Arthroplasty of the Hand and Wrist:
Surgeon's Perspective

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Many diseases cause joint destruction of the hand and wrist, which results in impaired function. An arthroplasty cannot truly replace the native joint, as the precise function and versatility cannot be replicated by current techniques. An arthroplasty represents an attempt to restore function to a degenerated joint in order to reduce disability.

The advances in arthroplasty of the hand and wrist have paralleled our increased understanding of anatomy and biomechanics. A knowledge of joint structure and motion is a prerequisite to the design of a credible joint replacement that will simulate function and provide longevity. The introduction of sophisticated biomechanical and tissue engineering techniques into orthopedics has expanded our knowledge of joint movement, repair, and regeneration. Three-dimensional tracking systems, strain gauges, load cells, sophisticated computer software, and histologic preparations are mainstays of orthopedic research laboratories. The data derived from this highly technologic research add insight into joint kinetics, kinematics, and physiology. This information is directly applicable to joint arthroplasty development and implantation.

The advances in arthroplasty of the hand and wrist over the past decade have focused on the assessment of previous attempts at joint replacement and the development of new implants and techniques. This article discusses the current state of the art for replacement of digital joints, the thumb carpometacarpal joint, carpal bones, and the wrist. The focus is on advances and regressions in hand and wrist arthroplasty in an attempt to determine: what works, what does not work, and what may someday work?

This paper is followed, on p. 133, by a paper presenting a hand therapist's commentary on the same subject.

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SILICONE BIOMATERIALS

In the 1960s, silicone implants were introduced for replacement of the finger joints, carpal bones, radial head, distal ulna, and elbow joint. Silastic is a medical-grade silicone rubber of very high molecular weight, manufactured by Dow Corning (Midland, Michigan). The initial implants were composed of medical-grade elastomer of medium hardness, which has since undergone numerous modifications to decrease tear propagation ("HP" implant) and to increase fatigue-crack growth resistance ("HP-100" implant). Recently, Avanta (San Diego, California) and Depuy (Warsaw, Indiana) have introduced silicone implants composed of different silicone polymers.

Silicone was initially believed to act as an inert spacer that underwent encapsulation over time. Silicone elastomer appears to be biocompatible, but debris particles can be liberated because of silicone wear or implant failure. These particles can induce an intense inflammatory response, depending on the number, size, and shape of the particulate debris.[1,2] The tissue surrounding a degenerated silicone implant may contain an astonishing amount of debris, and recent quantitative methods indicate billions of very small particles.[2] These particles are present in connective tissue, synovial tissue, and giant cells.[3] Larger particles are phagocytized by giant cells, while smaller debris can be phagocytized by microphages and transported from the implant site.[1] Silicone-induced axillary lymphadenopathy has been reported after implantation of a silicone finger joint prosthesis.[2,4,5]

The amount of wear debris is related to the load borne by the silicone implant and the length of time since prosthesis insertion.[1] Implants loaded by heavy activity in young patients are prone to breakdown and can result in silicone synovitis. The clinical presentation of silicone synovitis is characterized by pain, joint tenderness, loss of motion, and soft tissue swelling (Figure 1).[1] Bony erosions

FIGURE 1 **(above).** *Dorsal swelling and synovitis after failure of a silicone carpometacarpal arthroplasty.*
FIGURE 2 **(right).** *Radiograph of lunate prosthesis ten years after implantation, with loss of height and particulate debris throughout the carpus.*

and subchondral cysts around the implant can be observed on radiographs. Other bones throughout the carpus and hand may be involved (Figure 2). Standard treatment involves removal of the implant, synovectomy, and debridement. However, this treatment regimen does not consistently resolve symptoms, and progressive destruction of bone can ensue.[1] Continued deterioration occurs because of the enormous amount of silicone debris surrounding the implant and the presence of remote particles throughout the hand, which preclude complete surgical eradication.

Because of the problems with silicone debris, protective titanium grommets have been added to shield implants from bone edges (Figure 3). The efficacy of the grommets in prevention of wear and debris formation is open to question.[6,7] Capone[7] reported no implant fractures or particulate synovitis at five-year follow-up[7] after silicone radiocarpal arthroplasty implanted with titanium grommets. These clinical results are encouraging but should be viewed with caution until longer follow-ups and additional series are available. Remember that the early results of silicone arthroplasty results without grommets were also encouraging. Currently, silicone arthroplasties are used in low-demand applications or where other options are not viable. The risks of silicone are problematic, however, and will, I think, ultimately lead to its discontinuation.

