performed with the use of autogenous iliac-crest bone graft and an intramedullary Steinmann pin for failed wrist arthroplasty in 12 patients. Seven patients had solid fusions, 4 had pseudarthrosis at the graft-metacarpal junction, and 1 patient had graft-radius pseudarthrosis. All but 1 patient had markedly decreased pain. There were 12 complications in 9 patients: Steinmann pins accounted for 6, iliac-crest complications occurred in 5 patients, and 1 patient had an iliac-crest fracture.

We have evaluated our own experience with 12 arthrodeses for failed wrist arthroplasty. An intramedullary Steinmann pin was combined with a femoral-head allograft in 7 cases; autogenous iliac-crest bulk graft was used in 4; and local bone graft was used in one instance. Pseudarthrosis developed in 2 of the 12 patients; both had received an iliac-crest bone graft, and both underwent subsequent iliac-crest bone-grafting procedures with eventual fusion. Two patients experienced complications related to the use of a Steinmann pin. All patients eventually proceeded to union and were satisfied with their results 2 years after the arthrodesis procedure. At the present time, the decreased morbidity, the avoidance of iliac-crest bone graft, and the higher success rate with femoral head allograft makes this our procedure of choice when converting a failed total wrist arthroplasty to an arthrodesis. Conversion of the failed total wrist arthroplasty to an arthrodesis or a painless pseudarthrosis has thus far been more reliable for long-term function than a revision wrist replacement.

Summary

Despite vast improvements in implant materials, designs, and surgical techniques, total wrist arthroplasty continues to have a high complication rate. The Swanson silicone wrist implant was a good first step toward a wrist replacement that relieved pain and provided motion. The metal-and-plastic designs provide a fixed fulcrum and stability by virtue of their solid components. These implants distract a collapsed joint to restore myotendinous balance across the wrist and hand. Wrist arthroplasty effectively relieves pain and provides adequate short-term stability.

Total wrist arthroplasty remains a highly technical procedure with limited indications. Partial and total wrist arthrodesis remain the standard treatment for pain and deformity about the wrist. However, improvements in implant instrumentation and surgical techniques may increase the reliability of total wrist arthroplasty in the future.

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