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Component fracture after total elbow arthroplasty

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Background: Ulnar or humeral component stem fractures after total elbow arthroplasty (TEA) are serious complications. We hypothesized that TEA stem component fractures are fatigue fractures that result from periarticular osteolysis caused by bushing wear, which leads to a region of unsupported stem adjacent to a region where the stem is well-fixed.
Methods: A review of 2637 primary and revision TEA cases from 1972 to 2016 revealed that 47 operations in 46 patients were complicated by or performed to deal with component stem fractures. Bushing wear was graded according to percentage loss of polyethylene thickness and metal wear.
Results: In the 39 cases in which bushing wear was able to be quantitated, it was severe in 34, moderate in 2, and mild in 3. Radiographs at final follow-up were available in 47 cases. All 47 cases showed evidence of periarticular osteolysis, which was in zone 1 in 17, in zones 1 and 2 in 29, and diffuse in 1. The length of the well-fixed stem, expressed as a percentage of total stem length, averaged 63% (range, 29%-86%). Stem fractures most often (27 of 47 cases) occurred at the junction between the well-fixed stem and unsupported stem. The median distance between the site of stem fracture and the unsupported–well-fixed stem junction was 0 mm (interquartile range, 0-5 mm).
Conclusion: On the basis of our findings, a component stem fracture after TEA seems to occur by fatigue failure at or near the junction between an unsupported stem and well-fixed stem. This area of unsupported stem occurs as a result of osteolysis caused by bushing wear. The solution for component fractures requires a solution for bushing wear.
Level of evidence: Level III; Retrospective Cohort Design; Treatment Study
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Keywords: Total elbow arthroplasty; component fracture; bushing wear; metallosis; complication; bone loss

Total elbow arthroplasty (TEA) is a useful treatment option for severe articular injuries and pathologies such as rheumatoid arthritis, primary osteoarthritis, traumatic arthritis, distal humeral fractures and nonunion, and instability with severe ligament injury.[4,5,7,9,12,15,17,18,26] TEA is becoming increasingly popular because of the improved surgical technique and implant design. However, complications such as aseptic loosening, polyethylene wear, periprosthetic fracture, ulnar neuropathy, and infection are still challenges.[2,7,11,13,14,19,20]

It is generally believed that femoral stem fractures after total hip arthroplasty are due to fatigue failure.[10,16,24] Similarly, Zuckerman et al[27] reported a fracture of the humeral component due to fatigue failure after shoulder

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hemiarthroplasty. Although relatively rare, stem fractures of the ulnar and humeral components of a TEA implant do occur and are serious complications.[6,22] The incidence of component fractures reported in the literature ranges from 1% to 5%.[1,2,21,23] Schneeberger et al[22] described 5 ulnar component fractures associated with strenuous physical activity and patient noncompliance. Wright and Hastings[25] reported that overuse and bushing wear can act together to cause TEA failure. Athwal and Morrey[2] reported that component fracture can occur from various causes such as notch sensitivity, component design, and high stresses due to bone deficiency.

The purpose of this study was to test the hypothesis that TEA stem component fractures are fatigue fractures that result from periarticular osteolysis caused by bushing wear, which leads to a region of unsupported stem adjacent to a well-fixed stem.

Methods

Patient cohort

A review of the records in our institutional total joint registry between 1972 and 2016 revealed 2637 primary and revision TEA cases. Of these cases, 57 were complicated by or performed to deal with component stem fractures. We excluded 10 of these 57 cases: 5 cases that did not have radiographs of the component fracture, 4 that had non-metal component fractures, and 1 that had a stem fracture at the site of a nonunion. Therefore, 47 cases (46 patients) were included. There were 11 revision and 36 primary cases. Of the 47 cases included, 39 were analyzed for bushing wear because 8 patients did not have sufficient documentation (no operative records in 3 cases and no mention of bushing wear, metallosis, or black staining in the operative records in 5 cases); however, these patients were not excluded (Fig. 1).

Of the 47 cases, 43 were operated on at our institution. Four cases received diagnoses at our institution but underwent surgery at another institution. The clinical and operative records of 44 cases were analyzed (all 43 from our institution and 1 from another institution).

