A Review Paper

Total Wrist Arthroplasty

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Abstract

In the article, I review the history of total wrist arthroplasty designs; give an overview of and design rationale for the ReMotion (Small Bone Innovations, Morrisville, PA) total wrist arthroplasty; describe the indications, technique, and postoperative care for this implant; and present some early, very encouraging results.

Traditional management of wrist arthritis consists of proximal row carpectomy, partial carpal fusions, or, in the event of pancarpal arthritis, total wrist fusion. Although proximal row carpectomy and partial wrist fusions preserve some motion at the wrist while relieving pain symptoms, the quality of results obtained from these procedures is not predictable or optimal in many instances. Total wrist fusions are credited with universal pain relief at the expense of wrist motion. However, critical analysis of the results of total wrist arthrodesis shows that the results are not always consistent with what has been claimed and that pain relief is unpredictable at best. In a recent study, 14 of 22 patients who had undergone wrist arthrodesis had residual pain, and 4 of these patients had severe pain 6 years later.[1] In another study, only 6 of 36 patients remained pain-free 4 years after wrist arthrodesis.[2]

Moreover, many patients do not like loss of motion in their wrists. In a study of wrist arthrodesis, only 40% of patients were satisfied at 1 year.[3] In another study, 100% of patients who had wrist arthrodesis indicated that they would have a procedure performed so they could move their wrists again.[1]

Management of hip, knee, ankle, and shoulder joints has evolved from arthrodesis to arthroplasty. The wrist joint awaits the same pattern of evolution with the advent of reliable designs.

Historical Overview

Since the early 1970s, investigators have sought a reliable total wrist implant design that would produce consistent results. The Swanson[4] 1-piece silicone elastomer implant design, though not a true total arthroplasty, was certainly a step in the direction of providing motion to the wrist while relieving pain. Despite good early results, implant breakage and subsidence required many revisions.

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The first true arthroplasty of the wrist was designed by Mueli.[5] This ball-and-socket design has 2 long prongs cemented into the metacarpals and had required a fairly large resection of the distal radius, including resection of the distal radioulnar joint, to cement the radial component. This design had many complications, including imbalance, loosening, and implant fracture. After undergoing multiple modifications to correct the problems, the design was finally discontinued.

The Mueli implant was contemporaneous with the Volz[6] implant. The Volz implant had an anteroposterior toroidal grooved polyethylene radial component sitting on a metal-backed radial component and an articulating metal implant cemented to the second and third metacarpals with 2 metal prongs. Similar to the Mueli design, it required a large amount of bone resection for insertion. Despite promising early results, this implant also was associated with high rates of loosening and was withdrawn.

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The next significant wrist arthroplasty was the biaxial implant.[7] This design had evolved to an ellipsoidal metal distal component cemented to the third metacarpal with a long stem. This articulated with a metal-backed polyethylene radial component that was fixed to the radius with cement. Despite extensive bone resection required to implant the device, most of the problems with this implant were related to the distal component. Carpal loosening, metacarpal fractures, imbalance, and implant subsidence resulted in many revisions and conversions to wrist arthrodeses. Although in the designer's hands the results were fairly good (Kaplan-Meier probability of revision-free survival at 6.5 years, 83%; no pain to mild pain in 94% of patients[8]), there were reports of many failures. Design modifications followed. In an effort to decrease the long moment arm of the distal component in the third metacarpal, the length of the distal part was reduced. Despite these efforts, the complication and revision rates of this implant were unacceptable, and the implant was finally withdrawn.

The trispherical total wrist arthroplasty (TWA) had a brief run.[9] Again, the implant had early good results in the designer's hands. In one study of 38 arthroplasties, all patients were "improved by the implants."

