Total Wrist Arthroplasty Versus Wrist Fusion in Rheumatoid Arthritis

Joseph G. Monir, MD[a], Thomas J. McQuillan, MD[b], Nina Suh, MD[c,*]

KEYWORDS

• Rheumatoid arthritis • Wrist fusion • Wrist arthroplasty • Wrist arthritis • Hand surgery

KEY POINTS

- Patients with rheumatoid arthritis who develop severe carpal arthritis and deformity may be treated surgically with either total wrist fusion (TWF) or total wrist arthroplasty (TWA).
- Although various TWF implants have been developed, dorsal fusion plates are currently the most commonly used.
- TWA implants continue to improve with each generation. The most commonly used are the fourth generation implants, with fifth generation implants currently under development.
- Complications in TWF primarily include failure of fusion, implant loosening, and soft tissue irritation. Complications in TWA primarily include loosening, dislocation, and concerns of long-term longevity.
- Both TWF and TWA have acceptable survivorship and are viable treatment options for patients with rheumatic wrist.

INTRODUCTION

Rheumatoid arthritis (RA) is a relatively common inflammatory arthropathy, with a worldwide prevalence estimated to be up to 10.7%.[1] Patients with RA suffer from a predictable pattern of arthritis characterized by destruction of multiple joints, including the small joints of the wrist and hand (**Fig. 1**). While the advent of disease-modifying antirheumatic drugs (DMARDs) and biologic agents has markedly reduced the number of patients progressing to end-stage arthritis, hand surgeons still routinely treat patients affected by this condition.[2]

Total wrist fusion (TWF) and total wrist arthroplasty (TWA) are the mainstays of treatment for patients with end-stage pancarpal arthritis secondary to RA. Although both procedures ultimately aim to reduce disability and improve upper extremity function, TWF and TWA each convey specific benefits and drawbacks. Additionally, various surgical techniques and implants exist for TWF and TWA. Given a variety of patient-specific factors and evolving implant technology, controversy continues to exist regarding the most optimal treatment.

Faced with multiple surgical options and a paucity of conclusive data, surgeons unaccustomed to treating wrists with pancarpal RA may find treating these patients challenging. Therefore, the authors aim to consolidate and summarize the current state of the literature regarding TWF and TWA in patients with RA.

PRINCIPLES OF TREATMENT

The technical objective of TWF is to achieve a stable arthrodesis across the radiocarpal, midcarpal,

[a] Department of Orthopaedic Surgery, Orlando Health, Orlando, FL 32809, USA; [b] Department of Orthopaedics, University of Kansas, 4000 Cambridge Street, Kansas City, KS 66160, USA; [c] Department of Orthopaedic Surgery, Division of Hand & Upper Extremity, Emory University School of Medicine, 21 Ortho Lane, Atlanta, GA 30329, USA
* Corresponding author.
E-mail address: nina.suh@emory.edu

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Fig. 1. (*A*, *B*) Preoperative radiographs of end-stage wrist arthritis secondary to RA.

and carpometacarpal joints. The term pancarpal arthrodesis is used interchangeably throughout the literature. TWF necessarily eliminates all motion of the wrist, allowing the surgeon to correct the pre-existing deformity and optimally position the hand relative to the forearm. Additionally, fusion of the arthritic surfaces is intended to eliminate the associated pain of the arthritic joint surfaces.

TWA, in contrast, was developed as a motion-preserving alternative to TWF. Similar to TWF, modern TWA implants allow for deformity correction, improved hand position, and pain reduction via resection of the arthritic radiocarpal and midcarpal joints. The radiocarpal joint is then reconstructed using, most commonly, a metal-on-polyethylene bearing interface. The wrist flexor and extensor insertions are preserved, allowing for active wrist motion postoperatively.

INDICATIONS AND CONTRAINDICATIONS

RA remains the most common indication for TWF and TWA, although their use for other pathologies continues to expand.[3] This article will focus on their use in RA. TWF and TWA share most surgical indications. These procedures are generally indicated in patients with end-stage pancarpal arthritis, deformity that severely limits use of the hands and fingers for activities of daily living (ADLs), or severe pain recalcitrant to nonoperative treatment.

