■ SYSTEMATIC REVIEW

Total elbow arthroplasty in patients with rheumatoid arthritis

A SYSTEMATIC REVIEW AND META-ANALYSIS

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Aims

The aims of this study were to validate the outcome of total elbow arthroplasty (TEA) in patients with rheumatoid arthritis (RA), and to identify factors that affect the outcome.

Methods

We searched PubMed, MEDLINE, Cochrane Reviews, and Embase from between January 2003 and March 2019. The primary aim was to determine the implant failure rate, the mode of failure, and risk factors predisposing to failure. A secondary aim was to identify the overall complication rate, associated risk factors, and clinical performance. A meta-regression analysis was completed to identify the association between each parameter with the outcome.

Results

A total of 38 studies including 2,118 TEAs were included in the study. The mean follow-up was 80.9 months (8.2 to 156). The implant failure and complication rates were 16.1% (95% confidence interval (CI) 0.128 to 0.200) and 24.5% (95% CI 0.203 to 0.293), respectively. Aseptic loosening was the most common mode of failure (9.5%; 95% CI 0.071 to 0.124). The mean postoperative ranges of motion (ROMs) were: flexion 131.5° (124.2° to 138.8°), extension 29.3° (26.8° to 31.9°), pronation 74.0° (67.8° to 80.2°), and supination 72.5° (69.5° to 75.5°), and the mean postoperative Mayo Elbow Performance Score (MEPS) was 89.3 (95% CI 86.9 to 91.6). The meta-regression analysis identified that younger patients and implants with an unlinked design correlated with higher failure rates. Younger patients were associated with increased complications, while female patients and an unlinked prosthesis were associated with aseptic loosening.

Conclusion

TEA continues to provide satisfactory results for patients with RA. However, it is associated with a substantially higher implant failure and complication rates compared with hip and knee arthroplasties. The patient's age, sex, and whether cemented fixation and unlinked prosthesis were used can influence the outcome.

Level of Evidence: Therapeutic Level IV.

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Introduction

Rheumatoid arthritis (RA) is the most common form of chronic inflammatory arthritis and affects about 1% of adults.[1] It is characterized by progressive, symmetrical arthritis involving many joints, most commonly the knee, wrist and interphalangeal joints.[2] The elbow is affected in between 20% and 65% of patients, often causing severe painful disability.[1] In patients with severe arthritis, many forms of treatment are available to relieve pain and improve function.[3,4] Total elbow arthroplasty (TEA) is commonly performed for end-stage arthritis.[4] However, TEA has inferior implant survival and higher complication rates compared with arthroplasties of other major joints.[6] This is usually thought to be due to the high risks associated with RA and the complex anatomy of the elbow joint.[7] Major improvements in the design and materials of TEA have been made in attempts at address these issues.[6] There are currently two major designs of TEA: a linked and an unlinked (semi-constrained and non-constrained) prosthesis. The unlinked design resembles the native elbow but requires intact surrounding ligamentous and soft tissue stabilizers to avoid devastating complications such as recurrent dislocation.[8]

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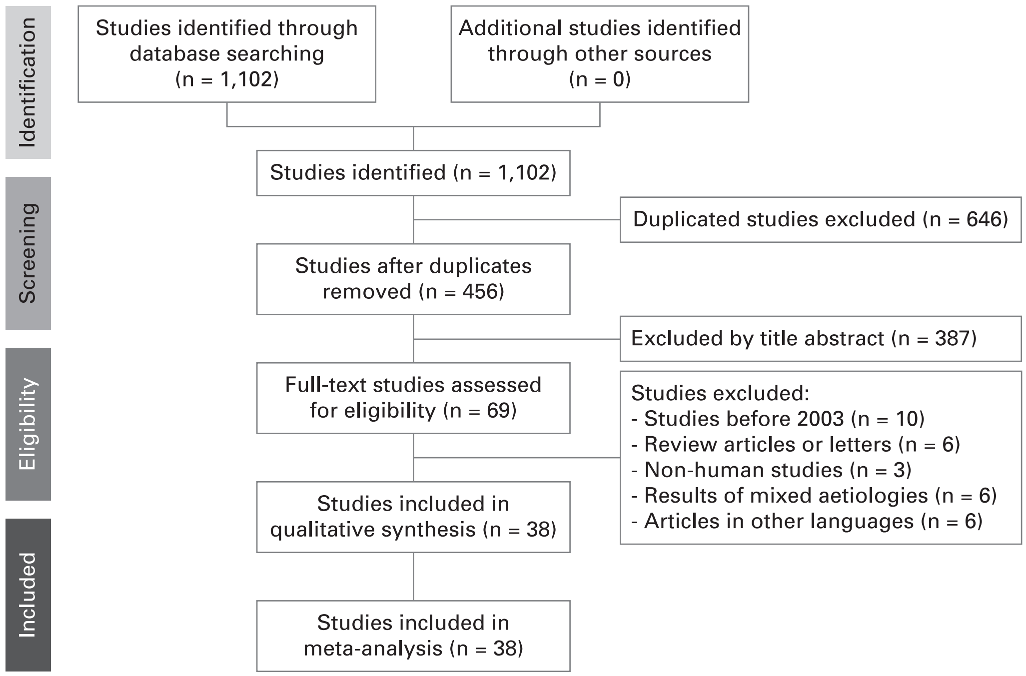

Fig. 1

Preferred reporting items for systematic reviews and meta-analysis (PRISMA) flowchart for the searching and identification of included studies.

On the other hand, the linked prosthesis allows for ligamentous deficiency, but has high rates of polyethylene (PE) wear secondary to the inherent stability.[9] A cemented technique was introduced in an attempt to reduce the incidence of loosening.[10] Most studies in the literature have focused on a single design, with only a few studies comparing different implants. Welsink et al[4] described the outcome of different TEA designs with emphasis on implant survival. However, the patients included those with many different aetiologies, including post-traumatic arthritis, osteoarthritis (OA), and RA. The risk factors associated with implant failure were also not discussed. Little et al[11] reported the results of TEA for studies completed before 2003. With recent advancements in the design of components and perioperative care, we aimed to provide an update on the overall outcome of TEA. Our main aim was to review the implant failure rate, complication rate, and functional performance of TEA in patients with RA, and to identify factors that affect the outcome.

Methods

A comprehensive search was completed on PubMed, MEDLINE, Cochrane Reviews, and Embase for studies evaluating TEA in patients with RA published between January 2003 and March 2019. The search was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. The following terms were used in variable combination: total elbow arthroplasty, total elbow replacement and rheumatoid arthritis. Two authors (TFC, SWT) independently conducted the searches and screened the titles and abstracts to identify relevant studies. The strategy is shown in Figure 1. If there was disagreement, a third author (HHM) was consulted and a consensus was obtained.

We identified original studies in English that presented data on patients with RA who had undergone TEA. We excluded studies before 2003, patients with other aetiologies, review articles, letters to the editor, expert opinion, and studies in which data were not obtainable. For studies in which different groups were compared (e.g. linked vs unlinked prosthesis), we analyzed each group separately if possible. If there was uncertainty regarding a study, we contacted the authors to clarify our concerns. If there was disagreement between the authors, a third author was consulted.

Two authors (TFC, SWT) examined all the identified studies and extracted data using a predetermined form. The primary aim was to determine the overall implant failure rate, failure mode, and risk factors predisposing to failure. A secondary aim was to validate the complication rate, identify associated risk factors, and assess the clinical performance. In this meta-analysis we recorded the first author, year of publication, study design, number of cases, age, length of follow-up, the type and design of the implant, the use of cement, and outcome parameters as shown in Table I. In order to determine the modes of failure, we recorded the rate of aseptic loosening, septic loosening, instability, bushing wear, axle failure, and implant fractures. We also recorded all complications, such as ulnar neuropathy, triceps injury, and infection, that are pertinent to TEA. A perioperative infection was defined based on the severity of the infection. A deep infection required a surgical procedure such as irrigation and debridement with retention of the implant. Aseptic loosening was defined as the most severe type of infection with

Table I. Characteristics of included studies.