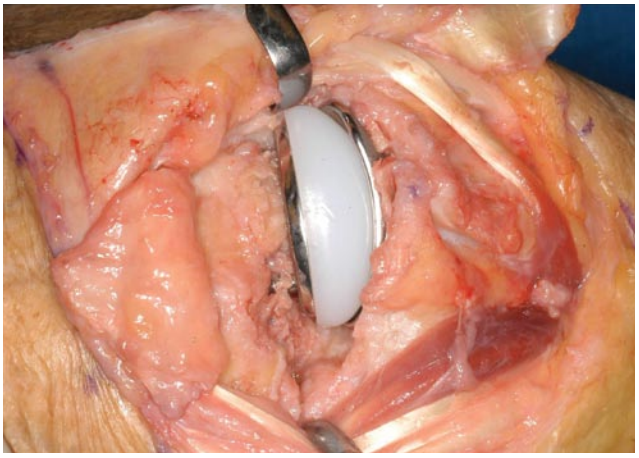

Figure 1. The amount of bone resected to insert the ReMotion (Small Bone Innovations, Morrisville, PA) total wrist arthroplasty is minimal.

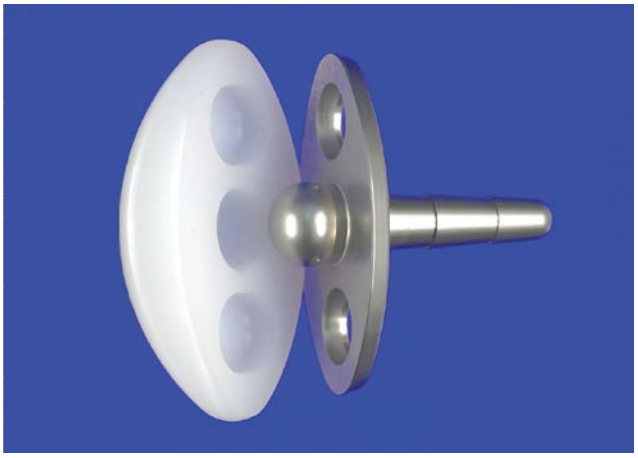

Figure 2. Carpal plate and rotating polyethylene ellipse.

Since in wrist arthroplasties the carpal side appeared to be the major problem because of loosening and imbalance, Menon[10] decided to keep all fixations in the carpus and the base of the metacarpals in his Universal Total Wrist Implant. This was a 3-piece design with the carpal component screwed to the distal carpal row with provision for intercarpal fusion. The radial component was made of cobalt-chromium (CoCr) and was cemented into the radius. Between the 2 components was a convex ultrahigh-density polyethylene component attached to the carpal plate and articulated with the radial component in a toroidal articulation. Because of the toroidal articulation, the design was inherently unstable, and early dislocation was a significant problem.[11] However, Menon[10] had shown very good results with his wrist implant, with 89% of patients pain-free at 42 months. The complication rate was high (25.5%), and dislocations occurred in 14% of cases.

After an elegant finite element analysis that concluded that ellipsoidal implants were inherently more stable than toroidal implants,[11] Grosland and colleagues modified the Menon design to the Universal 2 design incorporating the changes. The design changes have led to a reduction in the number of dislocations.

Design Rationale of ReMotion Total Wrist Arthroplasty

I now describe the design considerations of the ReMotion™ (Small Bone Innovations, Morrisville, Pa) TWA. In TWA design, the most important consideration is stability. If the joint is not stable, it cannot provide pain-free function. The best definition of stability is "control of degrees of freedom." Past designs that made the wrist into a ball-and-socket design increased the degrees of freedom. In an arthritic wrist with poor neuromuscular control, this increase often proved catastrophic. Designs that converted the wrist joint into a hinge joint decreased degrees of freedom, leading to increased transmission of stress to the metal–bone interface and loosening. Furthermore, a successful wrist arthroplasty design must have enough intrinsic stability to allow the muscle tendon units to function normally and not require a period of immobilization for that to happen. It has been clearly demonstrated that the ellipsoidal design articulating with a "cup" achieves this aim.

