SCIENTIFIC ARTICLE

Four-Year Outcomes of Midcarpal Hemiarthroplasty for Wrist Arthritis

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Purpose The purpose of this study was to review the average 4-year outcomes of a cohort of patients with wrist arthritis, treated by a single surgeon with a novel prosthetic hemiarthroplasty of the midcarpal joint. We hypothesized that midcarpal hemiarthroplasty would improve range of motion and grip strength of patients with wrist arthritis, with a complication profile comparable with that of alternative solutions for wrist arthritis.

Methods We reviewed a series of 20 patients treated with a midcarpal hemiarthroplasty at an average of 4 years following surgery. Patients were evaluated objectively with grip strength, wrist range of motion, serial radiographs, and subjectively surveyed with Disabilities of the Arm, Shoulder, and Hand (DASH) and Mayo scores.

Results Range of motion increased by a mean 33° in flexion-extension and 10° in radial-ulnar deviation compared with preoperative range of motion. Mean grip strength improved to 20.8 kg from 14.1 kg, and Mayo and DASH scores also significantly improved. Three patients had a manipulation under anesthesia for stiffness. One patient required open reduction internal fixation of an unstable fourth carpometacarpal joint after falling. Two patients were revised to a total wrist arthroplasty and 1 to a wrist fusion.

Conclusions Midcarpal hemiarthroplasty provides improved wrist range of motion, grip strength, and patient-reported outcome scores compared with preoperative values, with a complication profile comparable with that of other surgical options for patients with wrist arthritis. Advantages of midcarpal arthroplasty include retention of the native distal carpal row, preservation of midcarpal motion, as well as the option for conversion to a total wrist arthroplasty should revision be required. *(J Hand Surg Am. 2017;■(■):1.e1-e10. Copyright © 2017 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Therapeutic IV.

Key words Arthritis, SLAC, wrist arthroplasty, midcarpal joint, wrist.

Online Exclusive

PAINFUL WRIST ARTHRITIS MAY ARISE from trauma, scapholunate instability, scaphoid nonunion, Kienböck disease, and inflammatory or crystalline arthropathy.[1–3] The goal of treatment is a pain-free, durable, and stable joint that can bear load while preserving wrist motion and function. Denervation of the wrist is a simple way to relieve pain, but it does not improve range of motion (ROM) or

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prevent further deterioration.[4–7] Partial or complete wrist arthrodesis brings predictable improvement in pain, but it does not increase mobility compared with the preoperative state.[6–12] Proximal row carpectomy (PRC) is a viable option when the lunate facet is preserved, but it may be associated with progressive degenerative arthritis.[13–18] Both partial arthrodesis and PRC demonstrate deterioration of both wrist kinematics and performance compared with normal wrists.[19] Total wrist arthroplasty provides pain relief but not improved ROM and has a risk of distal component failure[20–23] and osteolysis.[24,25]

Failure of total wrist arthroplasty may be partly related to incomplete understanding of wrist kinematics. Clinical and basic research over the past decade has identified the importance of "coupled"[26] or composite motions of wrist flexion-extension and radioulnar deviation, best exemplified by the "dart-throwers motion" of the wrist.[27–29] This motion, from radial-extension to ulnar-flexion, occurs almost exclusively at the midcarpal joint.[27,30] It plays an important role in many high-demand activities of daily living.[29–33]

Studies of upper and lower extremity arthroplasty have demonstrated that prosthetic loosening is associated with failure to replicate normal joint kinematics.[34–37] In conventional total wrist arthroplasty, the midcarpal joint has been essentially eliminated, focusing instead on replacing the radiocarpal articular surface with a biaxial or ellipsoid shape. Electrogoniometric analysis of wrist motion following total wrist arthroplasty demonstrates a marked reduction of the circumduction arc and an alteration in the major axis of motion to a predominantly flexion-extension plane rather than the oblique dart-throwers plane of normal wrists.[38] Removal of the midcarpal joint may increase demands on the prosthetic articulation and bone-prosthetic interface during daily and occupational activities.[19,35–37,39] A proximal shift of the prosthetic wrist's center of rotation increases the moment arm on the distal component and may contribute to distal component failure.[40–44] We reasoned that preservation of the midcarpal joint in wrist arthroplasty would simultaneously increase coupled wrist motion and decrease component stress.

The growing evidence on wrist kinematics provided the impetus to design a midcarpal arthroplasty that would preserve the wrist's center of rotation, carpal height, the midcarpal joint, and the important dart-thrower's motion. The KinematX midcarpal hemiarthroplasty (Extremity Medical, LLC, Parsippany, NJ) (Fig. 1) replaces the proximal carpal row and removes the arthritic radiocarpal joint while preserving the native distal carpal row and midcarpal joint. Initial outcomes of the first 9 cases showed promising results.[45] The purpose of this study is to report the average 4-year outcomes of the first 20 patients with wrist arthritis treated with a midcarpal hemiarthroplasty. We hypothesized that midcarpal hemiarthroplasty would improve ROM, grip strength, and outcome scores of patients with wrist arthritis, with a complication profile comparable with those of alternative solutions for wrist arthritis.

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FIGURE 1: The KinematX midcarpal hemiarthroplasty.

KinematX Midcarpal Hemiarthroplasty is Conformité Européene-approved in Europe. Wrist hemiarthroplasty is not currently U.S. Food and Drug Administration–approved.