Author, year	Study design	Number of TEA surgery	Mean age, yrs	Follow-up duration, mths	Implant type	Design	Cemented/ hybrid/ cementless	Outcome measurements			
								A*	B†	C‡	D§
Lo et al,[13] 2003	Case series	17	58	36	Coonrad-Morrey¶	Linked	Cemented	V	V	V	V
Potter et al,[14] 2003	Case series	2	60	74	Kudo type 5**	Unlinked	Cemented	V	V	N/A	N/A
Reinhard et al,[15] 2003	Case series	44	53	92.4	Kudo type 4††	Unlinked	Cementless	V	V	N/A	N/A
Samijo et al,[16] 2003	Case series	35	63	98.4	Souter-Strathclyde‡‡	Unlinked	Cemented	V	V	V	N/A
Van der Lugt et al,[17] 2004	Case series	204	61	76.8	Souter-Strathclyde‡‡	Unlinked	Cemented	V	V	V	N/A
Willems and De Smet,[18] 2004	Case series	24	57.5	58	Kudo type 4†† and 5**	Unlinked	Cemented	V	V	V	V
Khatri and Stirrat,[19] 2005	Case series	47	59	82	Souter-Strathclyde‡‡	Unlinked	Cemented	V	V	N/A	N/A
Lee,[20] 2005	Case series	8	55.5	39.4	Coonrad-Morrey¶	Linked	Cemented	V	V	V	V
Little,[21] 2005	Cohort study	33	63	61	Souter-Strathclyde‡‡	Unlinked	Cemented	V	V	V	N/A
		33	60	67	Kudo type 5**	Unlinked	Cemented	V	N/A	V	N/A
		33	65	68	Coonrad-Morrey¶	Linked	Cemented	V	N/A	V	N/A
Ovesen et al,[22] 2005	Case series	43	56	82.8	Capitello-Condylar§§	Unlinked	Cemented	V	V	V	V
Jensen et al,[23] 2006	Case series	20	64	60	GSB III prosthesis¶¶	Linked	Cemented	V	V	V	N/A
Landor et al,[24] 2006	Case series	45	53	114	Souter-Strathclyde‡‡	Unlinked	Cemented	V	V	V	N/A
Mori et al,[25] 2006	Case series	14	53.3	91	Kudo type 5**	Unlinked	2 cemented, 10 hybrid, 2 cementless	V	V	V	V
Rauhaniemi et al,[26] 2006	Case series	28	58	58	Kudo type 5**	Unlinked	3 cemented, 25 hybrid	V	V	N/A	N/A
Thillemann et al,[27] 2006	Case series	17	60	114	Kudo type 3***	Unlinked	Cemented	V	V	V	V
Brinkman et al,[28] 2007	Case series	49	56	72	Kudo type 5**	Unlinked	Cementless	V	V	V	N/A
Cesar et al,[29] 2007	Case series	44	56	74	GSB III prosthesis¶¶	Linked	Cemented	V	V	V	N/A
Skyttä et al,[30] 2008	Cohort study	21	59	129.6	Souter-Strathclyde‡‡	Unlinked	Cemented	V	V	V	N/A
	Cohort study	21	62	81.6	Kudo type 5**	Unlinked	Cemented	V	V	V	N/A
Tachihara et al,[31] 2008	Cohort study	34	60	55.7	JACE†††	Unlinked	16 cemented, 18 cementless	V	V	V	N/A
	Cohort study	13	61	59.5	STABLE prosthesis‡‡‡	Unlinked	11 cemented, 2 cementless	V	V	V	N/A
	Cohort study	32	63	28.2	Kudo type 5**	Unlinked	17 cemented, 15 cementless	V	V	V	N/A
Amirfeyz and Blewitt,[32] 2009	Cohort study	31	67	53	GSB III prosthesis¶¶	Linked	Cemented	V	V	V	V
Kleinlugtenbelt et al,[33] 2010	Case series	20	62	49	iBP‡‡‡	Unlinked	Hybrid	V	V	V	V
Prasad and Dent,[34] 2010	Cohort study	44	60	108	Souter-Strathclyde‡‡	Unlinked	Cemented	V	V	N/A	N/A
	Cohort study	55	62	60	Coonrad-Morrey¶	Linked	Cemented	V	V	N/A	N/A
Qureshi et al,[35] 2010	Case series	22	56	142.8	Kudo type 5**	Unlinked	Cemented	V	V	V	V
Ishii et al,[36] 2012	Case series	35	66	75.6	GSB III prosthesis¶¶	Linked	Cemented	V	V	N/A	N/A

Continued

Table I. Continued

Author, year	Study design	Number of TEA surgery	Mean age, yrs	Follow-up duration, mths	Implant type	Design	Cemented/ hybrid/ cementless	Outcome measurements			
Nishida et al,[37] 2014	Case series	54	59	151.2	Stemmed Kyocera type I****	Unlinked	Cemented	V	V	V	V
Nishida et al,[38] 2014	Case series	17	64	47.7	PROSNAP elbow prosthesis§§§	Linked	Cemented	V	V	V	N/A
Mukka et al,[39] 2015	Case series	25	64	54	Discovery system¶¶¶	Linked	Cemented	V	V	V	N/A
Ogino et al,[40] 2015	Case series	55	64	90	Coonrad-Morrey¶ Discovery system¶¶¶	Linked	Cemented	N/A	N/A	V	V
Celli et al,[41] 2016	Case series	15	59	38	Coonrad-Morrey¶	Linked	Cemented	V	V	V	V
Sanchez-Sotelo et al,[1] 2016	Case series	461	64	108 (median)	Coonrad-Morrey¶	Linked	457 Cemented, 4 Cementless	V	V	N/A	N/A
Toulemonde et al,[7] 2016	Cohort study	45	63	62	Coonrad-Morrey¶	Linked	Cemented	V	V	V	V
Williams et al,[42] 2016	Case series	22	59	64	Coonrad-Morrey¶	Linked	Cemented	V	V	N/A	N/A
Hänninen et al,[43] 2017	Case series	55	57	64	Discovery system¶	Linked	Cemented	V	V	V	V
Kodama et al,[44] 2017	Case series	41	58.9	141	Kudo type 5**	Unlinked	Hybrid	V	V	V	V
Nishida et al,[45] 2017	Case series	17	54.8	128.4	JACE†††	Unlinked	Cementless	V	V	V	V
Nishida et al,[46] 2018	Case series	87	62	108	JACE†	Unlinked	Cemented	V	V	V	V
Pham et al,[47] 2018	Case series	54	60	84	Coonrad-Morrey¶	Linked	Cemented	V	V	V	V
Kondo et al,[48] 2019	Case series	75	64	62.4	Niigata-Senami-Kyocera modular****	Unlinked	Cemented	V	V	V	N/A

*Description of implant failures, including aseptic loosening, septic loosening, or instability.
†Description of complications, including triceps disruption, ulnar neuropathy, posterior interosseous neuropathy, radial neuropathy, intraoperative fracture, intraoperative stem penetration, postoperative fracture, surgical site infection, deep infection, heterotopic ossification, or stiffness.
‡Range of motion.
§Mayo elbow performance score(MEPS).
¶Zimmer Biomet, Warsaw, Indiana, USA.
**Biomet Ltd, Swindon, UK.
††Biomet Ltd, South Glamorgan, UK.
‡‡Stryker Howmedica, Newbury, UK.
§§Johnson & Johnson, New Brunswick, New Jersey, USA.
¶¶Allo Pro AG, Baar, Switzerland.
***Biomet Ltd, Swansea, UK.
†††Kyocera and Kobe Steel Ltd., Kyoto, Japan.
‡‡‡Kyocera Ltd, Kyoto, Japan.
§§§Kyocera Medical, Osaka, Japan.
¶¶¶Biomet, Warsaw, Indiana, USA.
****Kyocera, Kyoto, Japan.
N/A, not available; TEA, total elbow arthroplasty.

radiological evidence of loosening which required extensive debridement and removal of the implant. The clinical performance was assessed based on the range of motion (ROM) (flexion, extension, arc of motion, supination, and pronation) and Mayo Elbow Performance Score (MEPS).[12]

The quality of the methodology of the studies was assessed independently by two authors (TFC, SWT) using the NIH Quality Assessment Tool for Case Series Studies.[49] The maximum possible score on this scale is 9. 'Good' was defined as a score of between 7 and 9, 'fair' as a score between 4 and 6, and 'poor' as a score of < 4 (Table II). If there were disagreements, a third author was consulted.

Statistical analysis. A meta-analysis of proportions was conducted using the Freeman-Tukey analysis under random-effects model to calculate pooled estimates with a 95% confidence interval (CI). A random-effects model was used for differences among studies such as patient characteristics, the design of the prosthesis, different surgical technique, and methodology. For potential factors that may lead to implant failure, complications, or improved functional performance, a standard multivariate linear regression analysis (β) was performed. All analyses were completed with Comprehensive Meta-Analysis (CMA) v. 3 (Biostat, Englewood, New Jersey, USA) and significance was defined as a $p < 0.05$.

Results

After removing duplicate studies, 456 were identified for review. Those not in English were removed and 387 were

Table II. The assessment of the quality of the studies.

