International Orthopaedics (2019) 43:1421–1427
https://doi.org/10.1007/s00264-018-4267-2

ORIGINAL PAPER

Clinical results of revision total elbow arthroplasty: comparison of infected and non-infected total elbow arthroplasty

Jae-Man Kwak [1] · Erica Kholinne [2] · Yucheng Sun [1] · Myung-Sun Kim [3] · Kyoung-Hwan Koh [1] · In-Ho Jeon [1]

Received: 24 September 2018 / Accepted: 3 December 2018 / Published online: 7 January 2019
© SICOT aisbl 2019

Abstract

Background Total elbow arthroplasty (TEA) is considered a successful treatment for several conditions, including rheumatoid arthritis and comminuted fractures. However, failure rates as high as 62% have been reported, with many patients requiring surgical revision. Causes of failure requiring revision can be classified as infected or non-infected. This study evaluated the clinical and radiologic outcomes of TEA revision surgery according to causes of failure.

Methods Twenty patients undergoing revision TEAs in 2010–2015 were retrospectively evaluated. Mean follow-up was 52.7 months. Patients were categorized into infected and non-infected groups based on radiologic and serologic tests. Clinical outcomes included range of motion (ROM) and Mayo Elbow Performance Score (MEPS), and radiological outcomes included loosening signs on anteroposterior (AP) and lateral plain radiographs at final follow-up. Complications were assessed in both groups.

Results Overall, mean MEPS was 79.7, and mean ROM arc was 97.9° at final follow-up. Nine patients underwent revision due to infection, and 11 due to non-infectious causes. Mean MEPS in these two groups was 75.6 and 83.5, respectively, and mean ROM arc for flexion-extension was 89.4° and 108°, respectively. Two (22%) of the nine patients in the infection group required second revision surgery due to recurrent infection. No patient in the non-infected group underwent second revision surgery. The most frequent complication in the infected group was osteolysis, observed in five patients, including four with symptomatic aseptic loosening and one with non-symptomatic osteolysis. Two patients in the non-infected group demonstrated a non-progressive radiolucent line, which was asymptomatic at final follow-up.

Conclusion Revision TEA provided clinical improvement in elbow function and resulted in satisfactory outcomes. Outcomes were worse in the infected than in the non-infected groups. Comorbidities and older age were apparent risk factors for infected TEA.

Keywords Revision · Total elbow arthroplasty · Infection · TEA

Level of evidence: III
This manuscript has not been published elsewhere and is not under consideration by another journal. We have approved the manuscript and agree with submission to the International Orthopaedics. There are no conflicts of interest to declare. Our study is approved by the Institutional Review Board.
This study was accepted as oral presentation in the *2018 Annual International Congress of Hand Society in Korea* and *2018 SICOT congress in Montreal in Canada*.

✉ In-Ho Jeon
jeonchoi@gmail.com

1 Department of Orthopedic Surgery, Asan Medical Center, College of Medicine, Ulsan University, Seoul, South Korea

2 Department of Orthopedic Surgery, St. Carolus Hospital, Jakarta, Indonesia

3 Department of Orthopedic Surgery, Chonnam National University Hospital, Dong-gu, Kwangju, South Korea

Introduction

Total elbow arthroplasty (TEA) has become an acceptable option for the treatment of patients with end-stage rheumatoid arthritis [1]. TEA is also regarded as an effective surgical option to treat severe arthritis, including rheumatoid and post-traumatic arthritis, as well as non-salvageable intra-articular distal humerus fracture. TEA is performed to eliminate pain and restore joint function. However, failure rates as high as 62% have been reported [2–5], with various types of failure leading to revision surgeries. Few studies to date have reported outcomes in patients undergoing revision TEA. For example, one study reported successful outcomes in eight of 11 elbows undergoing revision TEA [6]. Another study reporting outcomes of infected TEAs found that Mayo Elbow Performance Scores (MEPSs) were 81.1 in patients without and 50 in patients with recurrence [7], and a third study reported good and excellent results after revision TEA in only 53% of patients, with radiographs showing osteolysis around the prosthesis in four patients (25%) [8]. In addition, the latitude system of TEA did not significantly improve range of motion (ROM) [9]. To our knowledge, however, no study to date has compared outcomes according to failure and implant types.