MATERIALS AND METHODS

After institutional review board approval by the Hospital's Medical Advisory Committee and the National Institute, 20 patients were recruited into a prospective, single-surgeon trial of midcarpal hemiarthroplasty between October 2011 and May 2013. Eleven patients were men and 9 patients were women (Table 1). The mean age was 51 years (range, 23–74

TABLE 1. Demographic Data

Patient	Age (y)	Sex	Side	Diagnosis	Previous Surgery	Occupation	Prior Medical History
1	41	M	R*	SLAC	Radial styloidectomy	Broker	None
2	37	F	R*	Rheumatoid arthritis	Lunotriquetral fusion	Secretary	DRUJ/neck/ shoulder inflammation
3	74	M	L*	OA	None	Retired	Warfarin
4	46	F	L	SNAC	None	Secretary	Smoker
5	46	M	R*	SLAC	None	Director	None
6	34	F	L	OA	DRUJ replacement.	Student	Scheker
7	48	F	R*	Kienböck	None	Retailer	None
8	23	F	L	Psoriatic arthropathy	None	Nurse	Psoriasis
9	70	F	R*	OA	None	Retired	None
10	62	M	L	SLAC	None	Retired	COPD
11	46	M	R	SNAC	None	Bricklayer	None
12	57	M	R*	SLAC	None	Retailer	None
13	45	M	R*	OA	Brunelli	Banker	None
14	62	M	L*	SLAC	None	Retired	None
15	32	M	R	OA	Wrist fracture Wrist denervation	Retailer	None
16	55	M	R*	SLAC	None	Office worker	None
17	51	F	R*	SLAC	None	Retired	Angina Pectoris
18	57	F	L	SLAC	Bone graft for scaphoid nonunion	Retired	None
19	71	F	R*	Psoriatic arthropathy	None	Retired	Psoriasis
20	54	M	R*	SLAC	None	Office worker	None

COPD, chronic obstructive pulmonary disease; DRUJ, distal radioulnar joint.
*Dominant hand.

years). Thirteen of the 20 patients had the surgery on their dominant wrist.

The diagnoses were scapholunate advanced collapse (SLAC) wrist (9 wrists), noninflammatory osteoarthritis (OA; 5), scaphoid nonunion advanced collapse (SNAC) wrist (2), psoriatic arthritis (2), rheumatoid arthritis (1), and Kienböck disease (1). All patients had failed nonsurgical treatment including orthosis wear, hand therapy, and steroid injection prior to surgery. All had pain, limited ROM, and substantial impairment of functional activities as demonstrated by a mean Mayo score of 34.1 and mean Disabilities of the Arm, Shoulder, and Hand (DASH) score of 50.3 (Table 2). All patients underwent wrist arthroscopy prior to surgery and were excluded if there was exposed bone on the articular surface of the capitate. Absolute contraindications to the procedure included recent or remote infection, previous surgical fusion, or lack of active wrist extension.

Surgical technique

The procedure is performed with the patient supine with the operative limb on an arm board and with tourniquet control. A dorsal 4- to 5-cm longitudinal incision is made just ulnar to Lister's tubercle, in line with the fourth extensor compartment. Full-thickness skin flaps are raised, elevating sensory nerve branches within the flaps. The extensor retinaculum is divided and the fourth compartment tendons are retracted ulnarly. The capsule is opened through a proximally based rectangular dorsal flap,[46] which allows preservation of the posterior interosseous nerve (PIN) if desired. The longitudinal arms of the proximally based flap underlie the second and fifth dorsal compartments, and the transverse arm is

TABLE 2. Preoperative and Postoperative (Latest Follow-Up in Parenthesis) Range of Motion and Functional Scores

Patient	F/E (°)	R/U (°)	Grip (kg)	Mayo	DASH	Follow-Up (mo)
1	60 (130)	30 (45)	20 (34)	50 (90)	43.2 (0)	62
2*	42 (60)	10 (15)	0 (7)	10 (5)	61.4 (65.9)	64
3	70 (130)	10 (15)	20 (20)	15 (75)	59.1 (18.2)	63
4†‡	45 (50)	5 (15)	12 (19)	50 (65)	29.5 (18.2)	35
5	70 (63)	10 (15)	35 (37)	60 (60)	34.2 (4.5)	59
6	55 (90)	20 (20)	10 (8)	10 (65)	70.5 (12.5)	59
7	52 (85)	10 (35)	10 (17)	45 (60)	22.7 (15.9)	59
8*†	40 (36)	5 (6)	6 (7)	35 (30)	61.4 (63.6)	52
9§	110 (100)	30 (35)	0 (6)	50 (50)	61.4 (31.8)	43
10	70 (110)	58 (64)	4 (22)	10 (50)	52.3 (2.3)	56
11	10 (75)	0 (24)	40 (40)	10 (80)	84.5 (15)	50
12‖	60 (104)	30 (54)	12 (18)	32 (75)	55.2 (11.4)	28
13†	80 (126)	35 (35)	38 (24)	60 (75)	34.1 (15.9)	42
14	50 (106)	30 (24)	8 (40)	10 (70)	52.3 (29.5)	51
15‡	35 (65)	15 (30)	11 (13)	25 (65)	43.1 (22.5)	44
16	53 (130)	31 (46)	8 (20)	50 (75)	32.5 (11.4)	45
17	118 (126)	35 (40)	13 (22)	45 (70)	51.6 (50)	41
18	60 (90)	20 (40)	11 (15)	30 (35)	45.5 (61.4)	39
19*	74 (113)	34 (47)	4 (14.5)	25 (60)	81.8 (40.9)	39
20	105 (130)	35 (42)	20 (33)	60 (90)	29.5 (0)	39
Mean, All Patients	**63 (96)¶**	**22.7 (32.4)¶**	**14.1 (20.8)¶**	**34.1 (62.3)¶**	**50.3 (24.6)¶**	**49**
Mean, Inflammatory Patients	**52.0 (69.7)**	**16.3 (22.7)**	**3.3 (9.5)**	**23.3 (31.7)**	**68.2 (56.6)**	**51.7**
Mean, Noninflammatory Patients	**64.9 (100.6)¶**	**23.8 (34.1)¶**	**16 (24.8)¶**	**36 (67.7)¶**	**47.1 (18.9)¶**	**47.9**

F/E, flexion/extension. R/U, radial-ulnar deviation.
*Inflammatory arthritis.
†Underwent manipulation under anesthesia.
‡Converted to total arthroplasty.
§Died from unrelated causes.
‖Converted to wrist fusion.
¶Reached statistical significance when before surgery was compared with after surgery ($P < .05$).

aligned with the carpometacarpal joint. Every effort is made to preserve the important dorsal intercarpal and radiocarpal ligaments on the triquetrum by reflecting a dorsal wafer of the triquetrum in continuity with the flap. Proximal reflection of the flap provides complete exposure of the proximal and distal carpal rows while preserving the dorsal capsuloligamentous anatomy and the PIN.