Cases with bushing wear were divided into grades 1, 2, and 3 (Table I). To assess bushing wear, we categorized polyethylene thickness loss of less than 50% as grade 1, polyethylene thickness loss of 50% to less than 99% as grade 2, and full-thickness polyethylene loss as grade 3. Grade 3 was then divided into 2 subcategories: full-thickness polyethylene loss (grade 3a) and full-thickness polyethylene loss plus metal wear (grade 3b) (Table I).

Patients were also classified as having grade 3 if the ulnar component and humeral component were in contact with each other on the radiograph, the patient underwent bushing-exchange surgery prior to component fracture surgery, the patient felt squeaking in the elbow before the procedure (assumed to be caused by metal-on-metal contact), or metallosis or black staining was mentioned in the operative records (because this is caused by the presence of metal-on-metal contact).

Radiographic analysis

A total of 43 of 47 radiographs of implants prior to the stem fracture and 47 of 47 radiographs subsequent to the stem fracture were available for analysis. Bone loss in the distal aspect of the humerus was classified as grade 0 when the medial and lateral supracondylar columns had been preserved, grade I when either the medial or lateral supracondylar column was no longer supporting the prosthesis because of bone loss or fracture, and grade II when the entire distal aspect of the humerus or the aspect proximal to the level of the olecranon fossa was no longer supporting the prosthesis because of bone loss or fracture (Fig. 2). Bone loss in the proximal aspect of the ulna was classified as grade 0 when the olecranon and coronoid process area had been preserved, grade Ia when the olecranon area was no longer supporting the prosthesis because of bone loss or fracture, grade Ib when the coronoid process area was no longer supporting the prosthesis because of bone loss or fracture, and grade II when the proximal ulna was no longer supporting the prosthesis because of bone loss or fracture (Fig. 3).

On the lateral radiograph, the distance between the fracture site and the region of the stem no longer supported by bone owing to osteolysis was measured (line A, Fig. 4). This measured distance (A) was then subtracted from the length of the remaining fixed stem. After the center of the humeral component and the ulnar component joint was found, the distance to the fracture site was measured, and the measured distance (A) was added to obtain the total unsupported distance. The proportion of well-supported stem to total stem length was then calculated (Fig. 4).

The distance between the stem fracture site and the junction between the well-fixed stem and unsupported stem referred to earlier was measured. Magnification errors on the radiographs were corrected for based on the known implant length. Therefore, the length of the actual stem was confirmed, and a proportion was

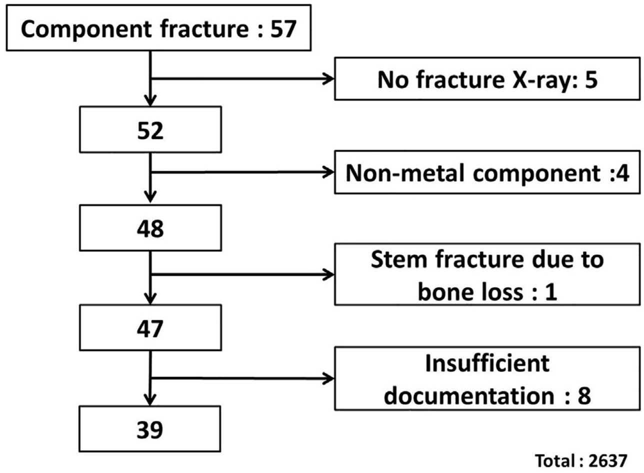

Figure 1 Flowchart of inclusion and exclusion criteria.

Table I Bushing wear classification

Grade	Loss of polyethylene thickness
1	<50%
2	50% to <99%
3	
a	Full thickness
b	Full thickness plus metal wear

