13 Total Elbow Arthroplasty

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13.1 Introduction

Total elbow arthroplasty (TEA) is a rare intervention. In 2016, the Dutch Arthroplasty Register included about 400 elbow arthroplasties compared with 28,000 hip arthroplasties and 27,000 knee arthroplasties overall. TEA is usually performed after other treatments aimed at relieving pain and improving joint function have been tried: either conservative treatment with physical medicine and rehabilitation and analgesics or surgical such as arthroscopic joint debridement. In patients with mild to moderate elbow osteoarthritis (OA) and in young patients, these therapeutic options are preferable, as they delay the need for TEA. For each patient, the most appropriate implant should be chosen on the basis of its stability and extensibility; that is, a decision should be made whether to use an unlinked implant, which has less intrinsic stability, or a linked implant, which has more intrinsic stability; it should also be decided whether or not the replacement of the ulnohumeral joint should be accompanied by a replacement of the radiocapitellar joint [1].

Total joint replacements for the treatment of elbow arthritis were developed in the late 1960s, at the same time as total joint replacements for the treatment of knee arthritis. Since then, the number of arthritis patients treated with total knee joint replacements has been steadily increasing, in contrast to TEA, which has been decreasing since its peak in the 1990s. The main reasons for this decline are the continuing controversy over implant design, the relatively high rates of complications associated with TEA, the difficulties often encountered in revision surgery, and recent changes in the population of patients treated with TEA [2].

As published in 2021 by Poff et al., TEA is an effective treatment for multiple elbow pathologies. However, those authors identified a marked decline in the use of TEA after 2011. The article by Poff et al. also showed that from 2002 to 2017, TEA was primarily performed on fracture-related elbow problems. However, inflammatory arthropathy-related TEA steadily decreased during that time period, although it was the second most frequent diagnosis. The aforementioned article also showed that during the period 2002–2017, TEA was most frequently used in women over 65 years of age with various comorbidities [3].

The Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) was analyzed in 2019 by Vivieen et al. to determine trends in primary TEA use, types of prostheses used, primary diagnoses, causes and types of revision, and whether primary diagnosis or prosthetic design influenced

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E. C. Rodríguez-Merchán, A. Moreno-Garcìa (eds.), *Controversies in Orthopedic Surgery of The Upper Limb*, https://doi.org/10.1007/978-3-031-04907-1_13

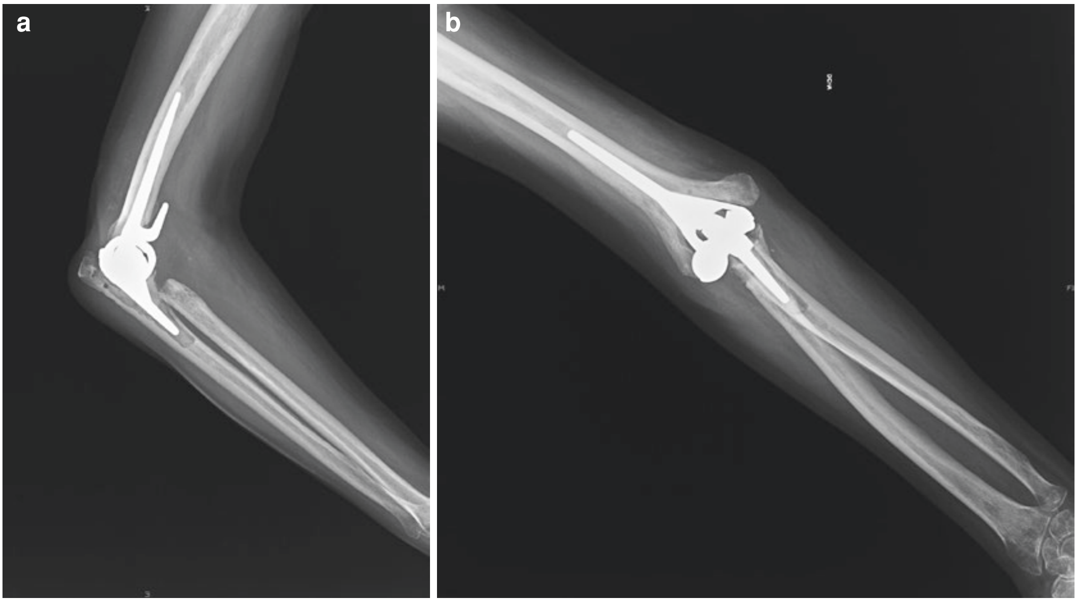

Fig. 13.1 (**a**, **b**) Loosening of both components. A major cause for loosening of both components is infection and should always be ruled out. When loosening affects only to one component, infection still remains the first cause to investigate but component loosening due to bushing wear or an incorrect cementing technique can be contributing factors. (**a**) Lateral view and (**b**) anteroposterior (AP) view

revision rate. During 2008–2018, 1220 primary TEAs were recorded, of which 140 were revised. Kaplan-Meier survival estimates were used to determine time to first revision and hazard ratios from Cox proportional hazard models, adjusted for age and sex, to compare revision rates. The annual number of TEAs performed was held constant. The three most frequent diagnoses for a primary TEA were fracture/dislocation (trauma) (36%), OA (34%), and rheumatoid arthritis (RA) (26%). The cumulative percentage of revision of all TEAs performed for any reason was 10%, 15%, and 19% at 3, 6, and 9 years, respectively. TEAs performed for OA had a higher revision rate than TEAs performed for trauma. The most commonly used prosthetic designs were Coonrad-Morrey (50%), Latitude (30%), Nexel (10%), and Discovery (9%). There was no difference in revision rates when comparing the four aforementioned designs. The most common causes of revision were infection (35%) and aseptic loosening (34%) (Fig. 13.1). Vivieen et al. also noted that the indications for primary and revision TEA in Australia were similar to those reported in other registries. However, revisions for trauma were lower than previously published in other registries [4].

In this chapter we will review the literature on primary and revision TEA in an attempt to clarify some of the current controversies surrounding these surgical interventions.

13.2 Primary TEA

13.2.1 Biomechanics

To optimize outcomes and minimize complications of a primary TEA, it is critical to understand its biomechanics. Nonconstrained TEA prostheses have little intrinsic stability and rely on soft tissue balance. The medial and lateral collateral ligaments are the main stabilizers of nonconstrained TEAs. The anterior capsule, posterior capsule, and surrounding muscles act as secondary stabilizers. There are implants not bound by a hinge mechanism that can be very constrained by virtue of their high degree of articular compliance. Semiconstrained TEAs use a hinge mechanism that allows small degrees of off-axis movement in order to reduce stress on the bone-cement interface of the components. During implantation, the components reproduce the alignment and rotation of the elbow axis. Malalignment of the components will increase the bending and torsional loading of the implant and may contribute to premature aseptic loosening and polyethylene wear. However, axis landmarks may not be present in some revision surgeries or fracture surgeries, which hinder proper implantation. Most current TEA systems employ Morrey's anterior flange design on the humeral implant, which reduces rotational stress at the bone-cement interface (as compared to a purely intramedullary humeral component) and counteracts extension forces at the elbow. If the flange does not have adequate contact with the anterior cortex, it should be augmented with a bone wedge. The anterior flange and the semi-constrained articulation are considered to be the main reasons why current designs outperform constrained hinged designs [5].

13.2.2 Patient Selection

Most of the existing TEA designs since the early 1970s have been successful in treating patients with severe degenerative changes secondary to RA, which was originally the main surgical indication. In the mid-1990s, the type of patients changed, as effective drugs against RA became available and, consequently, patients with RA became rare. The disease-modifying drugs have served to preserve normal bone architecture and, as a result, the elbows of RA patients increasingly resemble those of patients with OA. However, TEA has been less successful in treating patients with OA than in treating patients with RA. Consequently, since the mid-1990s, surgeons performing TEA have become increasingly aware that their results are less satisfactory than those they obtained in the past. Thus, despite further improvements in implant design, surgeons are increasingly reluctant to recommend TEA for the treatment of elbow arthritis. The use of TEA for fractures began in rheumatic patients with severe joint involvement who suffered a fracture of the columns. Good initial results facilitated its extension of use to patients without inflammatory disease [2, 6].

13.2.3 Preoperative Planning

The preoperative planning of a TEA is relatively handcrafted. There are several stem thicknesses, various stem lengths, and anterior lozenge (flange) lengths, providing hundreds of possible combinations. Component orientation is based on coarse bone references, although these are assumed to be predictable. The use of newer technologies for planning may help to improve component positioning and, perhaps, improve implant survival.