The proximal carpal row is excised using joysticks and sharp curved elevators. The radial articular surface is exposed by palmar dislocation of the distal carpal row and maintained with a Bennett retractor. Care is taken to preserve the cartilage of the capitate. The radius is prepared using a custom elliptical power rasp to remove cartilage, flatten the interfacet ridge, and shape the subchondral plate to precisely match the base of the implant. The origins of the extrinsic volar and dorsal wrist ligaments as well as the radial subchondral plate are preserved.

A 2.5-mm guidewire is inserted into the medullary canal of the radius under fluoroscopic control. The entry point is between the middle and the dorsal thirds of the radial articular surface at the ulnar border of Lister's tubercle. A box chisel is used to create a window in the subchondral bone. The osteotomized bone is impacted into the medullary canal during

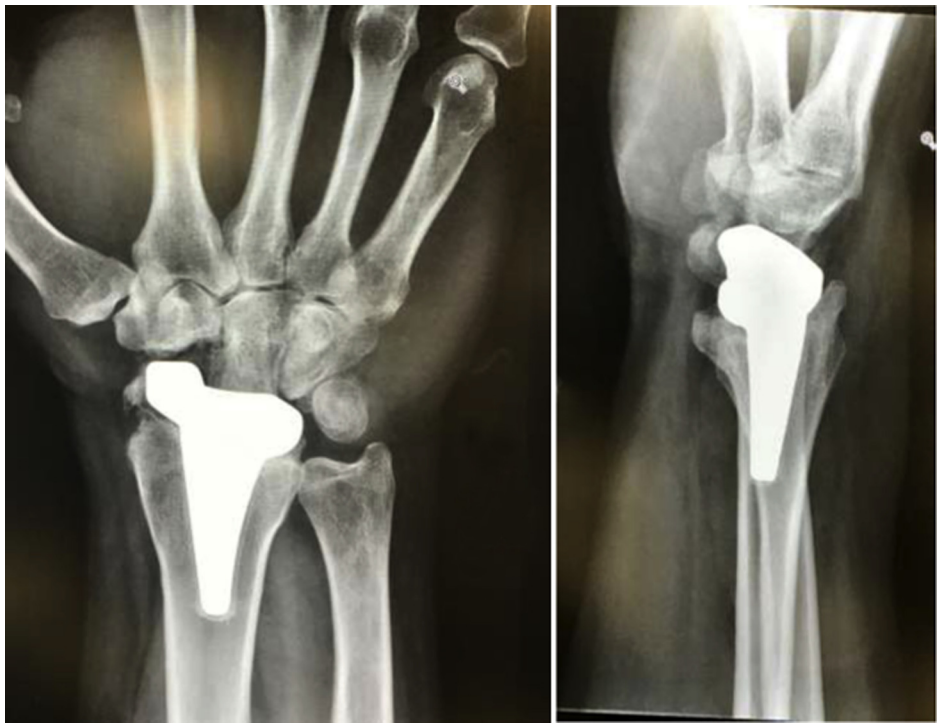

FIGURE 2: Postoperative radiographs on patient 1.

sequential broaching. Maintaining appropriate coronal, sagittal, and rotational alignment is important for the subchondral bone to be able to support the implant on all sides.

The trial component is inserted, the carpus reduced, and ROM and stability are assessed. A degree of laxity is preferred over tension in the volar and dorsal ligaments. When satisfied with the position and stability, the trial is removed and the corresponding press-fit prosthesis is gently impacted into the subchondral bed. Cement was not utilized in this series. The carpus is reduced and the capsule repaired anatomically with a single running suture. The retinaculum and skin is closed in layers and the wrist immobilized in a volar plaster orthosis in neutral position. Active digital, elbow, and shoulder motion is begun immediately, and active wrist motion is begun in a supervised therapy program after suture removal on day 10. Weight-bearing began 4 to 6 weeks after surgery and full activity was permitted at 8 weeks with no activity restrictions.

Outcome assessment

All patients were evaluated before and after surgery by a hand therapist who measured wrist ROM and grip strength and was independent of the study. The DASH and Mayo wrist scores were completed at each visit. Radiographs were evaluated for loosening, osteolysis of the capitate, or component migration at each follow-up visit (Fig. 2). Data were analyzed using the Kolmogorov-Smirnov and the Shapiro-Wilk test of normality. A paired-samples *t* test was used to determine statistically significant mean difference between pre- and postoperative results using an alpha value of .05.

RESULTS

The mean surgical time was 54 minutes (range, 45−66 minutes). The mean clinical and radiographic assessment for all 20 patients was 4.1 years (range, 2.3−5.3 years). Mean postoperative flexion-extension arc was 96°, and mean radioulnar deviation arc was 32.4°. Mean ROM significantly improved in both flexion-extension (33° improvement; SD. 26) and radial-ulnar deviation (10° improvement; SD. 9) with respect to the preoperative values (Figs. 3, 4). An example of the smooth wrist circumduction and coupled motion that resulted from midcarpal preservation is provided in Video A (available on the *Journal*'s Web site at www.jhandsurg.org). Mean grip strength improved significantly from 14.1 kg to 20.8 kg, an increase of 6.7 kg (SD, 9) (Fig. 5). The mean postoperative ROM compared with the contralateral side was 68%, 58%, and 74% for flexion-extension, radial-ulnar deviation, and grip strength, respectively. The DASH score significantly improved from 50.3 to 24.6 (Fig. 6), and mean Mayo scores

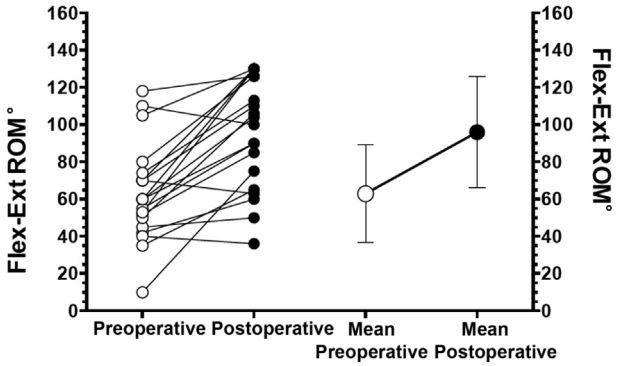

FIGURE 3: Pre- to postoperative difference in range of motion in flexion-extension (°) across 20 patients. Flex-Ext ROM, flexion-extension range of motion.