Types of failure can be classified as infected and non-infected based on serologic markers, imaging, and intra-operative histology. Revision TEA should therefore be based on the type of failure. In the infected type, infectious foci should be eliminated surgically, by implant removal followed by reimplantation, and by treatment with systemic antibiotics. By contrast, treatment of the non-infected type should consist primarily of addressing mechanical problems at the implant-bone or implant-implant interface. Therefore, understanding the pathological mechanism of failure is mandatory for managing revision surgery and complications of TEA. To date, few studies have assessed outcomes in patients undergoing revision TEA, and no studies have compared the outcomes of revision TEA based on type of failure and pathomechanism. This study evaluated the clinical and radiographic outcomes of TEA revision surgery in patients with infected and non-infected types of failure. These results can help predict patient prognosis and provide proper information to patients.

Materials and methods

The study protocol was approved by the institutional board review of our institution. The study subjects included 20 patients who underwent revision TEAs between 2010 and 2015 at a single tertiary referral centre. Mean patient age was 65.7 years (range, 53–83 years) at surgery. The primary reason for TEA was rheumatoid arthritis in 14 patients and osteoarthritis in six. Causes of revision surgery were categorized as infected and non-infected based on radiologic, serologic tests, and intra-operative histology (Table 1). All revisions for infected TEA were performed using the Discovery Elbow System (Biomet, Warsaw, IN, USA). Of the 12 patients who underwent revision for non-infected TEA, four underwent revision using the Coonrad Morrey System (Zimmer, Warsaw, IN, USA) and eight using the Discovery Elbow System. Clinical and radiological outcomes were assessed at final follow-up. Clinical outcomes were assessed by measuring ROM arc and MEPS, which are used to determine pain, motion, stability, and daily function. The primary radiological outcome, as assessed by two surgeons (JMK, EK), was signs of loosening at final follow-up on anteroposterior (AP) and lateral projection plain radiographs. Implant survival rate and complications were assessed depending on type of failure (infected and non-infected). Disease interval was defined as the time periods from the day of first hospital visit for main symptoms to the day of discharge after admission. This interval includes both pre-admission and admission periods because some patients were treated conservatively before admission.

Table 1 Demographic and clinical characteristics of patients undergoing revision TEA

Variable	Infected	Non-infected	*P* value
No. of patients	9	11	
Male	3	2	–
Female	6	9	–
Age (year)	69.1	62.6	0.05
Cause of primary TEA			
Rheumatoid arthritis	6	8	–
Osteoarthritis	3	3	–
Preop. VAS	6.1	5.2	0.21
Preop. ROM			
Flexion-extension	67.7	78.5	0.23
Supination-pronation	88.3	92.5	0.37
Preop. MEPS	46.1	54.4	0.09
Follow-up duration (mos)	62.96	44.0	0.59
Time to revision (mos)	148.8	151.0	0.60

Diagnosis

Similar to standard diagnostic criteria for hip and knee periprosthetic joint infections (PJIs), infected TEA was diagnosed according to the standard for infection after artificial joint implantation proposed by the Musculoskeletal Infection Society (MSIS) [10] and based on the diagnosis standard for culture-negative PJI [11].

Type of implant

Minimally constrained condylar-bearing design (Discovery Elbow System)

The Discovery Elbow System was designed to reduce complications associated with other hinged constrained-type floppy TEAs, later modified to allow press-fit implantation. Its minimally constrained design provides more closely matching articular surfaces, avoids the use of a true hinge, and anatomically reproduces the axis of elbow motion. Its floppy hinge allows for 6° to 8° of varus-valgus motion and rotational motion; the increased area of contact between the cobalt-chrome and ultrahigh molecular weight polyethylene avoids edge loading and reduces stresses within the polyethylene; and the design allows for posterior access during bushing revision [12]. The cementless stem has a porous hydroxyapatite coat to enhance biologic integration.