Criteria	1. Was the study question or objective clearly stated?	2. Was the study population clearly and fully described, including a case definition?	3. Were the cases consecutive?	4. Were the subjects comparable?	5. Was the intervention clearly described?	6. Were the outcome measures clearly defined, valid, reliable and implemented consistently across all study participants?	7. Was the length of follow-up adequate?	8. Were the statistical methods well-described?	9. Were the results well-described?	Quality of the cohort study* (score)
Lo et al,[13] 2003	Y	Y	NR	Y	Y	Y	N	Y	Y	Good (7)
Potter et al,[14] 2003	Y	Y	Y	Y	Y	Y	Y	Y	Y	Good (9)
Reinhard et al,[15] 2003	Y	Y	NR	Y	Y	Y	Y	Y	Y	Good (9)
Samijo et al,[16] 2003	Y	Y	NR	Y	Y	Y	Y	Y	Y	Good (8)
Van Der Lugt et al,[17] 2004	Y	Y	CD	Y	Y	Y	Y	Y	Y	Good (8)
Willems et al,[42] 2004	Y	Y	CD	Y	Y	Y	N/A	Y	Y	Good (7)
Khatri and Stirrat,[19] 2005	Y	Y	CD	Y	Y	Y	N/A	Y	Y	Good (7)
Lee et al,[20] 2005	Y	Y	CD	Y	Y	Y	Y	Y	Y	Good (8)
Little et al,[21] 2005	Y	Y	Y	Y	Y	Y	CD	Y	Y	Good (8)
Ovesen et al,[22] 2005	Y	Y	CD	Y	Y	Y	Y	Y	Y	Good (8)
Jensen et al,[23] 2006	Y	N	CD	Y	Y	Y	Y	Y	Y	Good (7)
Landor et al,[24] 2006	Y	N	Y	Y	Y	Y	N	Y	Y	Good (7)
Mori et al,[25] 2006	Y	Y	CD	Y	N/A	Y	Y	N/A	Y	Fair (6)
Rauhaniemi et al,[26] 2006	Y	Y	CD	Y	Y	Y	Y	N	Y	Good (7)
Thillemann et al,[27] 2006	Y	Y	CD	Y	Y	Y	Y	Y	Y	Good (8)
Brinkman et al,[28] 2007	Y	Y	CD	Y	Y	Y	Y	Y	Y	Good (8)
Cesar et al,[29] 2007	Y	Y	CD	Y	Y	Y	Y	Y	Y	Good (8)
Skyttä et al,[30] 2008	Y	Y	Y	Y	Y	Y	Y	Y	Y	Good (9)
Tachihara et al,[31] 2008	Y	Y	CD	Y	Y	Y	CD	Y	Y	Good (7)
Amirfeyz and Blewitt,[32] 2009	Y	Y	CD	Y	Y	Y	CD	Y	Y	Good (7)
Kleinlugtenbelt et al,[33] 2010	Y	Y	CD	Y	Y	Y	Y	Y	Y	Good (8)
Prasad and Dent,[34] 2010	Y	CD	CD	CD	CD	Y	CD	Y	Y	Fair (4)
Qureshi et al,[35] 2010	Y	Y	Y	Y	Y	Y	Y	N	Y	Good (8)
Ishii et al,[36] 2012	Y	Y	CD	Y	Y	Y	Y	Y	Y	Good (8)
Nishida et al,[37] 2014	Y	Y	CD	CD	Y	Y	Y	N	Y	Fair (6)
Nishida et al,[38] 2014	Y	N	CD	CD	Y	Y	Y	N	Y	Fair (5)
Mukka et al[39] 2015	Y	Y	Y	Y	Y	Y	N	Y	Y	Good (8)
Ogino et al[40] 2015	Y	Y	Y	Y	Y	Y	Y	Y	Y	Good (9)
Celli et al,[41] 2016	Y	Y	Y	Y	Y	Y	Y	Y	Y	Good (9)
Sanchez-Sotelo et al[1] 2016	Y	Y	Y	Y	Y	Y	Y	Y	Y	Good (9)
Toulemonde et al,[7] 2016	Y	N	Y	Y	Y	Y	Y	Y	Y	Good (8)
Williams et al,[42] 2016	Y	N	CD	CD	N	Y	CD	N	Y	Poor (3)
Hänninen et al,[43] 2017	Y	N	CD	CD	Y	Y	Y	Y	Y	Fair (6)
Kodama et al,[44] 2017	Y	Y	CD	Y	Y	Y	Y	Y	Y	Good (8)
Nishida et al,[45] 2017	Y	Y	CD	Y	N	Y	CD	Y	Y	Fair (6)

Continued

Table II. Continued

Criteria	1. Was the study question or objective clearly stated?	2. Was the study population clearly and fully described, including a case definition?	3. Were the cases consecutive?	4. Were the subjects comparable?	5. Was the intervention clearly described?	6. Were the outcome measures clearly defined, valid, reliable and implemented consistently across all study participants?	7. Was the length of follow-up adequate?	8. Were the statistical methods well-described?	9. Were the results well-described?	Quality of the cohort study* (score)
Nishida et al,[46] 2018	Y	Y	CD	Y	Y	Y	Y	Y	Y	Good (8)
Pham et al,[47] 2018	Y	Y	CD	Y	Y	Y	Y	Y	Y	Good (8)
Kondo et al,[48] 2019	Y	Y	CD	Y	Y	Y	Y	Y	Y	Good (8)

*The maximum possible score on this scale is 9. 'Good' was defined as a total score of 7 to 9; 'fair' as a score 4 to 6, and 'poor' as a score of less than 4.
CD, cannot determine; N, no; N/A, not available; NR, not reported; Y, yes.

excluded after reviewing the title and abstract. Another 21 were excluded after reading the full text as the study did not meet the inclusion criteria. Five evaluated different designs of prosthesis and each was divided into groups based on the design that was reported. After exclusion, a total of 38 studies were included[1,7,39-48] (Figure 1).

Baseline characteristics. A total of 2,118 patients were included. The mean follow-up was 80.9 months (28.2 to 156.0). The mean age was 61.0 years (42.6 to 67.0) and 1,705 patients (80.5%) were female. A total of 1,120 elbows (46.0%) were treated with a linked prosthesis and 2,206 elbows (90.6%) were cemented.

Implant failure rate. A total of 36 studies, with 2,063 patients, reported implant failure rates. The pooled rate was 16.1% (95% CI 0.128 to 0.200) (Figure 2, Table III). A multivariate linear regression analysis showed that younger age (β = -0.08, CI -0.16 to -0.01) and an unlinked design (β = -0.72, CI -1.27 to -0.18) were associated with a higher risk of failure. We further analyzed the pooled incidence (Table III) and risk factor for each type of failure (Table IV).

Aseptic loosening. A total of 33 studies including 1,928 patients reported aseptic loosening rates. The pooled rate was 9.5% (95% CI 0.071 to 0.124) (Figure 3, Table III). A multivariate linear regression analysis showed that female patients (β = 2.34, 95% CI 0.04 to 4.64) and an unlinked design (β = -1.02, 95% CI -1.7 to -0.34) were risk factors for aseptic loosening (Table IV).

Septic loosening. A total of 33 studies, including 1,979 patients, reported septic loosening rates. The pooled rate was 3.5% (95% CI 0.028 to 0.045) (Figure 4, Table III). A multivariate linear regression analysis did not reveal specific factors that were associated with a higher risk of septic loosening (Table IV).

Instability. A total of 36 studies including 2,042 patients reported the rate of instability. The pooled rate was 5.3% (95% CI 0.038 to 0.074) (Figure 5, Table III). A multivariate linear regression showed that younger patients (β = -0.14, 95% CI -0.24 to -0.04) and a trend toward an unlinked design (β = -0.8, 95% CI -1.87 to 0.04) were risk factors for instability (Table IV).

Bushing wear, axle failure, or component fracture. A total of 33 studies including 1,986 patients reported bushing wear, axle failure or implant fracture. The pooled rate was 2.6% (95% CI 0.019 to 0.035) (Figure 6, Table III). Multivariate linear regression analysis showed that cemented fixation (β = 1.65, 95% CI 0.34 to 2.96) was a risk factor for bushing wear, axle failure, and implant fracture (Table IV).

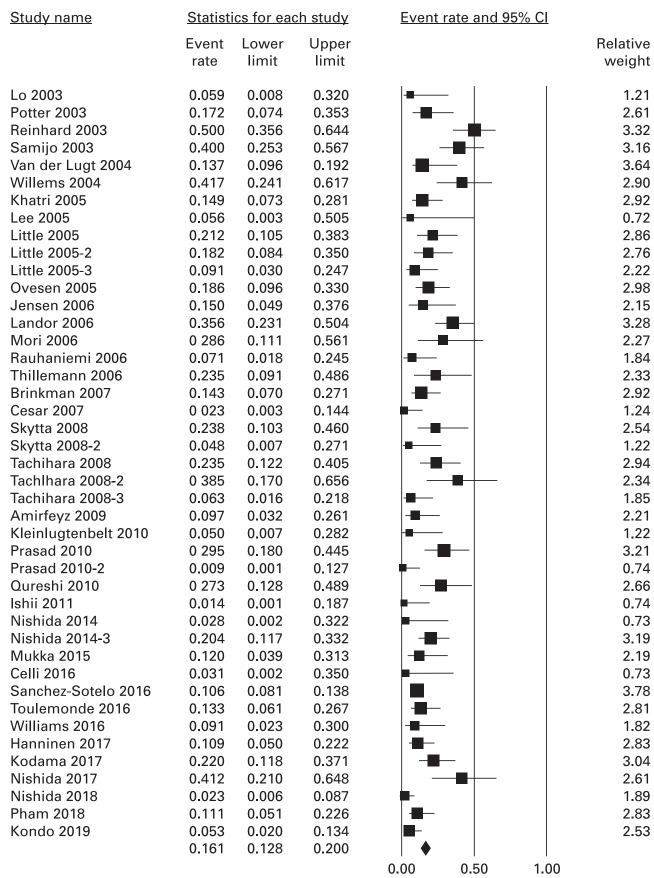

Fig. 2

Forest plot of pooled implant failure rates among included studies. CI, confidence interval.

Complications. A total of 36 studies including 2,008 patients reported complication rates. The pooled total complication rate was 24.5% (95% CI 0.203 to 0.293) (Figure 7, Table III). A multivariate linear regression analysis showed that younger age (β= -0.13, 95% CI -0.2 to -0.06) was a covariate associated with higher complication rates (Table IV). The most common perioperative complications were: ulnar neuropathy (134; 8.5%), wound healing problems (21; 7.6%), deep infection (71;

Table III. Pooled event rate and clinical performance.