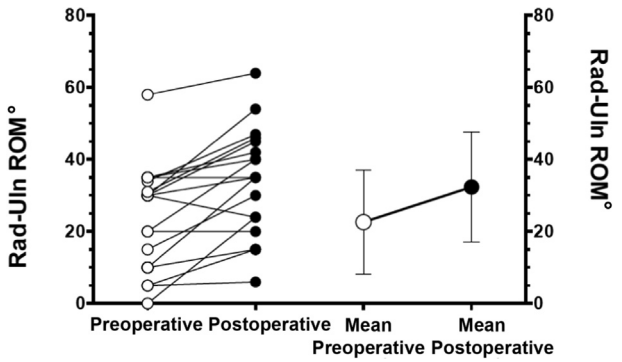

FIGURE 4: Pre- to postoperative difference in range of motion in radial-ulnar deviation (°), across 20 patients. Rad-Uln ROM, radial-ulnar range of motion.

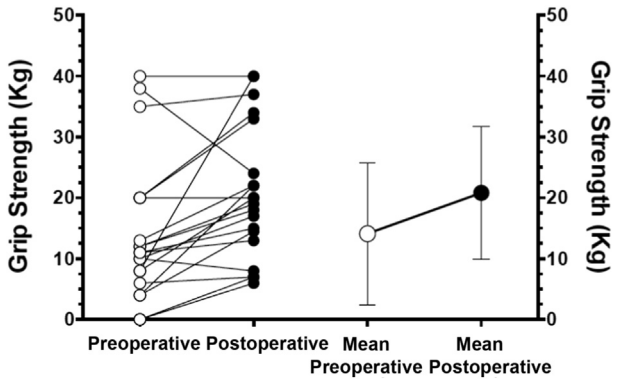

FIGURE 5: Pre- to postoperative difference in grip strength (kg) across 20 patients.

significantly improved from 34.1 before surgery to 62.3 after (Fig. 7; Table 2).

Compared with the noninflammatory patients, the 3 patients with inflammatory arthritis showed less improvement in all objective and patient-derived outcome parameters, although the small number of

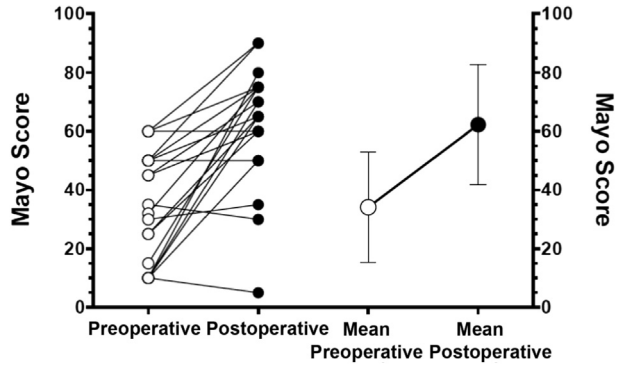

FIGURE 6: Pre- to postoperative difference in Mayo score across 20 patients.

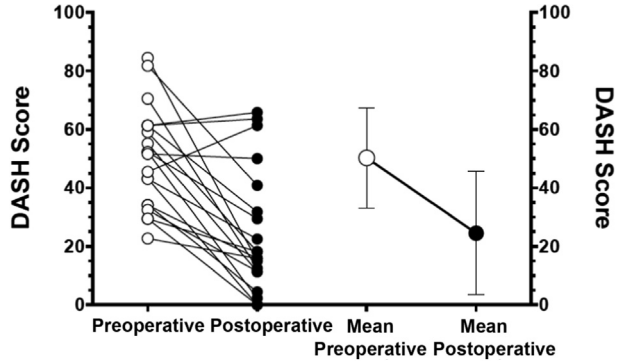

FIGURE 7: Pre- to postoperative difference in DASH score across 20 patients.

inflammatory patients precluded a valid statistical comparison. No patients with inflammatory disease required a revision.

Complications

Three patients (patient 4 [SNAC], 8 [psoriatic arthritis], and 13 [OA]) underwent closed manipulation under anesthesia for wrist stiffness at an average of 3.2 months (range, 3–5 months) after surgery. Patient 4 gained 50° in flexion/extension, patient 8 gained 29°, and patient 13 did not benefit from manipulation. Patient 11 fell and fractured his fourth carpometacarpal joint and underwent successful plate stabilization. There were no cases of superficial or deep infection.

Failures

Patient 4 was the only patient who demonstrated radiographic evidence of component loosening and underwent successful conversion to total wrist arthroplasty for aseptic loosening at 1 year after surgery. Patient 15 (OA) was diagnosed with complex regional pain syndrome prior to hemiarthroplasty surgery. This

TABLE 3. Return to Work at Latest Follow-Up

Patient	Occupation	Back to Work
1	Broker	Yes
2	Secretary	No
4	Secretary	Yes
5	Director	Yes
6	Student	Yes
7	Retailer	Yes
8	Nurse	No
11	Bricklayer	Yes
12	Retailer	Yes
13	Banker	Yes, restricted
15	Retailer	No
16	Office worker	Yes
20	Office worker	Yes

persisted following surgery, and despite conversion to a total wrist arthroplasty, his pain persisted. There was no sign of prosthetic loosening or capitate osteolysis on radiographs and the capitate cartilage was intact at reoperation. Patient 12 (SLAC) went on to have a wrist fusion by another surgeon to treat ulnar-sided pain. One patient (patient 9) died of unrelated causes, but her results at 31 months were good and there were no known issues with her implant.

From the 13 patients who were employed at the time of surgery, 10 had returned to work at latest follow-up (Table 3). Four patients that could not participate in sporting activities before surgery because of pain resumed recreational activities including golf and shooting after surgery (patients 1, 3, 5 and 20; Video A; available on the *Journal*'s Web site at www.jhandsurg.org). Excluding the patient who died, 16 of the initial 19 prostheses (84%) were *in situ* at the most recent follow-up (Fig. 8) with an average flexion-extension ROM of 100°, radioulnar deviation arc of 32°, grip strength 22.5 kg, Mayo score of 61.9, and an average DASH score of 25.4. Figure 8 shows the survival analysis in a Kaplan-Meier plot. The patient who died is censored and the failures were taken out at time for conversion.