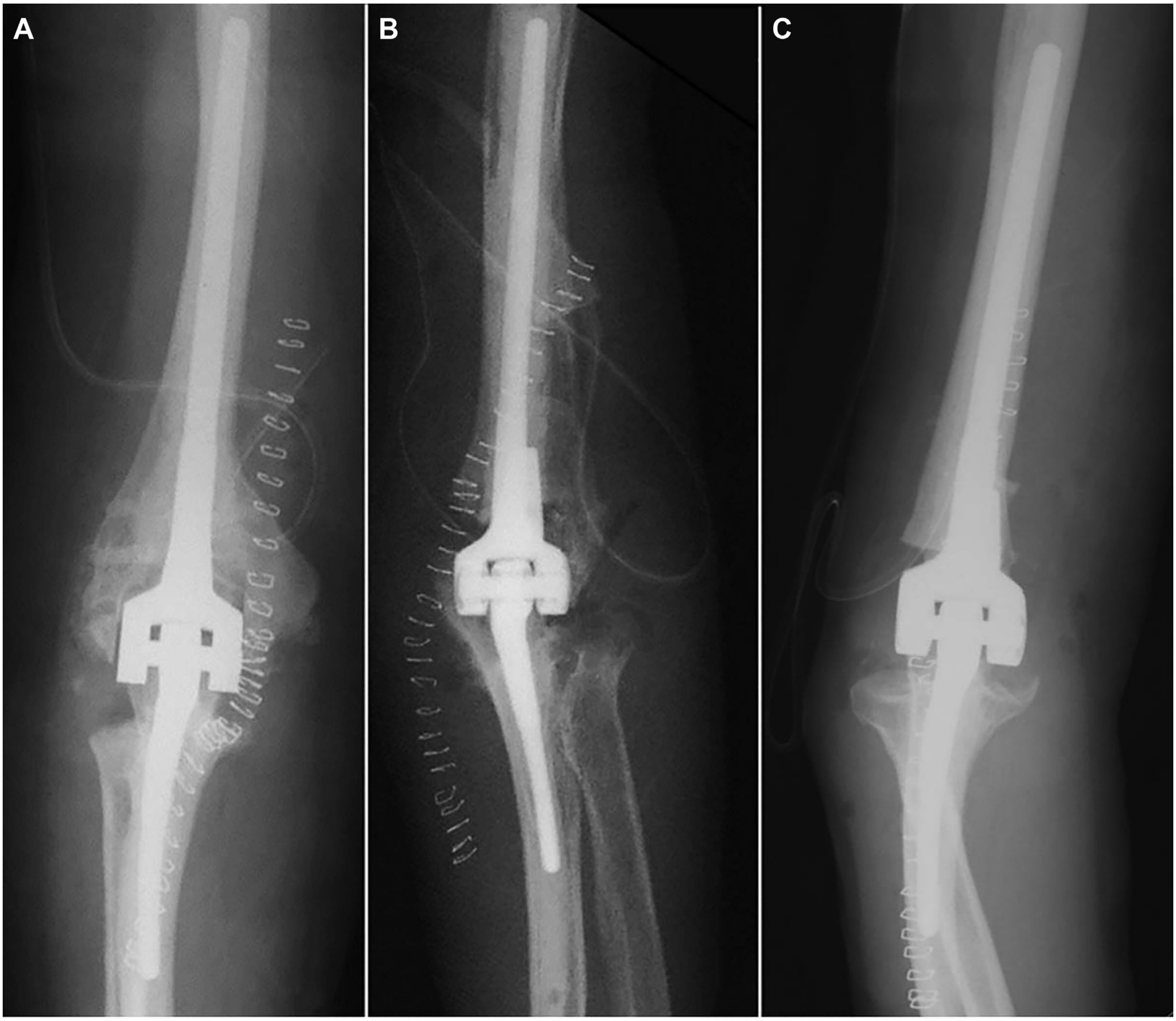

Figure 2 Preoperative bone loss in the distal aspect of the humerus was classified as grade 0 when the medial and lateral supracondylar columns had been preserved (**A**), grade I when either the medial or lateral supracondylar column was no longer supporting the prosthesis because of bone loss or fracture (**B**), or grade II when the entire distal aspect of the humerus or the aspect proximal to the level of the olecranon fossa was no longer supporting the prosthesis because of bone loss or fracture (**C**). Used with permission of Mayo Foundation for Education and Research. All rights reserved.

created to solve for the actual length between the fracture and unsupported stem:

$$\frac{Length\ of\ total\ stem\ measured\ on\ x\text{-}ray}{Actual\ length\ of\ stem} = \frac{Length\ between\ fracture\ and\ unsupported\ stem}{x}$$