In 2018, Iwamoto et al. analyzed the role of computed tomography-based three-dimensional preoperative planning for unlinked TEA. In a basic science (computer modeling) study, they observed that 3-D surgical planning enabled accurate calculation of implant size and proper placement of implant components. They analyzed 28 patients operated on for TEA with an unlinked total elbow implant (unlinked-type K-NOW implant [Teijin-Nakashima Medical, Okayama, Japan]). With two-dimensional planning, humeral stem sizes were accurately estimated in 57% of patients and 68% of ulnar stems, compared with 86% for the humerus and 96% for the ulna with 3D planning. The mean differences between the prosthesis positions after surgery with respect to the planned positions were 0.8° of varus and 1.5° of flexion for the humeral component and 0.7° of varus and 2.9° of flexion for the ulnar component. Rotational position was not evaluated in this study. The method described by Iwamoto et al. could help reduce the complication rate of TEA and improve its long-term outcomes [7].

13.2.4 Surgical Approaches for TEA

Most elbow approaches use a posterior midline skin incision with full-thickness flaps and identify the ulnar nerve early. It is generally accepted that the nerve should be identified early and decompressed superficially and protected throughout the procedure. However, the nerve is at risk when manipulated, and whether or not to transpose it depends on the surgeon's preference. Transposition is recommended when there is a previous nerve deficit or when the prosthesis affects the usual nerve pathway. However, the risk of injuring the blood supply to the nerve has led some authors to advocate leaving it in its bed with its deep soft tissues, in order to reduce the risk of postoperative neuritis. Trans-olecranon osteotomy is rarely used due to the involvement of the ulna for insertion and fixation of the component. Approaches can be broadly classified into triceps-on and triceps-off. Triceps-on approaches maintain the triceps mechanism and its insertion into the ulna. Triceps-off approaches imply that part or all of the triceps is removed from its insertion into the ulna or that the triceps mechanism is cut at some point. Triceps-off approaches can be subdivided into triceps turndown, triceps elevating, or triceps splitting. A triceps turndown involves cutting the triceps tendon above the ulnar insertion. A triceps elevating approach elevates the triceps off the ulna subperiosteally. A triceps splitting approach splits the triceps tendon longitudinally along its length and across its insertion. The triceps-on approach has functional advantages over the other approaches, although it provides reduced exposure that may compromise the correct position of the implants [8].

Some patients with inflammatory disease may have a compromised triceps insertion and in these cases a triceps-on approach may be chosen, generally respecting the triceps tendon. The most commonly used are the Alonso-Llames bilaterotricipital approach and the lateral para-olecranial approach [9]. All of them affect in some way the comfort of implant placement, especially the ulnar component. Recently, Celli and Bonucci published their experience with the anconeus-triceps lateral flap approach for TEA in patients with RA. They suggested that the decision not to separate the medial insertion of the triceps influenced the risk of triceps insufficiency and allowed patients to begin an active, unrestricted rehabilitation program earlier. It also provided adequate surgical exposure of the olecranon articular surface, particularly in patients with severe elbow joint deformity. This type of approach allowed adequate alignment between the olecranon and the posterior surface of the ulna, without interfering with the entire triceps muscle tendon between the two planes. The relationship between the two aforementioned planes was an important landmark during the implantation of the ulnar component. Whichever triceps-on approach is used, two windows are used (one medial and one through the per se approach), and one must try to dislocate the elbow through the surgical window in the position where the ulnar nerve is protected and free of tension and the exposure is adequate to achieve the correct orientation of the implant [10].

In 2018, in a level IV therapeutic study (case series), Na et al. evaluated the clinical outcomes and extensor strengths of primary TEAs implanted with a modified triceps fascial tongue approach. They concluded that it was an easy and effective approach for primary TEA, which prevented triceps weakness after arthroplasty. Triceps strength was normal (Medical Research Council [MRC] grade V) in 10 elbows (48%) and good (MRC grade IV) in 11 (52%). Triceps strength after arthroplasty was significantly improved over preoperative strength. This approach is a modification of the classic Campbell approach. They share the advantage that suprafascial dissection is minimal compared to approaches in which the triceps is approached medially and laterally but carries the potential risk of fascial tongue necrosis [11].

According to a level IV therapeutic study reported by Cottias et al., the digastric olecranon osteotomy approach allowed excellent joint exposure and preserved the main vascular supply and continuity of the extensor apparatus. These authors evaluated the early clinical and radiological results after Coonrad-Morrey-type TEAs were implanted using the aforementioned approach. The mean age of the patients was 80 years (range: 50–96). The causes of the interventions were 20 fractures, 2 malunions, and 4 elbows with RA. The mean follow-up time was

30 months (range: 6–132). At the last evaluation, the mean flexion arc increased from 23° to 112°. The Mayo Elbow Performance Score (MEPS) was 92 points on average. Mean triceps strength in extension and flexion was 1.9 and 4.7 kg, respectively. All elbows were stable. There was a single wound infection in the immediate postoperative period, which did not require any surgical revision. Heterotopic ossifications were observed in one elbow. One patient suffered an elbow dislocation due to fracture of the axe's component. The clinical and radiological results encountered were considered promising and supported the use of the digastric olecranon osteotomy for the implantation of TEAs [12].

13.2.5 Outcomes of TEA

13.2.5.1 Thirty-Day Readmissions and Reoperations After TEA

Cutler et al. have published that the 30-day unplanned reoperation rate was 2.4%, and the unplanned readmission rate was 5.1%. A low BMI (body mass index) predicted readmission. Contaminated or dirty wounds were predictors of reoperation. Dependent functional status and contaminated wounds were predictors of local complications. The indication for TEA (fracture vs. OA vs. RA) was a risk factor for reoperation or readmission after TEA [13].

13.2.5.2 Long-Term Outcomes of TEA

Davey et al. published a systematic review of the literature (level IV evidence) in which they evaluated functional outcomes and dislocation and revision rates of TEA. The mean minimum follow-up was 10 years. They analyzed 23 publications that included 1429 elbows (60.4% linked TEA) that met the inclusion criteria. There were 1276 patients (79% female), with a mean age of 64.7 years (range: 19–93). The mean follow-up was 137.2 months (range: 120–216). At final evaluation, the mean MEPS, Oxford Elbow Score, and Quick DASH (Disabilities of the Arm, Shoulder and Hand) scores were 89.1, 64.4, and 39.2, respectively. Further, 63.3% of patients claimed to be pain-free. The rates of aseptic loosening, infection, implant dislocation, and nerve injury were 12.9%, 3.3%, 4.2%, and 2.1%, respectively. The overall complication and revision rates were 16.3% and 14.6%, respectively [14].

13.2.5.3 Risk Factors for Reoperation After TEA

A traumatic indication has a higher risk of reoperation than other indications according to several studies. The reason is unclear and may be related to a worse patient condition that may affect immune status, wound healing capacity, use of canes for ambulation, or increased frequency of falls.

In a level IV evidence therapeutic study (case series), primary TEAs performed in two hospitals were retrospectively reviewed. Perretta et al. identified 102 primary TEAs in 82 patients performed by nine surgeons. The mean age of the patients was 61 years. Women accounted for 81% of the TEAs performed. The mean follow-up was 6.1 years. The main diagnosis was inflammatory arthritis in 63 patients (62%), acute or posttraumatic trauma in 28 (27%) and primary OA in 9 (8.8%). The mean reoperation rate was 41%. The mean time to first reoperation was 1.8 years. The percentage of elbows in which one or both components were revised was 30%. The most frequent indication for reoperation was component loosening (Fig. 13.1). Six elbows were treated with resection arthroplasty, and in one elbow fusion was performed. The implant revision rate was 27% for inflammatory arthritis, 11% for OA, and 57% for trauma. Trauma-related TEA was more likely to require additional reoperation and implant revision [15].

13.2.5.4 Mid- to Long-Term Survivorship of Cemented Semiconstrained "Discovery" TEA

In 2021, Borton et al. presented a mid- to long-term survivorship study of the "Discovery" TEA, with a follow-up of 5–12 years. This implant contains a spherical bearing designed to minimize polyethylene wear. According to the Kaplan-Meier method, they demonstrated an implant survival of 76.8% at 119 months. Borton et al. analyzed 67 TEAs in 58 patients, with a mean follow-up since surgery of 98.5 months. Four cases (6%) were lost to follow-up. The implant was revised in 14 cases (20.9%). There was a significant difference in survival between dominant and nondominant elbows (Breslow test $p = 0.012$). Elbow dominance implied a 4.5-fold increased risk of revision [16].

13.2.6 Complications After TEA

13.2.6.1 Periprosthetic Infection: Resection Arthroplasty

Resection arthroplasty is sometimes the best or only effective alternative to treat some of the complications of failed implants. It is surprising how well some of these patients can function, in some cases with remarkable elbow stability and good hand grip strength.