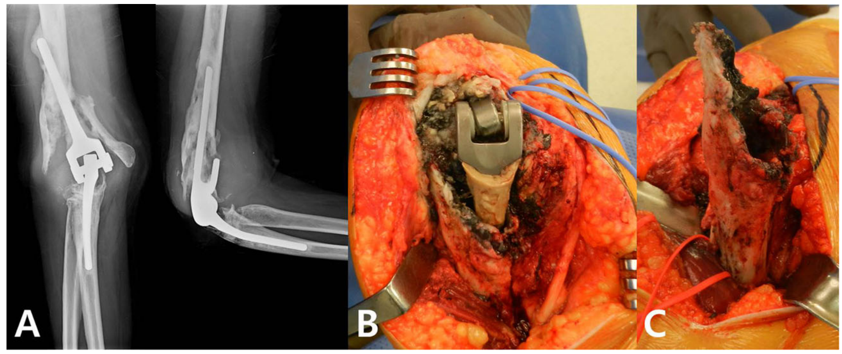

Fig. 1 Fifty-seven years old female patient who got TEA surgery 7 years ago. A periprosthetic fracture. **a** Pre-operative plain X-ray. **b** Humeral bone periprosthetic fracture with central locking pin loosening. **c** Thin and weak humeral bone stock with metallosis

Linked semi-constrained design (Coonrad Morrey System)

The Coonrad-Morrey prosthesis is a linked and semi-constrained implant and one of the most frequently used devices [13]. The implant allows for 7° to 10° of varus-valgus movement and 7° to 10° of axial rotation. The central locking pin was redesigned in 1996, and the ulnar component was altered from a beaded surface to a precoat of polymethylmethacrylate in 1992 and then back to a beaded surface in 2001. This design has been utilized long-term to treat conditions that include rheumatoid and degenerative arthritis and trauma reconstruction. Revision elbow arthroplasty using the Coonrad-Morrey implant is reported to yield satisfactory results [14].

Surgical technique

Two different surgical techniques were used following the diagnosis. Patients diagnosed with infected TEA underwent two-stage surgery, whereas those with no suspected signs of infection, based on the standards of the MSIS, underwent single-stage revision surgery. If one of the components was intact (no loosening), the type of implant was chosen to match the original implant.

Single-stage revision surgery for the non-infected group

The incision from the previous surgery was used. The ulnar nerve was routinely identified and transposed. After exposure of the joint using a triceps-tongue technique, the remaining bone stock and the quality of the soft tissues were carefully inspected. This was followed by sharp subperiosteal release of collateral ligament structures from the medial and lateral epicondyles. The pre-existing components were completely and carefully removed to prevent further damage to bones. As much cement as possible was removed from the medullary canal; however, tightly adhered cement was left in place if it did not interfere with introduction of the revision stem. Bone loss was managed with either cement or shortening of the humerus or ulna. If fractures involving the epicondyles were present, the fragments were temporarily fixed with Kirschner (K)-wires before reimplantation of the components. Cerclage wire was used if there was a longitudinal fracture of the humerus or ulna. The humeral and ulnar shafts were extensively irrigated with saline before introducing cement with a third generation cementing technique. Fluoroscopy was used if there was difficulty in finding the intramedullary canal of the humerus or ulna. The longer component was preferred in all patients.