DIGITAL JOINTS

Metacarpophalangeal Joints

Despite its shortcomings, silicone arthroplasty remains the procedure of choice for advanced arthritis of the metacarpophalangeal (MP) joint. The choice of silicone for implants at this site is based on numerous considerations. First, the diseased MP

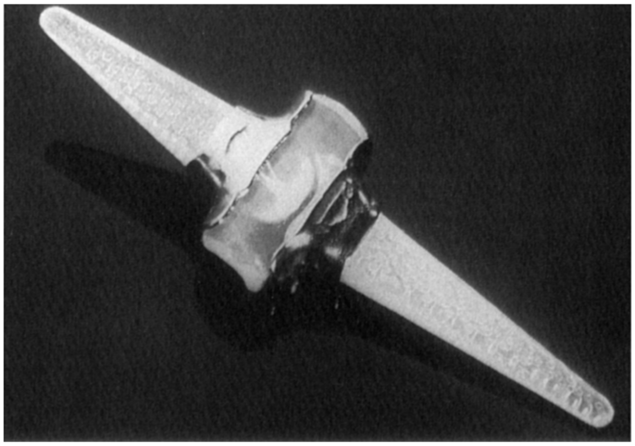

FIGURE 3. Grommets by Dow Corning (Midland, Michigan) placed on silicone prosthesis in an attempt to protect stems from wear.

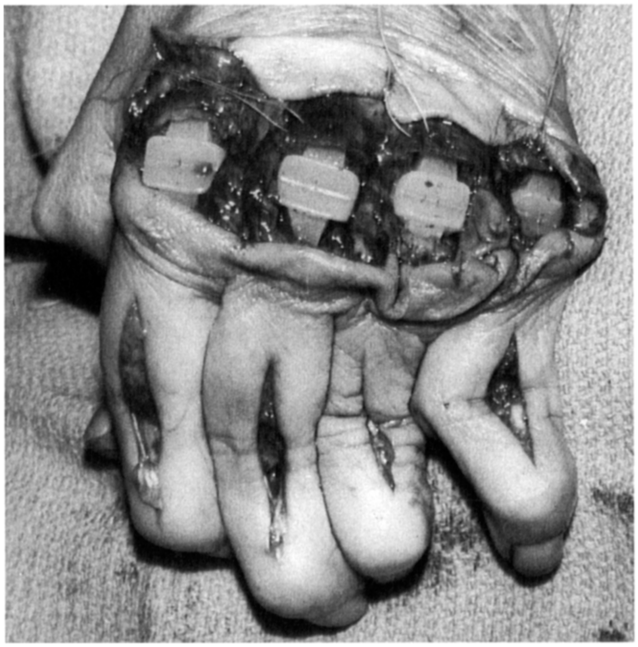

FIGURE 4 **(left).** *Hand diseased by rheumatoid arthritis, with marked deformity including metacarpophalangeal subluxation, Swan neck deformity, and ulnar drift.*

FIGURE 5 **(above).** *Silicone arthroplasties of the metacarpophalangeal joints for severe rheumatoid arthritis with advanced destruction.*

joint is usually seen in a patient with multiple joint involvement secondary to inflammatory arthritis (e.g., rheumatoid arthritis, Figure 4). Such a hand has relatively low demands, compared with that of a young laborer. Second, the compressive load at the MP joint is less than the load on silicone carpal bones, and this results in diminished silicone degradation.[5] Third, the results after silicone arthroplasty have been favorable in numerous series. Fourth, implant breakage does not always require revision surgery, and satisfactory results can be maintained. Fifth, attempts at more complicated total joint arthroplasties have not been successful.[8,9] Last, the biomechanics of the MP joint are not completely understood, which hampers our ability to improve joint designs. The classic concept of a complex hinge joint with two degrees of freedom (flexion/extension and radial/ulnar deviation) is being questioned.[10] We have investigated the axial rotation of the MP joint in a cadaveric model and found significant supination and pronation during radial and ulnar deviation. These additional degrees of freedom about the MP joint must be considered during the development of a suitable prosthesis. Therefore, until the biomechanics of the normal and diseased MP joint are fully defined, the simpler silicone spacer will remain the preferred implant (Figure 5).

The functional results of silicone MP arthroplasty have been well defined over the past decade.[11-15] This information has allowed surgeons and therapists to develop realistic goals following arthroplasty. The total arc of motion is usually not increased after arthroplasty, with an ultimate range of approximately 40° to 60° of motion depending on the preoperative motion, status of the soft tissue, interphalangeal joint motion, and therapy. The arc of motion after surgery will be in a more favorable position, as most patients have significant preoperative MP extension lags or flexion contractures combined with ulnar deviation that decrease their ability to grasp large objects (see Figure 4). Pinch is also hampered by the ulnar drift of the digits, which precludes lateral and oppositional pinch. Arthroplasty improves the finger alignment and provides a more functional arc of flexion. However, loss of fingertip-to-palm contact is common and can be disabling for certain activities that require complete grasp.