On the anteroposterior radiograph, the angle of the line parallel to the yoke of the humeral component and parallel to the medial or lateral surface of the articular surface of the ulnar component was obtained to determine the degree of bushing wear.[14] On the anteroposterior and lateral radiographs, each component was divided into 4 parts and the parts with osteolysis were identified and classified according to Morrey et al.[18] For the humeral component, the portion of the implant with the anterior flange was defined as zone 1. The rest of the component was divided into 3 parts with the same length. For the ulnar component, the proximal

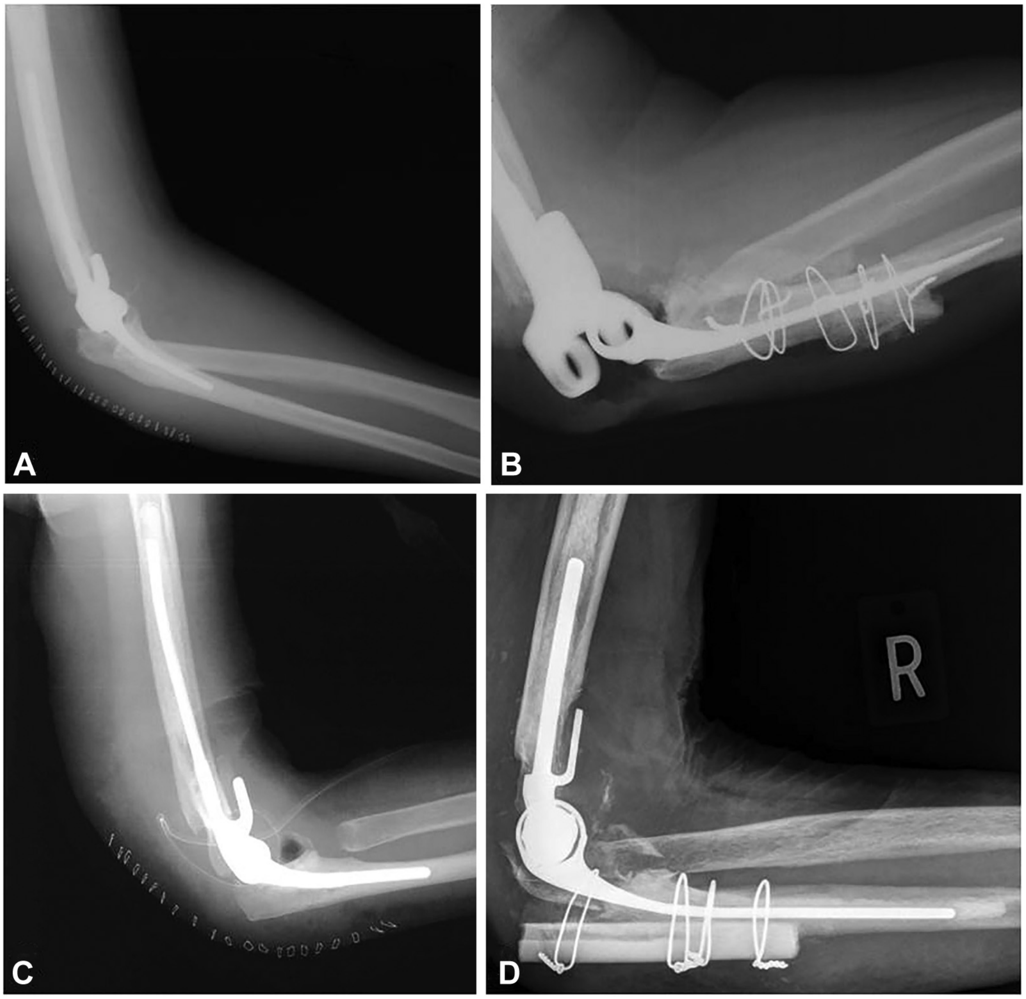

Figure 3 Preoperative bone loss in the proximal aspect of the ulna was classified as grade 0 when the olecranon and coronoid process area had been preserved (**A**), grade Ia when the olecranon area was no longer supporting the prosthesis because of bone loss or fracture (**B**), grade Ib when the coronoid process area was no longer supporting the prosthesis because of bone loss or fracture (**C**), or grade II when the proximal ulna was no longer supporting the prosthesis because of bone loss or fracture (**D**). *R*, right. Used with permission of Mayo Foundation for Education and Research. All rights reserved.

curved part was defined as zone 1. The rest of the component was divided into 3 parts with the same length (Fig. 5).[8] Osteolysis occurring in at least 3 zones on any radiograph was defined as diffuse. Osteolysis occurring in no more than 2 zones on any radiograph was defined as focal.