DISCUSSION

We report significant improvement in ROM, grip strength, and patient-reported outcomes in our initial cohort of 20 patients following midcarpal hemiarthroplasty at average 4-year follow-up. This compares favorably with a recent multicenter analysis of 215 total wrist arthroplasties that showed no pre- to postoperative improvement in ROM.[20] A review of the published outcomes for partial arthrodesis or PRC did not identify another surgical alternative for SLAC arthritis that improved pre- to post-operative ROM.[8–10,13,14,18,20–23,47–50]

The conversion rate to total wrist arthroplasty or fusion was 3 of 20. Other series of patients treated with prostheses have documented revision rates ranging from 0% to 39%; but given the small sample sizes in these series, the true revision rate is difficult to assess.[20,42,51,52] Three patients underwent manipulation under anesthesia within 5 months of surgery with limited or no improvement in ROM. Based on this and the demonstrated early stability of the prosthesis, we changed our postoperative protocol to begin active ROM on day 7 following patient 13, and have performed no further manipulations.

Although we report only a small cohort of patients at 4 years after surgery, our results compare favorably with radiocarpal hemiarthroplasty, which articulates the radial component of a total wrist arthroplasty system with the native distal carpal row. Culp et al[51] presented a series of combined PRC and radiocarpal hemiarthroplasty in 10 patients using the radial polyethylene component of the Maestro Wrist Reconstructive System (BioMet, Warsaw, IN) or ReMotion Total Wrist Implant (Stryker, Kalamazoo, MI). After 19 months, mean ROM had decreased and 9 of 10 patients had complications of which 7 required reoperation (aseptic loosening requiring revision, 2; tenosynovitis. 2; contracture, 2; tendon adhesions, 2; ulnar nerve compression, 1; painful clicking, 1; and asymptomatic osteolysis, 1). Two patients were revised to a different prosthesis. The authors discontinued the use of this prosthesis for hemiarthroplasty.

In 2013, Adams[52] reported 3-year follow-up of 26 cases of PRC combined with radiocarpal hemiarthroplasty using the Universal 2 Wrist Arthroplasty System (Integra Life Sciences, Plainsboro, NJ). They reported satisfactory pain relief, but mean ROM, grip strength, or outcome scores were not reported. In 22 of 26 wrists, the procedure generated a minimum of 60° of flexion-extension, but preoperative ROM was not reported. One patient showed radiographic erosion of the capitate and 1 was converted to total wrist fusion.

Total joint arthroplasty is considered the gold standard for treatment of severe arthrosis of most joints in the body. Total wrist arthroplasty has been an option since Alfred Swanson developed a silicone prosthesis in 1967,[53] and many designs and materials have followed, each with inherent complication risks. In recent years, the outcomes of total wrist replacement have improved, but the procedure continues to have

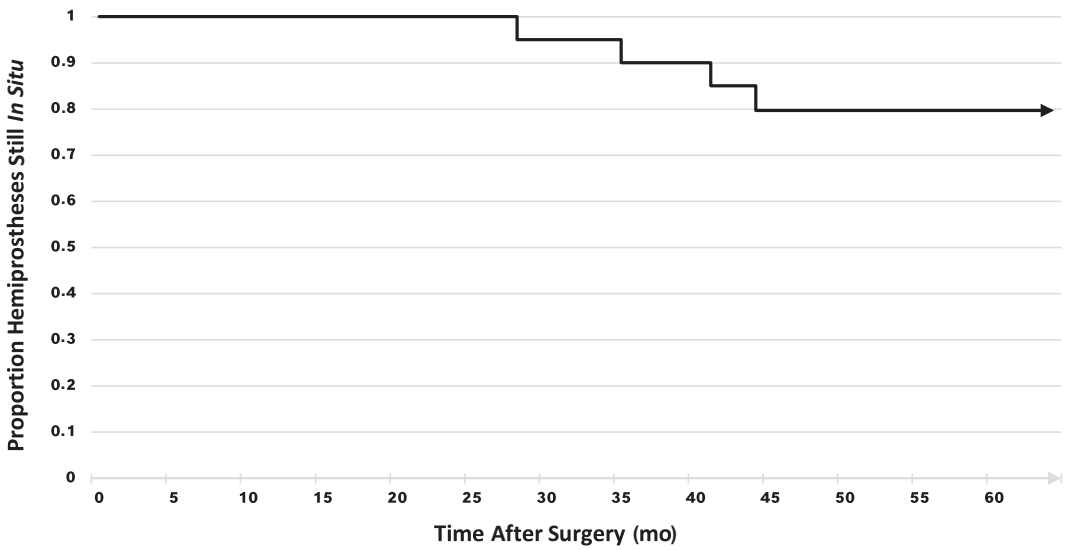

FIGURE 8: Kaplan-Meier survival plot.

problems of distal component failure[1,3,36,52,54–56] and periprosthetic osteolysis.[24,25] The ROM following total wrist arthroplasty is predicted by preoperative wrist ROM.[20–23,38]

Total wrist arthroplasty converts the obliquely inclined axis of normal wrist circumduction into a nearly vertical axis of flexion-extension, with marked restriction of circumduction and radioulnar deviation.[38] A 2015 systematic review of 405 total wrist arthroplasties from 7 manufacturers[57] demonstrated that only 1 prosthesis achieved the functional ROM defined by Palmer et al in 1985.[58]

Midcarpal hemiarthroplasty must also be evaluated in the light of nonprosthetic surgical options for wrist arthritis. Denervation is simpler than reconstructive procedures. Because it involves dividing the PIN, there may be theoretical concerns with loss of proprioceptive control of the wrist.[9,46] Braga-Silva et al[5] evaluated 49 patients at 6 years following wrist denervation. They found that average pain improvement (visual analog score) was 79% but they reported no significant improvement in ROM in any plane.

