Systematic Review of Total Wrist Arthroplasty and Arthrodesis in Wrist Arthritis

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Abstract

Background End-stage wrist arthritis has traditionally been treated with a total wrist fusion. There is a recent trend toward motion preserving surgery in the form of total wrist replacement.

Questions Is there a functional benefit to performing a total wrist replacement instead of a total wrist fusion in patients with end-stage wrist arthritis? Is there any difference in secondary outcome measures including pain, grip strength, and range of motion? Does the risk of adverse events and treatment failure differ between the two techniques?

Methods A systematic literature search was performed to identify studies reporting either total wrist arthrodesis or arthroplasty for end-stage wrist arthritis. Studies were systematically screened and assessed for risk of bias and quality. Data were extracted and reviewed.

Results A total of 43 studies were included in the review: 17 on arthrodesis, 24 on arthroplasty, and 2 matched cohort studies. This represented 669 index arthrodesis operations in 603 patients, and 1,371 index arthroplasty operations in 1,295 patients. A significant improvement in functional outcome was seen with both interventions. Similar improvements were seen in pain scores, and modest improvements were seen in grip strength. Range of motion following arthroplasty improved to a functional level in two studies. Complication rates were higher after arthroplasty (range: 0.2–9.5%) than those after arthrodesis (range: 0.1–6.1%; $p = 0.06$). Fourth-generation implants (range 0.1–2.9%) performed better than earlier designs (range: 0.2–8.1%; $p = 0.002$). Implant revision rates ranged from 3.5 to 52.6%. Fourth-generation prostheses survival rates were 78% at 15 years (Universal 2), 86% at 10 years (Motec), 90% at 9 years (Re-Motion), and 95% at 8 years (Maestro).

Conclusion The newer fourth-generation wrist implants appear to be performing better than earlier designs. Both wrist arthrodesis and wrist arthroplasty improve function, pain, and grip strength. The risk of complication following wrist replacements is higher than that after total wrist arthrodesis.

Keywords

- wrist
- arthritis
- arthroplasty
- arthrodesis
- systematic review

Total wrist arthrodesis has been the gold standard for managing advanced inflammatory and degenerative arthritis of the wrist for many years. Some of the first techniques described to achieve wrist fusion used intramedullary pins,

such as a Steinman pin with a radial bone graft by Clayton, later modified by Mannerfelt and Malsten, who used a Rush pin through the third metacarpal into the radius and two staples to prevent rotation.^{1,2} The next development came

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from the AO (Arbeitsgemeinschaft für Osteosynthesefragen) group with the advent of dorsal plate fixation in the 1970s. Initially, a conventional dynamic compression plate was used; however, later, a dedicated wrist fusion plate was introduced.³

Wrist arthroplasty has been compared with wrist arthrodesis through retrospective matched cohort studies by Murphy et al and Nydick et al and through a systematic review.^{4–6} Patients in the arthroplasty group showed a trend toward better performance of certain activities such as personal hygiene.⁵ Pain scores, satisfaction, and complication rates were similar in both groups.^{4,5} While Nydick et al reported better functional outcomes in the arthroplasty group, this was not detected in the study by Murphy et al.^{4,5} These findings were partly reflected in the systematic review by Cavaliere and Chung.⁶ No or mild pain was experienced by 90% of patients in the arthroplasty group and 98% of patients in the arthrodesis group. Satisfaction appeared comparable between groups.⁶ The rates of major complication were higher in the arthroplasty group (25%) compared with the arthrodesis group (13%). Newer third-generation prostheses had a lower major complication rate (21%) than older generation implants. A functional range of motion, as defined by Palmer et al,⁷ was achieved by patients in only 3 of the 14 studies in the review. The systematic review by Yeoh and Tourret had similar findings, with arthroplasty having higher complication rates and functional range of motion only achieved by the Maestro implant.⁷ Maintenance of a range of motion is seen as the clear advantage of wrist arthroplasty, yet this benefit is not always reflected by objective assessment. The National Institute for Health and Care Excellence (NICE) has provided cautious recommendations for the use of total wrist arthroplasty by experienced surgeons in specialist centers with special arrangements for clinical governance, consent, and audit or research.⁸ National Joint Registry data are limited to Norway and Australia currently.

Since the last comparative systematic review, there have been several new publications including data on contemporary fourth-generation implants and a new matched cohort study comparing wrist arthroplasty to arthrodesis.^{4,9–15} The availability of this new data together with previously available studies presents an ideal opportunity to revisit the ongoing debate on the efficacy of wrist arthroplasty compared with arthrodesis. The proposed research questions forming the basis for this study are as follows: “Is there a functional benefit to performing a total wrist replacement instead of a total wrist fusion in adult patients with end-stage wrist arthritis? Is there any difference in secondary measures including pain, grip strength, and range of motion? Is there a difference between the two techniques in terms of adverse events and treatment failure?”

Methods

A study protocol was created prior to undertaking this systematic review. This protocol was approved by the Brighton and Sussex Medical School Research Governance

and Ethics Committee. The protocol was published on the National Institute for Health Research PROSPERO database (CRD42017067377).

Inclusion and Exclusion Criteria

Studies were included if participants were adults over the age of 16 years. The underlying clinical diagnosis was arthritis of the wrist of any type. The two intervention categories compared in this study were total wrist arthroplasty and total wrist arthrodesis. Both, studies comparing the two treatment modalities and studies focusing on only one of the treatments, were included. Studies comparing either technique to another established technique, for example, total wrist arthrodesis to partial wrist arthrodesis, were excluded. Analysis by the generation of arthroplasty implant was also performed. The studies included were at a minimum “case series,” level IV evidence but also included cohort studies and randomized control trials. Exclusion criteria included patients having undergone revision operations, studies with less than five patients, and failure to report on any of the primary or secondary outcomes. The minimum acceptable duration of follow-up was set at 1 year. Only studies published in the English language were reviewed.

The types of outcome measures chosen for the review were based on the recommendations from OMERACT (Outcome Measures for Rheumatoid Arthritis Clinical Trials) for both rheumatoid arthritis and osteoarthritis.^{16,17} The primary outcome was physical function, and the secondary outcome measures were pain, grip strength, range of motion, adverse events, and implant survival.

Search Strategy

The following databases were searched: OVID Medline, OVID Embase, Cochrane Central Register of Controlled Trials, CINAHL, and BNI. Two trial registers were also searched for relevant studies: ClinicalTrials.gov and the World Health Organization Clinical trials portal. Finally, the NICE database was also searched. The primary search date for all the above was chosen as June 2, 2017. A final repeat of the search was performed on January 20, 2018. The “PICOS” elements (Population, Intervention, Comparator, and Outcomes) were used to construct an effective search strategy. However, not all the elements were used: “Outcomes,” for example, was excluded from the search as it was felt too restrictive for the primary search. Only studies published in the English language were considered, and animal or cadaveric studies were excluded. No date restrictions were applied to maximize search numbers. Search terms included arthropathy, arthritis, osteoarthritis, wrist injury, arthroplasty, joint prosthesis, replacement, arthrodesis, and fusion. The search strategies are provided in ► **Appendices A–D**.