TWF is thought to be a more durable treatment option than TWA, so it is preferentially indicated when the patient has higher functional demands or younger age. TWA is optimally indicated in patients who are older and have lower functional demands. TWA additionally requires sufficiently normal neuromuscular control. Patients with neuromuscular deficits, such as those who have had a stroke, brachial plexus injury, cerebral palsy, or other similar condition would be contraindicated for TWA and would generally be better served with a TWF.

Osteomyelitis has historically been a contraindication to TWF and TWA. Placing implants in the setting of infection leads to biofilm formation, which significantly reduces the chances of successful infection eradication.[4] Mattos and colleagues[5] recently described a series of 4 patients who underwent successful TWF in the setting of osteomyelitis. All 4 of their patients were initially treated with intravenous antibiotics, had nonviable bone debrided, and subsequently underwent successful fusion using a medial femoral condyle (MFC) vascularized bone graft to reconstruct the bone loss resulting from debridement. Although this technique is not commonly performed, their results demonstrate that successful fusion may be possible in the setting of treated osteomyelitis. Active osteomyelitis remains a contraindication to TWA.

Relative contraindications include uncontrolled comorbid conditions that increase the risk of postoperative complications after TWF or TWA. Althoff and colleagues[6] identified smoking, diabetes, depression, and chronic kidney disease (CKD) as risk factors for infection. The former three are modifiable, and the authors recommend preoperative optimization of these conditions. Additionally, TWF and TWA require adequate bone stock.

TWA may not be feasible in the setting of massive bone loss or resection. TWF using a vascularized fibula has been described for use in such cases.[7,8]

IMPLANT OPTIONS

Total Wrist Fusion

Various implants are currently available for TWF. Historic options including Steinmann pins, Rush pins, and staples were used with early success but have been supplanted by more modern implant choices.[9,10]

Precontoured dorsal plates are currently the most commonly used implant for TWF (**Fig. 2**). These plates are manufactured by multiple vendors and generally use locking and nonlocking screws. RA can lead to marked osteoporosis,[11] so having the option for locking screws improves fixation when necessary. These plates are generally precontoured to approximately 10° to 15° of wrist extension, allowing surgeons to use the plate as a template for ideal intraoperative wrist positioning. Modern dorsal plates are designed to be more low-profile than their predecessors, in an effort to minimize the well-documented complications of extensor tendon irritation and attritional rupture.[12,13] These plates are affixed proximally into the radius. Distal fixation is most commonly performed to the third metacarpal, although plates designed for fixation into the second metacarpal are available.

Intramedullary constructs for wrist fusion were first described using pins.[14,15] More recently, dedicated locked intramedullary wrist fusion nails have been developed. The proposed benefit of these TWF nails is decreased soft tissue complications. Orbay and colleagues[16] published an early study examining short-term outcomes of 7 wrists that underwent fusion with the IMPLATE (Skeletal Dynamics, Miami, Florida) wrist fusion nail and found a 100% rate of fusion with no complications. However, these promising initial results have not been replicated by subsequent studies, and currently no long-term outcomes data exist on these implants.

Samade and colleagues[17] examined 38 wrists that underwent TWF using the same implant and found a 74% rate of successful bony fusion, a 55% rate of implant-related complications, and 13% rate of reoperation. Most of these complications involved the distal (metacarpal) portion of the implant. Walker and colleagues[18] examined 9 cases of TWF with an intramedullary nail and found successful fusion in 89% after the first surgery, with successful fusion in the final patient after 1 revision for bone grafting. However, they noted 6 complications and 3 patients who required reoperation (33%). The most common complication was migration of the metacarpal locking screw, which occurred in 3 patients (33%). Similarly, Kachooei and colleagues[19] described a series of 3 patients who suffered implant failure secondary to migration of the metacarpal locking screws. In summary, short-term data appear to demonstrate acceptable rates of bony fusion, although with a high rate of postoperative complications. Further implant and technique refinement supported by long-term data comparing these implants to dorsal fusion plates will be required before widespread adoption is recommended.