Variable	Rate or mean value (95% CI)
Implant failure	0.161 (0.128 to 0.200)
Aseptic loosening	0.095 (0.071 to 0.124)
Septic loosening	0.035 (0.028 to 0.045)
Instability	0.053 (0.038 to 0.074)
Bushing wear, axle failure or component fracture	0.026 (0.019 to 0.035)
Total complications	0.245 (0.203 to 0.293)
Ulnar neuropathy	0.085 (0.057 to 0.125)
Wound healing problems	0.076 (0.039 to 0.144)
Deep infection	0.055 (0.042 to 0.071)
Postoperative fracture	0.052 (0.041 to 0.065)
Triceps disruption	0.032 (0.019 to 0.055)
Range of motion, °	
Flexion	131.5 (124.2 to 138.8)
Extension	29.3 (26.8 to 31.9)
Pronation	74 (67.8 to 80.2)
Supination	72.5 (69.5 to 75.5)
Arc of ROM	104.5 (100.3 to 108.6)
MEPS, points	89.3 (86.9 to 91.6)

CI, confidence interval; MEPS, Mayo Elbow Performance Score; ROM, range of motion.

5.5%), fracture (74; 5.2%), and triceps disruption (23; 3.2%) (Table III).

Clinical performance. A total of 24 studies including 1,132 patients reported ROM. The pooled mean postoperative ROM was: flexion 131.5° (124.2° to 138.8°), extension 29.3° (26.8° to 31.9°), pronation 74.0° (67.8° to 80.2°), and supination was 72.5° (69.5° to 75.5°). The mean arc of flexion-extension was 104.5° (100.3° to 108.6°) (Figures 8 to 12, Table III).

A total of 18 studies including 613 patients reported the MEPS. The pooled mean MEPS was 89.3 (95% CI 86.9 to 91.6) (Figure 13, Table III). A multivariate linear regression analysis showed that a cemented prosthesis (β = 15.53, 95% CI 4.7 to 26.36) was associated with improved MEPS. (Table IV).

Table IV. Multivariate linear regression analysis.

Independent variable	ß-coefficient (95% CI)	p-value
Implant failure		
Age	-0.08 (-0.16 to -0.01)	0.034
Female sex	0.60 (-1.27 to 2.47)	0.529
Cemented fixation	-0.09 (-0.89 to 0.71)	0.830
Linked design	-0.72 (-1.27 to -0.18)	0.010
Aseptic loosening		
Age	-0.01 (-0.11 to 0.08)	0.757
Female sex	2.34 (0.04 to 4.64)	0.047
Cemented fixation	-0.51 (-1.36 to 0.35)	0.246
Linked design	-1.02 (-1.7 to -0.34)	0.003
Septic loosening	()	
Age	-0.02 (-0.12 to 0.08)	0.680
Female sex	-0.33 (-2.84 to 2.17)	0.795
Cemented fixation	0.81 (-0.63 to 2.25)	0.270
Linked design	-0.31 (-0.92 to 0.29)	0.314
Instability	()	
Age	-0.14 (-0.24 to -0.04)	0.005
Female sex	0.07 (-2.55 to 2.7)	0.957
Cemented fixation	-0.2 (-1.23 to 0.82)	0.696
Linked design	-0.8 (-1.87 to 0.04)	0.061
Bushing wear, axle failure or component fracture		
Age	-0.02 (-0.15 to 0.11)	0.729
Female sex	1.45 (-3.07 to 5.97)	0.530
Cemented fixation	1.65 (0.34 to 2.96)	0.013
Linked design	-0.68 (-1.65 to 0.28)	0.165
Total complications		
Age	-0.13 (-0.2 to -0.06)	<0.001
Female sex	-1.15 (-2.89 to 0.59)	0.196
Cemented fixation	0.11 (-0.66 to 0.88)	0.781
Linked design	0.00 (-0.46 to 0.47)	0.994
Mayo Elbow Performance Score		
Age	0.17 (- 0.57 to 0.91)	0.649
Female sex	-0.31 (-24.86 to 24.25)	0.980
Cemented Fixation	15.53 (4.7 to 26.36)	0.005
Linked design	-0.67 (-5.61 to 4.27)	0.790

CI, confidence interval

Discussion

There are few systematic reviews discussing the outcome of TEA in patients with RA in the literature. We previously compared the results for patients with RA and traumatic OA after TEA. Those with RA had a higher risk of septic loosening (odds ratio (OR) 3.96, 95% CI 1.11 to 14.12), while there was an increased risk of bushing wear, axle failure, component disassembly, and component fracture in the post-traumatic group.[50] The systemic involvement of RA with potent medications such as steroids and disease-modifying antirheumatic drugs (DMARDs) may hinder the recovery of patients with RA after arthroplasty.[51] Despite these challenges, several improvements in surgical technique and implant design have allowed TEA to evolve into an effective treatment for end-stage arthritis. In this study, we reviewed 38 studies to determine the failure rate and associated risk factors that may predispose to failure. A previous comprehensive review evaluating TEA in RA was conducted by Little et al.[24] This study included studies up to 2003, which is now 17 years ago. During the subsequent period, advances in medical treatment, modified surgical techniques, and improved implant designs have been introduced. Welsink et al[4] performed a meta-analysis with emphasis on implant designs. However, they combined different aetiologies such as post-traumatic and degenerative conditions. Patients with different aetiologies have different baseline characteristics such as immune status, bone stock, ligamentous integrity, and age. Therefore, this study updates several significant parameters after TEA in patients with RA. At a mean follow-up of 80.9 months, we noted an implant failure rate of 16.1% with aseptic loosening being the most common mode of failure. The total complication rate was 24.5% and the mean MEPS score was 89.3. TEA continues to be an excellent form of treatment for patients with RA, but additional attention should be paid to younger patients and those receiving an unlinked prosthesis as several adverse outcomes have been associated with these two factors.

In previous studies, the implant failure rate after TEA was reported to be between 4% and 32%.[4,9,52] Aseptic loosening was the most common mode of failure.[4,11] The overall incidence of loosening ranged from 5% to 20%, and can vary according to the design of the implant.[1,11] We noted a failure rate of 16.1% which is consistent with previous reports that also

Study name	Event rate	Lower limit	Upper limit	Relative weight
Lo 2003	0.028	0.002	0.322	0.97
Potter 2003	0.069	0.017	0.238	2.45
Reinhard 2003	0.136	0.063	0.272	3.75
Samijo 2003	0.314	0.183	0.483	4.14
Van der Lugt 2004	0.054	0.030	0.095	4.41
Willems 2004	0.167	0.064	0.369	3.22
Khatri 2005	0.021	0.003	0.136	1.64
Lee 2005	0.056	0.003	0.505	0.94
Little 2005	0.152	0.065	0.316	3.52
Little 2005-2	0.121	0.046	0.282	3.29
Little 2005-3	0.030	0.004	0.186	1.63
Ovesen 2005	0.023	0.003	0.147	1.64
Jensen 2006	0.050	0.007	0.282	1.61
Landor 2006	0.222	0.124	0.366	4.16
Mori 2006	0.033	0.002	0.366	0.96
Thillemann 2006	0.118	0.030	0.368	2.38
Brinkman 2007	0.143	0.070	0.271	3.91
Cesar 2007	0.023	0.003	0.144	1.64
Skytta 2008	0.190	0.073	0.412	3.18
Skytta 2008-2	0.048	0.007	0.271	1.61
Tachihara 2008	0.147	0.063	0.308	3.52
Tachihara 2008-2	0.231	0.076	0.522	2.73
Tachihara 2008-3	0.015	0.001	0.201	0.98
Amirfeyz 2009	0.032	0.005	0.196	1.63
Prasad 2010	0.182	0.094	0.323	4.00
Prasad 2010-2	0.009	0.001	0.127	0.98
Qureshi 2010	0.182	0.070	0.396	3.19
Ishii 2011	0.014	0.001	0.187	0.98
Nishida 2014	0.028	0.002	0.322	0.97
Nishida 2014-2	0.074	0.028	0.181	3.35
Mukka 2015	0.040	0.006	0.235	1.62
Celli 2016	0.031	0.002	0.350	0.96
Sanchez-Sotelo 2016	0.063	0.044	0.089	4.94
Toulemonde 2016	0.067	0.022	0.187	2.99
Williams 2016	0.045	0.006	0.261	1.62
Haminen 2017	0.055	0.018	0.156	3.01
Kodama 2017	0.195	0.101	0.344	3.98
Nishida 2017	0.412	0.210	0.648	3.48
Pham 2018	0.056	0.018	0.159	3.01
Kondo 2019	0.007	0.000	0.097	0.98
	0.095	0.071	0.124	

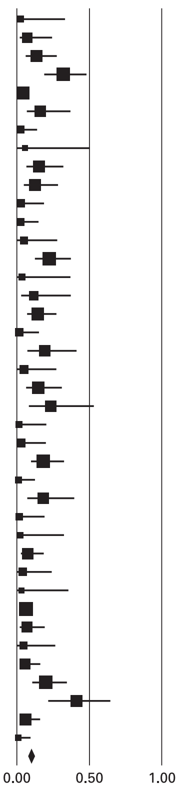

Fig. 3

Forest plot of pooled aseptic loosening rates among included studies. CI, confidence interval.