The other aspect of a stable joint involves the surrounding ligaments. In most wrist arthroplasty designs to date, a segment of the distal radius, often a large segment, is excised. Doing that renders all wrist ligaments nonfunctional. So, the ideal wrist arthroplasty design must preserve the rim of the distal radius where the ligaments are attached. There are 2 other advantages to this action. First, the proprioceptive properties of the wrist ligaments are maintained, which helps in the neuromuscular control of the wrist joint and gives the patient the impression of normal joint motion. Second, when the distal radius is not excised, the distal radioulnar joint (DRUJ) and the triangular fibrocartilage complex are preserved. It is particularly important to preserve the integrity and stability of the DRUJ, especially when the DRUJ is uninvolved in the disease process.

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Avoiding resection of the distal radius also achieves another goal: minimal bone resection. Not only does minimal bone resection contribute to stability, but it preserves bone for future reconstruction or salvage, planning for which is vital in implant design. In the design being described, the bone resection amount is minimal (Figure 1). Only half of the scaphoid, triquetrum, and lunate is excised, leaving substantial bone mass for arthrodesis between the distal carpal row and the radius in the event of implant failure.

Minimal bone resection should be combined with avoiding use of cement in the implant arthroplasty of the wrist. In the wrist and hand, cement use has not been successful over the

Figure 3. All components.

Figure 4. Radial component with undercut volar side.

long term. In the current wrist arthroplasty design, efforts have been made to avoid using bone cement. The carpal plate is made of CoCr with commercially pure titanium coating to encourage bone ingrowth. The central stem of the carpal component is press-fit into the capitate (Figure 2). Efforts have also been made to limit carpal fixation to the carpus and base of the metacarpals and to avoid any long-lever arms by having long stems extending into the metacarpal shafts. The central peg inserts into the capitate and may cross the third carpometacarpal (CMC) joint into the base of the third metacarpal. Two screws compress the carpal plate to the cut end of the carpus and fix the plate to the hamate on one side and the scaphoid, trapezoid, and base of the second metacarpal on the other. This pattern of carpal fixation, along with packing the remaining carpal interstices with cancellous bone taken from the resected proximal carpal row or radius, results in the carpal side being converted into a solid bony mass by intercarpal fusion. Carpal fixation is thus enhanced, as is uniform load transmission. I have not observed any case of carpal loosening with this implant. The specially designed 4.5-mm CoCr alloy screws with wide cancellous pitch form provide firm fixation in the cancellous bone. These screws can be angled 30° for versatility in fixation.

The distal carpal row has an inherent arch. If a straight carpal plate were to be screwed into this arched articulation, it would flatten the carpal curvature, resulting in tendonitis and neuritis by irritation of the contents of the carpal tunnel. Avoiding this eventuality involves offsetting the 2 screw holes palmar to the central peg of the carpal plate such that the carpal curvature is maintained.

The next design feature unique to this implant is that it provides an ultrahigh-density polyethylene ellipse that rotates on the carpal plate (Figure 2). This ellipse, snap-fit on a ball on the proximal side of the carpal plate, can rotate 10° relative to the carpal plate and in doing so acts as a dampener and avoids torque transmission to the metal carpus component. We believe that this feature also preserves the complex "dart thrower's" motion of the wrist with relative axial rotation between the intercalated segment and the carpal plate.

The proximal component of this implant is a moderately deep ellipse cup that approximates anatomical centers of rotation with an anatomically shaped intramedullary stem (Figure 3). The radial component is made of CoCr and has a commercially pure titanium coating. This implant is press-fit into the radius, the rim of which is preserved. If necessary, impact grafting may be added to enhance the radius fixation. Certain features of the radial component should be discussed. The articulating part of the radius has 10° of palmar tilt to match the native radius. It has 10° of radioulnar inclination. The palmar surface of the radial cup is undercut to prevent median nerve or tendon impingement (Figure 4).