Total Wrist Arthroplasty

TWA implants have undergone multiple iterations since their advent in the late 19th century, with each generation of implants aiming to solve the

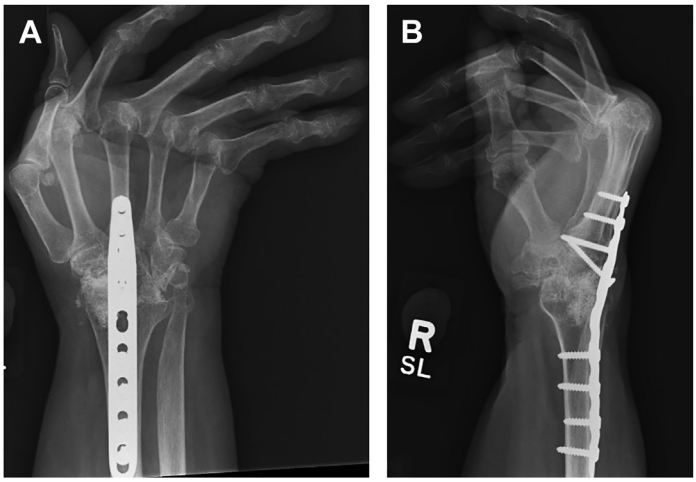

Fig. 2. (*A*, *B*) Postoperative radiographs of the same patient as **Fig. 1** demonstrating TWF with a dorsal fusion plate. Note the restoration of neutral coronal alignment and slight wrist extension, a position that optimizes hand function.

problems of its predecessors.[20] Multiple authors have discussed the history of these implants in detail, describing their progression from silicone spacers, to ball-and-socket designs, to cemented partially constrained implants, to the modern uncemented, bone-preserving, more anatomic prostheses.[21,22]

The most commonly used implants today are the fourth generation TWA systems (**Fig. 3**). These implants require a smaller radial resection and rely on bony ingrowth instead of cementation. These design choices were made to minimize bone destruction and implant loosening, which were common modes of failure for third generation cemented TWAs.[23] Stability is improved compared with prior implants, owing to an updated ellipsoidal articular geometry.[24]

Several fourth generation TWA systems allow for distal radius hemiarthroplasty also. Although outcomes of hemiarthroplasty have not been specifically evaluated in patients with RA, early studies raise concerns regarding high complication rates and do not recommend routine use of hemiarthroplasty.[25–28]

New implants, dubbed fifth generation, continue to be developed and tested.[29–31] These implants are iterative improvements of their predecessors. They promise to be more bone preserving, cause less soft tissue irritation, and offer more natural wrist kinematics. These implants are relatively new and have yet to gain clinical popularity. As more fifth generation implants come to market, further outcomes data will be needed before widespread adoption.

SURGICAL CONSIDERATIONS (PEARLS AND PITFALLS)

TWA and TWF in the setting of RA present multiple other treatment considerations. With respect to TWA, because of limited bone stock or quality, cemented prostheses remain the standard for treatment in the United States; however, some surgeons opt for an uncemented impaction grafting technique to preserve bone stock and facilitate osseous union.[32]

In TWF, a proximal row carpectomy may be performed if there is severe pre-existing bony deformity. This improves deformity correction in the face of chronically contracted soft tissues and also provides a source of autograft. Allograft may also be used to augment the bony fusion. The necessity of bone grafting in TWF has not been systematically evaluated, although literature from lower extremity fusions generally demonstrates that bone grafting may not improve fusion rates in uncomplicated primary fusions.[33] Further studies focused on the impact of bone grafting in TWF are needed. Vascularized and nonvascularized bone grafts have been described to further improve union in cases of bone loss in TWF.[5,8,14]

In TWA and TWF, a Darrach procedure may be considered for several indications. It can be particularly beneficial in cases symptomatic distal radioulnar joint (DRUJ) arthritis, severe deformity, or attritional extensor tendon ruptures.[12,34] Most authors prefer splint or cast immobilization after TWA for 2 to 4 weeks followed by a removable orthosis while working with hand therapy; longer periods of immobilization are typically indicated for TWF.[10,12,18,32,35–37]