Ablative surgery removes the pain-generating degenerative portions of the carpus. The most common are PRC, radial styloidectomy, and distal scaphoidectomy (as treatment for SNAC wrist).[8,17,59–61] Ablative procedures are motion-sparing and are often successful in reducing pain, although progressive articular degeneration is often seen. Degeneration is, however, poorly correlated to symptoms or failure.[2,7,62–64] Didonna et al[14] published their 10-year follow-up on 22 patients treated with PRC. Four procedures failed (18%) and results were analyzed for the 15 patients available at follow-up. Flexion-extension averaged 72°, grip strength averaged 91% of that of the contralateral side, and the DASH score averaged 9. Preoperative DASH was not reported. All but 3 patients showed signs of radiographic degeneration of the radiocapitate space. At 20 years follow-up on the same series,[17] 2 additional wrists were fused and 1 was unsatisfied with the result, yielding a failure rate of 35%. Like partial arthrodesis, PRC has been demonstrated to reduce motion, wrist coupling, and functional performance compared with normal wrists.[19]

Partial arthrodesis involves fusion of a portion of the carpus, thereby gaining pain relief while preserving some motion. Scaphoid excision with 4-corner fusion is the most commonly performed.[12,65] The procedure considerably alters the biomechanics[66–69] and function[19] of the wrist, has a 39% rate of moderate-severe radiolunate arthritis at 7 years,[70] and is associated with a rate of nonunion ranging from 5% to 55%.[10–12] Radioscaphoid-lunate fusion and distal scaphoid excision spare the midcarpal joint and preserve carpal height, thus simulating midcarpal hemiarthroplasty.[29,31,33] Garcia-Elias et al[9] reported an average flexion-extension arc of 67° (64° before surgery) and 33° (27° before surgery) of radial-ulnar deviation in 16 patients at an average 3-year follow-up. Mulford et al[12] reported a high rate of satisfaction following 4-corner fusion, and Cha et al[71] reported statistical improvements in patient-reported outcomes at 5 years after this procedure. Both PRC and partial arthrodesis avoid the inherent risks of prosthetic arthroplasty, including loosening, component failure, particulate wear, or periprosthetic fracture.

Total arthrodesis is a reliable procedure that offers pain relief and restores strength, but at the expense of all wrist motion. Adey et al[72] reported an average of

79% grip strength of the uninvolved side in 22 patients. Twenty of the 22 would elect to have a surgery to make their wrist move again, if this was available. Wrist arthrodesis is generally considered a salvage procedure, but it may be indicated as a primary treatment in those with heavy manual requirements.[1,6,73–75]

The data presented in this retrospective study support our hypothesis that midcarpal hemiarthroplasty provides significant improvement in ROM, grip strength, and patient-reported outcome measures, with a complication profile comparable with those of alternative solutions for wrist arthritis. The preservation of the midcarpal joint geometry and extrinsic wrist ligaments may help explain this cohort's pre- to postoperative improvements in wrist ROM, despite the sacrifice of the radiocarpal joint.[19,39] These data cannot be directly compared with procedures that eliminate the midcarpal joint, but their 4-year complication and failure rates are comparable with all current solutions for wrist arthritis. Arthroplasty of the midcarpal joint should be considered a motion-improving option for SLAC arthritis that relieves pain, requires little postoperative immobilization, eliminates the risk of nonunion as seen in partial arthrodesis and the risk of osteolysis or distal component failure that may affect total wrist arthroplasty.[44,52,54] The procedure is relatively straightforward and preserves carpal bone stock and carpal height, should revision to total wrist arthroplasty be required.

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REFERENCES

1. Weiss KE, Rodner CM. Osteoarthritis of the wrist. *J Hand Surg*. 2007;32(5):725–746.
2. Fontaine C. Kienböck's disease. *Chir Main*. 2015;34(1):4–17.
3. Laulan J, Marteau E, Bacle G. Wrist osteoarthritis. *Orthop Traumatol Surg Res*. 2015;101(1 Suppl):S1–S9.
4. Geldmacher J, Legal HR, Brug E. Results of denervation of the wrist and wrist joint by Wilhelm's method. *Hand (N Y)*. 1972;4(1):57–59.