This implant has been tested extensively in the laboratory. Wear and fatigue testing was performed at the Mayo Clinic Biomechanics Laboratory. The primary parameters for wear testing were constant compressive load of 20 lb (89 N); articulation in a 40° conical range of motion (ROM); and 5 million cycles in bovine environment at 37°C. The secondary parameters for wear testing were constant compressive load of 20 lb (89 N), articulation in a 10° reciprocating ROM; and 5 million cycles in bovine environment at 37°C. Results showed that there was mild evidence of wear and cold flow, but there were no statistically significant changes in gravimetric or dimensional characteristics. The fatigue testing parameters were sinusoidal load of 0 to 20 lb (89 N); fixed flexion angle of 45°; and 5 million cycles in bovine environment at 37°C. Results showed that there was mild evidence of wear and cold flow, but there were no statistically significant changes in gravimetric or dimensional characteristics.

This implant is designed to provide 40° of flexion, 40° of extension, and 30° arc of radial/ulnar deviation (Figures 5, 6). Since its release for general use in 2002, there have been no major design modifications. Recently, a very small section of material was removed from the dorsoradial portion of the radial component for better fit. The implant is available in 3 sizes: small, medium, and large. An extra-small size is being added. The polyethylene ellipse is available in standard size and in a "plus" size that adds 1 mm to the height of the ellipse, enhancing stability.

Indications

The major indication of TWA is rheumatoid arthritis. Traditionally, wrist arthroplasty is recommended for rheumatoid wrists when wrist damage is extensive and there are severe bone

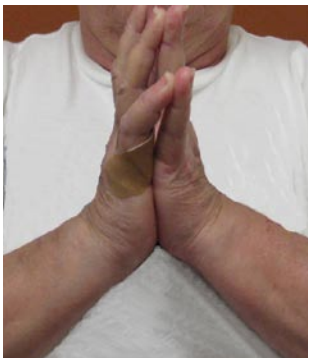

Figure 5. Right wrist extension 1 year after total wrist arthroplasty in a rheumatoid patient with bilateral wrist involvement.

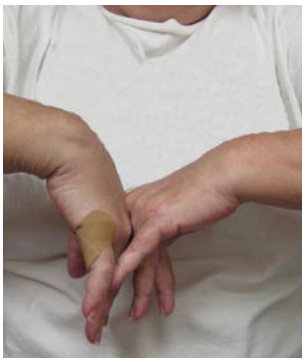

Figure 6. Right wrist flexion 1 year after total wrist arthroplasty in a rheumatoid patient with bilateral wrist involvement.

loss and gross soft-tissue imbalances. These situations set up the arthroplasty for failure. For a successful arthroplasty, good bone stock and soft-tissue balance are essential.

Osteoarthritis is a good indication for wrist replacement, as there usually are good bone stock and soft tissues. Indications will increase in number when TWA results become predictable.

Posttraumatic arthritis is a controversial indication for wrist arthroplasty, as there are more "conservative" options, like limited wrist fusions. However, the quality of results of wrist arthroplasty surpasses that of 4-corner fusion and scaphoid excision.

More controversial indications are failed proximal row carpectomies and failed 4-corner fusions. As TWAs become commonplace, young patients with wrist arthrodesis will demand "takedown" of their fusion and conversion to wrist arthroplasty.

Technique

The insertion is done with a dorsal longitudinal approach. Two retinacular flaps are elevated, one based on the radial side and the other ulnarly. A distally based dorsal capsular flap is elevated. Now precision guided technology instruments are used to accurately insert the implant, particularly to precisely center the capitate/third metacarpal axis to the central longitudinal axis of the radius. The lunate spacer is inserted into the lunate fossa and is used to assemble and position the radial block over the Lister's tubercle. The radial block is fixed to the radius with 2 thick Kirschner wires (K-wires) that are bent out of the way. The radiolucent marker is fixed to the radial block, and the wrist is imaged in 2 planes to confirm that the marker is aligned to the long axis of the radius in both planes. Now the carpal cutting guide is assembled into the radius block, and the distal "tang" is positioned over the third metacarpal. The carpus is resected along the guide, taking care not to damage the palmar capsule. The cutting guide and the resected carpals (part of the scaphoid, lunate, and triquetral) and the tips of the capitate and hamate are removed, and the burr guide is inserted into the radial block. Next, the articular surface of the radius is contour-burred after hyperflexing the wrist. The burring removes the articular cartilage and exposes the subchondral bone. The burr guide is now removed, and the radial drill guide is inserted into the radius block. The radial drill guide is appropriately positioned, and a 2-mm threaded pin is inserted into the medullary canal of the radius. Imaging is done in 2 planes. Once the pin is positioned in the central part of the radial medullary canal, the radial drill guide and radial block are removed, and the cannulated broaches of appropriate size are mounted over the pin, and the radius is broached. Once the broaching is complete, a trial radial component is inserted.