SURVIVORSHIP AND PATIENT-REPORTED OUTCOMES

Survivorship, patient-reported outcomes, and patient satisfaction are essential metrics to evaluate the efficacy of these treatment modalities. A review of the literature demonstrates a strong historical track record of TWF, although emerging

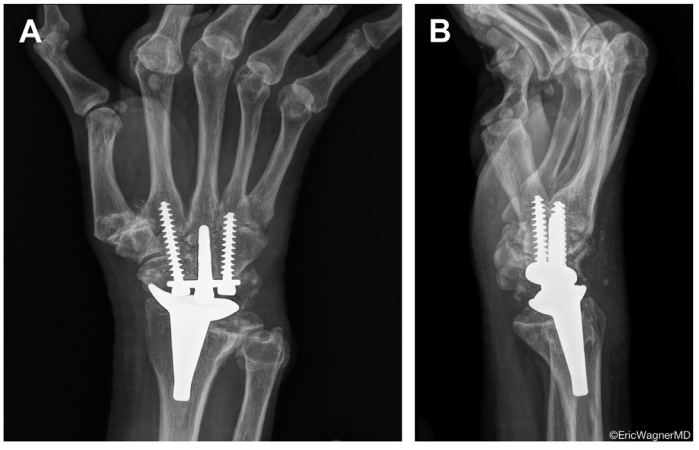

Fig. 3. (*A*, *B*) Postoperative radiographs of a TWA performed in a patient with RA. (Image courtesy of Eric Wagner, MD.)

techniques and fifth generation of TWA implants have demonstrated improved outcomes in the short and medium term.[32,37] It is therefore essential to consider the literature regarding survivorship and outcomes in terms of modern implants and techniques, particularly in the case of TWA.[21,38]

There is a heterogeneous group of outcome measures used in evaluating TWF in patients with RA, with some large series not using validated patient-reported outcomes.[3,39]

Satisfaction remains similar between the 2 procedures, ranging between 80% to 90% for TWF and TWA.[35,39–41] A recent systematic review by Zhu and colleagues[36] of TWA versus TWF in rheumatoid patients performed a meta-analysis of increase in grip strength after surgery with the contralateral side as a reference, finding higher strength in fusion patients of 76% compared with 31% for TWA. This same meta-analysis found overall increased wrist motion in the arthroplasty group with an acceptable arc of motion, with 47° flexion and extension, 18° radial/ulnar deviation, and 126° of pronosupination.

Survivorship and complication rates of TWA have improved with the development of newer generation implants.[42] An earlier review of the Universal prosthesis (Integra LifeSciences, Plainsboro, New Jersey) demonstrated a 45% complication rate over an average of 7.3 years follow-up.[43] Medium-term outcomes of the Universal 2 prosthesis at an average of 53 months demonstrated an improvement of QuickDASH from 61 to 46 and a 7% major complication rate; the authors recommended continued use of the prosthesis in the rheumatoid patient population.[44]

A systematic review in 2021 demonstrated much improved survivorship of later generation implants. The Universal 2 had survivorship of higher than 92% at 5 years, which declined to 78% at 15 years follow up, and the Motec (Swemac Orthopedics AB, Linköping, Sweden) demonstrated a 10-year survival of 86%.[37] One study using a nationwide inpatient sample demonstrated comparable rates of short-term complications from 2001 to 2010.[45]

COMPLICATIONS

It is pertinent to consider the relevant complication profile particular to each procedure. The most common complications after TWF are carpal tunnel syndrome and prosthetic loosening, followed by tendon irritation and adhesions, infection, and nonunion.[36] With respect to TWA, dislocation and loosening remain the most common complications. Radiographic loosening may or may not be correlated to clinical loosing. It is important to separate short-term loosening that may be caused by infection or technical error from long-term loosening that may be related to the survivorship of the implant.