In 2016, Rhee et al., in a level IV evidence therapeutic study (case series), published their results on the use of resection arthroplasty for the treatment of infections after TEA and the factors that influenced them. They stated that resection arthroplasty may be an acceptable salvage treatment for infections after TEA in low-demand patients. They published that to achieve a successful outcome, both columns of the distal humerus should be preserved at the time of implant removal. They analyzed 10 resection arthroplasties (nine patients) for infection after TEA. The mean follow-up was 52.4 months. According to the remnant distal humerus bone stock, the elbows were divided into three groups: lateral column, medial column, and both columns. The mean time to resolution of clinical infection symptoms and normalization of serologic markers after resection was 6.8 days and 68.5 days, respectively. The mean MEPS and DASH scores changed from 50 and 46.5 preoperatively to 73.5 and 53 at the end of follow-up ($p < 0.001$ and $p < 0.001$, respectively). Although not significant, the both-column group showed better functional outcomes (MEPS 80; DASH score 43.7) than either the lateral column (74, 54.6) or medial column (62.5, 63) groups. The mean satisfaction score at the end of follow-up was 70. Only one case required additional operations to treat recurrent infection. There were no refractory infections, no fractures, and no permanent nerve lesions. This work reflects the importance of the integrity of the columns in the stability of the ulnar remnant after resection. It is important to note that in distal fractures of both columns, many surgeons choose to resect the columns for the sake of quick and operative resolution. It is neither clear whether devoting surgical time to reconstructing the columns is an appropriate strategy, nor is it clear what the ideal method of achieving such fixation is [17].

13.2.6.2 Heterotopic Ossification Following TEA

In 2018, Robinson et al. analyzed the incidence of heterotopic ossification in 55 elective ($n = 29$) and traumatic ($n = 26$) TEAs (52 patients). Throughout follow-up 15 patients (17 TEAs) died of unrelated causes. There were 14 men and 38 women, with a mean age of 70 years. The mean clinical follow-up was 3.6 years and the mean radiological follow-up was 3.1 years. The overall incidence of heterotopic ossification was 84%. The overall incidence was higher in the trauma group (96%) than in the elective arthroplasty group (72%). In addition, patients in the trauma group had heterotopic ossification of higher Brooker class. The presence of heterotopic ossification did not significantly affect elbow range of motion (ROM) within the trauma or elective groups. These findings are not surprising and in general are not going to affect the evolution of the patients so it is not advisable to perform any associated medical (indomethacin) or physical (radiotherapy) treatment in the trauma group [18].

13.2.6.3 Component Fracture After TEA

Component fracture can be defined as a failure of the material to withstand cyclic loading (Fig. 13.2). This is more frequent in some designs with material changes, with wedges, notches, or different surface treatments on the same component. The presence of osteolysis in which the

Fig. 13.2 Component fracture. The radiograph shows a broken ulnar component at the site of a notch of this particular ulnar component. The site of rupture occurs usually at the point where the ulnar component becomes unsupported from the ulna, typically at the olecranon in patients in which the ulnar component insertion was introduced slightly in flexion

implant is uncovered and has to bear the full mechanical load seems to favor this complication.

According to Lee et al., ulnar or humeral component stem fractures after TEA are serious complications. In a retrospective therapeutic level III evidence study, they reported that a component stem fracture after TEA appears to be caused by fatigue failure at or near the junction between an unsupported stem and well-fixed stem (Fig. 13.2). This area of unsupported stem occurs as a result of osteolysis caused by bushing wear. To avoid fracture of the components, bushing wear needs to be addressed. A total of 2637 primary and revision TEAs were analyzed. It was found that 47 operations (in 46 patients) were performed to treat component stem fractures. Bushing wear was graded according to percentage loss of polyethylene thickness and metal wear. In the 39 cases in which bushing wear could be quantified, it was severe in 34, moderate in 2, and mild in 3. All 47 cases showed evidence of periarticular osteolysis, which was found in zone 1 in 17 cases, in zones 1 and 2 in 29, and diffusely in 1 case. The mean length of the well-fixed stem, expressed as a percentage of the total length of the stem, was 63%. Stem fractures occurred most frequently (27 of 47 cases) at the junction between the well-fixed stem and unsupported stem. Some studies have associated bushing wear with the presence of osteolysis, but it is probably not the only cause. Measurement of polyethylene wear is sometimes complex because it is performed in static positions and may risk underdiagnosis. It is important to recognize that different designs have different degrees of freedom and it is necessary to be aware of these in order to correctly calculate polyethylene wear [19].

13.2.6.4 Humeral Amputation Following TEA

Claxton et al. analyzed the incidence and etiology of upper extremity amputations in patients who had previously undergone TEA implantation ($n = 1906$). Upper extremity amputation was performed in seven (0.36%) elbows (seven patients): five transhumeral amputations and two shoulder disarticulations. There were five women and two men, mean age 64 years. The TEAs had been implanted for RA ($n = 2$), for RA with acute fracture ($n = 2$), for radiation-associated nonunion ($n = 2$), and for metastatic cancer ($n = 1$). The mean follow-up after amputation was 3 years. The mean time between amputation and TEA was 5 years. Indications for amputation were uncontrolled deep infection in six (86%) elbows and tumor recurrence in one (14%) elbow. Only one (14%) elbow was fitted with a prosthesis. Six (86%) patients died after a mean of 3 years after amputation [20].

13.2.7 Inpatient Versus Outpatient TEA

There is a trend in the USA to transition arthroplasty procedures from inpatient to outpatient centers, generally in ambulatory surgical centers. The change is that the cost of the episode decreases dramatically and that there is a favorable alignment between the interests of providers and funders. Whether this benefit extends to patients is under study. In 2020, Furman et al. compared the outcomes and short-term complications of TEA in the inpatient and outpatient operative settings in a level III evidence-based retrospective therapeutic study using a large database. They analyzed 575 patients operated on for TEA (458 were inpatient procedures and 117 were outpatient procedures). Inpatient TEA had a higher rate of complications than outpatient TEA, including non-home discharge (14.9% vs. 7.5%, $p = 0.05$), unplanned hospital readmission (7.4% vs. 0.9%, $p = 0.01$), surgical complications (7.6% vs. 2.6%, $p = 0.04$), and medical complications (3.6% vs. 0%, $p = 0.04$). Obviously, the criteria to perform this procedure on an outpatient basis is stricter, so there is a bias in what type of patients go to the outpatient center, and generally patients with a higher risk of complications go to a center with hospital admission [21].

13.2.8 Elective TEA Versus TEA for Fracture in Elderly Patients

In 2009, McKee et al. published a prospective, randomized, controlled trial comparing functional outcomes, complications, and reoperation rates in elderly patients with displaced intra-articular fractures of the distal humerus treated with open reduction and internal fixation (ORIF) or primary semiconstrained TEA. Twenty-one patients were randomized to each treatment group. Inclusion criteria were age greater than 65 years; displaced, comminuted, intra-articular fractures of the distal humerus (Orthopaedic Trauma Association [OTA] type 13C) and closed or open Gustilo grade I fractures treated within 12 h of injury. Two patients died before follow-up and were excluded from the study. Five patients randomized to ORIF were intraoperatively converted to TEA because of extensive comminution and inability to achieve sufficiently stable fixation to allow early joint mobility. Finally, in the ORIF group, 15 patients (3 men and 12 women) with a mean age of 77 years were analyzed, while in the TEA group, 25 patients (2 men and 23 women) with a mean age of 78 years were analyzed. Baseline demographics regarding mechanism of injury, classification, comorbidities, fracture type, activity level, and ipsilateral injuries were similar in the two groups. The mean duration of surgery was 32 min shorter in the TEA group ($p = 0.001$). Patients who had a TEA implanted had significantly better MEPS at 3 months (83 vs. 65, $p = 0.01$), 6 months (86 vs. 68, $p = 0.003$), 12 months (88 vs. 72, $p = 0.007$), and 2 years (86 vs. 73, $p = 0.015$) than patients in the ORIF group. Patients operated on using TEA had significantly better DASH scores at 6 weeks (43 vs. 77, $p = 0.02$) and 6 months (31 vs. 50, $p = 0.01$), but not at 12 months (32 vs. 47, $p = 0.1$) or 2 years (34 vs. 38, $p = 0.6$). The mean flexion-extension arc was 107° (range, 42°–145°) in the TEA group and 95° (range, 30°–140°) in the ORIF group ($p = 0.19$). Reoperation rates for TEA (3/25 [12%]) and ORIF (4/15 [27%]) were not statistically different ($p = 0.2$). According to MEPS, TEA for the treatment of comminuted intra-articular distal humerus fractures provided better and more predictable functional outcomes than ORIF at 2-year follow-up. DASH scores were better in the TEA group in the short term, but were not statistically different at 2-year follow-up. Considering that 25% of fractures randomized to the ORIF group were not amenable to internal fixation, it appears that ORIF may cause the reoperation rate to decrease. Ultimately, McKee et al. concluded that in elderly patients with complex fractures of the distal humerus not amenable to stable fixation, implanting a TEA is preferable to performing an ORIF [22] (Fig. 13.3).