Therapy after MP joint arthroplasty must be performed in a meticulous fashion and on a frequent basis. The early detection of problems by an astute therapist can allow for alterations in the standard postoperative protocol or adjustments in the dynamic extension splint to correct potential problems. Communication between the surgeon and therapist is mandatory to optimize patient outcome.

The long-term outcome after MP arthroplasty has been better defined over the past decade.[11-14]

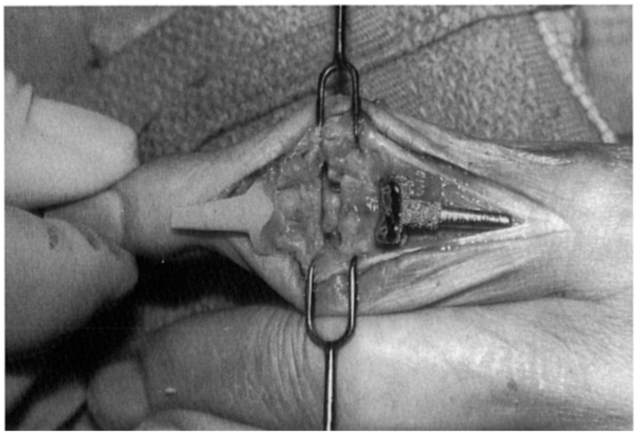

FIGURE 6. *New-generation resurfacing proximal interphalangeal arthroplasty with cobalt chromium proximal phalangeal component and polyethylene middle phalangeal base.*

This information is important for the surgeon performing MP arthroplasty and the patient considering such a procedure. Some recurrence of the ulnar deviation will occur over time, and implant fracture can occur, with its reported incidence varying from 1% to 26%. The incidence of fracture appears to have decreased (to the 1% to 10% range) since the introduction of the mechanically stronger silicone polymer. Implant fracture does not always necessitate revision, and adequate function can continue; however, silicone synovitis after fracture remains a concern as particulate debris is liberated.

Alternative MP silicone arthroplasties have been introduced by Avanta and Depuy, with design differences. The Avanta, or Sutter, prosthesis has a palmarly displaced hinge designed to increase the digital extensor moment arm, duplicate the center of MP motion, and decrease the palmar bony im-

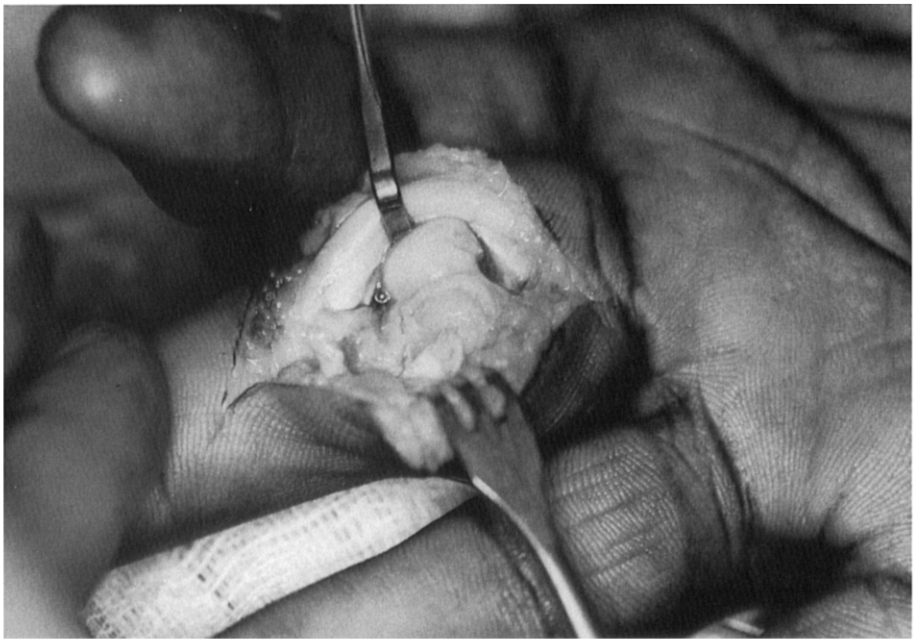

FIGURE 7. *Volar approach for proximal interphalangeal arthroplasty with retraction of the flexor tendons, collateral ligament release, and joint exposure.*

FIGURE 8. *Radiograph of proximal interphalangeal (PIP) Silastic implant (Sutter) inserted by a volar approach, with good position and reconstitution of the PIP space.*

pingement potential; however, fracture incidence may be increased with use of this prosthesis.[16] The Neuflex, or Depuy, design has a similar offset hinge that is also positioned in 30° of flexion to allow for an improved MP flexion arc. Currently, there are no clinical trials of the Neuflex implant that assess function, motion, and implant durability.

