

**CURRENT CONCEPTS REVIEW****Total Wrist Arthrodesis: An Update on Indications, Technique and Outcomes**E. Carlos **Rodriguez-Merchan**, MD, PhD; Eloy D. **Tabayo-Alvarez**, MD; Babak **Shojaie**, MD; Amir R. **Kachooei**, MD*Research performed at the Department of Orthopedic Surgery, La Paz University Hospital, Madrid, Spain**Received: 8 June 2022**Accepted: 13 September 2022***Abstract**

Painful end-stage wrist osteoarthritis (OA) unresponsive to conservative treatment is frequently managed with total wrist arthrodesis (TWA), which might render pain alleviation and ameliorate function, pain, and grip strength. Usual indications for TWA include inflammatory arthritis, idiopathic degenerative OA and posttraumatic OA, Kienböck's illness, brachial plexus palsy, cerebral paralysis, infraclavicular brachial plexus blocks and other spastic and contracture base illnesses, scapholunate advanced collapse, scaphoid nonunion advanced collapse, and failure of other surgical techniques such as after failed total wrist arthroplasty, four-corner fusion, proximal row carpectomy and severe ligament injuries (this procedure is carried out when all other treatment alternatives have failed to control the individual's symptoms). TWA is commonly carried out with a dorsal plate fixed from the distal radius to the third metacarpal. However, other surgical procedures have been reported, including intramedullary fixation and new implants that do not cross the third carpometacarpal joint or some procedures without utilizing hardware for example using a vascularized fibular grafting in individuals with rheumatoid arthritis. TWA has been shown to give persistent and painless stability for 20 years or more. The rate of adverse events for TWA ranges from 0.1% to 6.1%, though some authors have published that it can be as high as 27%. The most common adverse events are tendon ruptures, peri-implant fractures of the third metacarpal, the need for hardware removal, and constant pain at the third carpometacarpal joint. In idiopathic degenerative OA, the reoperation rate following TWA has been reported as high as 63%. While TWA can render foreseeable pain alleviation and ameliorate function, orthopedic surgeons should remember that this surgical technique is not without its risks and that the accessibility of many surgical procedures requires orthopedic surgeons to scrupulously contemplate the risks and benefits of each alternative for the individual in front of them.

**Level of evidence:** III**Keywords:** Total wrist arthrodesis, Wrist osteoarthritis, Post-traumatic osteoarthritis, Radiocarpal osteoarthritis, Failed wrist arthroplasty, Wrist salvage operations**Introduction**

**S**ymptomatic end-stage wrist arthritis of different etiologies can be painful and debilitating. When conservative treatment fails to control symptoms or other motion-sparing techniques have failed to provide durable and satisfactory relief, total wrist arthrodesis (TWA) may be considered a definitive primary or salvage treatment option. This procedure has been demonstrated to render pain alleviation and ameliorate function and grip strength.<sup>1-4</sup> Some data have demonstrated high levels of patient satisfaction and good functional outcomes after bilateral wrist fusion.<sup>5</sup> This article aimed to review the current indications for TWA, outcomes according to clinical diagnosis and surgical technique, and special

considerations in challenging scenarios.

**Indications**

Many wrist conditions may benefit from TWA, such as rheumatoid arthritis and other autoimmune conditions, post-traumatic osteoarthritis (OA), cerebral palsy with associated wrist contracture, brachial plexus injuries with unstable wrists, congenital problems (for example secondary to Madelung's deformity) or after prior wrist illnesses such as Preiser disease (avascular necrosis of the scaphoid).<sup>6,7</sup> It is also used as a salvage operation after failed total wrist arthroplasty and other motion-sparing

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procedures.<sup>5</sup> The fundamental indications for TWA are shown in [Table 1].<sup>1-9</sup>

**Table 1. Indications for total wrist arthrodesis (TWA) 1-9**

Non-inflammatory arthritis: pancarpal idiopathic degenerative osteoarthritis
Inflammatory arthritis: rheumatoid arthritis, juvenile inflammatory arthropathy, psoriasis
Post-traumatic osteoarthritis
Brachial plexus paralysis
Cerebral palsy
Post-infectious wrist
Large bone defects in the wrist joint
Wrist tumor
Failed hemi or total wrist arthroplasty
Failed four-corner fusion, failed proximal row carpectomy
Kienböck's disease