Data Collection and Analysis

The basic dataset was adapted from recommendations in the Cochrane Handbook for Systematic Review of Interventions.¹⁸ Studies were selected through two stages of screening. The first stage involved a review of the study title and abstracts to remove obviously irrelevant articles. The full text of the

remaining articles was then reviewed in more detail independently by the first author (O. B.) and another qualified researcher. Disagreement was resolved by the study supervisors (S. G. and L. G.). The risk of bias in studies was assessed with the Cochrane Collaboration's Risk of Bias tool.¹⁸ A judgment of "low risk," "high risk," or "unclear risk" of bias was made. The GRADE system was chosen to perform a quality appraisal of case series.¹⁹ This system specifies four levels of quality (high, moderate, low, very low).

The results of the literature search are summarized in ►Fig. 1. Of the remaining 43 articles, 17 studies reported wrist arthrodesis outcomes,^{3,20–35} 24 reported the outcomes from wrist arthroplasty,^{9–15,36–52} and 2 undertook a retrospective matched cohort review of arthroplasty versus arthrodesis.^{4,5}

Results

►Table 1 summarizes the overall patient demographics. All arthrodesis studies were retrospective in nature apart from Riches et al, which was prospective.²⁶ Of the arthroplasty studies, seven were prospective in nature.^{13,37,38,44,45,47,51}

A variety of wrist arthrodesis techniques were described in the studies and are summarized in ►Table 2. In rheumatoid arthritis patients, Rush pin and staples were commonly used employing the technique widely advocated by Mannerfelt and Malsten.^{2,20,22,29,30,32} The majority of the arthrodesis studies employed more than one surgical technique.

►Table 3 provides a summary of the different implants used throughout the arthroplasty studies. There were a total of 14 different implants used, ranging from earlier second-generation prostheses, such as Volz and Motec, to contemporary fourth-generation systems such as Universal 2 and Maestro.

A common issue across most studies was the lack of blinding of study personnel, therefore creating a performance and detection bias. Several study authors were

Table 1 Patient demographics

	Total wrist arthrodesis	Total wrist arthroplasty
Total number of patients	603	1,295
Total index operations	669	1,371
Male:female	1:1.6	1:2.9
Average age	52.6 y	58.4 y
Underlying pathology		
Inflammatory arthritis	71.6%	72.7%
Rheumatoid arthritis	70.9%	63.2%
Psoriatic arthritis	0.7%	0.4%
Other	–	0.3%
Not classified	–	8.8%
Noninflammatory	28.4%	27.3%
Posttraumatic arthritis	25.8%	6%
Degenerative arthritis	–	8.8%
Lunate AVN	2.1%	0.3%
Other	0.5%	0.2%
Not classified		12.1%

Abbreviation: AVN, avascular necrosis.
Note: Average age is calculated through weighted average.

involved in product design.^{38,39,42,46,47,51} while, Divelbiss et al received benefits for their work.⁴⁴ Both issues create a conflict of interest and a potential detection bias. Several studies had missing outcome data, including Owen et al, where only 59% of functional outcome data were available.²⁵ The GRADE quality assessment was generally very low to low, as most studies were retrospective observational studies, with no blinding, often with missing data or high patient loss to follow-up numbers.¹⁹ Several studies,

Fig. 1 Summary of the study selection process according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.

Table 2 A summary of the different wrist arthrodesis techniques employed by the studies included in the systematic review

Study	Arthrodesis technique	Underlying pathology	Number of index procedures	Length of follow-up (range)
Brumfield et al (1979)	Not defined	RA	41	58 mo (>12 mo)
Vahvanen and Tallroth (1984)	Rush pin (modified from Mannerfelt and Malmsten (1971) No BG	RA	45	3.9 (1–11 y)
Vicar and Burton (1986)	Millender and Nalebuff (1973) technique including Darrach procedure	RA	33	82 mo
Lee and Carroll (1994)	Intramedullary fixation with Steinman pin in third MC and K-wire second MC; ICBG	RA, <i>n</i> = 18; PA, <i>n</i> = 1	25	74 mo
Sauerbier et al (2000)	AO wrist fusion plate, <i>n</i> = 30; 3.5-mm DCP, <i>n</i> = 30; all with ICBG	Post-traumatic, <i>n</i> = 45; Kienböck's disease, <i>n</i> = 6	60	37 (15–120 mo)
Voutilainen et al (2001)	Self-reinforcing poly-L-lactide bioabsorbable implants; distal ulna resection as BG	RA, <i>n</i> = 17; PA, <i>n</i> = 1	21	5.4 (3–8 y)
Masada et al (2003)	Intramedullary fixation with two K-wires with ICBG; distal ulna resection	RA	18	27 (13–68 mo)
De Smet and Truyen (2003)	Rayan (1986) technique: ICBG screw fixation, <i>n</i> = 24; AO/ASIF plate with ICBG, <i>n</i> = 12; Darrach procedure, <i>n</i> = 12	Post-traumatic, <i>n</i> = 35; Kienböck's disease, <i>n</i> = 6	36	7 (4–9 y)
Rauhaniemi et al (2005)	Mannerfelt and Malsten (1971), <i>n</i> = 113; Staples, <i>n</i> = 1; ICBG, <i>n</i> = 1, latter two as MC was too narrow Distal ulna resection in all cases Autograft (ICBG/ulna), <i>n</i> = 114	RA	115	4 (1–6 y)
Adey et al (2005)	Weiss and Hastings (1995): plate, 20 cases (DCP, <i>n</i> = 17; wrist fusion plate, <i>n</i> = 3; Synthes, Paoli, PA); screw arthrodesis, <i>n</i> = 2 Autograft (ICBG/ulna) in all cases	OA (post-traumatic)	22	6 (1.5–15 y)
Solem et al (2006)	Mannerfelt and Malsten (1971) technique, <i>n</i> = 21; plate, <i>n</i> = 21 (AO plate, <i>n</i> = 11; Synthes plate, <i>n</i> = 9) BG in most cases	RA, <i>n</i> = 34; PA, <i>n</i> = 1; Post-traumatic, <i>n</i> = 1; Kienböck's disease, <i>n</i> = 3; Unspecified, <i>n</i> = 1	42	10.5 (6–15 y)
Toma et al (2007)	Mannerfelt and Malsten (1971) technique, <i>n</i> = 19; AO plate, <i>n</i> = 23 Distal ulna resection, <i>n</i> = 28/42 Autograft 40/42, allograft 2/42	RA	42	76 (24–210 mo)
Lautenbach et al (2013)	Rush pin (modified from Mannerfelt and Malmsten 1971) No BG	RA	34	34 ± 28 mo
Fontaine et al (2014)	Rush pin and ICBG (modified from Lee and Carroll 1994) Distal ulna resection	RA	6	2.1 (1.5–3.6 y)
Onuma et al (2015)	Wrist fusion rod (Nakashima Medical, Okayama, Japan) Distal ulna excision as BG	RA	6	6 (2–9.2 y)
Owen et al (2016)	Wrist fusion plate (DePuy Synthes International; Leeds; United Kingdom) either with ICBG or distal ulna resection if DRUJ disease for BG	RA, <i>n</i> = 24; PA, <i>n</i> = 1; Post-traumatic, <i>n</i> = 38; Kienböck's, <i>n</i> = 3; Other, <i>n</i> = 2	68	Median: 6 y (IQR: 3–11)
Riches et al (2016)	Not defined	RA	16	3.5 (SD: ± 2 y)
Murphy et al (2003)	Dorsal wrist plate, 83%; other pin/rod fixation Autograft in most cases	RA	24	48 ± 25 mo
Nydick et al (2013)	Synthes wrist fusion plate (Synthes, West Chester, PA)	OA (post-traumatic)	15	68 ± 36 mo
		Total	669	

Abbreviations: AO, Arbeitsgemeinschaft für Osteosynthesefragen; BG, bone graft; DCP, dynamic compression plate; DRUJ, distal radioulnar joint; ICBG, iliac crest bone graft; IQR, interquartile range; K-wire, Kirschner wire; MC, metacarpal; PA, psoriatic arthritis; RA, rheumatoid arthritis; SD, standard deviation.