Proximal Interphalangeal Joints

At present, silicone arthroplasty is also the preferred technique for replacement of the proximal interphalangeal (PIP) joint. The basis for the continued use of silicone implants mirrors that for silicone MP arthroplasties described above with only minor differences. The PIP joint functions as a bicondylar hinge-like joint with monoaxial motion in flexion and extension. This single plane of motion would, intuitively, seem to make the PIP joint amenable to total joint replacement; however, metal and plastic prosthetic designs have been fraught with problems including loosening, subsidence, breakage, and metalosis of the joint (Figure 6).[8,17–20] Therefore, a spacer such as silicone remains the implant of choice until the problems of total joint replacement are solved.

The advantages of silicone arthroplasty are the ease of insertion and the acceptable motion obtained. The procedure can be performed by a volar or dorsal exposure of the joint surfaces.[21–23] The volar approach, which has been advocated by both Schneider[24] and Lin et al.[23] because of ease of access and avoidance of extensor tendon manipulation, is my preferred approach for silicone arthroplasty of the PIP joint (Figure 7). An intact extensor mechanism facilitates postoperative rehabilitation, as flexion can be initiated immediately with limitation of PIP extension until healing of the volar restraints (Figure 8). As with the MP joint, the postoperative motion is essentially unchanged from the preoperative status, with an expected arc motion of approximately 30° to 60°.[21,23,25–27] In general, less motion is obtained after silicone arthroplasty for post-traumatic arthritis than degenerative or rheumatoid arthritis.

The disadvantages of silicone PIP arthroplasty are the lack of stability, failure to reproduce normal joint mechanics, and implant failure that can lead to silicone synovitis. The incidence of silicone synovitis at the PIP level appears greater than at the MP joint, but less than for wrist or carpal implants.[5] This incidence probably reflects the load borne by the implant and the fact that PIP arthroplasties tend to be performed in higher-demand hands afflicted by osteoarthritis or post-traumatic arthritis.

THUMB CARPOMETACARPAL JOINT

The thumb carpometacarpal (CMC) joint is a very mobile articulation with minimal bony constraint. It is a frequent site of osteoarthritis, which causes painful pinch and grasp. Significant research

FIGURE 9. Radiograph of pantrapezial arthritis, with joint narrowing and osteophyte formation.

into the anatomic restraints and contact areas of this saddle-shaped joint has improved our understanding of the pathoanatomy of CMC arthritis over the last decade.[28–30] The action of pinch produces high forces across the CMC joint, and lateral pinch specifically produces high contact stress in the central, volar, and volar-ulnar regions.[30–32] These areas concur with the cartilage thinning seen clinically in abnormal joints and implicate high stress as the initiating factor in articular degeneration. The palmar oblique (beak) ligament interconnects the volar ulnar beak of the thumb metacarpal to the trapezium and functions as the prime stabilizer of the trapeziometacarpal joint. The attenuation or attrition of this ligament may be the initiating factor in CMC arthritis. Loss of trapeziometacarpal stability allows radial joint subluxation during pinch and grasp, which causes synovitis, incongruity, and abnormal joint forces.[28,29] These areas of high-contact stress will eventually degenerate and lead to joint narrowing with osteophyte formation. Progression results in pantrapezial joint arthrosis with pain, loss of motion, and weakness (Figure 9).[33]

The improved knowledge of the natural history of CMC joint degeneration also supports the concept of ligament reconstruction as part of the operative strategy in CMC arthritis. Reconstruction of CMC joint stability will prevent continued sublux-