5. Braga-Silva J, Román JA, Padoin AV. Wrist denervation for painful conditions of the wrist. *J Hand Surg Am*. 2011;36(6):961–966.
6. Riches PL, Elherik FK, Breusch SJ. Functional and patient-reported outcome of partial wrist denervation versus the Mannerfelt wrist arthrodesis in the rheumatoid wrist. *Arch Orthop Trauma Surg*. 2014;134(7):1037–1044.
7. Ben Amotz O, Sammer DM. Salvage operations for wrist ligament injuries with secondary arthrosis. *Hand Clin*. 2015;31(3):495–504.
8. Klausmeyer M, Fernandez D. Scaphocapitolunate arthrodesis and radial styloidectomy: a treatment option for posttraumatic degenerative wrist disease. *J Wrist Surg*. 2012;1(2):115–122.
9. Garcia-Elias M, Lluch A, Ferreres A, Papini-Zorli I, Rahimtoola ZO. Treatment of radiocarpal degenerative osteoarthritis by radioscapholunate arthrodesis and distal scaphoidectomy. *J Hand Surg Am*. 2005;30(1):8–15.
10. Vance MC, Hernandez JD, Didonna ML, Stern PJ. Complications and outcome of four-corner arthrodesis: circular plate fixation versus traditional techniques. *J Hand Surg Am*. 2005;30(6):1122–1127.
11. Larsen CF, Jacoby RA, McCabe SJ. Nonunion rates of limited carpal arthrodesis: a meta-analysis of the literature. *J Hand Surg Am*. 1997;22(1):66–73.
12. Mulford JS, Ceulemans LJ, Nam D, Axelrod TS. Proximal row carpectomy vs four corner fusion for scapholunate (SLAC) or scaphoid nonunion advanced collapse (SNAC) wrists: a systematic review of outcomes. *J Hand Surg Eur Vol*. 2009;34(2):256–263.
13. Croog AS, Stern PJ. Proximal row carpectomy for advanced Kienböck's disease: average 10-year follow-up. *J Hand Surg Am*. 2008;33(7):1122–1130.
14. DiDonna ML, Kiefhaber TR, Stern PJ. Proximal row carpectomy: study with a minimum of ten years of follow-up. *J Bone Joint Surg Am*. 2004;86-A(11):2359–2365.
15. Elfar JC, Stern PJ. Proximal row carpectomy for scapholunate dissociation. *J Hand Surg Eur Vol*. 2011;36(2):111–115.
16. Stern PJ, Agabegi SS, Kiefhaber TR, Didonna ML. Proximal row carpectomy. *J Bone Joint Surg Am*. 2005;87(Suppl 1 Pt 2):166–174.
17. Wall LB, Didonna ML, Kiefhaber TR, Stern PJ. Proximal row carpectomy: minimum 20-year follow-up. *J Hand Surg Am*. 2013;38(8):1498–1504.
18. Wyrick JD, Stern PJ, Kiefhaber TR. Motion-preserving procedures in the treatment of scapholunate advanced collapse wrist: proximal row carpectomy versus four-corner arthrodesis. *J Hand Surg Am*. 1995;20(6):965–970.
19. Wolff AL, Garg R, Kraszewski AP, et al. Surgical treatments for scapholunate advanced collapse wrist: kinematics and functional performance. *J Hand Surg Am*. 2015;40(8):1547–1553.
20. Herzberg G, Boeckstyns M, Sorensen AI, et al. "Remotion" total wrist arthroplasty: preliminary results of a prospective international multicenter study of 215 cases. *J Wrist Surg*. 2012;1(1):17–22.
21. Reigstad O, Lütken T, Grimsgaard C, Bolstad B, Thorkildsen R, Røkkum M. Promising one- to six-year results with the Motec wrist arthroplasty in patients with post-traumatic osteoarthritis. *J Bone Joint Surg Br*. 2012;94(11):1540–1545.
22. 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):914–919.
23. Sagerfors M, Gupta A, Brus O, Pettersson K. Total wrist arthroplasty: a single-center study of 219 cases with 5-year follow-up. *J Hand Surg Am*. 2015;40(12):2380–2387.
24. Boeckstyns MEH, Herzberg G. Periprosthetic osteolysis after total wrist arthroplasty. *J Wrist Surg*. 2014;3(2):101–106.
25. Boeckstyns MEH, Toxvaerd A, Bansal M, Vadstrup LS. Wear particles and osteolysis in patients with total wrist arthroplasty. *J Hand Surg Am*. 2014;39(12):2396–2404.
26. Li Z-M, Kuxhaus L, Fisk JA, Christophel TH. Coupling between wrist flexion-extension and radial-ulnar deviation. *Clin Biomech (Bristol Avon)*. 2005;20(2):177–183.
27. Werner FW, Green JK, Short WH, Masaoka S. Scaphoid and lunate motion during a wrist dart throw motion. *J Hand Surg Am*. 2004;29(3):418–422.
28. Moritomo H, Apergis EP, Herzberg G, Werner FW, Wolfe SW, Garcia-Elias M. 2007 IFSSH committee report of wrist biomechanics committee: biomechanics of the so-called dart-throwing motion of the wrist. *J Hand Surg Am*. 2007;32(9):1447–1453.
29. Moritomo H, Apergis EP, Garcia-Elias M, Werner FW, Wolfe SW. International Federation of Societies for Surgery of the Hand 2013 Committee's report on wrist dart-throwing motion. *J Hand Surg Am*. 2014;39(7):1433–1439.
30. Crisco JJ, Coburn JC, Moore DC, Akelman E, Weiss A-PC, Wolfe SW. *In vivo* radiocarpal kinematics and the dart thrower's motion. *J Bone Joint Surg Am*. 2005;87(12):2729–2740.