Table 3 A summary of the different wrist arthroplasty implants used in the studies included in the systematic review

Study	Wrist arthroplasty implant	Underlying pathology	Generation of implant	Number of index procedures	Length of follow-up (range)
Menon (1987)	Volz (Howmedica, Rutherford, NJ)	RA, $n = 14$; PA, $n = 1$; OA, $n = 1$	Second	18	40 (24–66 mo)
Menon (1988)	Universal (Kinetikos Medical, San Diego, CA)	RA, $n = 23$; OA, $n = 8$	Third	37	79.4 (48–120 mo)
Figgie et al (1990)	Trispherical	RA	Third	35	9 (5–11 y)
Meuli and Fernandez (1995)	MWP II Meuli	RA, $n = 33$; Post-traumatic, $n = 12$	Second	49	4.5 (2–6 y)
Gellman et al (1997)	Volz (Howmedica)	RA, $n = 12$; PA, $n = 1$; Post-traumatic, $n = 1$	Second	14	6.5 (3.5–11.5 y)
Takwale et al (2002)	Biaxial (DePuy Orthopaedics Inc, Leeds, United Kingdom)	RA	Third	66	52 (12–99 mo)
Divelbiss et al (2002)	Universal (Kinetikos Medical)	RA	Third	22	1–2 y
Levadoux and Legré (2003)	Destot	OA (post-traumatic)	Third	28	47 (12–72 mo)
Rahimtoola and Rosing (2003)	RWS (Howmedica, Pfizer Hospital Products Group)	RA, $n = 24$; PA, $n = 1$; OA, $n = 2$	Second	27	4 (2–8 y)
Radmer et al (2003)	APH (Implant-Service Vertriebs-GmbH, Hamburg, Germany)	Seropositive RA, $n = 36$; seronegative RA, $n = 4$	Third	40	52 (24–73 mo)
Ward et al (2011)	Universal (KMI, Carlsbad, CA)	RA	Third	19	7.3 (5–10.8 y)
Reigstad et al (2011)	Motec (Elos Medical AB, Timmersdala, Sweden)	Post-traumatic arthritis including SLAC/SNAC	Second	8	7.6 (7–9 y)
Ferrerres et al (2011)	Universal 2 (Integra Life-sciences, Plainsboro, NJ), $n = 19$	Inflammatory including RA, $n = 15$; Psoriatic, $n = 1$; and other, $n = 2$;	Fourth	21	5.5 (3–8 y)
	Universal (KMI), $n = 2$	Noninflammatory including Kienböck's disease, $n = 2$; other, $n = 2$	Third		
Krukhaug et al (2011)	Biaxial, $n = 90$ (80/90 uncemented) (DePuy, Warsaw, IN)	Inflammatory (RA, PA), $n = 116$; Noninflammatory (OA, post-traumatic, ligamentous, post-infective), $n = 73$	Third	189	
	Elos, $n = 23$ (three versions preceding Gibbon, v1 = v2; v2 = 6; v3 = 15)		Third		
	Gibbon, $n = 76$ (Swemac, Linköping, Sweden, later called Motec)		Third		
Cooney et al (2012)	Biaxial, $n = 16$	RA, $n = 29$; Post-traumatic, $n = 10$	Third	46	6 (3.5–15 y)
	Re-Motion (Small Bone Innovations Inc., Morrisville, PA), $n = 22$		Fourth		
	Universal 2 $n = 8$		Fourth		
Ekroth et al (2012)	Biaxial, $n = 6$ (Biomet, Warsaw, IN)	RA	Third	12	17.8 (11.7–28.3 y)
	Volz, $n = 1$ (Stryker, Mahwah, NJ)		Second		
Bidwai et al (2013)	Re-Motion (Small Bone Innovations Inc.)	RA	Fourth	13	33 (14–56 mo)
Herzberg et al (2012)	Re-Motion (Small Bone Innovations Inc.)	RA, $n = 129$ (60%); Non-RA, $n = 86$ (40%)	Fourth	215	4 (2–8 y)
Boeckstyns et al (2013)	Re-Motion (Small Bone Innovations Inc.)	RA, $n = 50$; OA, $n = 6$; post-traumatic, $n = 8$; Kienböck's disease, $n = 1$	Fourth	52	6.5 (5–9 y)

Table 3 (Continued)

Study	Wrist arthroplasty implant	Underlying pathology	Generation of implant	Number of index procedures	Length of follow-up (range)
Sagerfors et al (2015)	Biaxial, <i>n</i> = 52 (DePuy Orthopedics, Warsaw, IN)	RA, <i>n</i> = 185; OA, <i>n</i> = 34	Third	219	7 (2–13 y)
	Universal 2 <i>n</i> = 12 (Integra Lifesciences)		Fourth		
	Re-Motion, <i>n</i> = 87 (Stryker, Kalamazoo, MI)		Fourth		
	Maestro, <i>n</i> = 68 (Biomet)		Fourth		
Badge et al (2016)	Universal 2 (Integra Lifesciences)	RA	Fourth	95	53 (24–120 mo)
Chevrollier et al (2016)	Universal, <i>n</i> = 10 (KMI)	RA, <i>n</i> = 6; Other, <i>n</i> = 1; Post-traumatic, <i>n</i> = 8; Kienbock's disease, <i>n</i> = 1, Post-septic, <i>n</i> = 1	Third	17	5.2 (1.1–10 y)
	Re-Motion, <i>n</i> = 7 (SBI, Morrisville, PA)		Fourth		
Gil et al (2017)	Universal 2 (Integra Lifesciences)	RA, <i>n</i> = 29; PA, <i>n</i> = 1; JIA, <i>n</i> = 1; Degenerative OA (including post-traumatic), <i>n</i> = 8	Fourth	39	9 (4.8–14.7 y)
Reigstad et al (2017)	Motec (Swemac Orthopaedics AB, Linköping, Sweden)	OA Degenerative	Second	56	8 (5–11 y)
Murphy et al (2003)	Universal (KMI)	RA	Third	27	26 ± 16 mo
Nydick et al (2013)	Maestro (Biomet)	OA (post-traumatic)	Fourth	7	56 ± 10 mo
			Total	1,371	

Abbreviations: JIA, juvenile idiopathic arthritis; OA, osteoarthritis; PA, psoriatic arthritis; RA, rheumatoid arthritis; SNAC, scaphoid nonunion advanced collapse; SLAC, scapholunate advanced collapse.

however, had a low risk of bias, and the reported outcome effect sizes were sufficient to qualify the studies as of moderate grade.^{3–5,12,13,15,26,30,31,49,51} The GRADE assessment is summarized in ►Appendix E.

Is There a Functional Benefit to Performing a Total Wrist Replacement Instead of a Total Wrist Fusion in Adult Patients with End-Stage Wrist Arthritis?