An additional question is what happens to these patients after some time. Given that ORIF complications are early and TEA complications occur throughout the history of the implant, with equal complications the only difference between the two indications would be the postoperative restrictions of TEA. In a long-term follow-up of 12.5 years in the surviving patients, the authors noted that there were 3/25 reoperations in the TEA group and 4/15 in the ORIF group. Only one patient with TEA required implant revision and 15 of the patients who died during follow-up did so with the implant in situ and functioning well [23].

It is important to appreciate that it is unclear what constitutes stable fixation in an osteoporotic patient. Additionally, the age range of the

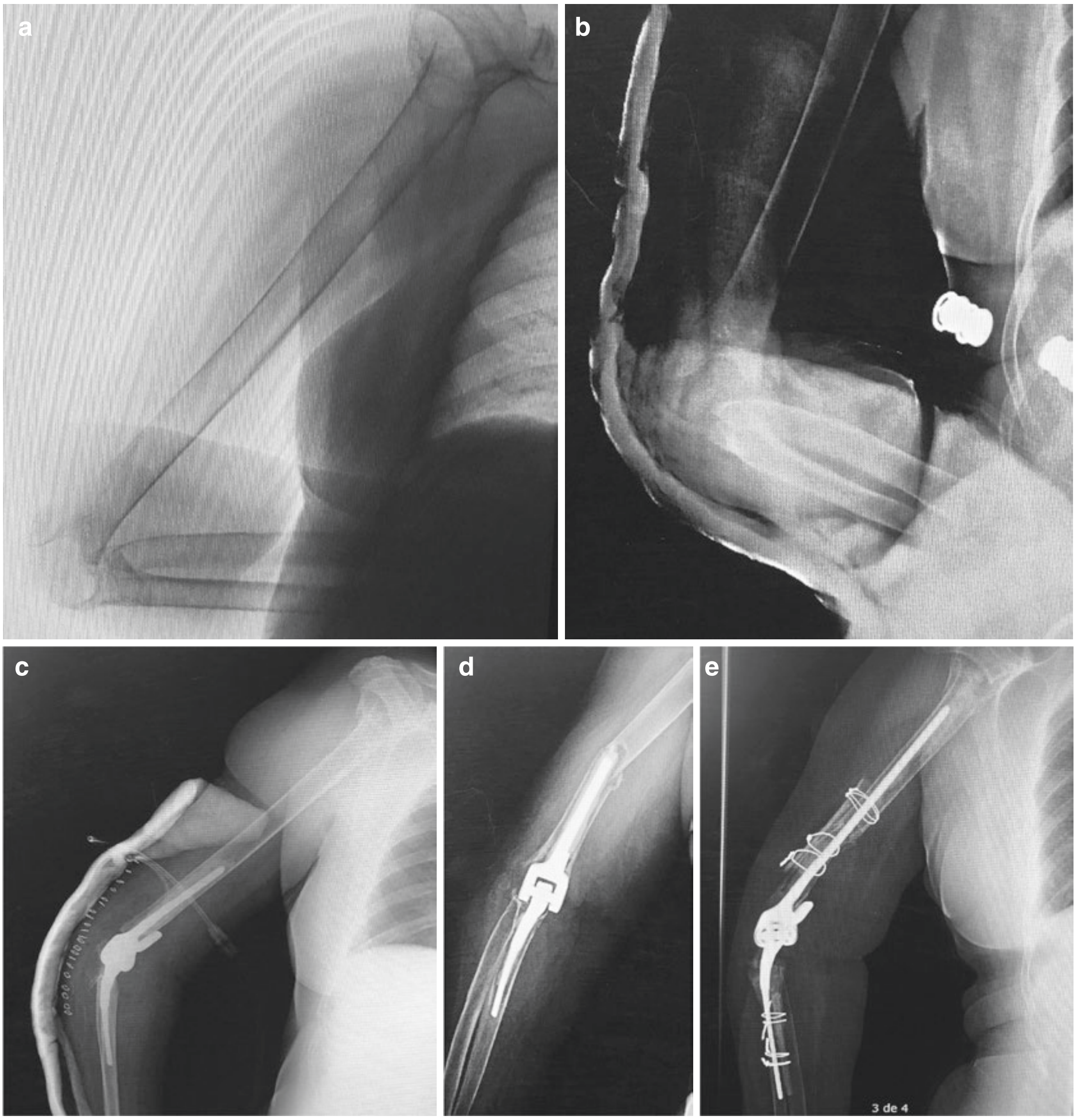

Fig. 13.3 (**a**–**e**) TEA for a distal humerus fracture is a good indication in cases where there is poor distal bone for fixation or extensive comminution and the patient is compliant with postoperative restrictions. However, TEA for fractures in elderly and weakened patients is subject to periprosthetic fractures which require complex revision surgery. (**a**, **b**) A patient with rheumatoid arthritis and elbow disease sustained a fall with a fracture of the proximal humerus and the distal humerus. (**c**) A linked TEA was implanted with a good outcome. (**d**) After 8 years the patient sustained a new fall with a humeral periprosthetic fracture at the tip of the humeral stem. (**e**) At revision the implant was found to be loose and a one-stage revision with longer implants and augmentation with strut allograft was performed with a good outcome

patients included is very wide and may not reflect well the different circumstances of an ORIF procedure in a 63-year-old patient versus an ORIF in an 82-year-old patient. It does seem clear that the best outcome is obtained from a single operation and that the outcome of a TEA after a failed ORIF is worse than that of a primary TEA [24].

In 2013, Mansat et al., in a case series (therapeutic study with level IV evidence), observed that reliable results can be obtained in patients with RA and in traumatic conditions and that the survival rate was similar or better than that published for unlinked implants. They analyzed 70 consecutive patients (78 elbows) who underwent implantation of a Coonrad-Morrey design TEA for inflammatory arthritis (45 elbows) or traumatic conditions (33 elbows: 18 acute distal humerus fractures, 10 nonunions, and 5 posttraumatic arthritis). Coonrad-Morrey-type TEA allowed treating a wide spectrum of indications with satisfactory results. Better results were obtained in patients with RA than in trauma patients. The complication rate was high, although the implant revision rate was low. However, with follow-up, there was an increased incidence of lucent lines around the ulnar component and bushing wear (which were of concern). After a mean follow-up of 5 years (range: 2–11 years), the mean MEPS for the RA group (89 points) was significantly higher than that of the trauma group (80 points). The QuickDASH score was not significantly different according to etiology. Radiolucencies were observed in 17 cases around the humeral component and in 14 cases around the ulnar component. Bushing wear was observed in 14 cases. There were 27 complications, 9 of which required revision surgery. Considering revision for aseptic loosening as an end point, the survival rate was 97.7% at 5 years and 91% at 10 years [25].

In 2016, Sánchez-Sotelo et al., in a therapeutic study with level IV evidence, published that elbow arthroplasty using a cemented linked semiconstrained design provided satisfactory clinical results in the treatment of RA, with a reasonable mechanical failure-free survival rate at 20 years. Although bushing wear was identified on radiographs in a quarter of the patients, revision for isolated bushing wear was infrequent. A total of 461 primary TEAs were performed with the Coonrad-Morrey prosthesis in 387 patients with RA. Fifty-five of the arthroplasties were performed to treat concurrent traumatic or posttraumatic conditions. A total of 305 women (365 elbows, 79%) and 82 men (96 elbows, 21%) underwent surgery. Ten patients (10 elbows) were lost to follow-up, 9 patients (10 elbows) died, and 6 patients (6 elbows) underwent revision surgery in the first 2 years. In the 435 elbows (362 patients, 94%) that had a minimum follow-up of 2 years, the median follow-up was 10 years (range: 2–30 years). At final evaluation, 49 (11%) of the elbows were found to have undergone surgical revision or component removal (10 elbows for deep infection, 39 elbows for mechanical failure). In another 8 elbows there was radiographic evidence of loosening. In the surviving implants, with a minimum follow-up of 2 years, the median MEPS was 90 points; in 71 (23%) of these implants bushing wear was identified radiographically; however, only 2% of the elbows had required surgical revision for isolated bushing wear. The rate of survivorship free of implant revision or removal for any reason was 92% at 10 years, 83% at 15 years, and 68% at 20 years. Survival at 20 years was 88% with revision for aseptic loosening as the end point and 89% with isolated bushing exchange as the end point. Risk factors for implant revision for any cause were male sex, history of concomitant traumatic pathology, and implantation of an ulnar component with polymethylmethacrylate surface finish [26].