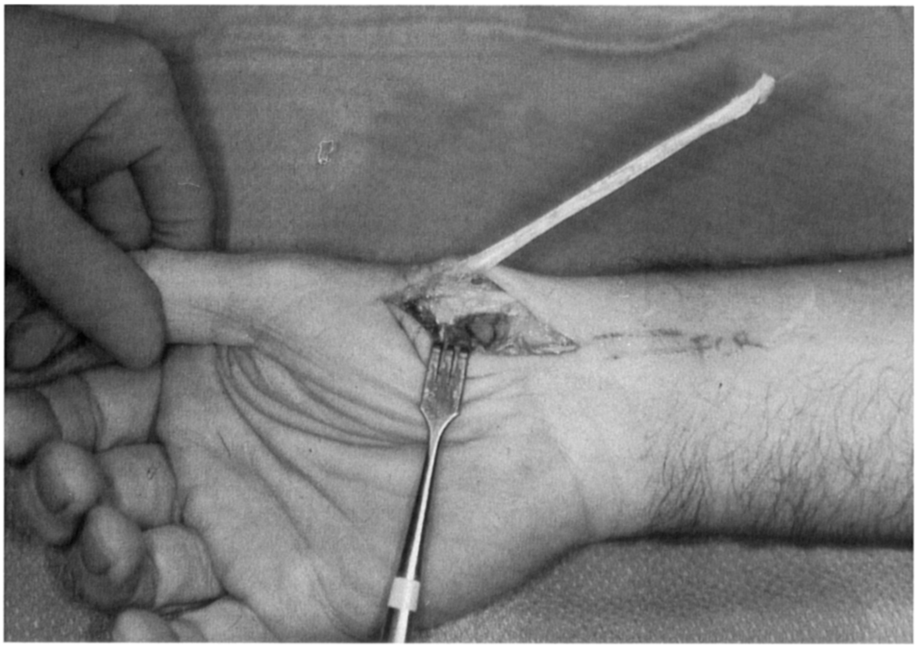

FIGURE 10. Intraoperative photograph of half the flexor carpi radialis tendon passed through the base of the metacarpal after trapezial resection to reconstruct the volar beak ligament.

ation and provide a stable fulcrum for pinch. The technique of ligament reconstruction with tendon interposition using a portion of the flexor carpi radialis tendon has become the gold standard for the treatment of advanced CMC arthritis.[34] Excision of the trapezium without ligament reconstruction results in initial good results, but weakness and instability are long-term consequences.[34,35] The addition of tendon or fascial interposition without ligament reconstruction does not prevent a decrease in pinch strength or shortening over time.[36] In contrast, the combination of trapezial excision and ligament reconstruction has produced good results at two-, six-, and nine-year follow-up periods with maintenance of the trapezial space and continued functional improvement (Figure 10).[34,37] Grip and pinch strengths improved, as did the ability to perform activities of daily living. These lasting results exceed those of any studies of prosthetic replacement or simple interposition techniques, which tend to decline over time. Numerous variations of the ligament reconstruction–tendon interposition technique use different routes to suspend the thumb metacarpal (suspensionplasty) or other tendons for ligament reconstruction (e.g., abductor pollicis longus).[38–40] These procedures should produce comparable results if the fundamental components of trapezium excision, ligament reconstruction, and interposition are performed.[37]

The use of a replacement prosthesis for the CMC joint has not been as successful as ligament reconstruction and tendon interposition. Silicone implants provided good stability and pain relief initially, but longer follow-up studies have reported implant failure and silicone synovitis (Figure 11).[41] Metal and plastic replacements have also been attempted in the thumb CMC joint. The semiconstrained Caffiniere CMC joint is an example of a total joint replacement with a snap fit between a plastic trapezium and a metallic shaft.[42] Both the trapezium and metacarpal implants are secured with methyl methacrylate. Loosening at the bone–cement interface remains the highest source of failure. Titanium hemiarthroplasty has been performed for trapeziometacarpal arthritis without involvement of the trapezioscaphoid articulation. Removal of the base of the metacarpal and trapezial surface allows preparation and "press-fit" of

FIGURE 11. Fracture and radial subluxation of carpometacarpal Silastic implant, with surrounding bony erosions.

the titanium prosthesis into the shaft. This procedure can produce satisfactory pain relief in more than 90% of patients with maintenance of thumb length; however, long-term results are unavailable, and the procedure bears the risks of implant wear and fracture.[43] The results of total joint replacement for CMC arthritis are generally unacceptable to date, and most surgeons use some form of soft tissue interposition with ligament reconstruction.[44]

ISOLATED CARPAL BONE REPLACEMENTS

The current role of implant arthroplasty of the carpal bones is very limited. Pathology of the proximal carpal row is one of the most difficult problems encountered in hand surgery. Fractures of the scaphoid and lunate, dissociative instability, and avascular necrosis (Preiser disease, Kienböck disease) are challenging conditions to treat. These conditions affect young persons and can cause significant disability. The natural history of many of these ailments results in carpal collapse and progressive arthritis. Advances in understanding kinematics and load mechanics of the wrist have underscored the complexities of the carpal joints.[45,46] The multiple degrees of freedom and motion of the carpal bones during flexion/extension, radial/ulnar deviation, and intercarpal supination/pronation defy any joint replacement of an isolated carpal bone.