31. Crisco JJ, Heard WMR, Rich RR, Paller DJ, Wolfe SW. The mechanical axes of the wrist are oriented obliquely to the anatomical axes. *J Bone Joint Surg Am*. 2011;93(2):169−177.
32. Upal MA, Crisco JJ, Moore DC, Sonenblum SE, Wolfe SW. *In vivo* elongation of the palmar and dorsal scapholunate interosseous ligament. *J Hand Surg Am*. 2006;31(8):1326−1332.
33. Calfee RP, Leventhal EL, Wilkerson J, Moore DC, Akelman E, Crisco JJ. Simulated radioscapholunate fusion alters carpal kinematics while preserving dart-thrower's motion. *J Hand Surg Am*. 2008;33(4):503−510.
34. Wilke H-J, Schmidt R, Richter M, Schmoelz W, Reichel H, Cakir B. The role of prosthesis design on segmental biomechanics: semiconstrained versus unconstrained prostheses and anterior versus posterior centre of rotation. *Eur Spine J*. 2012;21(Suppl 5):S577−S584.
35. Banks SA, Hodge WA. 2003 Hap Paul Award Paper of the International Society for Technology in Arthroplasty. Design and activity dependence of kinematics in fixed and mobile-bearing knee arthroplasties. *J Arthroplasty*. 2004;19(7):809−816.
36. Kennedy CD, Huang JI. Prosthetic design in total wrist arthroplasty. *Orthop Clin North Am*. 2016;47(1):207−218.
37. Rosenfeld JF, Nicholson JJ. History and design considerations for arthroplasty around the wrist. *Hand Clin*. 2013;29(1):1−13.
38. Singh HP, Bhattacharjee D, Dias JJ, Trail I. Dynamic assessment of the wrist after total wrist arthroplasty. *J Hand Surg Eur Vol*. 2017;42(6):573−579.
39. Garg R, Kraszewski AP, Stoecklein HH, et al. Wrist kinematic coupling and performance during functional tasks: effects of constrained motion. *J Hand Surg Am*. 2014;39(4):634−642.e1.
40. Cobb TK, Beckenbaugh RD. Biaxial total-wrist arthroplasty. *J Hand Surg Am*. 1996;21(6):1011−1021.
41. Harlingen D, Heesterbeek PJ. High rate of complications and radiographic loosening of the biaxial total wrist arthroplasty in rheumatoid arthritis: 32 wrists followed for 6 (5−8) years. *Acta Orthop*. 2011;82(6):721−726.
42. Krukhaug Y, Lie SA, Havelin LI, Furnes O, Hove LM. Results of 189 wrist replacements. A report from the Norwegian Arthroplasty Register. *Acta Orthop*. 2011;82(4):405−409.
43. Rizzo M, Ackerman DB, Rodrigues RL, Beckenbaugh RD. Wrist arthrodesis as a salvage procedure for failed implant arthroplasty. *J Hand Surg Eur Vol*. 2011;36(1):29−33.
44. Adams BD, Kleinhenz BP, Guan JJ. Wrist arthrodesis for failed total wrist arthroplasty. *J Hand Surg Am*. 2016;41(6):673−679.
45. Vance M, Packer G, Tan D, Crisco JJ, Wolfe S. Midcarpal hemiarthroplasty for wrist arthritis: rationale and early results. *J Wrist Surg*. 2012;1(1):61−68.
46. Hagert E, Ferreres A, Garcia-Elias M. Nerve-sparing dorsal and volar approaches to the radiocarpal joint. *J Hand Surg Am*. 2010;35(7):1070−1074.
47. Lumsden BC, Stone A, Engber WD. Treatment of advanced-stage Kienböck's disease with proximal row carpectomy: an average 15-year follow-up. *J Hand Surg Am*. 2008;33(4):493−502.
48. Jebson PJL, Hayes EP, Engber WD. Proximal row carpectomy: a minimum 10-year follow-up study. *J Hand Surg Am*. 2003;28(4):561−569.
49. Tomaino MM, Miller RJ, Cole I, Burton RI. Scapholunate advanced collapse wrist: proximal row carpectomy or limited wrist arthrodesis with scaphoid excision? *J Hand Surg Am*. 1994;19(1):134−142.
50. Ali MH, Rizzo M, Shin AY, Moran SL. Long-term outcomes of proximal row carpectomy: a minimum of 15-year follow-up. *Hand (N Y)*. 2012;7(1):72−78.
51. Culp RW, Bachoura A, Gelman SE, Jacoby SM. Proximal row carpectomy combined with wrist hemiarthroplasty. *J Wrist Surg*. 2012;1(1):39−46.
52. Adams BD. Wrist arthroplasty: partial and total. *Hand Clin*. 2013;29(1):79−89.
53. Swanson AB. Flexible implant arthroplasty for arthritic disabilities of the radiocarpal joint. A silicone rubber intramedullary stemmed flexible hinge implant for the wrist joint. *Orthop Clin North Am*. 1973;4(2):383−394.
54. Adams BD. Complications of wrist arthroplasty. *Hand Clin*. 2010;26(2):213−220.
55. O'Donovan TM, Terrono AL, Millender LH. Silicone rubber arthroplasty of the wrist. *Semin Arthroplasty*. 1991;2(2):85−90.
56. Laulan J, Bacle G, de Bodman C, et al. The arthritic wrist. II—the degenerative wrist: indications for different surgical treatments. *Orthop Traumatol Surg Res*. 2011;97(4 Suppl):S37−S41.
57. Yeoh D, Tourret L. Total wrist arthroplasty: a systematic review of the evidence from the last 5 years. *J Hand Surg Eur Vol*. 2015;40(5):458−468.
58. Palmer AK, Werner FW, Murphy D, Glisson R. Functional wrist motion: a biomechanical study. *J Hand Surg Am*. 1985;10(1):39−46.
59. Wall LB, Stern PJ. Proximal row carpectomy. *Hand Clin*. 2013;29(1):69−78.
60. Ruch DS, Papadonikolakis A. Resection of the scaphoid distal pole for symptomatic scaphoid nonunion after failed previous surgical treatment. *J Hand Surg Am*. 2006;31(4):588−593.
61. Matsuki H, Horii E, Majima M, Genda E, Koh S, Hirata H. Scaphoid nonunion and distal fragment resection: analysis with three-dimensional rigid body spring model. *J Orthop Sci*. 2009;14(2):144−149.
62. Kruse K, Fowler JR. Scapholunate advanced collapse: motion-sparing reconstructive options. *Orthop Clin North Am*. 2016;47(1):227−233.
63. Green DP, Perreira AC, Longhofer LK. Proximal row carpectomy. *J Hand Surg Am*. 2015;40(8):1672−1676.
64. Wagner ER, Werthel J-D, Elhassan BT, Moran SL. Proximal row carpectomy and 4-corner arthrodesis in patients younger than age 45 years. *J Hand Surg Am*. 2017;42(6):428−435.
65. Saltzman BM, Frank JM, Slikker W, Fernandez JJ, Cohen MS, Wysocki RW. Clinical outcomes of proximal row carpectomy versus four-corner arthrodesis for post-traumatic wrist arthropathy: a systematic review. *J Hand Surg Eur Vol*. 2015;40(5):450−457.
66. Sobczak S, Rotsaert P, Vancabeke M, Van Sint Jan S, Salvia P, Feipel V. Effects of proximal row carpectomy on wrist biomechanics: a cadaveric study. *Clin Biomech (Bristol Avon)*. 2011;26(7):718−724.
67. Zhu Y-L, Xu Y-Q, Ding J, Li J, Chen B, Ouyang Y-F. Biomechanics of the wrist after proximal row carpectomy in cadavers. *J Hand Surg Eur Vol*. 2010;35(1):43−45.
68. Tang P, Gauvin J, Muriuki M, Pfaeffle JH, Imbriglia JE, Goitz RJ. Comparison of the "contact biomechanics" of the intact and proximal row carpectomy wrist. *J Hand Surg Am*. 2009;34(4):660−670.
69. Hawkins-Rivers S, Budoff JE, Ismaily SK, Noble PC, Haddad J. MRI study of the capitate, lunate, and lunate fossa with relevance to proximal row carpectomy. *J Hand Surg Am*. 2008;33(6):841−849.
70. Wagner ER, Werthel JD, Elhassan BT, Moran SL. Proximal row carpectomy and 4-corner arthrodesis in patients younger than age 45 years. *J Hand Surg Am*. 2017;42(6):428−435.
71. Cha S-M, Shin H-D, Kim K-C. Clinical and radiological outcomes of scaphoidectomy and 4-corner fusion in scapholunate advanced collapse at 5 and 10 years. *Ann Plast Surg*. 2013;71(2):166−169.
72. Adey L, Ring D, Jupiter JB. Health status after total wrist arthrodesis for posttraumatic arthritis. *J Hand Surg Am*. 2005;30(5):932−936.
73. Kobus RJ, Turner RH. Wrist arthrodesis for treatment of rheumatoid arthritis. *J Hand Surg Am*. 1990;15(4):541−546.
74. Weiss AC, Wiedeman G, Quenzer D, Hanington KR, Hastings H II, Strickland JW. Upper extremity function after wrist arthrodesis. *J Hand Surg Am*. 1995;20(5):813−817.
75. Field J, Herbert TJ, Prosser R. Total wrist fusion. A functional assessment. *J Hand Surg Br*. 1996;21(4):429−433.