The nature of the total wrist implant also plays an important factor; a recent meta-analysis using third and fourth generation total wrist implants was found to have a lower complication rate (11%) compared with the previously reported 30% complication rate in a 2008 study by Cavaliere and Chung.[36,39] Despite the high complication rate noted in the 2008 study, a minority of these complications (5% total) went on to explantation of the implant. Data on reoperation requiring implant removal were not assessed in the more recent meta-analysis, and it is unknown whether newer generation implants resulted a lower rate of complete implant removal in the follow-up period.[36]

LIMITATIONS OF CURRENT LITERATURE

In their systematic review of TWF and TWA, Berber and colleagues[3] found the vast majority of the literature to be of low to very low methodological quality, although a minority of published studies did meet the criteria for moderate quality. The literature is currently lacking a high-quality, prospective, randomized trial comparing TWF and TWA in patients with RA. Additionally, there is a paucity of high-quality long-term data evaluating newer implants, such as the fifth generation TWA implant and the locked intramedullary TWF nail. Further studies in these areas are needed.

CLINICS CARE POINTS

- Appropriate medical management of RA should be instituted prior to surgical intervention.
- Patients with Rheumatoid Arthritis have shown historically improved survivorship and patient-reported outcomes with TWF but newer generations of TWA are showing significant promise.
- Bone stock, functional activity levels, and medical comorbidities should be considered prior to embarking on TWA or TWF.