Functional outcomes were poorly reported across the studies, and often nonvalidated assessment tools were used. The DASH (Disabilities of the Arm, Shoulder and Hand) functional score (range 0–100, where 0 is good function and 100 is poor function) was most commonly used, a summary of which is presented in ►Tables 4 and 5.⁵³

In Sauerbier et al's study of wrist arthrodesis performed using either an AO wrist fusion plate or a conventional dynamic compression plate, 80% of patients reported difficulties with personal hygiene and 70% felt less capable.³ Patients with inflammatory arthritis, in particular polyarticular disease, had a higher/poorer DASH score compared with those with noninflammatory disease ($p = 0.005$).²⁵ A poorer DASH score has also been correlated with increased pain postoperatively ($r = 0.63$).²⁰ Riches et al using the M-SACRAH (Modified Score for the Assessment and Quantification of Chronic Rheumatic Affections of the Hands) score reported a significant improvement in the function, stiffness, and pain domains ($p < 0.001$) following arthrodesis.²⁶

Several arthroplasty studies reported a significant improvement in outcome scores following surgery (►Table 5).^{12,44,51} Sagerfors et al observed this improvement up to 5 years after surgery in outcome measures also including the Canadian Occupational Performance Measure (COPM) and patient-reported wrist evaluation (PRWE).¹³ In addition, Herzberg et al and Boeckstyns et al reported no statistically significant difference in the QuickDASH score for wrist arthroplasty performed in either rheumatoid or non-rheumatoid patients.^{12,52}

Is There Any Difference in Secondary Measures Including Pain, Grip Strength, and Range of Motion?

A statistically significant improvement in pain scores was seen in four arthrodesis studies (►Table 6),^{3,20,26,32} and five arthroplasty studies (►Table 7).^{12–14,45,50,51} Generally, post-operative scores across both arthrodesis and arthroplasty studies demonstrated a good level of pain control.

The general trend is for an improvement in grip strength. There was a statistically significant increase in only a few studies.^{12–14,31,51} The grip strength compared with the normal contralateral side in wrist arthrodesis ranges from 50 to 79% and in arthroplasty ranges from 58 to 72%.^{3,15,31,33,38} Reigstad et al noted an average increase from 20 kg preoperatively to 24 kg on average follow-up in their series of patients undergoing wrist arthroplasty.⁵¹ Following an arthrodesis, a good range of pronation (range:

Table 4 A summary of the DASH scores for the arthrodesis studies

Study	Arthrodesis technique	Preoperative DASH score	Postoperative DASH score (range)	Notes
Sauerbier et al (2000)	AO wrist fusion plate, <i>n</i> = 30; 3.5-mm DCP, <i>n</i> = 30		51.4	DASH part A (function) = 48.57 DASH part B (symptoms) = 61.03
De Smet and Truyen (2003)	Rayan (1986) technique: ICBG screw fixation, <i>n</i> = 24; AO/ASIF plate, <i>n</i> = 12		44 (SD: 22)	
Adey et al (2005)	DCP, <i>n</i> = 17, wrist fusion plate, <i>n</i> = 3 (Synthes, Paoli, PA); screw arthrodesis, <i>n</i> = 2		25 (4–43)	Poor correlation with pain (<i>r</i> = 0.36; <i>p</i> < 0.05)
Solem et al (2006)	Mannerfelt and Malsten (1971) technique, <i>n</i> = 21; plate, <i>n</i> = 21 (AO plate, <i>n</i> = 11; Synthes plate, <i>n</i> = 9)		Overall: 38 (2–75) Plate: 33 (5–57) Mannerfelt: 43 (2–75)	One fused wrist: 36 (2–75) Bilateral fused wrists: 42 (18–68) All scores nonsignificant
Lautenbach et al (2013)	Rush pin (Modified from Mannerfelt and Malmsten 1971)		63.3 ± 25.3	Good correlation with pain (<i>r</i> = 0.63)
Owen et al (2016)	Wrist fusion plate (Synthes, DePuy International, Leeds, United Kingdom)		Median at 6 y: 19 (IQR: 7–45)	Significant association of higher DASH with inflammatory arthritis (<i>p</i> = 0.005) PRWE at 6 y: 13 (IQR: 1–31)
Murphy et al (2003)	Wrist arthrodesis (dorsal wrist plate 83%; other pin/rod fixation) vs. arthroplasty (Universal, KMI, San Diego, CA)		No difference between arthrodesis and arthroplasty	No difference between groups for PRWE
Nydick et al (2013)	Synthes wrist fusion plate (Synthes, West Chester, PA) vs. arthroplasty (Maestro, Biomet, Warsaw, IN)		Arthrodesis: 38 Arthroplasty: 29	No difference between groups Note: PRWE significantly better for arthroplasty (<i>p</i> = 0.01)

Abbreviations: AO, Arbeitsgemeinschaft für Osteosynthesefragen; BG, bone graft; DASH, Disabilities of the Arm, Shoulder and Hand; DCP, dynamic compression plate; ICBG, iliac crest bone graft; IQR, interquartile range; PRWE, patient-reported wrist evaluation; SD, standard deviation.

Note: DASH scores are presented as the mean (range) unless otherwise stated. *r*: Pearson's correlation coefficient.

73–83 degrees) and supination (range: 68–71 degrees) is maintained (►Table 8).^{3,30,35} Only two studies reported a gain in range of motion to functional levels as reported by Palmer et al.⁵⁴ Levadoux and Legré, in their series of wrist arthroplasty with the Destot prosthesis, and Herzberg et al with use of the Re-Motion wrist in their nonrheumatoid patient subgroup.^{39,52}

Is There a Difference between Adverse Events and Treatment Failure?

Complications rates were higher in arthroplasty patients (range: 0.2–9.5%) than in arthrodesis patients (range: 0.1–6.1%) (►Table 9). This did not reach significance, however (*p* = 0.1). Subgroup analysis of the newer fourth-generation implants revealed a significantly lower complication rate (range: 0.1–2.9%) compared with second- and third-generation arthroplasty cases (range: 0.2–8.1%; *p* = 0.002). There was no significant difference in complication rates between arthrodesis and fourth-generation wrist arthroplasty (*p* = 0.06). Metalwork-related issues contributed to the majority of complications in the arthrodesis group. This included metalwork prominence requiring removal in 6.1%

of cases. Osteolysis was a major issue in wrist arthroplasty, typically on the carpal side (9.5%) rather than radial side (3.2%). This is less of an issue with more recent fourth-generation implants (carpal osteolysis: 1.2%; radial osteolysis: 0.7%).

If the study by Radmer et al was excluded from analysis, implant revision rates ranged from 3.5 to 52.6%, and the rate of conversion to arthrodesis ranged from 0 to 42.1% (►Table 10).⁴⁸ The former study demonstrated a 100% revision rate to arthrodesis.