In 2016, Prasad et al. published their experience with the Coonrad-Morrey TEA in distal humerus fractures in nonrheumatoid patients. The minimum follow-up was 10 years. Between 1996 and 2004 they performed TEAs through a triceps splitting approach in 37 nonrheumatoid patients with distal humerus fractures. One patient could not be located and 17 died before the tenth anniversary of surgery. Therefore, the study group consisted of 19 patients, with a minimum follow-up of 10 years. Of these, 13 patients were still alive at the time of the final assessment. The other 6 had died, but after at least 10 years of follow-up. The mean follow-up of the 19 patients was 156 months (range: 120–210). Two patients required revision surgery. Another patient underwent two-stage revision surgery for infection, but died before the 10-year follow-up. Six other patients showed signs of loosening or wear. Two were clinically symptomatic and were offered revision surgery. Male patients showed a higher incidence of loosening and wear. Survivorship, with revision and definite loosening as end points, was 89.5% at 10 years in patients with a minimum follow-up of 10 years and 86% in the entire group of 36 patients. Prasad et al. observed that only 53% of nonrheumatoid patients operated on for TEA for distal humerus fracture survived to the tenth anniversary of surgery. In those who survived, TEA provided acceptable results in terms of function and implant survival [27].

In 2017, in a level IV evidence study, Barco et al. evaluated the long-term outcomes of TEA after distal humerus fractures and compared elbows with or without inflammatory arthritis at the time of fracture. In surviving patients, they observed that the selective use of a TEA for the treatment of distal humerus fractures in elderly and less active patients and in patients with inflammatory arthritis had acceptable longevity, but with significant complications. Forty-four TEAs were performed on distal humerus fractures; minimum follow-up was 10 years. Pain, joint mobility, MEPS, complications, and reoperations were evaluated. Outcomes were compared between elbows with and without inflammatory arthritis and a Kaplan-Meier survivorship analysis was performed. TEA provided good pain relief and joint mobility. The mean visual analog scale for pain was 0.6. The mean joint flexion was 123° and the mean joint extension loss was 24°. The mean MEPS was 90.5 points, and three patients scored less than 75 points. Five elbows (11%) developed deep infection, which was treated surgically with component retention (three acute) or resection (two chronic). In eight elbows (18%) implant revision or resection was performed: three for infection (one reimplantation and two resections), three for ulnar loosening (associated with a periprosthetic fracture in one) and two for ulnar component fractures. Periprosthetic fractures occurred in five other elbows. Survival rates of TEAs in patients with RA were 85% at 5 years and 76% at 10 years. Survival rates for TEAs in patients without RA were 92% at both 5 years and 10 years. The most important risk factor for surgical revision was male sex. Since mechanical failure due to component fracture has been eliminated with the change in component design, the mechanical complications of the implant are small and most patients when they die during follow-up do so with the component "in place" [6].

In 2020, Strelzow et al., in a therapeutic study with level IV evidence, reviewed the results and complications of a cemented convertible TEA system in a linked configuration in patients with distal humerus fractures. Forty patients met the inclusion criteria (35 women, 5 men). The mean follow-up was 4 years (range: 2–13 years). The mean age of the patients at the time of surgery was 79 years. All implants were linked. Seven patients had heterotopic ossification. Lucent lines were observed mainly in the V-zone of the humeral implant. No lucent lines were observed around the ulnar component in any radiographic area. Complications occurred in nine patients (22%) and two surgical revisions were performed: one for infection and one for late periprosthetic fracture. Fracture TEA in elderly patients provided pain relief, functional range of motion, and good patient-reported outcome scores. No implant-related complications of this convertible implant system were encountered [28].

In 2021, Aziz et al. compared TEA in distal humerus fracture and arthritis cases. They analyzed in-hospital and postoperative complications 30 days after TEA implantation. A total of 646 TEAs were implanted, of which 149 (23.1%) were implanted in distal humerus fractures. Patients undergoing TEA for fracture had an overall complication rate of 13.42%, compared with a complication rate of 12.47% in patients undergoing elective primary TEA ($p = 0.76$). In univariate analysis, patients undergoing TEA for fracture were not significantly more likely to require reintervention within 30 days (1.34% vs. 4.63% for RA and 4.11% for OA, $p = 0.24$) or to require readmission within 30 days (5.37% vs. 4.63% for RA and 4.88% for OA, $p = 0.52$). Multivariable logistic analysis found that fracture TEA was not independently associated with readmission, reoperation, or major or minor complications. Increasing age was associated with an increased risk of minor complications. Female sex was associated with a lower risk of major complications, and higher ASA (American Society of Anesthesiology) classification was associated with higher odds of readmission. Ultimately, patients undergoing TEA surgery for distal humerus fracture did not have a higher risk of acute postoperative complications than patients undergoing elective primary TEA implantation [29].

13.2.9 TEA in Rheumatoid Arthritis Patients

The use of biologic medication has decreased the TEA implantation rate of these patients. At the same time, it has delayed their implantation and has decreased the severity of the lesions at the time of implantation. On the other hand, the increased activity that these patients engage in may not make valid the scientific papers describing the results of rheumatoid arthritis patients when such medication did not allow them to lead such an active lifestyle.

The fundamental controversy in patients with an inflammatory disease is which design to use. Although good results have been achieved with linked and unlinked systems, the pathogenesis of the disease would explain the failure of unlinked arthroplasties due to residual instability, making it a good option to opt for an unlinked but linkable implant (convertible system). The use of a linked, semiconstrained system has provided good results in the medium and long term and is the safest option with similar loosening figures to nonlinked implants. Obviously the decision depends on the degree and severity of joint and soft tissue involvement, assessed through the clinical and radiological examination. Implantation of a nonlinked implant requires accurate and balanced reconstruction of the collateral ligaments, which may be difficult to attain in practices with low annual case volume. The challenge in these patients depends on the degree of bone loss, the incidence of intraoperative fractures, the difficulty in component orientation due to lack of accurate bony landmarks, and the prevention of infection.

In 2005, Little et al. compared, in a level III evidence study, three TEA designs (Souter-Strathclyde, Kudo, Coonrad-Morrey) in patients with RA. The Souter is an unlinked implant with a highly congruous articulation with a metal distal humerus without an anterior flange and a polyethylene ulnar component. The Kudo is an unlinked elbow implant with less constraint than the Souter with a metallic unflanged humeral component and the option of a metallic or an all-poly ulnar component. The Coonrad-Morrey is a semiconstrained linked elbow arthroplasty through a loose hinge where there is a metal on polyethylene bearing. They found that all three implant types relieved pain. The sustained improvement in range of flexion was comparable among the three groups. No design drastically modified fixed flexion deformity and all three improved maximum flexion. Indications for revision surgery were infection, dislocation, and aseptic loosening. Survival of the Coonrad-Morrey implant was better than that of the other two implants. The 5-year survival rates, with revision and radiographic signs of loosening as end points, were 85% and 81% for the Souter-Strathclyde implant, 93% and 82% for the Kudo implant, and 90% and 86% for the Coonrad-Morrey implant. Although radiological signs of loosening of the Coonrad-Morrey implants were less frequent, adjacent focal osteolysis was observed in 16% of the ulnar components, and in fact, half of these cases progressed to clear loosening. All three implants were similar in terms of pain relief and elbow ROM. Little et al. considered that component linkage with the Coonrad-Morrey component prevented dislocation without increasing the risk of loosening [30].

In 2015, Mukka et al. investigated the outcomes and survival of the Discovery design of TEA in patients with RA. In a prospective cohort study, an elbow surgeon performed 31 TEAs in 25 consecutive patients. They had complete results in only 19 of the patients (25 elbows). The mean range of motion (ROM) improved in flexion/extension from 88° to 113° and in pronation/supination from 55° to 68° ($p < 0.05$). The mean QuickDASH score also improved from 66.5 to 40.2 ($p < 0.01$). The mean EQ-5D (EuroQol-5D) score improved from 0.68 to 0.75, but was not statistically significant ($p = 0.09$). Three patients were revised for loosening and two were reoperated. Thus, the Kaplan-Meier survival was 90%. The Discovery system showed satisfactory results in patients with RA, although the complication rate was relatively high [31].

In 2017, Kodama et al. evaluated the long-term results (more than 10 years of follow-up) of the Kudo type-5 elbow prosthesis in patients with RA. They analyzed 41 elbows (Larsen grade IV, $n = 21$; grade V, $n = 20$) in 31 patients with RA who had undergone such type of arthroplasty. In all patients the humeral component was cementless and the all-polyethylene ulnar component cemented. The clinical outcome was assessed using the MEPS. The revision rate was calculated and potential risk factors for revision were assessed. The mean follow-up was 141 months (range: 120–203). Aseptic loosening of the ulnar component occurred in 11 elbows. There was no radiolucency around any humeral component. There was one deep infection. The survival rate by Kaplan-Meier survival analysis was 87.8% at 5 years and 70.7% at 10 years. The mean extension/flexion amplitude was −38°/105° before surgery and −40°/132° at final evaluation. The mean MEPS was 43 before surgery and 80 at final assessment. Significant risk factors for revision or aseptic loosening were a duration of RA to TEA of less than 15 years and a preoperative ROM of >85°. The conclusion was that, although Kudo type-5 TEA provided satisfactory short-term results, aseptic loosening increased after 5 years. In most cases, elbow function was maintained in the long term, without implant loosening [32].