## Outcomes

### Outcomes According to Surgical Technique

TWA is often carried out with a dorsal plate that extends from the distal radius to the third metacarpal. Although TWA using a plate is a well-established technique with satisfactory fusion rates in symptomatic end-stage osteoarthritis, plate-related complications remain a concern.<sup>10, 11</sup> Therefore, several alternative fixation techniques have been developed, including a new implant that spares the carpometacarpal (CMC) joint, arthroscopic assisted techniques, and an intramedullary (IM) device.<sup>12-14</sup> Debate still remains as to the perfect position of the hand. Usually the wrist is placed in slight dorsiflexion and ulnar deviation to optimize power grip. In individuals with bilateral involvement, the nondominant hand might be placed in 5 degrees -10 degrees of flexion to facilitate perineal care.<sup>15</sup>

### Dorsal Plating with or without Third Carpometacarpal Joint Sparing

Dorsal plating from the radius to the third metacarpal (spanning plate) might be the most common technique employed [Figure 1]. While it provides early stable fixation and facilitates reliable fusion, it might not be adequate in all scenarios. Individuals with soft tissue concerns (potentially impaired wound healing or thin tissue, for example) may benefit from a lower profile implant or IM device. The newer fourth-generation wrist designs seem to be functioning better than earlier implants.<sup>3</sup> Surgeons today have many implants at their disposal, some with tapered designs and variable plate width to better match the radius and metacarpal, as well as with varying degrees of wrist extension built into the design for improving power grip. Precontoured plates normally have a dorsal angulation of 15 degrees to match the contour of the dorsal aspect of the wrist and also to render maximum functional outcomes. The plates can be bent more throughout the surgical procedure to accommodate the anatomy of the individual; nevertheless, it is desirable to avert bending the plate at the level of the holes as well as prevent bending the plate many times in opposite directions as this will make the plate weaker. The screws utilized in this surgical technique can be

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of different sizes, most usually of 2.3 mm, 2.7 mm, and 3.5 mm, and they can be utilized in either locking or non-locking manner depending on which holes of the plate they are inserted in (threaded or nonthreaded). Bone grafts are occasionally utilized throughout the surgical procedure, depending on the surgeon's inclination, expertise, and individual needs. The bone graft can either be harvested directly from the individual during the surgical procedure or can be utilized from a tissue donation bank.<sup>16</sup>



**Figure 1 (a-b).** Total wrist arthrodesis (TWA) for painful post-traumatic osteoarthritis after distal radius fracture malunion by means of plate and screws: **(a)** Lateral radiograph of distal radius fracture malunion with post-traumatic arthrosis (carpal instability non-dissociative). **(b)** Postoperative lateral radiographs after TWA. Note short bend in the plate to pre-position the wrist for power grip

A recent retrospective review of the spanning plates found a reoperation rate of almost 20% for symptomatic hardware (27%), hardware failure (20%), infections (17%), and nonunion (15%). In addition, 33% of patients overall experienced a complication that may or may not have resulted in reoperation. Fusion in the dominant wrist and smoking were independently associated with a higher risk of complications.<sup>17</sup> Rancy et al. compared 15 cases of non-spanning wrist fusion with a locking T plate to 11 patients of spanning wrist fusion with a locking compression plate.<sup>2</sup> All the wrists were fused. There were no significant differences in objective and subjective results between cohorts. There were three adverse events (27%) in the spanning cohort, including tendon rupture and peri-implant fracture at the third metacarpal, comparable with three adverse events of unplanned secondary surgery (20%) in the non-spanning cohort, consisting of hardware removal. They advocated non spanning arthrodesis as an alternate technique for total wrist fusion with an elevated union rate and minimal risk of adverse events at the CMC joint.<sup>2</sup>