DISCLOSURE

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REFERENCES

1. Alamanos Y, Voulgari PV, Drosos AA. Incidence and prevalence of rheumatoid arthritis, based on the 1987 American College of Rheumatology criteria: a systematic review. Semin Arthritis Rheum 2006;36(3):182–8. https://doi.org/10.1016/j.semarthrit.2006.08.006.
2. Callhoff J, Weiß A, Zink A, et al. Impact of biologic therapy on functional status in patients with rheumatoid arthritis–a meta-analysis. Rheumatology 2013;52(12): 2127–35. https://doi.org/10.1093/rheumatology/ket266.
3. Berber O, Garagnani L, Gidwani S. Systematic review of total wrist arthroplasty and arthrodesis in wrist arthritis. J Wrist Surg 2018;7(5):424–40. https://doi.org/10.1055/s-0038-1646956.
4. Veerachamy S, Yarlagadda T, Manivasagam G, et al. Bacterial adherence and biofilm formation on medical implants: a review. Proc Inst Mech Eng H 2014; 228(10):1083–99. https://doi.org/10.1177/0954411914556137.
5. Mattos D, Ko JH, Iorio ML. Wrist arthrodesis with the medial femoral condyle flap: Outcomes of vascularized bone grafting for osteomyelitis. Microsurgery 2019;39(1):32–8. https://doi.org/10.1002/micr.30368.
6. Althoff AD, Reeves RA, Traven SA, et al. Risk factors for infection following total wrist arthroplasty and arthrodesis: an analysis of 6641 patients. Hand (N Y) 2021;16(5):657–63. https://doi.org/10.1177/1558944719890036.
7. Lehner B, Jung M, von Stillfried F. [Total wrist fusion with vascularized fibula graft after tumor resection of the distal radius]. Operat Orthop Traumatol 2012;24(3): 186–95. https://doi.org/10.1007/s00064-011-0102-2.
8. Muramatsu K, Ihara K, Azuma E, et al. Free vascularized fibula grafting for reconstruction of the wrist following wide tumor excision. Microsurgery 2005; 25(2):101–6. https://doi.org/10.1002/micr.20088.
9. Clayton ML. Surgical treatment at the wrist in rheumatoid arthritis: a review of thirty-seven patients. J Bone Joint Surg Am 1965;47:741–50.
10. Mannerfelt L, Malmsten M. Arthrodesis of the wrist in rheumatoid arthritis. A technique without external fixation. Scand J Plast Reconstr Surg 1971;5(2):124–30. https://doi.org/10.3109/02844317109042952.
11. Adami G, Saag KG. Osteoporosis pathophysiology, epidemiology, and screening in rheumatoid arthritis. Curr Rheumatol Rep 2019;21(7):34. https://doi.org/10.1007/s11926-019-0836-7.
12. Hastings H, Weiss AP, Quenzer D, et al. Arthrodesis of the wrist for post-traumatic disorders. J Bone Joint Surg Am 1996;78(6):897–902. https://doi.org/10.2106/00004623-199606000-00013.
13. Rozental TD, Beredjiklian PK, Bozentka DJ. Functional outcome and complications following two types of dorsal plating for unstable fractures of the distal part of the radius. J Bone Joint Surg Am 2003;85(10):1956–60. https://doi.org/10.2106/00004623-200310000-00014.
14. Lee DH, Carroll RE. Wrist arthrodesis: a combined intramedullary pin and autogenous iliac crest bone graft technique. J Hand Surg Am 1994;19(5):733–40. https://doi.org/10.1016/0363-5023(94)90176-7.
15. Viegas SF, Rimoldi R, Patterson R. Modified technique of intramedullary fixation for wrist arthrodesis. J Hand Surg Am 1989;14(4):618–23. https://doi.org/10.1016/0363-5023(89)90177-9.
16. Orbay JL, Feliciano E, Orbay C. Locked intramedullary total wrist arthrodesis. J Wrist Surg 2012;1(2): 179–84. https://doi.org/10.1055/s-0032-1329630.
17. Samade R, Campbell AB, Awan HM, et al. Total wrist fusion with an intramedullary device: a single-institution series with a minimum of one year follow-up. J Wrist Surg 2022;11(5):395–405. https://doi.org/10.1055/s-0041-1740404.
18. Walker MR, Hoben GM, Best CM, et al. Early experience with locked intramedullary wrist arthrodesis. J Hand Surg Am 2021;46(7):620.e1–6. https://doi.org/10.1016/j.jhsa.2020.11.015.
19. Kachooei AR, Jones CM, Beredjiklian P. Locked intramedullary total wrist arthrodesis: a report of three patients with distal screw migration. Cureus 2022; 14(7):e27420. https://doi.org/10.7759/cureus.27420.
20. Ritt MJPF, Stuart PR, Naggar L, et al. The early history of arthroplasty of the wrist from amputation to total wrist implant. J Hand Surg 1994;19(6):778–82. https://doi.org/10.1016/0266-7681(94)90257-7.
21. Weiss APC, Kamal RN, Shultz P. Total wrist arthroplasty. J Am Acad Orthop Surg 2013;21(3):140–8. https://doi.org/10.5435/JAAOS-21-03-140.
22. Rosenfeld JF, Nicholson JJ. History and design considerations for arthroplasty around the wrist. Hand Clin 2013;29(1):1–13. https://doi.org/10.1016/j.hcl.2012.08.017.
23. Rizzo M, Beckenbaugh RD. Results of biaxial total wrist arthroplasty with a modified (long) metacarpal stem. J Hand Surg Am 2003;28(4):577–84. https://doi.org/10.1016/s0363-5023(03)00204-1.
24. Grosland NM, Rogge RD, Adams BD. Influence of articular geometry on prosthetic wrist stability. Clin Orthop Relat Res 2004;421:134–42. https://doi.org/10.1097/01.blo.0000126304.79828.2c.
25. Culp RW, Bachoura A, Gelman SE, et al. Proximal row carpectomy combined with wrist hemiarthroplasty. J Wrist Surg 2012;01(1):39–46. https://doi.org/10.1055/s-0032-1323643.
26. Huish EG, Lum Z, Bamberger HB, et al. Failure of wrist hemiarthroplasty. Hand (N Y) 2017;12(4): 369–75. https://doi.org/10.1177/1558944716668836.
27. Gaspar MP, Lou J, Kane PM, et al. Complications following partial and total wrist arthroplasty: a single-center retrospective review. J Hand Surg 2016;41(1):47–53.e4. https://doi.org/10.1016/j.jhsa.2015.10.021.