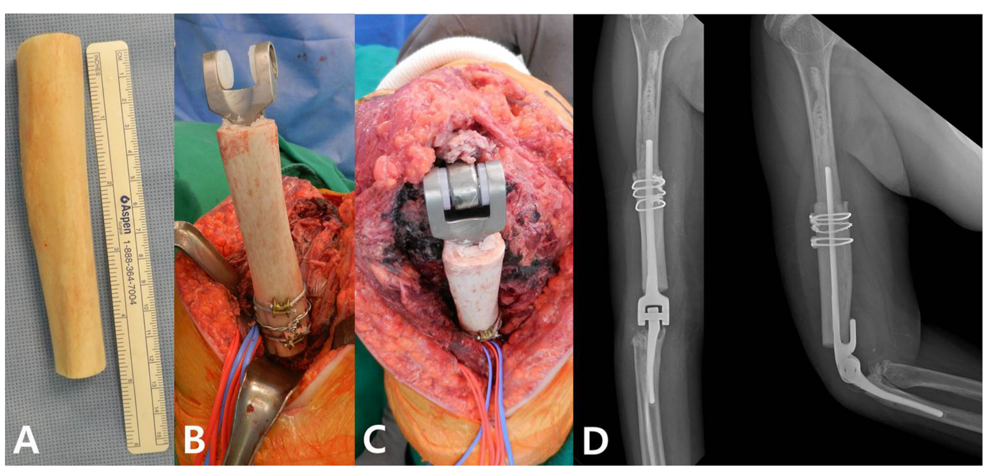

Fig. 2 Reverse intussusception-type APC. **a** Allograft of a femur shaft was prepared after pre-measurement on plain X-ray compared to opposite side humerus. **b**–**c** Proximal site of allograft was split partially. Distal end of humerus was inserted into allograft, and cerclage wire was applied. **d** Post-operative plain X-ray

Table 2 Reasons for non-infected TEA

Complication	No. of elbows
Aseptic loosening	6
Periprosthetic fracture	4
Instability	1
Total	11

Two-stage revision surgery for the infected group

The first stage of surgery focused on eradication of infected tissues and the prosthesis. All cement and any tissue suspected of being infected, including the synovial membrane, were meticulously removed. Tissue samples around the implants and joint fluid were cultured. The bones were windowed for well-fixed implants, and the canals were irrigated with chlorhexidine solution diluted with 0.9% sodium chloride. An antibiotic cement spacer (5-g gentamicin, 1-g vancomycin, and 1-g ceftriaxone per 40-g cement) was used. Patients were administered the optimum dosage of intravenous antibiotics, based on sensitivity tests, until all serologic markers, including white blood cell counts, erythrocyte sedimentation rates, and C-reactive protein concentrations, normalized completely for more than six weeks. The second stage of surgery focused on confirming infection control and reconstructing the joint with a new implant. The antibiotic cement spacer was removed, and tissue samples were obtained for follow-up sensitivity testing. Frozen intra-operative tissue samples were examined histologically to confirm real-time diagnosis tools. Five or more neutrophils per high-powered field were diagnostic of acute inflammation, with any positive result nullifying the reimplantation procedure. Bone loss was managed by three specific reconstructive techniques using allograft-prosthetic composite (APC) [15]. Type I, consisting of intussusception of APC into the host bone (intussusception type), was modified in the reverse fashion, such that the upper portion of host bone was inserted by the lower portion of the femur shaft as the allograft, in case the host bone was too narrow to insert the allograft bone (Figs. 1 and 2). Type II consisted of insertion of the distal aspect of the stem into the host canal with a strut-like extension of the graft coadapted externally to the cortex, and type III consisted of side-to-side contact between the cortices of the APC and host bone. Wiring was frequently added to enhance contact area and fixation between the host bones and APC.

Statistical analysis

Normality was tested using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Statistical analysis was performed with the Mann-Whitney U test, with $P < 0.05$ considered statistically significant. Survival rate was analyzed by the Kaplan-Meier method and compared by the log-rank test. All statistical analyses were performed using SPSS v. 21.0 (SPSS, Inc., Chicago, IL, USA).