Regarding locking vs. non-locking plate, Owen et al. reported 77 TWAs carried out for inflammatory and post-

traumatic OA using a pre-contoured dorsally-applied non-locking wrist fusion plate. Polyarticular inflammatory arthritis and female gender were associated with poorer patient-reported results. However, there was no difference in the rate of adverse events for inflammatory and non-inflammatory indications.<sup>18</sup> In a cohort of individuals with rheumatoid arthritis (RA), a non-locking plate was compared to a locking compression plate (LCP) patients.<sup>11</sup> Bone union was accomplished in all individuals in the two cohorts. However, plate-related complications occurred in 4 of 9 individuals in the non-locking plate and no patients out of 7 in the locking plate cohort, including pain over the plate, wound dehiscence with infection, extensor tendon adhesion, and fracture in four separate patients. The authors advised LCP metaphyseal plate as the recommended fixation in the RA patients.<sup>11</sup> This method is a great way to ameliorate functional utilization of the hand by alleviating pain and ameliorating grip strength. It can be also useful for the bilateral arthrodesis of the wrist, if all other possibilities are exhausted.<sup>19</sup>

Regarding the controversy about including or not including the third CMC, some authors have reported complications regarding nonunion of the third CMC joint, leading to increased hardware failure and residual pain.<sup>20,21</sup> The early experience with a new CMC joint-sparing implant showed similar functional outcomes, grip, and pain with a theoretically lower risk of hardware removal compared to a standard spanning locking compression plate [APTUS®, Medartis, Switzerland in 10 patients vs. Depuy-Synthes® LCP plates (AO-ASIF) in 10 patients].<sup>10</sup> Except for one non-union in the Aptus group, all individuals achieved osseous healing without adverse events. The Aptus group exhibited a substantially augmented passive range of motion of the third CMC joint than the unaffected contralateral side with no clinical significance.<sup>10</sup>

#### **Arthroscopic Total Wrist Arthrodesis (TWA)**

An alternative to the well-established open TWA is the arthroscopic technique, which may place the extensor compartments at lower risk and may improve cosmesis with a lower scar burden.<sup>20, 21</sup> Nazerani et al. recently described an arthroscopic TWA technique debridement, and cartilage extraction is performed through radiocarpal and midcarpal portals and places four self-tapping cannulated screws in different trajectories under fluoroscopic guidance. The authors reported satisfactory results and no complications in four individuals with a minimum follow-up of three months. All the individuals had complete union after 12 weeks.<sup>22</sup>

#### **Intramedullary Techniques**

IM fixation has been utilized with some success in individuals with a poor soft tissue envelope [Figure 2]. Often used for patients with RA, IM fixation has been achieved with Steinmann pins, locking IM nails, and other similar devices.<sup>23-25</sup> since this fixation strategy is often employed for patients with inflammatory arthritis, differentiating outcomes between techniques vs. etiology can be difficult. It will be discussed in more detail in the next section.

Although the locked IM wrist fusion system yields high fusion rates, it must be used with a great caution because

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of its elevated rate of adverse events, particularly from



**Figure 2 (a-d).** Total wrist arthrodesis (TWA) for painful idiopathic osteoarthritis with no prior injury by means of an intramedullary device. The patient had pain since one year ago and failed to respond to conservative treatment: (a) Preoperative anteroposterior (AP) radiograph; (b) Preoperative lateral view; (c) Postoperative AP radiograph; (d) Postoperative lateral view

Distal screw migration, and its high revision rate.<sup>24</sup> Table 2 shows the results of TWA according to the surgical technique used [Table 2].

#### **Outcomes According to Etiology**

Some authors have observed that outcomes of TWA can be influenced by the etiology, suggesting that this should also be considered when determining the appropriate technique and implant for each patient.