Study name	Event rate	Lower limit	Upper limit	Relative weight
Lo 2003	0.059	0.008	0.320	1.64
Reinhard 2003	0.011	0.001	0.154	0.86
Van der Lugt 2004	0.049	0.027	0.089	16.53
Willems 2004	0.042	0.006	0.244	1.67
Khatri 2005	0.064	0.021	0.180	4.88
Lee 2005	0.056	0.003	0.505	0.82
Little 2005	0.030	0.004	0.186	1.69
Little 2005-2	0.015	0.001	0.196	0.86
Little 2005-3	0.061	0.015	0.212	3.27
Ovesen 2005	0.070	0.023	0.195	4.85
Jensen 2006	0.024	0.001	0.287	0.85
Landor 2006	0.022	0.003	0.142	1.70
Mori 2006	0.033	0.002	0.366	0.84
Rauhaniemi 2006	0.017	0.001	0.223	0.85
Thillemann 2006	0.059	0.008	0.320	1.64
Brinkman 2007	0.010	0.001	0.141	0.86
Cesar 2007	0.011	0.001	0.154	0.86
Skytta 2008	0.023	0.001	0.277	0.85
Skytta 2008-2	0.023	0.001	0.277	0.85
Tachihara 2008	0.029	0.004	0.181	1.69
Tachihara 2008-2	0.036	0.002	0.384	0.84
Tachihara 2008-3	0.063	0.016	0.218	3.26
Amirfeyz 2009	0.016	0.001	0.206	0.86
Prasad 2010	0.023	0.003	0.144	1.70
Prasad 2010-2	0.009	0.001	0.127	0.86
Qureshi 2010	0.091	0.023	0.300	3.16
Ishii 2011	0.014	0.001	0.187	0.86
Nishida 2014	0.028	0.002	0.322	0.84
Nishida 2014-2	0.009	0.001	0.129	0.86
Mukka 2015	0.080	0.020	0.269	3.20
Celli 2016	0.031	0.002	0.350	0.84
Sanchez-Sotelo 2016	0.022	0.012	0.040	17.01
Toulemonde 2016	0.044	0.011	0.161	3.32
Williams 2016	0.045	0.006	0.261	1.66
Hanninen 2017	0.018	0.003	0.118	1.71
Kodama 2017	0.024	0.003	0.154	1.70
Nishida 2017	0.028	0.002	0.322	0.84
Nishida 2018	0.011	0.002	0.077	1.72
Pham 2018	0.037	0.009	0.136	3.35
Kondo 2019	0.027	0.007	0.100	3.38
	0.035	0.028	0.045	

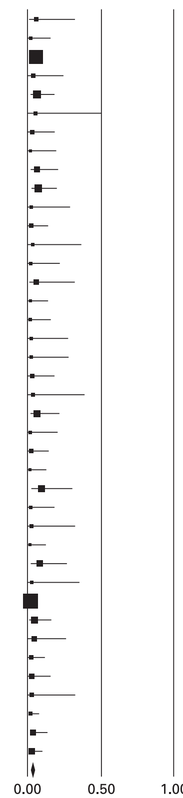

Fig. 4

Forest plot of pooled septic loosening rates in the studies. CI, confidence interval.

included patients with mixed aetiologies.[9] Aseptic loosening (9.5%) remained the most common mode of failure. Currently, aseptic loosening is thought to be caused by either inadequate initial mechanical fixation or loss of biological fixation due to particle-induced osteolysis.[53] Several authors have reported that loosening is due to the multidirectional forces exerted at the implant-cement-bone interfaces.[9] We performed a regression analysis of potential risk factors and further identified younger age (β = -0.08, 95% CI -0.16 to -0.11) and unlinked TEAs (β = -0.72, 95% CI -1.27 to -0.18) as risk factors that may predispose to failure. Patients with RA underwent TEA at mean age of 61.0 years, which is consistent with previous reports.[4,9] The trend for higher failure rates in younger patients can be attributed to the increased levels of activity in these patients,[54] which increase PE wear ultimately resulting in revision surgery.[55] In a cohort study, Sanchez-Sotelo et al[1] noted a gradual increase in failures with the passage of time, further raising concerns about performing TEA in young patients. There are two main reasons for the higher rate of failure in those with an unlinked TEA. First, an unlinked TEA requires larger PE bearings with larger surfaces for microabrasions.[9] Secondly, a higher rate of dislocation and failure is seen if unlinked TEAs are used in patients with suboptimal surrounding capsuloligamentous structures.[9]

A multivariate analysis noted that women (β = 2.34, 95% CI 0.04 to 4.64) and unlinked TEAs (β = -1.02, -1.7 to -0.34) were associated with an increased risk of aseptic loosening. Currently, there is limited literature on the possible causes of increased rates of aseptic loosening in women after TEA. We hypothesize that active RA may play a role in this finding. Sokka et al[56] reported that women were more likely to have a higher disease activity with increased comorbidity based on the Core Data Set measures. As RA activity progresses, the bone erosion may cause loosening at the interfaces.[57]

Theoretically, unlinked designs should have lower rates of loosening given the relatively superior surrounding soft tissue envelope.[58] However, comparative studies have shown mixed results.[6,9,11] Some authors have hypothesized that accelerated wear may be due to increased microabrasions occurring with larger PE bearings.[9] Furthermore, the mixed results can be explained by the different definitions used for aseptic loosening in different studies. For instance, some authors have further subdivided aseptic loosening into radiolucency and clinical loosening.[11] Further high-level studies are required to determine the association between clinical loosening and implant designs.

Due to the systemic involvement of RA and the fragile soft-tissue envelope of the elbow, patients are at an increased risk of infection compared with the general population. In the current literature, the overall risk of infection for patients with RA undergoing arthroplasty ranges from 2% to 4% with a 1.8- to

Study name	Event rate	Lower limit	Upper limit	Relative weight
Lo 2003	0.028	0.002	0.322	1.30
Potter 2003	0.103	0.034	0.276	3.64
Reinhard 2003	0250	0.144	0.397	4.96
Samijo 2003	0.057	0.014	0.202	3.11
Van der Lugt 2004	0.034	0.016	0.070	4.77
Willems 2004	0208	0.089	0.413	4.16
Khatri 2005	0.064	0.021	0.180	3.70
Lee 2005	0.056	0.003	0.505	1.27
Little 2005	0.030	0.004	0.186	2.14
Little 2005-2	0.061	0.015	0.212	3.10
Little 2005-3	0.015	0.001	0.196	1.31
Ovesen 2005	0.093	0.035	0.223	4.05
Jensen 2006	0.100	0.025	0.324	3.04
Landor 2006	0.089	0.034	0.214	4.06
Mori 2006	0286	0.111	0.561	3.72
Rauhaniemi 2006	0.071	0.018	0.245	3.09
Thillemann 2006	0.059	0.008	0.320	2.09
Brinkman 2007	0.010	0.001	0.141	1.32
Cesar 2007	0.011	0.001	0.154	1.32
Skytta 2008	0.048	0.007	0.271	2.11
Tachihara 2008	0.059	0.015	0.207	3.11
Tachihara 2008-2	0.154	0.039	0.451	2.95
Tachihara 2008-3	0.015	0.001	0.201	1.31
Amirfeyz 2009	0.016	0.001	0.206	1.31
Kleinlugtenbelt 2010	0.050	0.007	0.282	2.11
Prasad 2010	0.091	0.035	0.218	4.05
Prasad 2010-2	0.009	0.001	0.127	1.32
Qureshi 2010	0.022	0.001	0.268	1.31
Ishii 2011	0.014	0.001	0.187	1.31
Nishida 2014	0.028	0.002	0.322	1.30
Nishida 2014-2	0.111	0.051	0.226	4.52
Mukka 2015	0.019	0.001	0.244	1.31
Celli 2016	0.031	0.002	0.350	1.30
Sanchez-Sotelo 2016	0.001	0.000	0.017	1.33
Toulemonde 2016	0.011	0.001	0.151	1.32
Williams 2016	0.022	0.001	0.268	1.31
Haminen 2017	0.009	0.001	0.127	1.32
Kodama 2017	0.012	0.001	0.164	1.32
Nishida 2017	0.028	0.002	0.322	1.30
Nishida 2018	0.011	0.002	0.077	2.16
Pham 2018	0.009	0.001	0.129	1.32
Kondo 2019	0.027	0.007	0.100	3.16
	0.053	0.038	0.074	

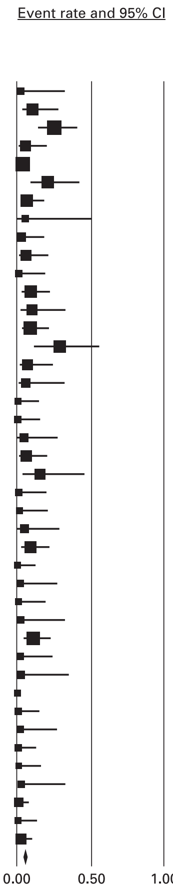

Fig. 5

Forest plot of pooled instability rates in the studies. CI, confidence interval.