Survival of Wrist Arthroplasty

Increasing data on implant survival are now available. Survival is defined as revision of the index procedure for any cause. ►Table 11 summarizes the latest figures. The worst performing implant appears to be the Biaxial, with survival as low as 50% in one study,¹⁰ although other studies have shown survival rates of 81 to 85% at 5 to 8 years^{13,43,49} and 78% at 12 years.¹³ The Motec metal on metal implant, used specifically in osteoarthritic patients, is performing at 86% survival at 10 years.⁵¹ The three other currently available implants are Universal 2 with 78% survival at 15 years,

Table 5 A summary of the DASH and QuickDASH scores for the arthroplasty studies

Study	Arthroplasty technique	Preoperative DASH score (range)	Postoperative DASH score (range)	Notes
Divelbiss et al (2002)	Universal	46	1 y: 32.1 ($p < 0.05$) 2 y: 22.4 (8 wrists)	Significant improvement at 1 y
Ward et al (2011)	Universal	62 (42–80)	Mean: 7.8 y Median: 40 (18–80)	
Reigstad et al (2011)	Motec		Mean 7.6 y Median: 10.3 (1.7–71.2)	
Cooney et al (2012)	Biaxial, $n = 16$ Re-Motion, $n = 22$ Universal 2, $n = 8$		Biaxial ($n = 8$) = 48 Re-Motion ($n = 16$) = 37 Universal 2 ($n = 7$) = 20	DASH scores not available for all cases No significant difference between implants ($p = 0.07$)
Ekroth et al (2012)	Biaxial, $n = 6$ Volz, $n = 1$		60.7	5/7 wrists revised to arthrodesis DASH for arthrodesis patients: 46.2
Herzberg et al (2012)	Re-Motion		% Improvement: rheumatoid, 20; nonrheumatoid, 21	No significant difference between rheumatoid and non-rheumatoid patients
Boeckstyns et al (2013)	Re-Motion	QuickDASH median: 58 (14–89)	QuickDASH median: 42 (0–84)	Significant improvement: $p = 0.001$
Sagerfors et al (2015)	Biaxial, $n = 52$ Universal 2, $n = 12$ Re-Motion, $n = 87$ Maestro, $n = 68$		Biaxial: 12.8 (–21.9 to 4.2) Universal 2: 13.7 (–27.1 to –6.2) Re-Motion: –12.3 (–25.5 to –1.4) Maestro: –16.8 (–29.5 to –5.3)	Scores reported are preoperative minus postoperative at 5 y (median and interquartile range) All changes significant at $p < 0.05$ PRWE and COPM also significant ($p < 0.05$)
Badge et al (2016)	Universal 2	QuickDASH ($n = 40$) = 61.3 (range: 16–91)	QuickDASH ($n = 59$) = 45.8 (0–89)	Significant improvement: $p < 0.001$ Wrightington wrist score also significant ($p < 0.001$)
Chevrollier et al (2016)	Universal, $n = 10$ Re-Motion, $n = 7$		QuickDASH = 29% (2.3–65.9%)	PRWE = 26% (range: 2–55.3%)
Reigstad et al (2017)	Motec	QuickDASH 39 (SD: 18)	25 (SD: 19)	$p < 0.05$

Abbreviations: COPM, Canadian Occupational Performance Measure; DASH, Disabilities of the Arm, Shoulder and Hand; PRWE, patient-reported wrist evaluation; SD, standard deviation.

Note: Scores are presented as the mean (range) unless otherwise stated.

Re-Motion with 94% survival at 8 years, and Maestro with a survival of 95% at 8 years.^{10,13,50}

Discussion

Over the recent years, there have been several new publications investigating total wrist arthrodesis and wrist arthroplasty including a new matched cohort study and data on newer fourth-generation arthroplasty implants. With the ongoing controversy on which may be the better treatment choice for end-stage wrist arthritis, an updated review may help support decision-making.

As with all systematic reviews, the synthesis of trends and patterns from the available data is dependent on the quality of the included articles. According to the GRADE assessment, the majority of articles in this review were low or very low

quality retrospective case series. There was also a high degree of heterogeneity in the included studies in terms of the underlying pathology, interventions, and outcome measures.

Functional outcome following surgery was assessed with many different instruments. Pre- and postoperative scores were rarely reported in the arthrodesis studies and demonstrated significant improvement in only one study.²⁶ There appeared to be no significant differences between arthrodesis techniques for functional outcomes.^{29,30} A higher DASH score suggesting poorer function was seen with inflammatory arthritis ($p = 0.005$)²⁵ and was associated with higher pain levels ($r = 0.63$).²⁰ Wrist arthrodesis patients experienced specific difficulties with certain activities such as carrying a heavy object, pushing open a heavy door (50%), and personal hygiene (80%).³

Table 6 A summary of the pre- and postoperative pain scores in the arthrodesis studies

Study	Arthrodesis technique	Preoperative pain score (mean unless otherwise stated)	Postoperative pain score (mean unless otherwise stated)	Pain score scale
Vicar and Burton (1986)	Millender and Nalebuff (1973) technique	Severe: 9 Moderate: 7 Mild: 3 None: 0	Severe: 0 Moderate: 0 Mild: 10 None: 22	
Lee and Carroll (1994)	Steinman pin and K-wire	2.6, rest; 3.1, activity	1.1 rest, 1.1 activity	1–4 severe
Sauerbier et al (2000)	AO wrist fusion plate or 3.5-mm DCP	58	16.5 ($p < 0.05$)	0–100 severe
Rauhaniemi et al (2005)	Mannerfelt and Malsten (1971); staples, $n = 1$; ICBG, $n = 1$	3.6	1 y: 1.3 (range: 1–4) ($p < 0.001$)	1–4 severe
Lautenbach et al (2013)	Mannerfelt and Malsten (1971)	7.9 (range: 0–10)	1.9 (range: 0–9) ($p < 0.01$)	0–10 severe
Onuma et al (2015)	Wrist fusion rod	8 ± 1.1	1 ± 0.9	0–10 severe
Riches et al (2016)	Not defined	90 ± 33	8 ± 12 ($p < 0.001$)	0–100 severe

Abbreviations: AO, Arbeitsgemeinschaft für Osteosynthesefragen; DCP, dynamic compression plate; ICBG, iliac crest bone graft; K-wire, Kirschner wire.

Note: The scale of the scoring system is given unless a Likert system was used.

Table 7 A summary of the pre- and postoperative pain scores in the arthroplasty studies

Study	Arthroplasty technique	Preoperative pain score (mean unless otherwise stated)	Postoperative pain score (mean unless otherwise stated)	Pain score scale
Rahimtoola and Rozing (2003)	RWS	Moderate or Severe: 22 Mild: 4 Occasional: 1	Mild or Occasional: 10 Significant improvement ($p < 0.002$)	
Cooney et al (2012)	Biaxial, $n = 16$ Re-Motion, $n = 22$ Universal 2, $n = 8$	7	2.3	0–10 severe
Boeckstyns et al (2013)	Re-Motion	67 (SD: 17)	27 (SD: 29) ($p = 0.001$)	0–100 severe
Sagerfors et al (2015)	Biaxial, $n = 52$ Universal 2, $n = 12$ Re-Motion, $n = 87$ Maestro, $n = 68$		Significant improvement at rest and activity at 5 y ($p < 0.05$)	0–10 severe
Badge et al (2016)	Universal 2	8.1 (range: 3–10)	5.4 (range: 0–10) ($p < 0.001$)	0–10 severe
Gil et al (2017)	Universal 2	8.6 ± 1.2	0.4 ± 0.8 ($p < 0.001$)	0–10 severe
Reigstad et al (2017)	Motec	Radially rest: 34 (SD: 23) Active: 69 (SD: 20)	Radially rest: 8 (SD: 14) Active: 20 (SD: 22) ($p < 0.05$)	0–100 severe

Abbreviation: SD, standard deviation.

Note: The scale of the scoring system is given unless a Likert system was used.