#### **TWA in the Setting of Inflammatory Arthritis vs. non-inflammatory arthritis**

Patients with inflammatory arthritis may pose unique challenges due to soft tissue involvement, such as ligament attenuation and risk of tendon ruptures. To address these concerns, surgeons may consider IM techniques and other low-profile implants.<sup>11</sup> Recent studies did not find an increased risk of reoperation and complication rate in RA compared to non-RA patients, although it was the most common indication for TWA.<sup>17</sup> Even a high complication rate of 60% and reoperation rate of 63% were reported in non-inflammatory indications for TWA.<sup>1</sup> Although it is believed that the disease-modifying anti-rheumatic drugs (DMARDs) may pose the RA patients with an increased risk of complications due to immunity suppression, different studies did not find a significant difference compared to the non-RA group.<sup>26</sup> In ankle arthrodesis the only influencing factor for higher complication rate was active treatment with corticosteroids.<sup>27</sup> In a 20-year follow-up study of twenty wrist arthrodesis in 17 patients with RA (radiocarpal fusion combined with synovectomy and the Darrach technique), the authors found that TWA in a rheumatic wrist can provide painless durable stability and improve patients' activities of daily living.<sup>28</sup> Moreover, 94% of the RA patients were very pleased, and 6% were fairly pleased after a mean follow-up of 45 months.<sup>23</sup>

Table 2. Results of total wrist arthrodesis (TWA) according to highlighted surgical techniques

AUTHORS	YEAR	NUMBER OF PATIENTS	DIAGNOSIS	TYPE OF FIXATION	NUMBER OF NONUNIONS	NUMBER OF COMPLICATIONS	COMMENTS
Lee et al (13)	1994	36 (46 wrists)	Connective tissue wrist disorders; congenital wrist disorders; and acquired wrist disorders.	Autogenous iliac crest bone graft, with an intramedullary Steinman pin placed within the distal radial and third metacarpal shafts, and an obliquely-placed Kirschner wire across the second metacarpal base into the radius.	0	1 residual flexion, radial deviation deformity was noted with the congenital disorders.	All patients had low demand requirements for this fused wrists.
Nagy and Büchler (20)	2002	146	NA	AO plate fixation. In 79 wrist arthrodeses the 3rd CMC joint was also arthrodesed, and in 67 the 3rd CMC joint was simply bridged.	After plate removal only 81 wrists were evaluated with respect to the 3rd CMC joint. Of 47 wrists that had 3rd CMC joint arthrodesis and plate removal, 20 developed a nonunion.	Eleven of the nonunions were painful and further surgical treatment was required. In contrast, of 34 wrists with the 3rd CMC joint bridged all but one remained free of symptoms after the plate had been removed.	This retrospective study of 146 consecutive TWAs with AO plate fixation. In 79 wrist arthrodeses the 3rd CMC joint was also arthrodesed, and in 67 the 3rd CMC joint was simply bridged. The conclusion was that 3rd CMC joint must not be included in the arthrodesis when performing an AO-wrist arthrodesis.
Orbay et al (14)	2012	7	Indications for fusion were two posttraumatic arthritides, three rheumatoid arthritides, one spastic deformity, and one infection.	The Skeletal Dynamics IMPLATE (an intramedullary total wrist fusion device designed to provide stable fixation while avoiding the problems associated with plates).	0	One rheumatoid patient required secondary surgery for removal of a retained palmar osteophyte.	These authors used the Skeletal Dynamics This device delivered stable fixation, facilitated hand placement, and did not require removal. It should be noted that there is a potential conflict of interest as the implant was designed by the surgeon.
Elherik et al (23)	2014	14 (15 wrists)	Rheumatoid arthritis	Mannerfelt wrist arthrodesis	0	0	Mean follow up period of 45 months. All patients reported an overall improvement in pain and functional capacity. The satisfaction results were excellent.
Berling et al (21)	2015	122	NA	Plate fixation	13	20 (16%) hardware-related complications occurred and included screw fracture (n = 12), plate loosening (n = 5), and plate fracture (n = 3). Thirteen (65%) of the hardware complications occurred after the 3rd CMC joint was not fused during the procedure. The 3rd CMC joint did not fuse after attempted arthrodesis in 6 additional wrists.	The recommendation of these authors was that, unless one plans for routine plate removal within a given timeframe, the 3rd CMC joint must be included in the fusion mass.