Study name	Event rate	Lower limit	Upper limit	Relative weight
Lo 2003	0.028	0.002	0.322	1.28
Potter 2003	0.017	0.001	0.217	1.29
Reinhard 2003	0.114	0.048	0.245	11.63
Samijo 2003	0.029	0.004	0.177	2.55
Van der Lugt 2004	0.002	0.000	0.038	1.31
Willems 2004	0.020	0.001	0.251	1.29
Khatri 2005	0.010	0.001	0.146	1.30
Lee 2005	0.056	0.003	0.505	1.24
Little 2005	0.015	0.001	0.196	1.29
Little 2005-2	0.015	0.001	0.196	1.29
Little 2005-3	0.015	0.001	0.196	1.29
Ovesen 2005	0.011	0.001	0.157	1.30
Jensen 2006	0.024	0.001	0.287	1.28
Landor 2006	0.022	0.003	0.142	2.57
Mori 2006	0.033	0.002	0.366	1.27
Rauhaniemi 2006	0.017	0.001	0.223	1.29
Thillemann 2006	0.028	0.002	0.322	1.28
Brinkman 2007	0.010	0.001	0.141	1.30
Cesar 2007	0.011	0.001	0.154	1.30
Skytta 2008	0.023	0.001	0.277	1.28
Skytta 2008-2	0.023	0.001	0.277	1.28
Tachihara 2008	0.014	0.001	0.191	1.29
Tachihara 2008-2	0.036	0.002	0.384	1.27
Tachihara 2008-3	0.015	0.001	0.201	1.29
Amirfeyz 2009	0.065	0.016	0.224	4.91
Prasad 2010	0.011	0.001	0.154	1.30
Prasad 2010-2	0.009	0.001	0.127	1.30
Qureshi 2010	0.022	0.001	0.268	1.28
Nishida 2014	0.028	0.002	0.322	1.28
Nishida 2014-2	0.019	0.003	0.120	2.58
Mukka 2015	0.019	0.001	0.244	1.29
Celli 2016	0.031	0.002	0.350	1.27
Sanchez-Sotelo 2016	0.022	0.012	0.040	25.67
Toulemonde 2016	0.022	0.003	0.142	2.57
Hanninen 2017	0.036	0.009	0.134	5.06
Kodama 2017	0.012	0.001	0.164	1.30
Nishida 2017	0.028	0.002	0.322	1.28
Nishida 2018	0.006	0.000	0.084	1.30
Pham 2018	0.019	0.003	0.120	2.58
Kondo 2019	0.007	0.000	0.097	1.30
	0.026	0.019	0.035	

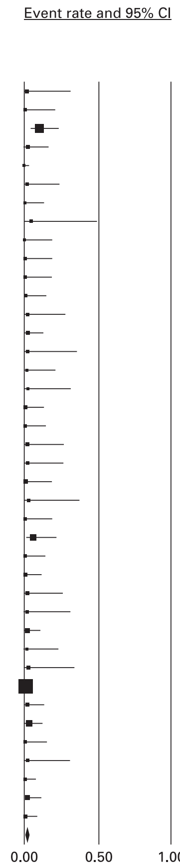

Fig. 6

Forest plot of pooled bushing wear, axle failure, or implant fracture rates in the studies. CI, confidence interval.

4-fold increased risk of infection compared with patients with OA.[51] However, most of the large studies evaluated total hip and knee arthroplasty, and few studies have discussed TEA in RA. In this study, the overall incidence of deep infection was 5.5%. Specifically, the need for a subsequent procedure such as debridement or removal of the prosthesis to manage septic loosening was 3.5%. Several authors have reported a higher infection rate for TEA compared with total hip and knee arthroplasty. Welsink et al[4] reported an overall infection rate after TEA of 6.9% with a deep infection rate of 3.4% which is slightly lower than our findings. They, however, included all aetiologies including OA, RA, and post-traumatic conditions, which may account for the slightly lower incidence of severe infection. In the study conducted by Sanchez-Sotelo et al,[1] which evaluated TEA in patients with RA, deep infection was diagnosed in 8%, with 2.3% requiring removal or revision TEA. Several measures have been taken to prevent infection after TEA. In particular, discontinuation of DMARDs and antibiotic-impregnated cement have shown promising results.[9] With appropriate perioperative managements, TEA can be performed safely with only a small increase of infection rate despite the complex medical status of RA.

Instability. Due to the complex ligamentous-capsular structures around the elbow, instability after TEA continues to be a challenge.[11] Unlinked TEAs have been associated with higher rates of instability.[9] Several significant postoperative anatomical features have been described. Most notably, the trochlear notch has a diminished circumference leading to a shallow groove compared with the preoperative status.[59] In addition, extensive soft tissue release, particularly of the collateral ligaments results in an unstable elbow and is more commonly seen in unlinked designs.[59] In linked designs, a certain degree of motion is permitted, such as valgus-varus of the ulna, so that the elbow performs as a 'sloppy-hinge' joint.[60] Since dislocation in a linked TEA represents failure of the axle locking mechanism or disassembly of the components, most authors have categorized instability in linked and unlinked TEAs as being different entities.[11] With the variable definition of instability including dislocation, subluxation, disassembly etc., we noted a pooled mean incidence of 5.3%. In a systematic review, Little et al[11] noted a 5% recurrent dislocation rate and instability in 14% of 3,618 patients. Similarly, Prkić et al[9] reported an incidence of about 1% for all types of design, with only one of 9,308 patients with an linked TEA having a dislocation. We performed a regression analysis and determined that linked designs were negatively correlated with instability which confirms previous reports. This analysis also revealed younger age to be a risk factor for instability. The higher levels of activity in younger patients may cause increased stress in the soft tissues as well

Study name	Event rate	Lower limit	Upper limit	Relative weight
Lo 2003	0.588	0.352	0.790	2.33
Potter 2003	0.310	0.170	0.497	2.65
Reinhard 2003	0.682	0.532	0.802	2.94
Samijo 2003	0.257	0.140	0.425	2.71
Van der Lugt 2004	0.201	0.152	0.262	3.42
Willems 2004	0.686	0.517	0.817	2.79
Khatri 2005	0.426	0.294	0.569	3.04
Lee 2005	0.250	0.063	0.623	1.42
Little 2005	0.091	0.030	0.247	1.96
Ovesen 2005	0.233	0.130	0.381	2.80
Jensen 2006	0.200	0 077	0.428	2.11
Landor 2006	0.311	0.194	0.459	2.94
Mori 2006	0.286	0.111	0.561	2.00
Rauhaniemi 2006	0.107	0.035	0.284	1.94
Thillemann 2006	0.353	0.168	0.596	2.28
Brinkman 2007	0.408	0.281	0.549	3.05
Cesar 2007	0.409	0.275	0.558	3.00
Skytta 2008	0.571	0.360	0.760	2.51
Skytta 2008-2	0.190	0 073	0.412	2.12
Tachihara 2008	0.206	0.101	0.373	2.57
Tachihara 2008-2	0.308	0.120	0.591	1.98
Tachihara 2008-3	0.125	0.048	0.289	2.19
Amirfeyz: 2009	0.065	0.016	0.224	1.62
Kleinlugtenbelt 2010	0.150	0.049	0.376	1.90
Prasad 2010	0.159	0.078	0.298	2.61
Prasad 2010-2	0.182	0.101	0.306	2.84
Qureshi 2010	0.182	0.070	0.396	2.13
Ishii 2011	0.229	0.119	0.395	2.65
Nishida 2014	0.059	0.008	0.320	1.04
Nishida 2014-2	0.296	0.190	0.430	3.03
Mukka 2015	0.160	0.061	0.357	2.15
Celli 2016	0.267	0.104	0.533	2.03
Sanchez-Sotelo 2016	0.171	0.140	0.209	3.54
Toulemonde 2016	0.222	0.124	0.366	2.81
Williams 2016	0.273	0.128	0.489	2.38
Hanninen 2017	0.218	0.128	0.346	2.93
Kodama 2017	0.024	0.003	0.154	1.07
Nishida 2017	0.235	0.091	0.486	2.07
Nishida 2018	0.126	0.071	0.214	2.94
Pham 2018	0.148	0.076	0.269	2.72
Kondo 2019	0.120	0.064	0.215	2.82
	0.245	0.203	0.293	

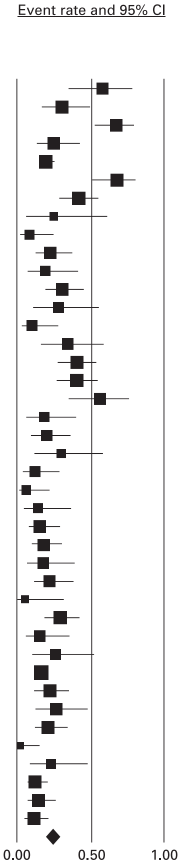

Fig. 7

Forest plot of pooled total complication rates in the studies. CI, confidence interval.

as increased PE wear. The combination of wear and loosening causes a higher incidence of revision surgery in younger patients.[61] Therefore, some authors have recommended the use of non-replacement surgery such as debridement and interposition arthroplasty for these patients.[61] In conclusion, a linked prosthesis appears to provide a more stable elbow which may correlate with better clinical performance for patients with RA.