In 2019, Strelzow et al. compared in patients with RA the outcomes and complications of linked and unlinked TEA using a convertible system. They found that such type of TEA provided good patient-reported outcomes in the medium term. This study found no difference between linked and unlinked designs. Eighty-two patients with RA (27 with nonlinked TEA and 55 with linked TEA) were evaluated. The mean age at the time of surgery was 61 years. The mean follow-up was 6 years. Demographic characteristics were similar in the two groups, with the exception of longer follow-up in the unlinked group (8 years vs. 5 years, $p = 0.001$). No differences in ROM were observed. Elbow strength was similar except for pronation strength (74% in the unlinked group vs. 100% in the linked group, $p = 0.03$). The mean MEPS was 83; the Patient-Rated Elbow Evaluation score, 15; and the QuickDASH score, 34. There were no differences in reoperation (17% vs. 24%, $p = 0.4$), complication (32% vs. 31%, $p = 0.4$), or revision (13% vs. 17%, $p = 0.3$) rates between the unlinked and linked prostheses. Four patients presented instability, all of them with unlinked designs, and required revision to a linked design. Four patients, all with linked designs, required revision due to aseptic loosening of the smooth short-stem ulnar components [33].

In a systematic review (therapeutic study with level IV evidence) on TEA in patients with RA, Chou et al. found in general satisfactory results. However, TEA had a much higher implant failure and complication rates than hip and knee arthroplasties. Patient age and sex and whether a cemented fixation or an unlinked prosthesis was used influenced the results. Thirty-eight studies (2118 TEAs) were included in the study. The mean follow-up was 80.9 months. Implant failure and complication rates were 16.1% and 24.5%, respectively. Aseptic loosening was the most common cause of failure (9.5%). The mean postoperative ROM was flexion 131.5°, extension 29.3°, pronation 74°, and supination 72.5°; the mean postoperative MEPS was 89.3. Meta-regression analysis identified that younger patients and implants with unlinked design correlated with higher failure rates. In addition, younger patients had a higher complication rate, and female sex and unlinked prostheses were associated with aseptic loosening [34].

13.2.10 TEA in Juvenile Idiopathic Arthritis (Juvenile Rheumatoid Arthritis) Patients

Patients with juvenile idiopathic arthritis (JIA) have the problem of age of indication (under 16 years of age) and underlying deformity which poses a therapeutic challenge. Some of these patients may have systemic symptoms that require the use of interleukin inhibitors. Despite this, some of them develop severe elbow arthrosis. Technically, these patients are characterized by significant stiffness, even ankylosis, requiring shortening of the humerus, and narrow canals that can facilitate the creation of false pathways. Flexible drills are now recommended for endomedullary canal preparation and the tip of the stems may have to be shaped, cut, or bent to fit the canals and the preexisting deformity. Some of these patients postoperatively compromise their implants because of the need to use crutches or unloading systems to ambulate due to lower limb involvement.

In 2014, in a level IV therapeutic study (case series), Baghdadi et al. evaluated the clinical benefit and prosthetic longevity of primary semiconstrained linked TEA performed to treat patients with JIA. Between 1983 and 2005, 29 elbows were replaced in 24 patients (20 women and 4 men) because of JIA. Their mean age was 37 years. Because of the underlying deformity, the implant contour was modified in 9 elbows (31%) and a customized implant was inserted in 5 elbows (17%). The mean follow-up was 10.5 years. During the follow-up period, 8 elbows were reoperated, of which 6 (21%) underwent implant revision. At final evaluation, 22 elbows (76%) had subjectively satisfactory overall functional outcome. The mean MEPS was 78 points. In 18 elbows, the result was considered excellent or good. Compared with preoperative ROM, the mean extension-flexion arc improved from 65 to 89 ($p = 0.01$); mean flexion improved from 113 to 126 ($p = 0.02$); mean extension improved from 48 to 37 ($p = 0.08$). Using the Kaplan-Meier survivorship method, the rate of TEA survival from any revision was 96.4% and 79.9% at 5 and 10 years, respectively. In short, primary TEA in patients with JIA often required implant modification or the use of customized designs. In addition, these patients had high rates of complications and revisions. However, in the long term most of them benefited from the intervention [35].

13.2.11 TEA in Osteoarthritis Patients

Primary OA is a disease of functionally demanding adults (manual laborers or weightlifters) and is usually treated with debridement, osteophyte removal, and capsulectomy, which usually results in improvement. Some of these patients do not improve with this procedure and continue to manifest joint pain in addition to the typical terminal motion pain. If this occurs in patients who are not very active or older, TEA is a good option, but unfortunately few patients fit this profile, so it is a rare procedure in this indication.

Technically the most important characteristic of these patients is stiffness and the presence of osteophytes which can limit joint access. For this reason, the soft tissue dissection has to be extensive and it is generally recommended to perform a linked arthroplasty. If the soft tissues are in good condition and the patient has minimal deformity, the patient may be a candidate for an unlinked (linkable) arthroplasty. These patients may develop heterotopic ossification although it does not usually limit postoperative function.

In 2017, Schoch et al., in a therapeutic level IV evidence study (case series), stated that in patients with primary OA, TEA was a reliable surgical option to relieve joint pain. However, they did not always achieve extension recovery, which indicated that more aggressive soft tissue releases or even bony resection might be necessary. Twenty TEAs were performed. Two patients died before 2 years of follow-up. The mean age at the time of surgery was 68 years. The mean follow-up was 8.9 years. Three elbows suffered mechanical failure. Regarding complications, there was one intraoperative fracture, one wound irrigation and debridement, one bony ankylosis, one humeral loosening, one humeral component fracture, and one mechanical failure of radial head component. Fifteen elbows that had not suffered mechanical failure were analyzed. In them, pain improved from 3.6 to 1.5 ($p < 0.001$). ROM remained unchanged ($p > 0.05$), and preoperative flexion contractures did not improve. The mean MEPS of 13 elbows without mechanical failure was 81.5 points; in 5 elbows the results were considered excellent, in 2 good, and in 6 fair. All patients without mechanical failure were subjectively satisfied with the outcome [36].

13.2.12 TEA in Posttraumatic Arthritis

Posttraumatic OA is usually the result of persistent instability, joint incongruity maintained by malreduction of a fracture, or secondary to extensive chondral injury. Generally, patients have undergone an average of three operations before opting for a TEA so it is important to investigate and rule out infection, and it occasionally requires removal of the implants and sampling in a first operation and placement of the TEA implant in a second operation. Ulnar nerve involvement is common and usually needs to be identified, dissected, and transposed at surgery. Ideally in these patients with posttraumatic sequelae, a linked implant is used due to the frequent associated instability and bone loss or deformity. Bone loss, stiffness, and three-dimensional deformity necessitate extensive but selective soft tissue releases and the use of a linked implant is often advisable. It is important to make patients aware of the lifelong restrictions of having an elbow implant and patients must understand that longevity is linked to the use of their elbow.

In 2014, Barthel et al., in a retrospective level IV evidence study, stated that in posttraumatic conditions, semiconstrained TEAs provided ROM recovery and stable, pain-free elbows. However, age at the time of surgery was a risk factor for complications. Nineteen patients underwent a semiconstrained Coonrad-Morrey TEA, in 12 cases for posttraumatic elbow arthritis (group 1) and in seven cases for 7 distal humerus nonunions (group 2). The mean age at the time of surgery was 60 years (56 in group 1 and 67 in group 2). The mean delay between the initial trauma and arthroplasty was 16 years (group 1) and 22 months (group 2). In group 1, after a mean follow-up of 5.5 years, the QuickDASH score was 34 points, with results considered good to excellent in 75% of cases according to the MEPS. Radiographic progressive radiolucencies were identified in 33% of cases and moderate polyethylene insert wear in 17%. There were seven complications (58%) requiring revision in three cases (25%). In group 2, after a mean follow-up of 4.6 years, the QuickDASH score was 39 points, with good and excellent results in 86% according to the MEPS. Radiolucency was observed in 28% and moderate wear of the inserts in 14%. There were two complications (28%), one of which (14%) required surgical revision. The indication for TEA in patients younger than 60 years should be carefully considered in relation to other therapeutic options [37].