Various materials have been used for replacement of the scaphoid or lunate, or both. Vitallium and acrylic prostheses for scaphoid nonunions were attempted in the 1960s with poor results.[47] Silicone replacements were popular in the 1970s for post-traumatic arthritis of the proximal carpal row and were even used for comminuted and displaced acute scaphoid fractures.[47] The early results were encouraging, but were followed by later reports of implant failure and silicone debris from the excessive load borne by these implants (see Figure 2). Subsequent particulate silicone synovitis resulted in soft tissue swelling and bony erosions. Interestingly, an occasional patient decades following silicone arthroplasty of the scaphoid or lunate will have good function and minimal radiographic changes. These patients represent the exception to the rule, and the reason for the preservation of their prostheses is unclear.

Intercarpal arthrodeses have been performed in conjunction with silicone arthroplasty in an attempt to decrease the load across the implant and prevent particulate debris. In these instances, the implant functions as a spacer. This interposition technique can be better performed with a biologic material such as a tendon or strip of fascia to avoid the potential for wear particles and silicone synovitis. Allograft replacements have been used in a small series of proximal scaphoid nonunions, and the long-term results are still unclear.[48]

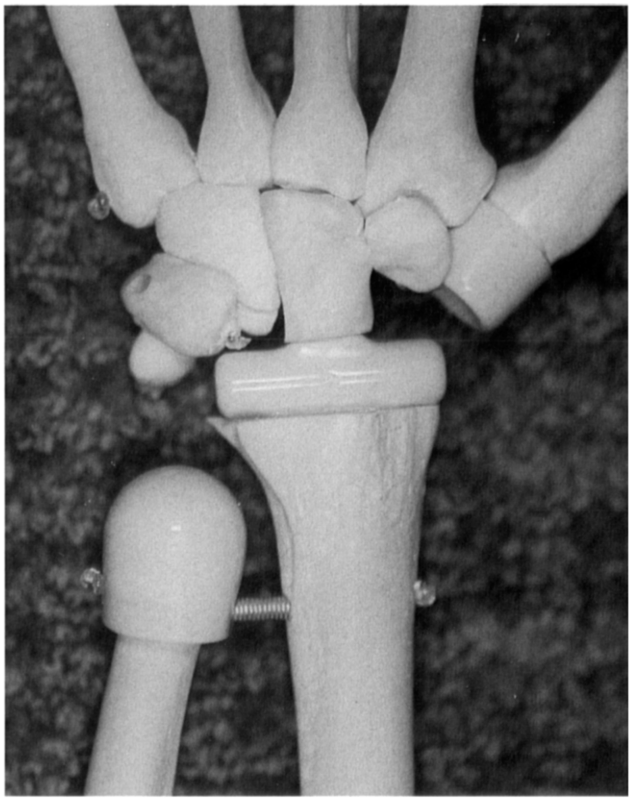

FIGURE 12. Bone model of Silastic wrist implant used as a spacer for advanced arthritis of the radiocarpal joint. Silicone carpometacarpal and ulnar head implants are also present.

Recently, titanium implants have been introduced as an alternative to silicone as potential carpal bone implants. The results of titanium arthroplasty are pending, but I am pessimistic about any metal implant functioning as a carpal replacement, given the complex intercarpal motion and load requirements in the wrist. The current recommended treatment of proximal carpal row disorders is based on the restoration of bony and ligamentous anatomy prior to the onset of arthritic changes, when possible (e.g., open reduction and internal fixation of scaphoid nonunion). When arthritic changes have occurred, salvage procedures (e.g., scaphoid excision and four-corner fusion or proximal row carpectomy) are preferred to implant arthroplasty.

WRIST ARTHROPLASTY

Arthrodesis has been the mainstay of treatment for the wrist with severe arthritis and remains the gold standard in the young patient with post-traumatic arthritis. The evolution of a wrist replacement began with attempts at rigid hinge constructs until the 1960s, when Swanson and Niebauer introduced the concept of resection arthroplasty accompanied by placement of a silicone spacer (Figure 12).[49,50] This pliable spacer would encapsulate over time to further stabilize the implant. The early results were encouraging, with good pain relief and improved function. However, long-term follow-up studies have revealed significant problems with