A significant improvement in function following wrist arthroplasty was noted in several studies.^{12–14,44,51} Sagerfors et al compared several different wrist implants in a large study of 189 patients (219 index operations) with a mean follow-up of 7 years (range: 2–13).¹³ This included Universal 2, Re-Motion, Maestro, and Biaxial, all but the last being currently available. All implants demonstrated a significant

improvement in function with the DASH, PRWE, and COPM tools at 5 years. There was no significant difference between the implant types. This was also reflected by Cooney et al reviewing the Biaxial, Re-Motion and Universal 2 wrist replacements in 39 patients at 6 years (range: 3.5–15).¹⁰

Two studies provided a direct comparison between wrist arthrodesis and wrist arthroplasty in retrospective matched

Table 8 A summary of the range of motion (all measures in degrees)

Study	Technique	Flexion	Extension	Radial deviation	Ulna deviation	Pronation	Supination	Total active range
Vicar and Burton (1986)	Millender and Nalebuff (1973) technique	–	–	–	–	77 (30–90)	68 (10–90)	–
Sauerbier et al (2000)	AO wrist fusion plate or 3.5-mm DCP	–	–	–	–	83	71	–
Toma et al (2007)	Mannerfelt and Malsten (1971) technique or AO plate	–	–	–	–	73 (45–90)	70 (40–90)	–
Menon (1987)	Volz	50.3 (15–80)	24.7 (–80 to 50)	–0.4 (–22 to 20)	20.3 (0–35)	–	–	–
Menon (1988)	Universal	41 (SD: 15)^a	36 (SD: 16)	–	–	–	–	–
Figgie et al (1990)	Tri-spherical	–	–	10 (0–15)	10 (0–15)	–	–	F/E arc: 50 (0–105)
Meuli and Fernandez (1995)	MWP II Meuli	30 (10–70)	40 (20–70)	10 (0–20)	10 (0–30)	85 (70–90)	85 (75–90)	–
Gellman et al (1997)	Volz	18.2 (0–40) 10.3 (0–25)	10.3 (0–25)	7.8 (0–25)	13.2 (5–45)	–	–	F/E arc: 26.6 (10–55)
Takwale et al (2002)	Biaxial	17.4	28.8	6	13	–	–	43.5
Divebiss et al (2002)	Universal	41^b	35^b	9	19	88^b	80^b	–
Levadoux and Legré (2003)	Destot	48 (10–70)	41 (30–50)	12 (5–20)	22 (10–30)	90	(50–90)	–
Rahimtoola and Rozing (2003)	RWS	35 (0–80; SD: 17)^a	24 (0–45; SD: 15)^a	10 (–15 to 45; SD: 12)^a	15 (–10 to 45; SD: 13)	83 (35–90; SD: 15)	57 (10–90; SD: 26)	60
Radmer et al (2003)	APH	5 (–10 to 20, SD: 9)	10 (0–30, SD: 4)	–20 (–30 to –5, SD: 7)	25 (10–35, SD: 5)	80 (75–90, SD: 4)	75 (50–85, SD: 6)	–
Ward et al (2011)	Universal	42 (30–55)	20 (–20–45)	8 (0–35)	17 (–20–32)	83 (60–90)^b	71 (40–90)	F/E arc: 62 (30–90)
Reigstad et al (2011)	Motec	–	–	–	–	–	–	F/E/R/U: 125 (100–48)
Ferreres et al (2011)	Universal 2 (Universal, <i>n</i> = 2)	42 (SD: 10)	26 (SD: 14)	1 (SD: 7)	26 (SD: 9)	–	–	F/E arc: 68
Cooney et al (2012)	Biaxial Re-Motion Universal 2	30	38	8	20	75	70	–
Ekroth et al (2012)	Biaxial Volz	–	–	–	–	–	–	P/S arc: 133.5
Bidwai et al (2013)	Re-Motion	22.5	34.5	6.81	15.46	–	–	F/E arc: 47.44
Herzberg et al (2012)	Re-Motion	Rheumatoid: 29 Nonrheumatoid: 37	29 36	5 10	24 28	–	–	–
Boeckstyns et al (2013)	Re-Motion	29 (SD: 19)	31 (SD: 18)	6 (SD: 8)	22 (SD: 14)^b	81 (SD: 11)	83 (SD: 12)^b	–
Sagerfors et al (2015)	Biaxial Universal 2 Re-Motion Maestro	No significant improvement.	Significant improvement for Biaxial and Maestro only	Significant improvement for Maestro only	Significant improvement for Maestro and Re-Motion	Significant improvement for Biaxial	Significant improvement for Re-Motion	–
Badge et al (2016)	Universal 2	30.7 (0–50)^a	29.1 (0–70)^b	4 (–10–15)	14.2 (0–30)	81.5 (45–90)	76.1 (20–90)	–
Chevrollier et al (2016)	Universal Re-Motion	–	–	–	–	–	–	F/E arc: 33 (18–57)
Gil et al (2017)	Universal 2	37 (SD: 14)	29 (SD: 13)	–	–	–	–	–
Reigstad et al (2017)	Motec	–	–	–	–	83 (SD: 7)	83 (SD: 11)	126 (SD: 37)^b

Abbreviations: F/E, flexion–extension; P/S, pronation–supination; R/U, radial–ulna; SD, standard deviation.

Note: Figures in bold represent significant post-operative improvement in range.

^a*p* < 0.001.^b*p* < 0.05.

Table 9 Specific complication rates (results given in percentage)

Complication	Arthrodesis (total cases: 669)	All arthroplasty (total cases: 1,371)	Second- and third-generation prosthesis (total cases: 720)	Fourth-generation prosthesis (total cases: 651)
Fracture	0.1	1	0.6	0.4
Nerve problems	2.7	1.1	0.9	0.2
CRPS	0.1	0.2	0.2	–
Wound problems	2.1	1.4	1.1	0.3
Superficial infection	0.7	0.7	0.5	0.3
Deep infection	0.9	1.6	1.4	0.1
Tendon problems	1.8	1.2	0.7	0.5
Impingement	1.4	1.6	1.5	0.1
Stiffness	0.1	1.4	0.4	1
Metalwork prominence	2.3	–	–	–
Metalwork breakage	1.4	0.4	0.4	–
Metalwork removal	6.1	–	–	–
Instability	–	1.5	1.5	–
Dislocation	–	2.4	2.1	0.3
Radiological				
Failure of arthrodesis	2.6	–	–	–
Radial osteolysis	–	3.2	2.4	0.7
Carpal/metacarpal osteolysis	3.7	9.5	8.1	1.2
General osteolysis	0.9	8.2	5.5	2.9
Implant migration	0.6	1.7	1.7	–
Other (e.g., screw loosening, malalignment, polyethylene liner wear)	–	2.4	2.3	0.4
Range	0.1–6.1% ^{a,b}	0.2–9.5% ^a	0.2–8.1% ^c	0.1–2.9% ^{b,c}
Total	28%	31%	47%	13%

Abbreviation: CRPS, chronic regional pain syndrome.

^aMann–Whitney *U* test: no significant difference ($p = 0.1$) between arthrodesis and arthroplasty.

^bMann–Whitney *U* test: no significant difference ($p = 0.06$) between arthrodesis and fourth-generation implants.

^cMann–Whitney *U* test: significant difference ($p = 0.002$) between second- and third-generation implants and fourth-generation implants.

cohort studies.^{4,5} Only Nydick et al found a significant difference between the two interventions and only with the PRWE score.⁴ Following wrist arthroplasty, patients were better able to perform certain activities including cutting meat with a knife, personal activities, and household work. While the strength of this study is limited by the small numbers of patients, it is one of only two studies to compare arthrodesis and arthroplasty directly.