Results

Overall outcomes

Nine patients underwent revision due to infection, and 11 due to non-infection. Mean patient age was 65.7 years (range, 53–83 years), mean follow-up was 52.7 months (range, 24–160 months), and mean interval from primary surgery to revision was 132.1 months (range, 16–564 months). Mean pre-operative ROM was 77.3° (flexion-extension), which improved to 97.9° (flexion-extension). Mean pre-operative MEPS was 50.0 (range, 0–70), which improved to 79.7 (range, 35–85) at the latest follow-up. Mean disease duration was 5.6 months (range, 2–20 months).

Comparisons of infected and non-infected groups

The causes of revision TEA in the non-infected group were aseptic loosening in six patients, periprosthetic fractures in four, and instability due to metal failure, including loosening of interlocking screws, in one (Table 2). At the last follow-up,

Table 3 Clinical and radiologic outcomes at final follow-up

Variable	Infected	Non-infected	*P* value
Final VAS	3.3	2.4	0.03*
ROM (flexion-extension)	89.4	108.0	0.04*
ROM (supination-pronation)	103.3	109.4	0.33
MEPS	75.6	83.5	0.04*
Osteolysis	5	2	0.29
Second revision rate at final follow-up	7 (77.7%)	0 (0%)	< 0.01*
Disease period (mos)	7.11	3.37	< 0.01*
No. comorbidity	22	7	< 0.01*

¶: from the first visit with symptoms to final discharge (months)

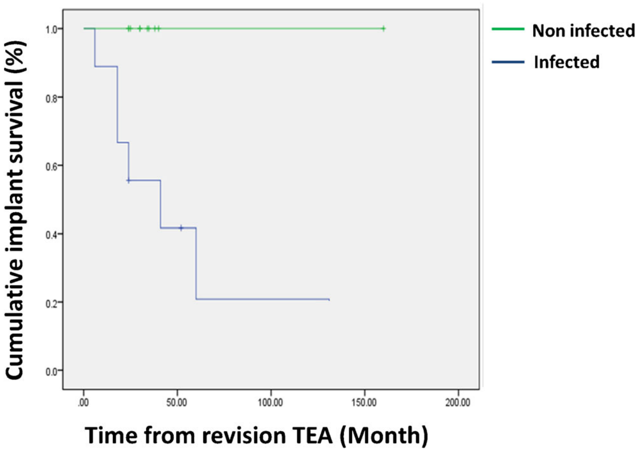

Fig. 3 Kaplan-Meier analysis of implant survival after revision TEA

mean MEPS was 75.6 in the infected and 83.5 in the non-infected group, and mean ROM arc was 89.4° and 108°, respectively. The two groups differed significantly in visual analog scale (VAS), ROM (flexion-extension), MEPS, and disease interval (Table 3).

Evaluation of the radiologic outcomes showed radiologic osteolysis in five patients in the infected and two in the non-infected group. Of the five patients in the infected group, four had symptomatic aseptic loosening and one had asymptomatic osteolysis. All four patients with aseptic loosening underwent revision surgery. Both patients in the non-infected group with radiologic osteolysis were treated conservatively because both were asymptomatic until final follow-up. The five and eight year implant survival rates in the infected group were 44.4 (four of nine) and 22.2% (two of nine). The implant survival rate in the non-infected group was 100% at final follow-up (Fig. 3).

Complications

The nine patients in the infected group experienced a total of ten complications. The most common complication was osteolysis in five patients, including four with symptomatic aseptic loosening and one with non-symptomatic osteolysis.

Table 4 Underlying disease comorbidity (number of patients)

	Infected	Non-infected
Diabetes	8	1
HTN	6	3
Cancer	3	0
Hepatitis	2	0
Osteoporosis	3	2
TB	1	0
Total	22	7

All four patients with symptomatic loosening underwent second, or repeat, revision surgery. Two patients experienced recurrent infection, requiring second revision surgery. The other three complications included temporary radial nerve palsy, ulnar nerve irritation, and periprosthetic fracture in one patient each. By contrast, the 11 patients in the non-infected group experienced only three complications, including two with asymptomatic osteolysis that did not require repeat revision. The third patient had ulnar nerve irritation, which was treated conservatively.