13.2.13 Outcomes Following TEA for Rheumatoid Arthritis Versus Posttraumatic Conditions

A systematic review and meta-analysis published in 2019 by Wang et al. compared the outcomes of TEA performed for RA with the outcomes of TEA performed in posttraumatic conditions. The parameters evaluated were implant failure, functional outcome, and perioperative complications. Of 679 TEAs, 482 operated for RA and 197 for posttraumatic conditions were analyzed. All TEAs were cemented with linked components. It was shown that the RA group had a higher risk of septic loosening after TEA. However, in the posttraumatic group there was a higher risk of bushing wear, axle failure, component disassembly, or component fracture. The MEPS was higher in the AR group. There were no significant differences in ROM, DASH questionnaire scores, and risk of aseptic loosening, deep infection, perioperative fracture, or ulnar neuropathy. After TEA, patients with RA had a better functional outcome [38].

13.2.14 Primary Versus Secondary TEA for Distal Humerus Fractures

In 2019, Ellwein et al., in a level III evidence study, analyzed 35 patients who had a semiconstrained, cemented total elbow prosthesis (Latitude, Tornier, Bloomington, IN, USA) implanted using a modified Campbell approach. It was observed that the primary TEA provided better functional results than the secondary TEA. Subjective assessment was better in the primary TEA group due to less pain than in the secondary TEA group. Despite the longer duration of surgery in secondary TEA, complication rates were comparable. Ellwein et al. stated that fracture reconstruction remains the treatment of choice due to the lifelong limitation of weight-bearing of up to 5 kg. Furthermore, revision options are limited and may result in complete loss of elbow function. When considering TEA, the 10- and 20-year survival rates are 81% and 61%, respectively, which are much lower than those of knee and hip arthroplasty. In view of the poor results after reconstruction, primary TEA should be recommended for elderly or selected patients, since primary TEA produces better functional results with less pain than secondary TEA. If complications develop after reconstruction, early revision to TEA should be recommended, as late conversion results in worse outcomes. Although secondary TEA requires removal of the implant in most cases, which implies a considerable prolongation of operative time, the rates of major complications were not significantly different [39].

13.3 Revision TEA

13.3.1 Outcomes After Revision TEA

In 2013, Plaschke et al. published the short- and midterm results of 20 Coonrad-Morrey revision TEAs. With a mean follow-up of 4.4 years, the results after revision TEA using the Coonrad-Morrey prosthesis were acceptable. The short- and midterm failure rate was low. Revision improved ROM and relieved pain. In one case there was a deep infection, which required further revision. In addition, two patients had ulnar nerve paresthesia postoperatively [40].

In 2016, De Vos et al. stated that revision surgery using the Latitude TEA improved elbow function, reduced joint pain, and provided greater elbow stability. Between 2006 and 2010, they used the Latitude TEA to revise 18 elbows (17 patients); their mean age was 53 years; 14 were women. Kudo TEAs were reviewed in 15 elbows and Souter-Strathclyde TEAs in three. Although the ulnar nerve was routinely identified during the operation, two patients (11.8%) had some sensory disturbance postoperatively. In one there was complete recovery 2 years postoperatively. In another patient there was a slight sensory loss of the radial nerve 2 months postoperatively, after removal of K-wires that had been used to fix a fracture of the medial epicondyle. Sensory loss was fully recovered at 6 months' follow-up. Intraoperative fracture occurred in seven patients (38%) [41].

In a systematic review (level of evidence IV) published in 2019, Geurts et al. stated that an improvement in functional outcomes is to be expected after revision TEA, but its complication rate remained high. Revision TEA should still be considered a salvage procedure of a failed TEA (Fig. 13.4). Linked designs of revision TEA give better results than unlinked designs in the medium term. Twenty-one articles with 532 cases were included in the study. The mean age at the time of review was 61 years. The mean interval between primary and revision arthroplasty was 77 months, and the mean follow-up period was 65 months. Different types of prostheses were included, with 69% of revision prostheses with linked designs and 31% with unlinked designs. The visual analog scale score, MEPS, Oxford Elbow Score, and ROM improved significantly after revision surgery. Complications occurred in 232 of 532 cases (44%), resulting in reoperations in 22%. After revision with linked prostheses, MEPS, flexion-extension, and pronation amplitude improved significantly more than with unlinked designs [42].

In 2020, DeBernardis et al. determined the impact that the cause of failure of a primary TEA could have on the failure rate of revision surgery (therapeutic level IV evidence study, case series). Forty-six patients were analyzed, whose mean age was 62.7 years. The minimum follow-up was 2 years. The causes of failure were infection (*n* = 20), aseptic loosening (*n* = 17), peripros-

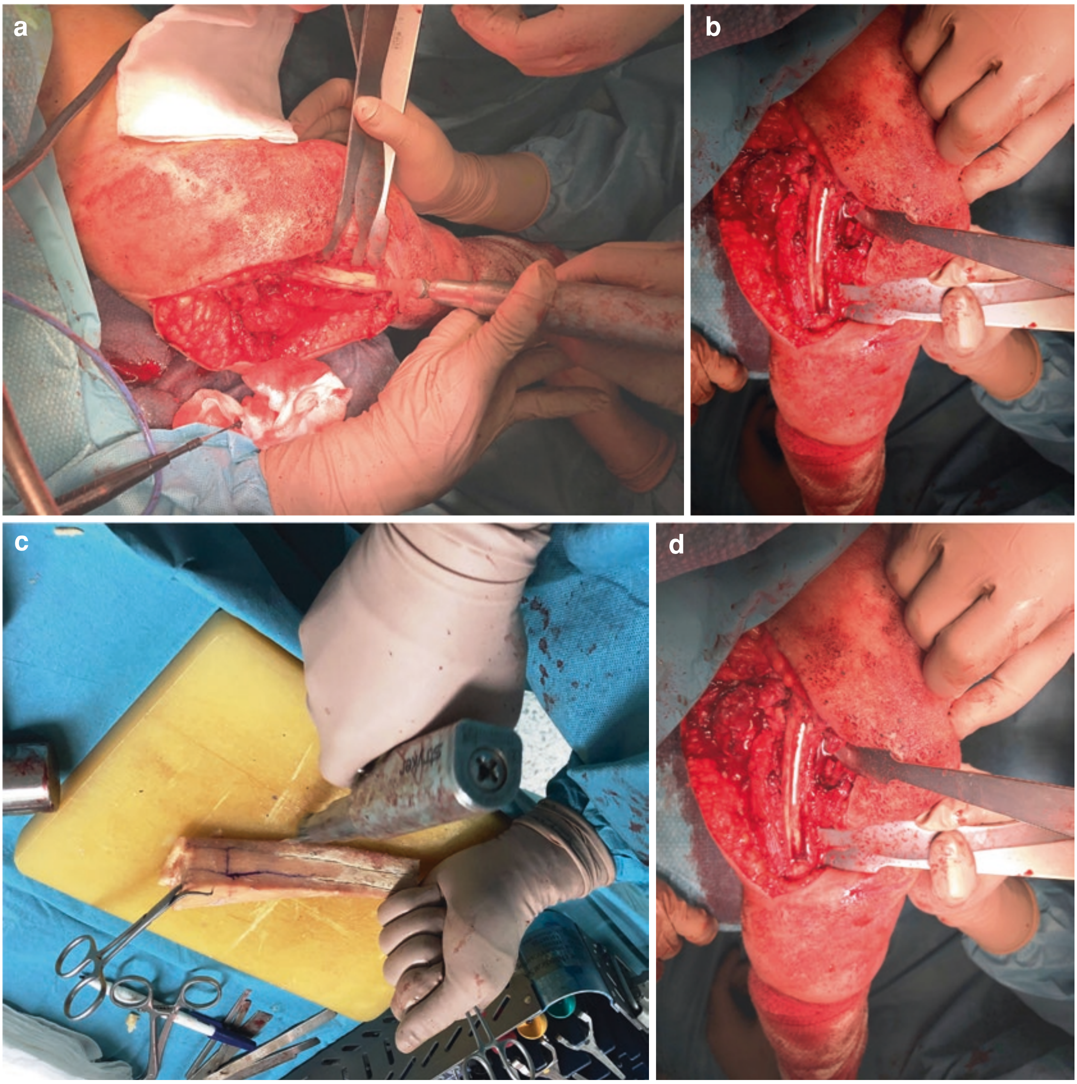

Fig. 13.4 (**a**–**d**) Revision total elbow arthroplasty surgery requires complex techniques including performing osteotomies for removal of the stem to decrease the risk of inadvertent fracture and allograft augmentation for appropriate reconstruction. (**a**) Longitudinal osteotomy with the aid of an oscillating saw and osteotomies is carried to the tip of the ulnar stem. (**b**) After opening the osteotomy, the stem is exposed, and after careful decortication, it can be easily extracted. (**c**) An allograft is prepared to obtain one or two struts. (**d**) After replacing the cortical window, strut allograft augmentation is performed with the use of wires, rather than cables

thetic fracture ($n = 6$), and bushing wear ($n = 3$). All noninfectious etiologies were grouped into an additional cohort. Patients who underwent revision for infection showed a significantly higher failure rate and number of new revisions per patient than those who underwent surgery for aseptic loosening, periprosthetic fracture, or noninfectious cause; they also showed a shorter time to failure than in the noninfectious group. Patients in whom primary TEA failed due to infection were more likely to have revision failure and required a greater number of subsequent operations than patients with other causes of primary TEA failure. This study questioned the efficacy of revision surgery in the treatment of infected TEA [43].