Although pain scores significantly improve following both interventions, patients often do not have complete pain relief, and pain scores are higher with activity.^{9,13,28,38,51} The perceived advantage of wrist arthroplasty over arthrodesis is maintenance of range of motion. The reported range following arthroplasty varied widely across studies and only significantly improved following surgery in a few. This included the Universal and Universal 2 implants, RWS, Maestro, and Re-Motion.^{13,14,44,45} This was not consistent

in all motion planes and only reached the functional range defined by Palmer et al with the Destot prosthesis and the Re-Motion prosthesis.^{39,52,54} Satisfaction rates have been studied in more detail by Cavaliere and Chung and were high for both interventions (arthroplasty 91% vs. arthrodesis 93%).⁶

The complication profile between the two intervention groups differed in this review. These were generally higher for arthroplasty cases compared with arthrodesis; however, the difference was not significant (range: 0.2–9.5 vs. 0.1–6.1%; $p = 0.1$). Newer fourth-generation implants appeared to have lower complication rates (range: 0.1–2.9%). This difference was significant when the complication rates of second- and third-generation implants (range: 0.2–8.1%) were compared with fourth-generation implants (0.1–2.9%; $p = 0.002$). This is also reflected in other studies.⁶ The main complication experienced with arthrodesis procedures was metalwork issues such as prominence (2.3%).

Table 10 Revision rates and conversion to arthrodesis rates for arthroplasty

Study	Implant	Implant generation	Revision rate (%)	Conversion to arthrodesis (%)	Length of follow-up
Menon (1987)	Volz	Second	33	0	40 (24–66 mo)
Menon (1988)	Universal	Third	26	5.4	79.4 (48–120 mo)
Figgie et al (1990)	Trispherical	Third	5.7	5.7	9 (5–11 y)
Meuli and Fernandez (1995)	MWP II Meuli	Second	18	12.2	4.5 (2–6 y)
Gellman et al (1997)	Volz	Second	13.3	7.1	6.5 (3.5–11.5 y)
Takwale et al (2002)	Biaxial	Third	7.6	4.5	52 (12–99 mo)
Divelbiss et al (2002)	Universal	Third	18.2	4.5	1–2 y
Levadoux and Legré (2003)	Destot	Third	14.3	14.3	47 (12–72 mo)
Rahimtoola and Rozing (2003)	RWS	Second	3.7	3.7	4 (2–8 y)
Radmer et al (2003)	APH	Third	100	100	52 (24–73 mo)
Ward et al (2011)	Universal	Third	52.6	42.1	7.3 (5–10.8 y)
Reigstad et al (2011)	Motec	Second	37.5	25	7.6 (7–9 y)
Ferreres et al (2011)	Universal 2, <i>n</i> = 19 Universal, <i>n</i> = 2	Fourth	4.8	0	5.5 (3–8 y)
Krukhaug et al (2011)	Biaxial, <i>n</i> = 90 (80/90 uncemented)	Third	21 (Elos = 10; Gibbon = 11; Biaxial = 18)	0	
	Elos, <i>n</i> = 23	Third			
	Gibbon, <i>n</i> = 76	Third			
Cooney et al (2012)	Biaxial, <i>n</i> = 16	Third	19.6 (Biaxial = 8; Universal 2 = 1)	13	6 (3.5 - 15 y)
	Re-Motion, <i>n</i> = 22	Fourth			
	Universal 2, <i>n</i> = 8	Fourth			
Ekroth et al (2012)	Biaxial, <i>n</i> = 6	Third	41.7	41.7	17.8 (11.7–28.3 y)
	Volz, <i>n</i> = 1	Second			
Reigstad et al (2011)	Motec	Second	6.7	6.7	3.2 (1.1–6.1 y)
Bidwai et al (2013)	Re-Motion	Fourth	7.7	0	33 (14–56 mo)
Herzberg et al (2012)	Re-Motion	Third	5.1	2.3	4 (2–8 y)
Boeckstyns et al (2013)	Re-Motion	Fourth	9.6	5.8	6.5 (5–9 y)
Sagerfors et al (2015)	Biaxial, <i>n</i> = 52 Universal, 2 <i>n</i> = 12	Third Fourth	8.7	0	7 (2–13 y)
	Re-Motion, <i>n</i> = 87	Fourth			
	Maestro, <i>n</i> = 68	Fourth			
Badge et al (2016)	Universal 2	Fourth	3.5	3.5	53 (24–120 mo)
Chevrollier et al (2016)	Universal, <i>n</i> = 10	Third	23.5	17.6	5.2 (1.1–10 y)
	Re-Motion, <i>n</i> = 7	Fourth			
Gil et al (2017)	Universal 2	Fourth	7.7	0	9 (4.8–14.7 y)
Reigstad et al (2017)	Motec	Second	14.2	7.1	8 (5–11 y)
Murphy et al (2003)	Universal	Third	3.7	3.7	26 ± 16 mo
Nydick et al (2013)	Maestro	Fourth	14.3	14.3	56 ± 10 mo
		Range ^a	3.5–52.6% ^a	0–42.1% ^a	

^aExcluding Radmer et al (2003).

Table 11 Implant survival

Study	Implant	Survival	
Takwale et al (2002)	Biaxial	83% at 8 y	
Krukhaug et al (2011)		85% at 5 y	
Cooney et al (2012)		50% at 6 y	
Sagerfors et al (2015)		81% at 8 y	78% at 12 y
Levadoux and Légré (2003)	Destot	85% 4 y	
Radmer et al (2003)	APH	100% failure at 52 mo (range: 24–73)	
Krukhaug et al (2011)	Elos	57% at 5 y	
Krukhaug et al (2011)	Gibbon	77% at 4 y	
Ward et al (2011)	Universal	75% at 5 y	60% at 7 y
Chevrollier et al (2016)		90% at 5 y	50% at 10 y
Cooney et al (2012)	Universal 2	97% at 6 y	
Badge et al (2016)		91% at 7.8 y	
Gil et al (2017)		78% at 15 y	
Cooney et al (2012)	Re-Motion	97% at 6 y	
Herzberg et al (2012)		92% at 8 y	
Boeckstyns et al (2013)		92% at 8 y	
Sagerfors et al (2015)		99% at 5 y	94% at 8 y (est)
Chevrollier et al (2016)		100% at 6 y	
Sagerfors et al (2015)	Maestro	95% at 8 y	
Reigstad et al (2017)	Motec	86% at 10 y	

Overall, metalwork removal was required in 6.1% of cases. Carpal and metacarpal osteolysis was also common (3.7%), especially with the Mannerfelt and Malsten technique.³²

Carpal and metacarpal osteolysis and lucency have been major issues with arthroplasty procedures (9.5%) also. This was seen in many studies as well as in registry data from both Norwegian and Australian registers.^{49,55} Our findings suggest that this appears to be improving with the newer fourth-generation implants (1.2%), which tend to have porous coatings to encourage osseointegration.^{13,40,43,46} One of the reasons behind the high carpal osteolysis rates has been attributed to nonunion at the third carpometacarpal joint, which may increase stress transfer to the carpal component of the prosthesis. Intercarpal fusion to limit this was initially proposed by Menon and subsequently adopted by several others.^{37–39,42,51}

Dislocation has been well documented in second- and third-generation implants including Volz, Universal, and Biaxial.^{41–44} The articular bearing shape of the Universal was modified from a toroidal to an ellipsoidal shape in the Universal 2 to counteract this problem.⁵⁶ Better soft tissue balancing and capsular repair techniques have also helped improve stability.⁴⁴