Results

Patient cohort

There were 23 female and 24 male cases with a mean age of 64 years (range, 32-87 years) at the time of the surgery. Among the 47 cases analyzed, the broken stem was on the right side in 28 and on the left side in 19. The stem fracture was in the dominant arm in 29 cases. The component fracture was due to trauma in 4 cases. In no case was the trauma apparently sufficient to cause stem fractures; indeed, in this study, osteolysis was present in all stem fracture cases. Only 4 cases had significant trauma (falling down, direct blow, and so on), and these 4 cases had moderate osteolysis. Six component fractures could be attributed to the patients having a strenuous occupation. Obesity was present in 11 component fracture cases. Patients were deemed obese if the body mass index was 30 or greater. An example of a component fracture from this cohort is shown in Figure 6.

The mean duration of component fracture after TEA was 9 years (range, 1-20 years). In 13 cases, the component fracture occurred within 4 years after TEA.

There were 24 humeral component fractures and 23 ulnar component fractures. The fractured humeral implants included 23 Coonrad-Morrey implants

Figure 4 Diagram showing how the distance between the fracture site and the region of the stem no longer supported was calculated. The distance between the fracture site and the region of the stem no longer supported by bone owing to osteolysis (*A*) was measured. The length of the remaining fixed stem (*B*) was determined. The center of the humeral component and the ulnar component joint (*C*) was found. The distance to the fracture site (*D*) was measured. Used with permission of Mayo Foundation for Education and Research. All rights reserved.

(Zimmer Biomet, Warsaw, IN, USA) and 1 Prichard II implant (DePuy, Raynham, MA, USA). The fractured ulnar implants included 22 Coonrad-Morrey implants and 1 Discovery Elbow System (Biomet, Warsaw, IN, USA). The underlying diagnosis leading to the primary elbow arthroplasty was rheumatoid arthritis in 13 cases, post-traumatic arthritis in 12, nonunion after fracture in 11, fracture in 7, and degenerative joint disease in 4.

The bushing wear classifications in the 39 patients reviewed were grade 1 in 3 patients, grade 2 in 2, and grade 3 in 34. Of the 34 cases with severe wear, 23 were of subtype b, which was defined as metal-on-metal squeaking in the elbow, a revision procedure and/or loss of metal detected during surgery, or metallosis and/or black staining described in the operative records (Fig. 7).

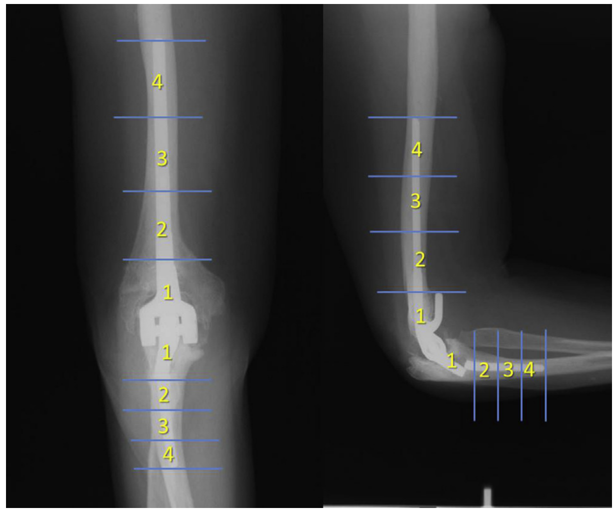

Figure 5 The humeral and ulnar components were divided into 4 parts, and the parts with osteolysis were identified and classified. Used with permission of Mayo Foundation for Education and Research. All rights reserved.

Radiographic analysis

Radiographs from the time of component fracture, as well as the most recent radiographs prior to the fracture, were analyzed for evidence of loss of bony structural support around the prosthesis that fractured. Radiographs from the time of component fracture as well as prior to fracture were available for 43 cases, whereas 4 only had radiographs from the time of component fracture.