Table 2. Continued

Rancy et al (2)	2018	26	Indications for fusion included rheumatoid arthritis, posttraumatic arthritis, Kienböck's disease, primary osteoarthritis, juvenile inflammatory arthropathy, psoriasis, brachial plexopathy, failed hemi or total wrist arthroplasty, failed four-corner fusion, and failed proximal row carpectomy.	These authors compared the outcomes of 15 cases of nonspanning wrist fusion with a 2.4/2.7 mm locking T plate to 11 cases of spanning wrist fusion with a 2.7/3.5 mm locking compression plate.	0	There were three complications (27%) in the spanning group, including tendon rupture and peri-implant fracture at the third metacarpal. This was compared with three complications (20%) in the nonspanning group, consisting of hardware removal.	Nonspanning TWA and spanning TWA showed no significant differences in the objective and subjective results.
Taii et al (11)	2018	16	Rheumatoid arthritis	AO wrist fusion plate in nine and a locking compression plate (LCP) metaphyseal plate in seven cases.	0	Plate-related complications occurred in four cases in the AO wrist fusion plate group and no cases in the LCP metaphyseal plate group. Complications included pain over the plate, wound dehiscence and infection, extensor tendon adhesion, and fracture in one case each.	These authors compared TWA using an AO wrist fusion plate in nine and a LCP metaphyseal plate in seven cases of rheumatoid arthritis. TWA using an LCP metaphyseal plate was favorable for rheumatoid arthritis patients with comparable stability to that of and a lower risk of plate-related complications than an AO wrist fusion plate.
Nazerani et al (22)	2019	4	NA	Minimally invasive arthroscopic TWA	0	0	Arthroscopic TWA had no complications and its functional results were acceptable.
Hernekamp et al (10)	2020	20	NA	A total of 20 patients underwent total wrist arthrodesis [10, using the new APTUS® implant (APT); 10 using the Depuy-Synthes® LCP plates (AO)].	1 in the APT group	1 nonunion	The APTUS 2.5 TriLock Wrist Fusion Plate, Medartis Suisse implant provided functional results similar to those of the standard technique (Depuy-Synthes locking compression plate LCP - AO Foundation). The main advantage of the new implant was that it was not necessary to remove it due to the unaffected third CMCJ.
Hazewinkel et al (17)	2020	215	Inflammatory arthritis, degenerative arthritis, and posttraumatic arthritis.	Dorsal fusion plate or dorsal spanning plate, either with a local autograft, iliac crest autograft, allograft, a combination of both, or without a graft.	6 (15%)	19% patients underwent reoperation at a median of 6.9 months. The indications included symptomatic implants (27%), implant failures (20%), infections (17%), and nonunions (15%).	33% of the patients undergoing TWA experienced a postoperative complication and 19% of the patients underwent a reoperation. TWA of the dominant hand resulted in higher reoperation rates. The risk of a soft tissue complication after TWA was increased in smokers.

Table 2. Continued

Walker et al (24)	2021	9	The indications for fusion included posttraumatic arthritis in 7 and inflammatory arthritis in 2. Two patients underwent primary arthrodesis and 7 had revision from prior partial wrist fusions.	Locked IM wrist fusion. Local bone graft at the radiocarpal joint was used in all cases.	Radiocarpal fusion was achieved in 8 patients after the initial procedure and in the ninth patient after revision.	There were 6 complications in 4 patients with revision reoperation required in 3. The complications were metacarpal locking screw migration in 3, metacarpal fracture in 1, radiocarpal nonunion in 1, and symptomatic middle finger CMC nonunion in 1. The revision surgeries include distal screw removal in 1, distal screw removal with replacement in 1, and bone grafting in the radiocarpal nonunion.	Nine TWAs were performed with locked IM wrist fusion in 5 women and 4 men. Use of the locked IM wrist fusion system yields high fusion rates. However, based on the high complication rate, particularly from distal screw migration, and the high revision rate in this series, these authors recommended caution with the use of this system.
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LCP = Locking compression plate; CMC = Carpometacarpal joint; IM = Intramedullary; NA = Nonavailable

**TWA in the Setting of Post-traumatic Arthrosis**

The results of TWA as salvage for post-traumatic OA suggest that pain relief may not be as predictable as desired and may be improved but not eliminated. Of the 22 individuals with a median follow-up of 6 years, Adey et al. reported 64% persistent pain and 18% severe pain, while 68% reported being satisfied or very satisfied and 10%

were mildly dissatisfied.<sup>29</sup> Patients with segmental bone loss (radiocarpal and/or midcarpal) seem to have higher failure rates, and vascularized bone grafting has been recommended as a potential solution, particularly when there is severe associated soft tissue loss [Table 3].<sup>30</sup> summarizes the outcomes according to etiology.