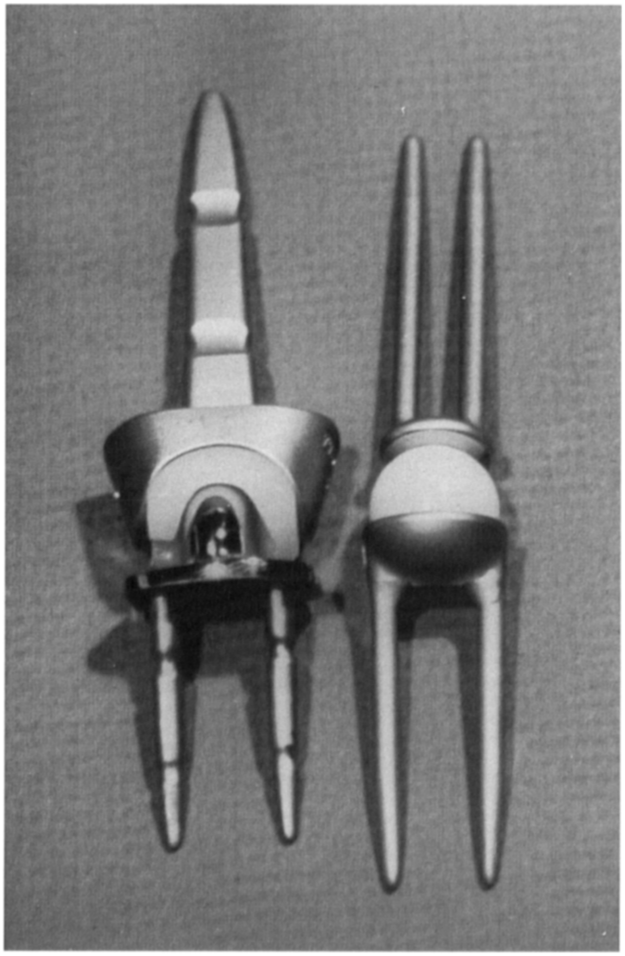

FIGURE 13. *Early Volz and Mueli designs for wrist arthroplasty.*

progressive subsidence, prosthesis fracture, silicone synovitis, and pain.[51–53] Interpositional arthroplasty of the wrist with fascia has also been performed with limited success but has been surpassed by mechanical prostheses.[54]

Initial attempts at fixed fulcrum prosthesis were the Mueli nonhinged ball-and-socket design or the Volz semiconstrained prosthesis with a flexion/extension track (Figure 13).[55–57] The original Mueli prosthesis is fixed by two malleable stems into the index and long metacarpals and the radius. This fixation offsets the normal center of wrist motion radial to the axis of the third metacarpal and capitate, which creates a force imbalance and a subsequent ulnar deviation deformity. In addition, the nonconstrained ball-and-socket design allows free range of motion, but loosening is common.[58] The Volz implant also offsets the normal wrist axis and allows only uniplane motion. Subsequent disruption of the normal moments and forces about the wrist results in loosening of this design.

As our understanding of wrist motion increased, a second generation of prostheses were introduced in the 1980s to better replicate normal joint kinetics and mechanics. The biaxial total wrist prosthesis made by Depuy is an example of the progression in design (Figure 14).[58] There is a convex-concave nonconstrained ellipsoidal articulating surface with cobalt chromium and polyethylene bearing surfaces. Porous coating has been applied to the stems to encourage bony ingrowth and enhance fixation. The center of motion is in line with the third metacarpal to better reproduce the normal wrist axis, and motion is allowed in flexion/extension and radial/ulnar deviation. Preoperative radiographic templates allow determination of the appropriate implant size. These new-generation designs resemble total hip and knee implants in an attempt to replicate the longevity achieved by those arthroplasties.

The indications for total wrist arthroplasty have not changed significantly over the past decade. Advanced articular degeneration with pain or severe deformity in an elderly patient are the principle indications for wrist replacement. Inflammatory arthritis is the primary etiology, as multiple upper extremity joint involvement is common. This polyarticular involvement limits the compensatory motion in the proximal joints required to accomplish activities of daily living following wrist fusion. Contraindications include severe instability, rupture of the wrist tendons, infection, inadequate bone stock, or a high-demand wrist.