Discussion

TEA, which has become more popular over the last four decades [16], is performed primarily to treat rheumatoid arthritis and unreconstructable trauma in geriatric patients. Despite current trends, its high failure rate remains a challenge for orthopaedic surgeons. The present study evaluated the radiologic and clinical outcomes in patients who underwent revision TEA for infected and non-infected causes. We found that the clinical outcome was inferior in the infected group. Although the incidence of deep infection after TEA is reported to be approximately 3 to 8%, management of infected TEA remains a challenge. A clear understanding of the different features of infected and non-infected revision TEA is necessary to obtain better outcomes and for better patient management (Tables 4 and 5).

We found that the rate of second revision was much higher in the infected than in the non-infected group. Once bone is infected, bacterial colonies destroy bony structure from the medullary canal to the cortical bone. This induces implant loosening and increases the chance of breakage due to the weakened bony structure. Moreover, incomplete resection of infected bone and inappropriate antibiotic use can be risk factors for increased recurrence rate of infection. Consequently, the total disease interval in infected patients is longer, a factor that may be associated with poorer clinical outcomes, including pain and lower MEPS score.

Radiologic features were observed to differ between the progression of infected and non-infected loosening (Fig. 4, Table 5). In infected loosening, the position of the implant stem is displaced eccentrically, especially anteriorly. This displacement is related to the specific elbow movement of flexion/extension with a cantilever effect, unlike movement of the hip and knee. Extensive localized bone resorption resulting in loosening was reported to be the main cause of infected loosening in four patients who underwent hip arthroplasty [17]. Osteolysis may be linear, equally distributed around the implant, or focal, with islands of bone loss in close relation to the implant. Once osteolysis occurs, repeated hinged movement of the elbow implant can induce a pinching out stress force due to the cantilever effect of the stem in the anterior

Table 5 Radiographic features of infected and non-infected loosening (Advanced stage)

	Infected	Non-infected
Stem position	Centric/eccentric	Eccentric (anterior cortical penetration)
Cortical bone	Destructive expanding (periosteal reaction)	Cortical thinning (shell-like appearance)
Medullary canal	Expanding and hazy (bubble-like appearance)	Recanalization

cortex. Consequently, this movement causes an eccentric stem position, especially in the anterior direction, with cortical thinning and a recanalization-like feature. A form of loosening can also result from anterior impingement of the coronoid process, with the latter driven into the anterior humeral flange after the implant attains maximum flexion [18]. Anterior impingement can lead to a distraction force on the humeral component and subsequent loosening. This complication may be avoided by ensuring that the coronoid process does not impinge anteriorly on the anterior humerus. By contrast, the medullary canal tends to be widened by infected osteolysis and by the volume of the bacterial colony that expands from the canal to the cortical bone. In addition, a periosteal reaction-like sun-burst appearance has been observed in elbows with advanced infection. However, this radiologic finding is not always clear in early stages of loosening [19]. Serial or single sodium fluoride positron emission tomography (18F-NaF-PET) is a sensitive and specific tool for diagnosing and distinguishing between septic and aseptic loosening in hip prostheses.

We also found that the comorbidity rate was higher in the infected than in the non-infected group (Table 4). All patients in our infected group had three or more comorbidities. Several related studies report a strong relationship between infection and comorbidity [20]. In addition, implant insertion increases the likelihood of infection in the elbow, a factor that should be considered prior to performing primary elbow arthroplasty.

Fig. 4 Different features in a plain radiograph. **a** Infected loosening. (Advanced stage) **b** Non-infected loosening

Even after elbow arthroplasty, prevention of infection requires general control of comorbidities.

We found that the mean age of the infected group (72.2 years) was significantly higher than that of the non-infected group (63.3 years). This result was in an agreement with the relationship between comorbidities and infection, because older patients tend to have higher comorbidity rates. Moreover, trauma-related TEA often leads to additional procedures [5].