Table 3. Results of total wrist arthrodesis (TWA) according to etiology

AUTHORS	YEAR	COMMENTS
<b>RHEUMATOID ARTHRITIS</b>		
Elherik et al (23)	2014	Tunnel Mannerfelt wrist fusion technique: All patients experienced an improvement in pain and functional capacity. All patients reported that they would undergo that procedure again if necessary; the vast majority was satisfied with the outcome of the surgery (93.7% very satisfied and 6.3% quite satisfied).
Taii et al (11)	2018	Wrist fusion with a standard locking metaphyseal plate was favorable. In fact, it provided reliable stability comparable to that of the specific wrist fusion plate.
Okabayasi et al (28)	2020	At 20 years after the operation, pain disappeared completely in all patients. Average grip strength increased in 16 wrists (80%) and decreased in 4 wrists (20%). TWA provided painless stability for 20 years or more.
<b>IDIOPATHIC DEGENERATIVE OSTEOARTHRITIS</b>		
Reigstad et al (1)	2019	These authors stated that TWA was a more complicated intervention than previously assumed. Many patients never got used to or accepted wrist stiffness. They also complained of substantial reduction in function and residual pain. These authors concluded that motion-sparing surgery should be offered prior to TWA
<b>POST-TRAUMATIC OSTEOARTHRITIS</b>		
Adey et al (29)	2005	Significant dysfunction was observed after TWA for post-traumatic osteoarthritis, both in the specific measurements for the upper extremities and in the general state of health. Overall, pain improved but did not disappear.
Kurlander et al (30)	2019	Case report: severe blast injury that resulted in significant bone and soft tissue damage to the right hand and wrist. An anterolateral thigh-medial femoral condyle chimeric flow-through flap and a concomitant wrist fusion in a single stage were performed. Except for a donor site seroma at the thigh, the patient's recovery was uneventful, with clinical and radiographic evidence of fusion at 9 weeks after the intervention.

**COMPLICATIONS AFTER TWA**

Reported complications include non-union, deep wound infection, neuroma, fracture of healed fusion, symptomatic hardware, and persistent pain.<sup>31,32</sup> Other minor complications include neurapraxias such as transient superficial radial nerve and median nerve paralysis, and soft tissue injury.<sup>31</sup> Regarding tendon injuries, the most common injury is to the extensor pollicis longus tendon due to its superficial anatomical location; besides, occasionally, the flexor tendons can also be injured.<sup>7</sup> Several circumstances can augment the risk of postoperative infection such as the age of the individual (the elderly population is at higher risk), immunocompromised individuals, individuals suffering from kidney disease or diabetes, and smoking individuals. The infection rate can be diminished by the utilization of prophylactic antibiotics preoperatively.<sup>33</sup> [Table 4] shows the most common complications of TWA.

**Table 4. Complications of total wrist arthrodesis (TWA)** <sup>7,31-33</sup>

Tendon rupture
Peri-implant fracture of the third metacarpal
Painful hardware
Nonunion
Deep wound infection
Neuroma
Fracture of healed fusion
Impingement of Steinmann pin in the metacarpophalangeal joint
Transient nerve paralysis
Superficial skin necrosis
Persistent pain
Plate breakage
Failure of fixation

**PREDICTIVE FACTORS FOR PATIENT OUTCOME**

Based on patient-reported outcomes, Owen et al. observed that polyarticular inflammatory arthritis and female gender are risk factors for poor outcomes after TWA.<sup>18</sup> In addition, workers' compensation involvement and non-inflammatory wrist pathology negatively influenced return to work. Interestingly, no difference in the rates of adverse events between inflammatory and non-inflammatory arthritis was observed.<sup>18</sup> Postoperative complications after TWA range from 30% to 60% and reoperation rate varies from 19%-64%.<sup>11,1,24,34</sup> TWA of the dominant hand leads to higher rates of reoperation. In the multivariable analysis, smoking was independently related to soft tissue complications after TWA.<sup>17</sup>