Of the current commercially available implants, the latest survival data are 86% at 10 years for Motec,⁵¹ 78% at 15 years for Universal 2,⁵⁰ 90% at 9 years for Re-Motion,¹² and 95% at 8 years for Maestro.¹³ Radiographic evidence of carpal component subsidence and carpal malalignment has been linked

to earlier revision.^{43,57} National joint registry data from Norway have found no association between the survival of wrist implants and the underlying etiology (Biaxial, Elos, and Gibbon prostheses).⁴⁹ Sagerfors et al also had similar findings.¹³

In conclusion, wrist arthroplasty has evolved considerably from the first-generation implants to current prostheses that appear to have better survival and lower complication profiles. Patients are experiencing improvement in physical function, satisfaction, pain control, and grip strength. Furthermore, wrist arthroplasty is maintaining range of motion, although this was not always significant or reaching predefined functional ranges. One aspect not answered in this review is whether current wrist arthroplasty systems would be suitable in the younger, more active patient. Some data does exist; however, this was not sufficient to reach a general consensus.⁵¹ Wrist arthrodesis remains a good option for patients with either inflammatory or noninflammatory wrist arthritis and is well established. Patients must be well informed about the risks and benefits of wrist arthroplasty compared with wrist arthrodesis to enable informed decision-making before embarking on any surgery.

Conflict of Interest
None.

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Appendix A OVID Medline search strategy (dates: 1946 to January 20, 2018)

1	exp Arthritis/
2	arthri*.ti,ab.
3	Osteoarthritis/
4	osteoarthr*.ti,ab.
5	\$arthri*.ti,ab.
6	(inflam* adj3 joint*).ti,ab.
7	1 or 2 or 3 or 4 or 5 or 6
8	Wrist/
9	Wrist Injuries/
10	Wrist Joint/
11	wrist*.ti,ab.
12	exp Carpal Bones/
13	carpal.ti,ab.
14	scaphoid*.ti,ab.
15	lunate.ti,ab.
16	triquetrum.ti,ab.
17	pisiform.ti,ab.
18	trapezium.ti,ab.
19	trapezoid*.ti,ab.
20	capitate.ti,ab.
21	hamate.ti,ab.
22	8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21
23	7 and 22
24	arthroplasty/ or arthroplasty, replacement/
25	replac*.ti,ab.
26	exp "Prostheses and Implants"/
27	Joint Prosthesis/
28	prosthe*.ti,ab.
29	24 or 25 or 26 or 27 or 28
30	Arthrodesis/
31	arthrodes*.ti,ab.
32	fusion*.ti,ab.
33	30 or 31 or 32
34	23 and 29 and 33

Appendix B OVID EMBASE search strategy (dates: 1974 to January 20, 2018)

1	exp arthropathy/
2	exp arthritis/
3	arthr*.ti,ab.
4	exp osteoarthritis/
5	osteoarthr*.ti,ab.
6	\$arthr*.ti,ab.
7	exp wrist injury/
8	1 or 2 or 3 or 4 or 5 or 6 or 7
9	exp wrist/
10	wrist.ti,ab.
11	exp carpal bone/
12	carpal.ti,ab.
13	scaphoid*.ti,ab.
14	lunate.ti,ab.
15	triquetrum.ti,ab.
16	pisiform.ti,ab.
17	trapezium.ti,ab.
18	trapezoid*.ti,ab.
19	capitate.ti,ab.
20	hamate.ti,ab.
21	9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20
22	8 and 21
23	exp arthroplasty/
24	arthroplasty.ti,ab.
25	exp joint prosthesis/
26	prosthe*.ti,ab.
27	replac*.ti,ab.
28	23 or 24 or 25 or 26 or 27
29	arthrodesis/
30	arthrodes*.ti,ab.
31	fusion.ti,ab.
32	29 or 30 or 31
33	22 and 28 and 32

Appendix C CINAHL search strategy (dates: 1981 to January 20, 2018)

1	exp *ARTHRITIS/
2	(arthr*).ti,ab
3	exp *OSTEOARTHRITIS/
4	(osteoarthr*).ti,ab
5	(inflamm* ADJ3 joint).ti,ab
6	**"WRIST INJURIES"/
7	exp *WRIST/
8	exp **"WRIST JOINT"/
9	"CARPAL BONES"/
10	(carpal).ti,ab
11	exp **"ARTHROPLASTY, REPLACEMENT"/
12	(replac*).ti,ab
13	exp **"ORTHOPEDIC PROSTHESIS"/
14	(prosth*).ti,ab
15	exp *ARTHRODESIS/
16	(arthrodes*).ti,ab
17	(fusion).ti,ab
18	(1 OR 2 OR 3 OR 4 OR 5 OR 8)
19	(6 OR 7 OR 9 OR 10)
20	(11 OR 12 OR 13 OR 14)
21	(15 OR 16 OR 17)
22	(18 AND 19 AND 20 AND 21)

Appendix D BNI search strategy (dates: 1992 to January 20, 2018)

1	exp "ARTHRITIS AND RHEUMATISM"/
2	(arthri*).ti,ab
3	(osteoarthr*).ti,ab
4	exp "JOINT DISORDERS"/
5	(wrist).ti,ab
6	(arthroplasty).ti,ab
7	(replacement).ti,ab
8	(prosthesis).ti,ab
9	(arthrodesis).ti,ab
10	(arthrodes*).ti,ab
11	(fusion).ti,ab
12	(1 OR 2 OR 3 OR 5)
13	(6 OR 7 OR 8)
14	(9 OR 10 OR 11)
15	(4 AND 12 AND 13 AND 14)

Appendix E A summary of the quality of evidence of articles included in this systematic review (grading according to the GRADE system¹⁹)

Arthrodesis study	Grade of evidence	Arthroplasty study	Grade of evidence
Brumfield et al (1979)	VL	Menon (1987)	VL
Vahvanen and Tallroth (1984)	VL	Menon (1988)	VL
Vicar and Burton (1986)	VL	Figgie et al (1990)	VL
Lee and Carroll (1994)	VL	Meuli and Fernandez (1995)	VL
Sauerbier et al (2000)	M	Gellman et al (1997)	VL
Voutilainen et al (2001)	L	Takwale et al (2002)	L
Masada et al (2003)	VL	Divelbiss et al (2002)	VL
De Smet and Truyen (2003)	M	Levadoux and Legré (2003)	VL
Rauhaniemi et al (2005)	VL	Rahimtoola and Rozing (2003)	L
Adey et al (2005)	VL	Radmer et al (2003)	L
Solem et al (2006)	VL	Ward et al (2011)	L
Toma et al (2007)	M	Reigstad et al (2011)	VL
Lautenbach et al (2013)	L	Ferreres et al (2011)	L
Fontaine et al (2014)	L	Krukhaug et al (2011)	M
Onuma et al (2015)	L	Cooney et al (2012)	VL
Owen et al (2016)	L	Ekroth et al (2012)	VL
Riches et al (2016)	M	Bidwai et al (2013)	VL
		Herzberg et al (2012)	L
		Boeckstyns et al (2013)	M
		Sagerfors et al (2015)	M
		Badge et al (2016)	VL
		Chevrollier et al (2016)	M
		Gil et al (2017)	VL
		Reigstad et al (2017)	M
		Murphy et al (2003)	M
		Nydick et al (2013)	M

Abbreviations: L, low; M, medium; VL, very low.