The carpal side is now addressed. The trial radial component is removed, the wrist is hyperflexed, and the carpal drill guide is aligned over the capitate with the tang aligned to the third metacarpal. The carpal post is drilled with a 2-mm wire. The position is confirmed with imaging. The drill guide is removed, and the capitate is broached to the appropriate size. Now the trial carpal and radial components are impacted in. At this point, if the distal scaphoid appears too loose, a K-wire can be used to stabilize it to the capitate. If, as is usually the case, the distal triquetral is outside the carpal plate, it should be excised. Trial reduction is performed. If the joint appears too loose, a plus-size polyethylene ellipse is selected. The definitive radial component is impacted in, with some impact grafting if necessary. The carpal component is inserted into the capitate, and the screw drill guides are used to aim the drill for the second metacarpal on the radial side and the fourth metacarpal on the ulnar side. After the screw lengths are measured, screws are inserted. The ulnar screw should not cross the CMC joint and should remain in the hamate. The radial screw crosses the second CMC joint, and the tip is positioned ideally in the base of the second metacarpal (Figure 7). While the screws are being tightened sequentially, care is taken to avoid rotating the carpal plate. Now an appropriate polyethylene insert is snap-fit onto the carpal component, and the joint is reduced. The wrist is imaged in 2 planes to confirm proper insertion of the components. At this point, a small osteotome is used to remove some of the cartilage between the capitate and the hamate and other carpal bones, and these spaces are packed with cancellous graft harvested from the excised carpus. The dorsal capsule is repaired with nonabsorbable sutures. The radially based retinacular flap is positioned over the capsule to prevent any portion of the metal radial rim from abrading the extensor tendons. The ulnar based retinacular flap is closed over all the extensor tendons except the extensor pollicis longus, which is left in an extra-retinacular position. Now the tourniquet is released, hemostasis obtained, and skin closure performed in routine fashion. The wrist is put in a well-padded plaster splint and kept well elevated during the postoperative period.

In special situations, modifications are needed. For rheumatoid wrists with bone loss, it may be necessary to cross the CMC joints with the central carpal peg and the 2 carpal screws. For bone deficiency, extra bone grafting may be necessary. For poor bone quality, I recommend using a small amount of cement with the radial and carpal components. For soft-tissue imbalance, tendon transfers may be necessary at time of arthroplasty. For capsular deficiency, the palmar capsule may be reinforced with cadaveric fascia lata or Graftjacket® (Wright Medical Technology, Arlington, TN). The dorsal capsule can be reconstructed with a retinacular flap.

In revising a failed proximal row carpectomy to wrist arthroplasty, it is first necessary to obtain sufficient "space" for the