**TWA IN CHALLENGING CLINICAL SCENARIOS****TWA after Osteomyelitis**

Mattos et al have utilized the free medial femoral condyle (MFC) flap for difficult non-unions.<sup>35</sup> they reported 4 cases of radiocarpal bone loss due to osteomyelitis. In all four patients, complete consolidation was achieved. In addition, there were no recurrences of the infection, and the morbidity of the donor site was low.<sup>35</sup> All underwent debridement of nonviable tissues and 6 weeks of intravenous antibiotics, followed by MFC vascularized bone grafting. The flap was based on the horizontal periosteal branch of the descending geniculate artery and was used to bridge the osseous defects after resection.

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Three individuals achieved primary union, and one individual needed secondary cancellous bone grafting to reach union. One individual needed revision of the donor site closure. None of the individuals had a recurrence of infection or other adverse events in a mean follow-up of 8.5 months after reconstruction. The mean time to union was 11.5 weeks. Three individuals exhibited a full composite fist, and one individual had an incomplete finger range of motion after several flexors and extensor tendon grafts.<sup>35</sup>

**TWA with Large Bone Defects**

The overall rate of nonunion after wrist arthrodesis with PRC was 2.3% and without PRC was 3.8%, but the difference was not significant.<sup>36</sup> The nonunion rate rises to 17.5% with revision arthrodesis following failed arthroplasty.<sup>3</sup> Regarding bone grafting of a wrist fusion, Gulia et al. have reported that minor defects ( $\leq 6$  cm) can be reconstructed utilizing autologous iliac crest bone graft, which leads to good cosmetic appearance and functional result.<sup>37</sup> However, in massive distal radius defects, vascularized fibula graft (VFG) is considered.<sup>38</sup> They reported bone healing in all 11 patients in 5 months. The rate of adverse events was 27%, but no flap loss occurred. The mean VAS for pain was 2.3, which ameliorated substantially from the pre-operative score of 7.9.

**TWA after Failed Total Wrist Arthroplasty**

Converting a wrist arthroplasty to TWA after a failed wrist arthroplasty can be technically challenging for several reasons, including restoring the wrist height in large defects, attaining stable fixation, and accomplishing bony fusion. Several surgical procedures have been described, with variable degrees of success. Rizzo et al. reported the outcomes of 21 wrist implant arthroplasty (17 patients) converted to TWA.<sup>39</sup> In 13 wrists there was aseptic loosening, and the mean time from the arthroplasty to TWA was 7.6 years. Autograft and allograft bone graft was utilized in all of the wrists. Bone union was accomplished in 11 wrists, while the other ten wrists resulted in a nonunion. Six nonunions underwent eight revision surgeries with only two reaching union. The pain score of the wrists with the successful union and the nonunion group was 2.1 and 3.3, respectively. Similarly, in a cohort of 12 patients, Beer and Turner reported an elevated rate of adverse events, with 17 complications in 9 patients. The original arthroplasties consisted of eight silicone implants and four metal-plastic total wrist implants. In the surgical technique a tricortical iliac bone graft and an IM Steinmann pin were used. Five patients developed nonunion, with the most common site being at the graft-metacarpal junction.<sup>40</sup> Although nonunions were asymptomatic, it is recommended to use a more rigid fixation for TWA. Our preferred technique includes using a femoral head structural allograft and wrist arthrodesis plate, with or without supplemental demineralized bone matrix combined with corticocancellous allograft chips. This technique has been previously published by Adams et al., achieving successful fusion in 19 of the 20 wrists reported.<sup>41</sup>