Management of bone loss is an important issue, especially in revision surgery, which always requires complete resection of pathologic bone. APC reconstruction has therefore been recommended. Larger graft-host contact areas in the APCs have provided good functional outcomes and a higher rate of union than resection arthroplasty [15, 21, 22]. Three of our patients underwent TEAs using APC, with all showing satisfactory bone healing. Deep infection is also detrimental to soft tissues, especially the triceps, which are frequently exposed at the time of index arthroplasty and during subsequent procedures and may result in triceps insufficiency [23]. A recent analysis from the Mayo Clinic involving 93 elbows with PJI after TEA demonstrated triceps weakness in 55% (51 elbows) following reimplantation or debridement for treatment of the infection [24]. This underscores the need to develop triceps-sparing exposures in primary and revision TEA.

The strength of this study is that, to our knowledge, no prior study has compared infected and non-infected TEA. However, this study was limited by its relatively small sample size and its retrospective design. Because of the rarity of these clinical entities, this study provides valuable information, including comparisons of clinical features, prognosis, and strategy for management of infected and non-infected TEA.

Conclusion

Revision TEA resulted in clinical improvement of elbow function and satisfactory outcomes. Outcomes were poorer in the infected than in the non-infected group. High comorbidity rates and older age are apparent risk factors for infected TEA.

Compliance with ethical standards

Conflict of interests The authors declare that there is no conflict of interest.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