Bushing wear, axle failure, or component fracture. Bushing wear is a common mode of failure, particularly in patients with long-term follow-up.[52] In the large series reviewed by Sanchez-Sotelo et al[1] , bushing wear was noted in 71 patients (23%) of the surviving elbows with a minimum of two years of follow-up (median 10 years (interquartile range (IQR) 2 to 30)). Despite this high incidence, only nine patients required revision. In another series with long-term follow-up (mean 11.3 years) of 15 patients after TEA, eight had evidence of bushing wear but only one required revision.[52] In our study, the rate of bushing wear that required revision surgery was 2.6%, which is similar to previous reports.[1,47,52] Several factors have been associated with bushing wear. The longevity of TEA is one of the limiting factors since it directly causes PE wear.[62,63] Also, pre-existing deformity of the elbow and younger age at the time of surgery were also factors predisposing to early wear.[63] Meanwhile, component fatigue fracture might be a consequence of bushing wear. Lee et al[64] identified 47 patients (1.8%) with component

Study name	Mean	Lower limit	Upper limit	Relative weight
Lo 2003	122.100	110.026	134.174	3.22
Samijo 2003	137.000	133.356	140.644	3.50
Van der Lugt 2004	133.400	131.904	134.896	3.53
Willems 2004	127.700	122.099	133.301	3.46
Lee 2005	133.800	128.672	138.928	3.47
Little 2005	134.000	130.929	137.071	3.51
Little 2005-2	129.000	124.906	133.094	3.49
Little 2005-3	128.000	123.906	132.094	3.49
Jensen 2006	135.300	129.515	141.085	3.45
Landor 2006	97.000	96.123	97.877	3.53
Thillemann 2006	132.900	128.432	137.368	3.48
Cesar 2007	133.700	131.543	135.857	3.52
Skytta 2008	132.000	126.012	137.988	3.45
Skytta 2008-2	134.000	125.874	142.126	3.38
Tachihara 2008	128.000	123.899	132.101	3.49
Tachihara 2008-2	133.000	127.292	138.708	3.46
Tachihara 2008-3	122.000	118.223	125.777	3.50
Amirfeyz 2009	137.000	132.072	141.928	3.47
Qureshi 2010	131.900	126.167	137.633	3.45
Ishii 2011	137.000	133.356	140.644	3.50
Nishida 2014	143.500	122.917	164.083	2.75
Ogino 2015	140.800	137.496	144.104	3.50
Celli 2016	130.000	125.294	134.706	3.48
Hanninen 2017	146.000	140.979	151.021	3.47
Kodama 2017	131.600	127.713	135.487	3.50
Nishida 2017	118.000	110.727	125.273	3.41
Nishida 2018	137.000	134.478	139.522	3.52
Pham 2018	136.000	132.799	139.201	3.51
Kondo 2019	134.000	131.511	136.489	3.52
	131.510	124.230	138.790	

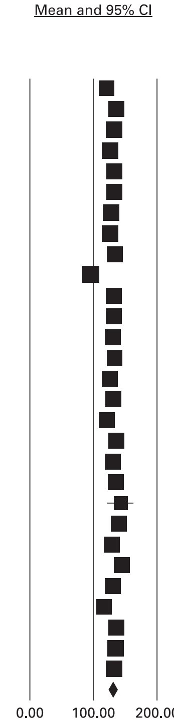

Fig. 8

Forest plot of pooled degrees of flexion in the studies. CI, confidence interval.

Study name	Mean	Lower limit	Upper limit	Relative weight
Lo 2003	24.400	16.176	32.624	2.93
Samijo 2003	40.000	34.699	45.301	3.58
Van der Lugt 2004	33.500	31.551	35.449	4.15
Willems 2004	38.800	31.999	45.601	3.25
Lee 2005	32.500	20.373	44.627	2.15
Little 2005	36.000	31.565	40.435	3.76
Little 2005-2	34.000	29.565	38.435	3.76
Little 2005-3	38.000	32.200	43.800	3.48
Jensen 2006	24.200	17.538	30.862	3.28
Landor 2006	28.000	27.182	28.818	4.24
Thillemann 2006	29.700	24.043	35.357	3.51
Cesar 2007	29.000	24.775	33.225	3.80
Skytta 2008	33.000	23.591	42.409	2.67
Skytta 2008-2	28.000	23.295	32.705	3.71
Tachihara 2008	31.000	25.756	36.244	3.60
Tachihara 2008-2	41.000	35.836	46.164	3.61
Tachihara 2008-3	14.000	9.912	18.088	3.83
Amirfeyz 2009	28.000	21.312	34.688	3.28
Qureshi 2010	25.700	21.829	29.571	3.87
Nishida 2014	30.300	25.356	35.244	3.66
Ogino 2015	29.500	24.373	34.627	3.62
Celli 2016	16.000	13.419	18.581	4.08
Hanninen 2017	22.000	18.564	25.436	3.95
Kodama 2017	39.500	36.011	42.989	3.94
Nishida 2017	37.000	27.112	46.888	2.58
Nishida 2018	17.000	13.638	20.362	3.96
Pham 2018	23.000	18.733	27.267	3.80
Kondo 2019	26.000	22.605	29.395	3.95
	29.327	26.803	31.851	

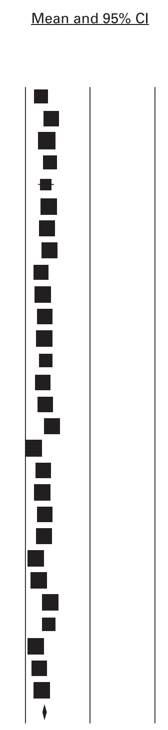

Fig. 9

Forest plot of pooled degrees of extension in the studies. CI, confidence interval.

Study name	Mean	Lower limit	Upper limit	Relative weight
Samijo 2003	77.000	74.018	79.982	4.47
Van der Lugt 2004	76.600	74.789	78.411	4.50
Willems 2004	66.700	59.419	73.981	4.25
Lee 2005	67.500	58.630	76.370	4.14
Jensen 2006	79.000	72.689	85.311	4.31
Landor 2006	66.000	65.635	66.365	4.51
Cesar 2007	65.000	60.922	69.078	4.43
Skytta 2008	76.000	70.012	81.988	4.33
Skytta 2008-2	90.000	89.572	90.428	4.51
Tachihara 2008	82.000	79.748	84.252	4.49
Tachihara 2008-2	85.000	82.119	87.881	4.47
Tachihara 2008-3	77.000	71.006	82.994	4.33
Amirfeyz 2009	63.000	58.776	67.224	4.42
Ishii 2012	66.000	56.061	75.939	4.05
Nishida 2014	80.600	72.994	88.206	4.23
Ogino 2015	71.700	65.278	78.122	4.31
Celli 2016	87.300	83.252	91.348	4.43
Hanninen 2017	71.000	67.564	74.436	4.45
Kodama 2017	60.000	54.307	65.693	4.35
Nishida 2017	68.000	54.642	81.358	3.74
Nishida 2018	81.000	77.218	84.782	4.44
Pham 2018	69.000	65.266	72.734	4.44
Kondo 2019	74.000	69.700	78.300	4.42
	73.998	67.754	80.241	

Mean and 95% CI

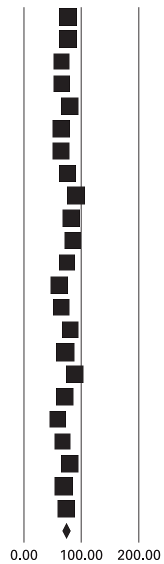

Fig. 10

Forest plot of pooled degrees of pronation in the studies. CI, confidence interval.

Study name	Mean	Lower limit	Upper limit	Relative weight
Samijo 2003	68.000	60.712	75.288	4.07
Van der Lugt 2004	64.200	61.071	67.329	5.05
Willems 2004	58.300	47.898	68.702	3.27
Lee 2005	63.800	52.713	74.887	3.11
Jensen 2006	71.800	62.947	80.653	3.66
Landor 2006	68.000	67.474	68.526	5.33
Cesar 2007	73.000	67.859	78.141	4.62
Skytta 2008	80.000	74.012	85.988	4.41
Skytta 2008-2	79.000	72.157	85.843	4.19
Tachihara 2008	78.000	72.017	83.983	4.41
Tachihara 2008-2	74.000	67.151	80.849	4.19
Tachihara 2008-3	67.000	61.006	72.994	4.41
Amirfeyz 2009	64.000	58.720	69.280	4.59
Ishii 2012	78.000	71.043	84.957	4.16
Nishida 2014	79.400	72.032	86.768	4.05
Ogino 2015	72.600	66.574	78.626	4.40
Celli 2016	86.000	81.395	90.605	4.75
Hanninen 2017	66.000	62.300	69.700	4.94
Kodama 2017	57.600	49.642	65.558	3.90
Nishida 2017	79.000	70.444	87.556	3.74
Nishida 2018	84.000	80.848	87.152	5.04
Pham 2018	70.000	65.733	74.267	4.82
Kondo 2019	80.000	75.926	84.074	4.87
	72.516	69.491	75.541	

Mean and 95% CI

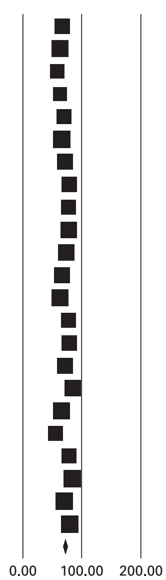

Fig. 11

Forest plot of pooled degrees of supination in the studies. CI, confidence interval.