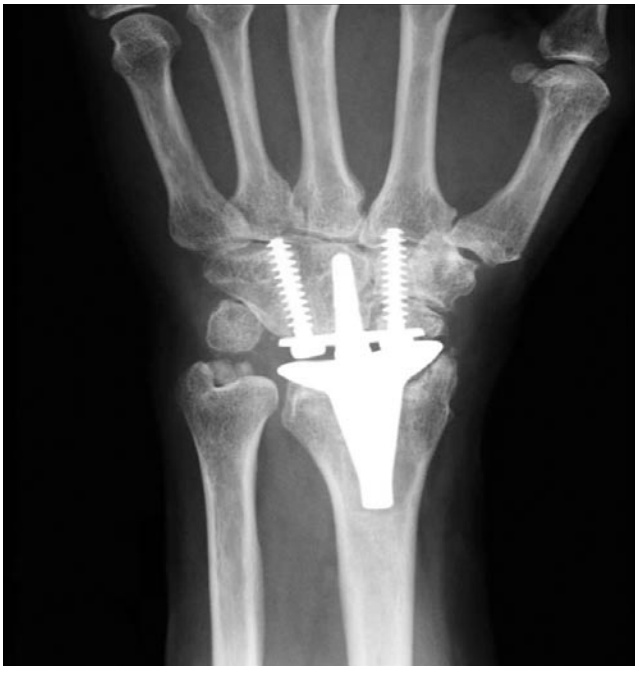

Figure 7. Radiograph of left total wrist arthroplasty shows radial screw crossing second carpometacarpal joint and ulnar screw in the hamate.

implant. After the joint is exposed, 2 laminar spreaders are used to distract the carpus from the radius. This maneuver may also be necessary in conversion of a wrist arthrodesis to arthroplasty. In failed proximal row carpectomy and failed scapholunate advanced collapse revisions, the missing scaphoid can be replaced by harvesting the pisiform through a separate palmar incision. With the pisiform held in the space normally occupied by the scaphoid, the radial carpal screw is inserted. In all these situations, the dorsal capsule should be reconstructed with a retinacular flap.

Postoperative Care

The patient comes to the office 5 to 7 days after surgery. If the swelling is manageable, an Orthoplast splint is fashioned for the wrist and finger motion, and gentle active wrist motions are encouraged. Formal physical and occupational therapy with digital motion, wrist motion, and edema-reducing protocols is started 10 days to 2 weeks after surgery. It typically takes 4 to 6 months to gain optimal ROM and strength.

Outcomes

In 2007, Sollerman and colleagues[12] reported preliminary results from a multicenter prospective study they had begun of this implant in Sweden and Denmark in 2004. Their plan was to use standardized measurements to study 60 patients with the implant for 5 years. There were 57 enrolled patients (12 men, 45 women). Mean age was 61 years (range, 30-82 years). Forty-eight patients had rheumatoid arthritis, 4 had osteoarthritis, 4 had posttraumatic arthritis, and 1 had Kienbock disease. Of these 48 patients, 22 reached the 1-year follow-up. No complications were seen at 1 year. All but 1 patient reported improved function and less pain. Mean ROM was 56° (range, 30°-135°). Preoperative DASH (Disabilities of the Arm, Shoulder, and Hand) score was 83 (range, 60-113), while DASH score at 1 year was 61 (range, 28-121). There was no radiologic loosening at 1 year.

Similar results were obtained at the Mayo Clinic (W. P. Cooney, MD, oral communication, October 2007). Twenty-seven patients (18 with rheumatoid arthritis, 9 with posttraumatic arthritis) had been followed up for more than 1 year. There were no major complications at follow-up, except 1 patient who had flexor carpi radialis tendonitis. Mean ROM was 50° extension, 45° flexion, and 43° radioulnar deviation.

Summary and Conclusions

I have given an overview of and the design rationale for the ReMotion TWA and provided some early, very encouraging results. In designing this joint, I believe we have clearly thought out many of the problems associated with TWAs, have incorporated the lessons of history, and have taken into account the recent biomechanical studies on the wrist joint and implant arthroplasty.

Bunnell wrote, "A painless stable wrist is the key to hand function." Up until now, to make the wrist stable, we have had to make it stiff too. But this does not have to be the case. The bar for functional motion at the wrist is very low. As estimated by Palmer and colleagues,[13] a functional wrist requires only 30° extension, 5° wrist flexion, 10° radial deviation, and 15° ulnar deviation. The question in 2008 is: Can we consistently and safely provide such ROM to our patients' wrists without resorting to a destructive procedure like wrist fusion? With improvements in design and long-term results showing that these designs work, indications for wrist arthrodesis will decrease and those for wrist arthroplasty will increase.

Author's Disclosure Statement and Acknowledgments

The author wishes to note that he has an ongoing relationship with Small Bone Innovations. The author would like to thank David Leibel for engineering input in the design of the implant.

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