1. Day JS, Lau E, Ong KL, Williams GR, Ramsey ML, Kurtz SM (2010) Prevalence and projections of total shoulder and elbow arthroplasty in the United States to 2015. J Shoulder Elb Surg 19(8):1115–1120. https://doi.org/10.1016/j.jse.2010.02.009
2. Brinkman JM, de Vos MJ, Eygendaal D (2007) Failure mechanisms in uncemented Kudo type 5 elbow prosthesis in patients with rheumatoid arthritis: 7 of 49 ulnar components revised because of loosening after 2–10 years. Acta Orthop 78(2):263–270. https://doi.org/10.1080/17453670710013780
3. Kim JM, Mudgal CS, Konopka JF, Jupiter JB (2011) Complications of total elbow arthroplasty. J Am Acad Orthop Surg 19(6):328–339
4. Park SE, Kim JY, Cho SW, Rhee SK, Kwon SY (2013) Complications and revision rate compared by type of total elbow arthroplasty. J Shoulder Elb Surg 22(8):1121–1127. https://doi.org/10.1016/j.jse.2013.03.003
5. Perretta D, van Leeuwen WF, Dyer G, Ring D, Chen N (2017) Risk factors for reoperation after total elbow arthroplasty. J Shoulder Elb Surg 26(5):824–829. https://doi.org/10.1016/j.jse.2016.12.064
6. Kiran M, Jariwala A, Wigderowitz C (2015) Medium term outcomes of primary and revision Coonrad-Morrey total elbow replacement. Ind J Orthop 49(2):233–238. https://doi.org/10.4103/0019-5413.152497
7. Peach CA, Nicoletti S, Lawrence TM, Stanley D (2013) Two-stage revision for the treatment of the infected total elbow arthroplasty. Bone Joint J 95-b(12):1681–1686. https://doi.org/10.1302/0301-620x.95b12.31336
8. Viveen J, Prkic A, Koenraadt KL, Kodde IF, The B, Eygendaal D (2017) Clinical and radiographic outcome of revision surgery of total elbow prosthesis: midterm results in 19 cases. J Shoulder Elb Surg 26(4):716–722. https://doi.org/10.1016/j.jse.2016.10.010
9. de Vos MJ, Wagener ML, Hannink G, van der Pluijm M, Verdonschot N, Eygendaal D (2016) Short-term clinical results of revision elbow arthroplasty using the latitude total elbow arthroplasty. Bone Joint J 98-b(8):1086–1092. https://doi.org/10.1302/0301-620x.98b8.35025
10. Hozack WJ, Parvizi J (2011) New definition for periprosthetic joint infection. J Arthroplast 26(8):1135. https://doi.org/10.1016/j.arth.2011.09.025
11. Osmon DR, Berbari EF, Berendt AR, Lew D, Zimmerli W, Steckelberg JM, Rao N, Hanssen A, Wilson WR (2013) Diagnosis and management of prosthetic joint infection: clinical practice guidelines by the Infectious Diseases Society of America. Clin Infect Dis 56(1):e1–e25. https://doi.org/10.1093/cid/cis803
12. Hastings H 2nd (2004) Minimally constrained elbow implant arthroplasty: the discovery elbow system. Tech Hand Upper Extrem Surg 8(1):34–50
13. Shi LL, Zurakowski D, Jones DG, Koris MJ, Thornhill TS (2007) Semiconstrained primary and revision total elbow arthroplasty with use of the Coonrad-Morrey prosthesis. J Bone Joint Surg Am 89(7):1467–1475. https://doi.org/10.2106/jbjs.f.00715
14. Sneftrup SB, Jensen SL, Johannsen HV, Sojbjerg JO (2006) Revision of failed total elbow arthroplasty with use of a linked implant. J Bone Joint Surg Br Vol 88(1):78–83. https://doi.org/10.1302/0301-620x.88b1.16446
15. Morrey ME, Sanchez-Sotelo J, Abdel MP, Morrey BF (2013) Allograft-prosthetic composite reconstruction for massive bone loss including catastrophic failure in total elbow arthroplasty. J Bone Joint Surg Am 95(12):1117–1124. https://doi.org/10.2106/jbjs.l.00747
16. Ramirez MA, Cheung EV, Murthi AM (2017) Revision total elbow arthroplasty. J Am Acad Orthop Surg 25(8):e166–e174. https://doi.org/10.5435/jaaos-d-15-00479
17. Harris WH, Schiller AL, Scholler JM, Freiberg RA, Scott R (1976) Extensive localized bone resorption in the femur following total hip replacement. J Bone Joint Surg Am 58(5):612–618
18. Cheung EV, O'Driscoll SW (2007) Total elbow prosthesis loosening caused by ulnar component pistoning. J Bone Joint Surg Am 89(6):1269–1274. https://doi.org/10.2106/jbjs.f.00376
19. Adesanya O, Sprowson A, Masters J, Hutchinson C (2015) Review of the role of dynamic 18F-NaF PET in diagnosing and distinguishing between septic and aseptic loosening in hip prosthesis. J Orthop Surg Res 10:5. https://doi.org/10.1186/s13018-014-0147-7
20. Pruzansky JS, Bronson MJ, Grelsamer RP, Strauss E, Moucha CS (2014) Prevalence of modifiable surgical site infection risk factors in hip and knee joint arthroplasty patients at an urban academic hospital. J Arthroplast 29(2):272–276. https://doi.org/10.1016/j.arth.2013.06.019
21. Renfree KJ, Dell PC, Kozin SH, Wright TW (2004) Total elbow arthroplasty with massive composite allografts. J Shoulder Elb Surg 13(3):313–321. https://doi.org/10.1016/s1058274604000278
22. Hackl M, Muller LP, Leschinger T, Wegmann K (2017) Total elbow arthroplasty in traumatic and post-traumatic bone defects. Orthopade 46(12):990–1000. https://doi.org/10.1007/s00132-017-3493-4
23. Somerson JS, Morrey ME, Sanchez-Sotelo J, Morrey BF (2015) Diagnosis and management of periprosthetic elbow infection. J Bone Joint Surg Am 97(23):1962–1971. https://doi.org/10.2106/jbjs.o.00170
24. Duquin TR, Jacobson JA, Schleck CD, Larson DR, Sanchez-Sotelo J, Morrey BF (2014) Triceps insufficiency after the treatment of deep infection following total elbow replacement. Bone Joint J 96-b(1):82–87. https://doi.org/10.1302/0301-620x.96b1.31127