fractures in 2,637 primary and revision TEAs. All 47 patients had periarticular osteolysis on radiographs. Of the 39 patients in whom bushing wear was quantified, it was considered to be severe in 34. In a well-fixed TEA, a cantilever loading effect can occur at the periarticular part of a stem, leading to stress concentration at this junction, and most component fractures

Study name	Statistics for each study: Mean	Lower limit	Upper limit	Relative weight
Lo 2003	104.000	96.870	111.130	5.05
Willems 2004	88.900	78.538	99.262	4.33
Lee 2005	101.300	88.203	114.397	3.73
Jensen 2006	116.000	106.227	125.773	4.46
Brinkman 2007	100.000	95.884	104.116	5.60
Skytta 2008	99.000	87.024	110.976	3.97
Skytta 2008-2	106.000	95.735	116.265	4.35
Tachihara 2008	97.000	88.597	105.403	4.77
Tachihara 2008-2	92.000	81.672	102.328	4.34
Tachihara 2008-3	108.000	102.110	113.890	5.30
Amirfeyz 2009	109.000	100.552	117.448	4.76
Kleinlugtenbelt 2010	105.300	92.897	117.703	3.88
Qureshi 2010	106.200	97.919	114.481	4.80
Nishida 2014	113.200	104.311	122.089	4.66
Mukka 2015	113.000	105.552	120.448	4.98
Celli 2016	114.000	109.395	118.605	5.52
Kodama 2016	91.900	86.482	97.318	5.38
Nishida 2017	81.000	68.403	93.597	3.84
Nishida 2018	119.000	115.323	122.677	5.66
Pham 2018	110.000	103.332	116.668	5.14
Kondo 2019	108.000	103.021	112.979	5.46
	104.467	100.306	108.629	

Mean and 95% CI

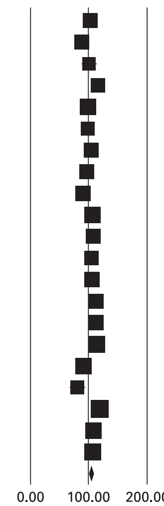

Fig. 12

Forest plot of pooled arc of range of motion in the studies. CI, confidence interval.

Study name	Statistics for each study: Mean	Lower limit	Upper limit	Relative weight
Lo 2003	93.000	88.294	97.706	5.57
Willems 2004	80.000	71.878	88.122	3.85
Lee 2005	93.100	86.170	100.030	4.40
Ovesen 2005	91.600	88.671	94.529	6.47
Mori 2006	85.400	81.209	89.591	5.84
Thillemann 2006	95.600	91.512	99.688	5.90
Amirfeyz 2009	86.200	80.075	92.325	4.81
Kleinlugtenbelt 2010	89.500	83.540	95.460	4.90
Qureshi 2010	81.900	76.461	87.339	5.18
Nishida 2014	89.700	85.593	93.807	5.89
Ogino 2015	90.600	88.063	93.137	6.64
Celli 2016	95.000	92.166	97.834	6.51
Toulemonde 2016	90.000	86.202	93.798	6.05
Hanninen 2017	93.000	90.093	95.907	6.48
Kodama 2017	80.200	76.955	83.445	6.32
Nishida 2017	66.800	53.585	80.015	2.18
Nishida 2018	94.700	92.241	97.159	6.67
Pham 2019	91.000	87.799	94.201	6.34
	89.252	86.919	91.585	

Mean and 95% CI

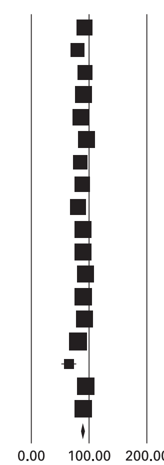

Fig. 13

Forest plot of pooled Mayo Elbow Performance Score (MEPS) in the studies. CI, confidence interval.

occurred in this area (57.4%, n = 27). They suggested that component fracture might result from osteolysis caused by bushing wear. In addition, younger patients with high activity, bone deficiency, weak soft-tissue stabilizers, and a prosthesis with a titanium alloy construct are additional factors which might predispose to stem fractures.[65,66] Interestingly, age was not identified as a risk factor for bushing wear and component fractures in our study. This might be because of our relatively homogenous study population involving patients with RA who have undergone primary TEA, all of whom have lower activity levels and similar soft tissue and bone stock. Moreover, we noted that a cemented TEA predisposed to bushing wear (β = 1.65, 95% CI 0.34 to 2.96). In a comprehensive review conducted by Goldberg et al,[62] all four modes of mechanical wear were reported in TEA. In particular, mode 3, which is secondary to cement debris destroying the PE surface, was also observed. However, they were not able to conclude that a cemented TEA predisposed to early wear. Currently, a cemented TEA remains the preferred option for most surgeons due to the high incidence of osteoporosis seen in patients with RA; 90.6% of the patients in this study received a cemented TEA.[9]

Complications. The most commonly seen complications in this study were ulnar neuropathy (8.5%), wound healing problems (7.6%), deep infection (5.5%), and fractures (5.2%). The incidence of ulnar nerve neuropathy varies widely, and is between 2% and 30%.[4,11] Most patients who experience ulnar neuropathy have transient symptoms, but between 4% and 8% have permanent nerve damage.[67] This high incidence of neuropathy may be related to surgical technique, vascular disruption secondary to tourniquet compression, thermal injury from cement, and RA-induced peripheral neuropathy.[67] Spinner et al[67] noted that four of ten patients with RA had peripheral neuropathy prior to TEA. Therefore, thorough electrophysiological evaluation may be required in patients with preoperative neurological symptoms.

Postoperative wound problems after TEA were noted in between 5.5% and 9% of patients.[11,68] Despite this high incidence, Jeon et al[68] noted that 88.7% of 97 patients were able to retain the prosthesis with only 11.3% requiring resection arthroplasty. In particular, RA was a risk factor, suggesting again that they are more vulnerable to serious infection. Appropriate prophylactic management in these patients may reduce wound complications and deep infections.

In the review conducted by Prkić et al,[9] periprosthetic fractures were the third-most commonly encountered mode of failure after aseptic loosening and deep infection. This high incidence may be due to the weakened bone stock around TEA predisposing to fracture.[9]

In addition to the complications mentioned above, humeral and ulnar osteolysis, heterotopic ossification, intraoperative fractures, and axillary vein thrombosis have been reported after TEA.[4,6,11,69]

ROM and clinical performance. Although the primary goal of TEA is pain-relief in patients with end-stage arthritis (Larsen grade[70] 4 or grade 5), improvement in clinical performance (e.g. Disabilities of the Arm, Shoulder and Hand[71] (DASH) scores and MEPS) and ROM remains critical. Morrey et al[72] reported that the elbow can accomplish most daily activities with an arc of motion between 30° to 130° and 100° of forearm rotation (50° each of supination and pronation). The pooled mean ROM in this current study was 131.5°, 29.3°, 74.0°, and 72.5° for flexion, extension, supination, and pronation, respectively, suggesting that patients with RA can perform most daily activities after TEA. Dysfunction of the extensor mechanism due to triceps deficiency has been frequently discussed as a cause of limited movement after TEA.[41] In our study, only 3.2% of the patients had triceps disruption.

In terms of clinical performance, the pooled mean MEPS was 89.3 points at a mean follow-up of 80.9 months. This finding is consistent with previous reports that TEA can lead to a satisfactory clinical performance in selected patients.[9,21] A regression analysis revealed that cemented implants correlated with improved MEPS. Currently, most surgeons advocate the use of a cemented TEA mainly because of osteoporosis in these patients.[6,10] In addition, loosening was less commonly seen with cemented implants which could partly explain the improved MEPS.[10] Further studies with emphasis on cemented versus cementless implants are required to analyze the differences.

Limitations. This study has limitations. First, we only included studies that were written in English. Secondly, due to the nature of our research question, the level of evidence of the studies which were included was low (III or IV). Thirdly, we could only analyze factors including age, sex, cemented or cementless fixation, and linked or unlinked design that were clearly stated in most studies. Factors that might determine outcome including RA disease activity, the baseline activity level of patients, or surgeons' experience could not be analyzed. We stratified all implants into linked or unlinked for analysis rather than to directly validate implant brands as risk factors because the brands were largely heterogenous in the included studies. Lastly, we included studies that were published over a time span of almost 17 years between 2003 and 2019. The studies may have several differences such as heterogenous designs, modified surgical techniques, and different follow-up times. Nonetheless, this study provides an updated review for physicians and revealed several differences compared with the comprehensive review performed by Little et al[11] in 2005.

In conclusion, TEA continues to provide satisfactory results in patients with RA. In this comprehensive review, the overall implant failure rate was 16.1% and the complication rate was 24.5%. Aseptic loosening remains the most common mode of failure after TEA. Importantly, younger patients and unlinked TEAs were associated with implant failure while female sex correlated with aseptic loosening. These results can be of use when counselling patients about the expectations of TEA.

Take home message

- Total elbow arthroplasty (TEA) provides satisfactory results in patients with rheumatoid arthritis (RA) but is associated with higher implant failure and complication rates compared with hip and knee arthroplasties.
- The patient's age, sex, cemented fixation, and prosthesis with unlinked designs may influence the outcome.
- Younger patients were associated with increased complications, while female patients and an unlinked prosthesis were associated with aseptic loosening.

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