**TWA Following Tumor Resection**

Giant cell tumors (GCT) are benign lesions, although locally aggressive. The distal radius is the third most frequent location for GCT.<sup>34, 42</sup> A wide variety of reconstructions have been described. Fibular arthroplasty (bloc resection and reconstruction with non-vascularized proximal fibular autografts) provides mobility to the wrist. However, it is associated with many complications, such as donor site morbidity and wrist pain. Wrist fusion with ulnar translocation renders a stable reconstruction, although cosmetically, it may be less appealing.<sup>43</sup> According to Barik et al., the main objective of treating GCTs of the distal radius is oncologically adequate resection with good functional result and cosmesis as being secondary. Reconstruction with a non-vascularized proximal fibular autograft is a sound alternative after en bloc resection of the distal radius for GCT of bone, having similar outcomes with other management options.<sup>44</sup> In a level IV evidence-based study published in 2020, Bianchi et al. compared two surgical techniques in 77 individuals who experienced distal radius GCT resection: osteoarticular graft reconstruction (47 patients) and wrist arthrodesis (20 patients).<sup>45</sup> At a mean follow-up of 105 months (range, 12-395 months), comparable functional result scores [MSTS (The Musculoskeletal Tumor Society) and DASH] were observed in both groups. In short, no advantage of one technique over the other was observed. Therefore, decisions should be made individually, both in terms of the type of reconstruction and the type of graft (allograft or autograft).<sup>45</sup>

**Wrist Fusion in Brachial Plexus Paralysis**

The prevalence of brachial plexus injuries has augmented over the years.<sup>46</sup> In global brachial plexus injuries and lower root injuries, wrist fusion is a viable option when wrist and hand function is lost. For example, when the patient preserves some residual functions of the hand, wrist fusion stabilizes the wrist, improving the function of the fingers. In this instance, wrist fusion can increase grip strength and power.<sup>47, 48</sup> Finally, it is perceived as more cosmetically pleasing when the wrist is held in slight extension.<sup>46</sup> The double-free muscle transfer technique allows restoration of some hand function in the complete brachial plexus injuries. To improve its outcomes, a stable wrist in neutral alignment is necessary; however, in cases of instability or inadequate muscle control, arthrodesis may be required.<sup>49</sup> Addosooki et al. analyzed the outcome of wrist arthrodesis in 18 individuals who underwent a double-free muscle transfer to define the effect of wrist stability on finger function.<sup>49</sup> Wrist arthrodesis after a double-free muscle transfer improved the ROM of the fingers and the general function of the hand in individuals with complete brachial plexus paralysis.<sup>49</sup>

**TWA in Cerebral Palsy**

According to Vergara-Amador and Franco-Chaparro, a well-intended TWA can improve function and cosmetic appearance in individuals with fixed flexion deformities. It is indicated in individuals over 12 years old with cerebral palsy and a fixed flexion deformity of the wrist.<sup>50</sup> Although the union rate (98%) and satisfaction (94%) are high in cerebral palsy, the complication and hardware removal

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rate is as common as the other indications for wrist arthrodesis.<sup>51</sup> Among patients with spastic deformity secondary to cerebral palsy, traumatic head injury, and cerebrovascular accident, a great improved appearance, hygiene, and a certain degree of upper extremity function, regardless of cognitive abilities, can be expected following arthrodesis.<sup>52</sup>

**Conclusion**

Total wrist arthrodesis (TWA) is a generally dependable salvage surgical technique for wrist pain due to end-stage osteoarthritis or other failed surgical interventions, but it is not exempt from complications. TWA is often carried out with a dorsal plate that extends from the distal radius to the third metacarpal. However, other surgical procedures have been reported to help address specific clinical scenarios and to avoid certain complications, such as IM fixation in individuals with rheumatoid arthritis or with tenuous soft tissue. New implants can spare the third carpometacarpal joint and provide satisfactory functional results similar to other fixation techniques while potentially minimizing hardware-related complications. Aside from potential complications, such as hardware failure, tendon ruptures, and peri-implant fractures, some patients may never grow accustomed to a non-mobile wrist and may continue to report reduced function and persistent pain. When possible, motion-sparing surgery should be offered before TWA. Although TWA can render foreseeable pain alleviation and ameliorated function, the orthopedic surgeon should be aware that this surgical technique is not without risk. In addition, the availability of various surgical options means that the orthopedic surgeon must contemplate the risks and benefits of each alternative for each individual patient. Smoking has been independently related to soft tissue adverse events after TWA. Smoking cessation is strongly advocated prior to offering TWA surgery.

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