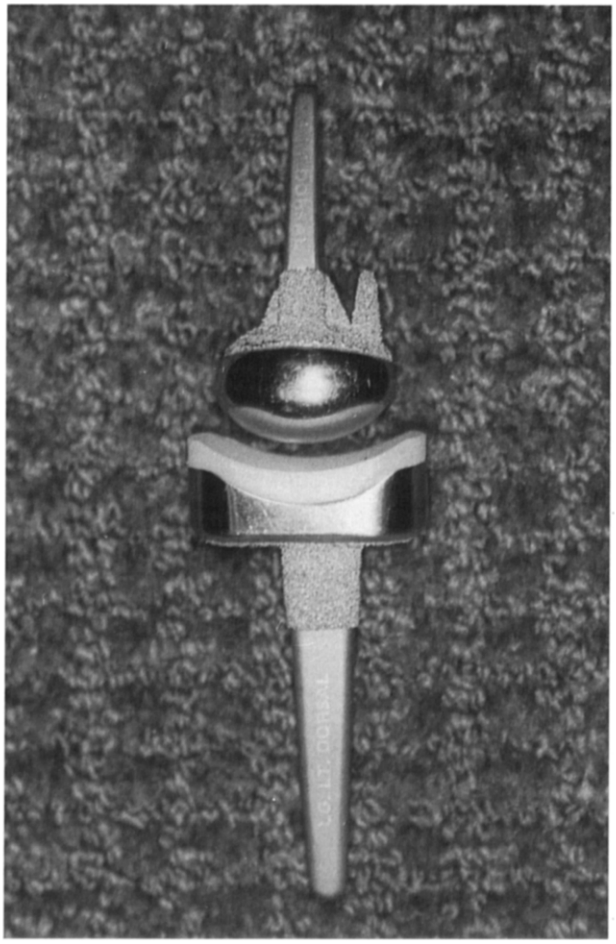

FIGURE 14. *New-generation biaxial prosthesis made by Depuy (Warsaw, Indiana) for wrist arthroplasty, with design modifications to reproduce normal wrist mechanics.*

The surgical technique and postoperative management of total wrist arthroplasty are critical to achieving a good result. The biaxial prosthesis is my preferred implant, and the surgical exposure is dorsal between the third and fourth extensor compartments.[58,59] Gentle tendon handling, precise bone preparation, prosthetic insertion with pressurized methyl methacrylate, and careful closure are important elements of the technique (Figure 15). Postoperative motion is initiated two to six weeks after surgery, depending on the prosthetic fit and soft tissue integrity. Gradual motion and use are allowed, with an ultimate goal of a 60° total flexion/extension arc. Lifting is limited to 10 lb after total wrist arthroplasty.

Early clinical reports on biaxial total wrist arthroplasty show 83% survival at a five-year minimum follow-up.[58] Complete pain relief occurred in 80% of patients, and mild to moderate discomfort persisted in 20%. Range of motion averaged 36° of extension, 29° of flexion, 10° of radial deviation, and 20° of ulnar deviation.[58] Implant failure can occur from loosening (usually the metacarpal component), dislocation, progressive imbalance, or infection. Treatment after failure is difficult and depends on the etiology, bone quality, and soft tissue status. Options include arthrodesis or revision arthroplasty with a custom-designed implant to compensate for deficient bone stock.[60,61]

THE FUTURE

The unpredictable results and complications with total joint arthroplasties of the hand and wrist have tempered surgeons' enthusiasm for implantation. The development and success of hand and wrist (smaller joint) arthroplasties lags behind hip and knee (larger joint) replacements. There are numerous explanations for this discrepancy, including lack of knowledge about normal function, fewer potential candidates, limited industry support, and less bone stock, which creates problems with implant fixation. However, the future of hand and wrist arthroplasty is resplendent, as our knowledge of normal function improves, newer biomaterials are introduced, and better implant fixation techniques (e.g., osteointegration) become commonplace.[62] The goal of a joint replacement that eliminates pain, provides stability, restores mobility, and lasts a lifetime is less of a vision and more capable of realization.

The future of arthroplasty may involve fewer biomaterials and metals as cartilage transplant technology advances. The use of rib perichondrium for arthroplasty of the hand has already been reported with limited success.[63] The methods to culture and grow cartilage cells are improving daily and are currently applicable to small defects in the knee. The ability to manipulate cells to perform specific tasks will represent the greatest advance in the next decade. The competition to develop a user-friendly, inexpensive, and reliable method to regenerate cartilage is ongoing. If this technique is perfected, the accepted treatment for a joint with arthritis may one day involve cartilage regeneration through cell harvest and gene manipulation.

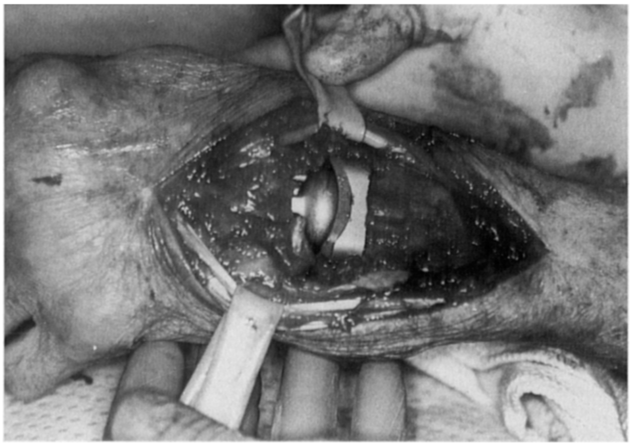

FIGURE 15. Trial biaxial implant components inserted into carpus and radius after bony preparation.

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