In 2021, in a level IV therapeutic study, Barret et al. evaluated the long-term outcomes of revision TEA using a single semiconstrained prosthesis design. They stated that revision TEA with this type of prosthesis could provide good clinical outcomes, which could be maintained during follow-up. However, the complication rate was high. They stated that proper evaluation of the risk-benefit ratio is essential for each revision TEA and the risk-benefit ratio should be discussed with each patient. Thirty-four revisions of TEA with Coonrad/Morrey prosthesis were performed in 32 patients; two patients were operated bilaterally. Their mean age was 61 years, and the revision TEA was performed at a mean time of 7.8 years after the primary TEA. The causes of revisions were humeral and ulnar aseptic loosening (n = 14), ulnar aseptic loosening (n = 8), humeral aseptic loosening (n = 6), septic arthritis (n = 4), and unstable unlinked prostheses (n = 2). The mean follow-up was 11.4 years. The MEPS at last follow-up was excellent in 6 cases, good in 18, fair in 8, and poor in 2, with a mean improvement between preoperative values of 42.4 points and postoperative values of 81.8 points ($p < 0.001$). Mean pain scores improved significantly from 6.7 points preoperatively to 1.4 points postoperatively ($p < 0.001$). The flexion-extension arc increased significantly ($p = 0.02$) from 74 preoperatively to 100 postoperatively. The total number of complications in 19 revision TEA was 29 (56%). Twenty of the 29 complications simply required management without surgical intervention. Six repeat surgical procedures were required and three implant revisions were performed (9%) [44].

13.3.2 Revision TEA: Comparison of Infected and Noninfected TEA

In 2019, Kwak et al. published the clinical and radiological results of revision TEA surgery according to the cause of failure (infection vs. noninfection). Those authors observed that revision TEA clinically improved elbow function and produced satisfactory results. Outcomes were worse in the infected group than in the noninfected group. Comorbidities and advanced age were risk factors for infected TEA. Twenty revision-operated patients were retrospectively evaluated. The mean follow-up was 52.7 months. Patients were classified into infected and noninfected based on radiological and serological evidence. Clinical outcomes included ROM and MEPS, and radiological outcomes included signs of loosening on anteroposterior and lateral plain radiographs at final assessment. Complications were also evaluated in both groups. Overall, the mean MEPS was 79.7 and the mean ROM was 97.9° at final follow-up. Nine patients required revision surgery due to infection, and 11 due to noninfectious causes. The mean MEPS in these two groups was 75.6 and 83.5, respectively, and the mean ROM for flexion-extension was 89.4° and 108°, respectively. Two (22%) of the nine patients in the infected group required a second revision surgery due to recurrent infection. No patient in the noninfected group required second revision surgery. The most frequent complication in the infected group was osteolysis, observed in five patients, four of them with symptomatic aseptic loosening and one with nonsymptomatic osteolysis. Two patients in the noninfected group showed a nonprogressive radiolucent line, which was asymptomatic at final evaluation [45].

13.3.3 Outcomes Following Revision of the Revision TEA

In 2020, Domos et al. published a level IV evidence-based therapeutic study (case series) in which they presented their results of the revision of revision TEA (RRTEA). Twenty-two patients operated on for RRTEA were identified. Of these, 14 were available for evaluation (2 died of unrelated causes, 2 could not be contacted, 2 declined to participate because of travel difficulties, and 2 had incomplete data). The mean age of the patients was 73 years. Follow-up since the last surgical procedure was 4.5 years. The mean number of previous revision arthroplasty procedures per patient was 3. The indications for RRTEA were aseptic loosening (60%), bushing wear (16%), fracture

(14%), and infection (10%). Of the patients, 30% required extra-long or custom-made implants and 50% required allograft augmentation. At final clinical evaluation, 56% of patients had triceps insufficiency, the mean flexion-extension arc was 90°, and the mean pronation-supination arc was 95°. Functional elbow scores revealed good results in most patients (mean visual analog scale score, 5; mean Oxford Elbow Score, 22; mean Mayo Elbow Performance Index score, 55; and mean QuickDASH score, 63). Eighty-one percent of patients were satisfied with their RRTEA. Encountered complications were infection in 2 patients (1 superficial and 1 deep), symptomatic aseptic loosening of the humeral component in 1, ulnar nerve sensory symptoms in 2, and radial nerve injury in 1. One patient required ulnar nerve release. Radiologic review revealed asymptomatic loosening in 1 patient (humeral component), and overall prosthesis alignment with cementation was adequate in 81%. Heterotopic ossification was present in 38% of cases. RRTEA was considered a satisfactory treatment option in these complex cases, with good short- and medium-term survival rates, but with a relatively high complication rate [46].

13.4 Conversion of a Surgical Elbow Arthrodesis to TEA

In 2015, Rog et al. published the first case in the English literature of conversion of a surgical elbow arthrodesis to a TEA. This was a 49-year-old man whose elbow had been surgically fused following trauma sustained 31 years earlier. However, the conversion of a surgically fused elbow had already been published in the German literature in 2013 by Burkhart et al. Rog et al. stated that in carefully selected patients who were dissatisfied with the functional limitations of elbow fusion, conversion of an elbow arthrodesis to a TEA was a feasible intervention. In addition, the duration of fusion and any anatomic alterations related to previous surgical interventions performed on the elbow had to be taken into account when performing preoperative planning [47, 48].

13.5 The Future for TEA

According to Pooley, TEA is now increasingly used to treat comminuted fractures of the distal humerus, especially in elderly patients. TEA has been shown to be superior to ORIF in such patients, which is why it is the most logical therapeutic choice, especially in type C distal humerus fractures of the OTA classification. However, complication rates associated with TEA remain much higher than those associated with replacement of other extremity joints (hip, knee). It seems logical to think that the improvements that are occurring in TEA design will reduce complication rates, especially implant wear and loosening [2].

TEA is a complex surgical technique, which when well indicated and in experienced hands can give excellent clinical results. The overall complication rate has decreased from 49% in 1993 to 25% in 2009. Some of the complications that occur may be facilitated by inadequate component orientation. Improved imaging and planning systems and possibly intraoperative navigation with or without virtual reality methods will improve proper component orientation. However, as with any arthroplasty surgery, soft tissue management is the key to achieving good functional outcomes. Lifestyle modifications after TEA are imperative to ensure optimal implant longevity. Patients should never lift 10 pounds or more and should not repeatedly lift weights of 2 pounds or more. To optimize the results of TEA, it is imperative to choose the right implant and patient type [49].

We know that patients do not remember postoperative restrictions after some time, which makes it extremely difficult for them to comply with them. Forty percent of patients perform high-demand activities, especially male patients and those who have undergone surgery for fracture or nonunion [50].

13.6 Conclusions

Currently, TEA is increasingly used for the treatment of traumatic elbow pathology (comminuted fractures of the distal humerus and posttraumatic OA), while the indication for inflammatory arthropathy has decreased due to the advance of medical treatments. TEA has proven to be a good option in elderly patients. It is therefore a logical therapeutic option, especially in type C distal humerus fractures of the OTA classification. The three most frequent indications for a primary TEA are fracture/dislocation (trauma) (36%), OA (34%), and RA (26%). The cumulative revision rate of all TEAs implanted for any reason is 10%, 15%, and 19% at 3, 6, and 9 years, respectively. TEAs performed for OA have a higher revision rate than TEAs performed for trauma, highlighting the importance of patient selection in achieving good results. The most commonly used prosthesis designs are linked (Coonrad-Morrey, Latitude) and linkable (Nexel and Discovery), with no differences between them in terms of revision rates. The most common causes of revision TEA are infection and aseptic loosening. A recent systematic review of the literature (level IV evidence) with a mean follow-up of at least 10 years showed that the rates of aseptic loosening, infection, implant dislocation, and nerve injury were 12.9%, 3.3%, 4.2%, and 2.1%, respectively. Moreover, the overall complication and revision rates were 16.3% and 14.6%, respectively. These figures are inferior to the ones reported with arthroplasties of other joints. We should reflect on the way forward in the evolution of these implants, including better patient selection, improvement of current designs, more refined preoperative planning, and more precise surgical technique with virtual, navigated, or robotic technical aids.

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