28. Reiser D, Sagerfors M, Wretenberg P, et al. Clinical, radiographic, and patient-perceived outcome after radial hemi-wrist arthroplasty with a new implant: 20 cases with 5-year follow-up. Hand (N Y) 2023. https://doi.org/10.1177/15589447231151427. 15589447231151427.
29. Walker R, Reynolds J, Evans P. Total wrist arthroplasty. Operat Tech Orthop. 2022;32(1):100948. https://doi.org/10.1016/j.oto.2022.100948.
30. Matsui Y, Minami A, Kondo M, et al. A minimum 5-year longitudinal study of a new total wrist arthroplasty in patients with rheumatoid arthritis. J Hand Surg Am 2020;45(3):255.e1–7. https://doi.org/10.1016/j.jhsa.2019.06.011.
31. Herzberg G. Prospective study of a new total wrist arthroplasty: short term results. Chir Main 2011;30(1):20–5. https://doi.org/10.1016/j.main.2011.01.017.
32. Gil JA, Kamal RN, Cone E, et al. High survivorship and few complications with cementless total wrist arthroplasty at a mean follow-up of 9 years. Clin Orthop Relat Res 2017;475(12):3082–7. https://doi.org/10.1007/s11999-017-5445-z.
33. Heifner JJ, Monir JG, Reb CW. Impact of bone graft on fusion rates in primary open ankle arthrodesis fixated with cannulated screws: a systematic review. J Foot Ankle Surg 2021;60(4):802–6. https://doi.org/10.1053/j.jfas.2021.02.006.
34. Grawe B, Heincelman C, Stern P. Functional results of the Darrach procedure: a long-term outcome study. J Hand Surg Am 2012;37(12):2475–80. https://doi.org/10.1016/j.jhsa.2012.08.044. e1-2.
35. Rauhaniemi J, Tiusanen H, Sipola E. Total wrist fusion: a study of 115 patients. J Hand Surg Br 2005;30(2):217–9. https://doi.org/10.1016/j.jhsb.2004.11.008.
36. Zhu XM, Perera E, Gohal C, et al. A systematic review of outcomes of wrist arthrodesis and wrist arthroplasty in patients with rheumatoid arthritis. J Hand Surg Eur 2021;46(3):297–303. https://doi.org/10.1177/1753193420953683.
37. Zijlker HJA, Ritt MJPF, Beumer A. Fourth-generation total wrist arthroplasty: a systematic review of clinical outcomes. J Wrist Surg 2021;11(5):456–64. https://doi.org/10.1055/s-0041-1735840.
38. Akhbari B, Shah KN, Morton AM, et al. Total wrist arthroplasty alignment and its potential association with clinical outcomes. J Wrist Surg 2021;10(4):308–15. https://doi.org/10.1055/s-0041-1725172.
39. Cavaliere CM, Chung KC. A systematic review of total wrist arthroplasty compared with total wrist arthrodesis for rheumatoid arthritis. Plast Reconstr Surg 2008;122(3):813–25. https://doi.org/10.1097/PRS.0b013e318180ece3.
40. Onuma K, Shintani R, Fujimaki H, et al. Total wrist arthrodesis with wrist fusion rod in patients with rheumatoid arthritis. Eklem Hastalik Cerrahisi 2015;26(1):41–8. https://doi.org/10.5606/ehc.2015.10.
41. Toma CD, Machacek P, Bitzan P, et al. Fusion of the wrist in rheumatoid arthritis: a clinical and functional evaluation of two surgical techniques. J Bone Joint Surg Br 2007;89(12):1620–6. https://doi.org/10.1302/0301-620X.89B12.18880.
42. Kennedy CD, Huang JI. Prosthetic design in total wrist arthroplasty. Orthop Clin North Am 2016;47(1):207–18. https://doi.org/10.1016/j.ocl.2015.08.018.
43. Ward CM, Kuhl T, Adams BD. Five to ten-year outcomes of the Universal total wrist arthroplasty in patients with rheumatoid arthritis. J Bone Joint Surg Am 2011;93(10):914–9. https://doi.org/10.2106/JBJS.H.01614.
44. Badge R, Kailash K, Dickson DR, et al. Medium-term outcomes of the Universal-2 total wrist arthroplasty in patients with rheumatoid arthritis. Bone Joint Lett J 2016;98-B(12):1642–7. https://doi.org/10.1302/0301-620X.98B12.37121.
45. Melamed E, Marascalchi B, Hinds RM, et al. Trends in the utilization of total wrist arthroplasty versus wrist fusion for treatment of advanced wrist arthritis. J Wrist Surg 2016;5(3):211–6.