There was a 100% correlation between stem fracture and lack of bony support. That is, a region of unsupported stem involving each fractured humeral or ulnar component was observed. Furthermore, all component fractures occurred at or near the junction between the areas where the stem was well fixed and unsupported owing to osteolysis. Loss of bony structural support was observed around 24 of the humeral stems that fractured and 23 of the ulnar stems that fractured. One patient had significant bone loss at the time of revision.

For the 24 cases with humeral component fractures, humeral bone loss was grade 0 in 10, grade I in 3, and grade II in 11. Humeral osteolysis was present in all 24 cases with component fracture radiographs: 7 in zone 1 and 17 in zones 1 and 2. Osteolysis involving 3 or more zones was not seen.

For the 23 cases with ulnar component fractures, bone loss was grade 0 in 15, grade Ia in 1, grade Ib in 3, and grade II in 4. Ulnar osteolysis was seen in all 23 cases with component fracture radiographs: 10 in zone 1, 12 in zones 1 and 2, and 1 involving 3 or more zones.

The length of the well-fixed stem, expressed as a percentage of total stem length, averaged 63% (range, 29%-86%). In 2 patients, less than 50% of the stem was well fixed (29% and 44%). Twenty-seven stem fractures

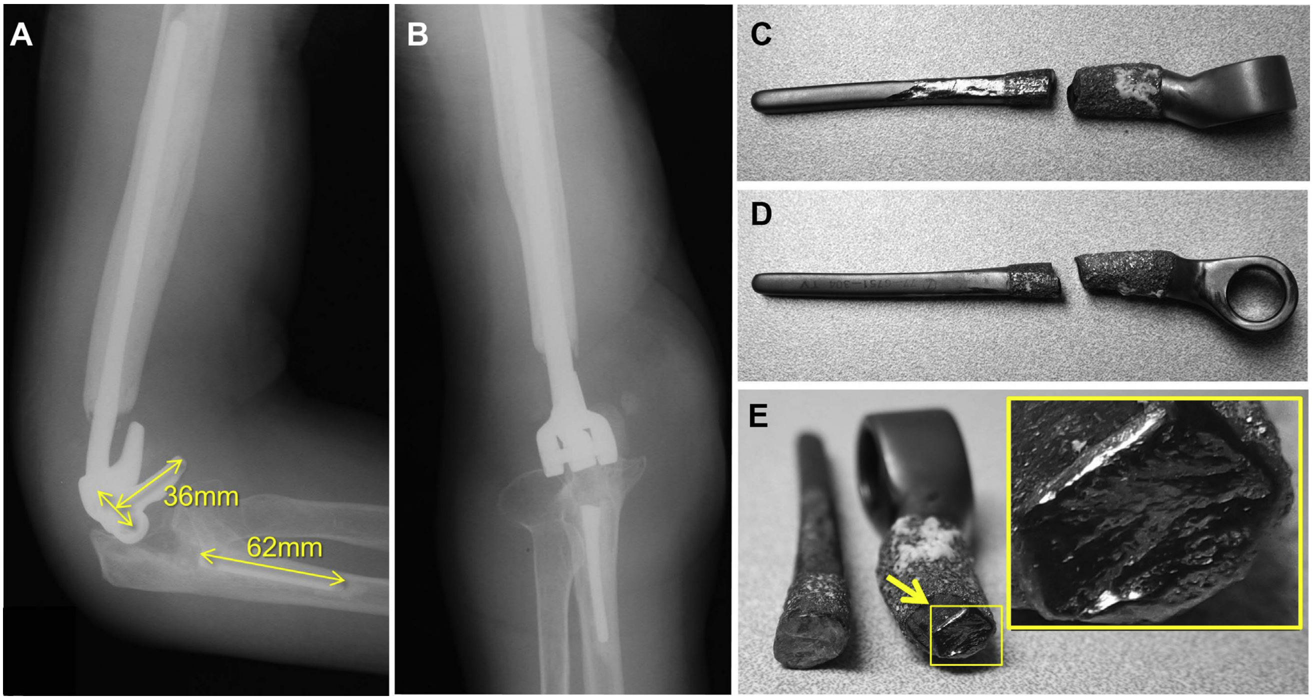

Figure 6 (**A**, **B**) X-ray of the component fracture. The well-fixed stem ratio was 63% [62 mm/(62 mm + 36 mm) × 100]. The length between the well-fixed stem and fracture of the component was 0 mm. Anterior (**C**) and medial (**D**) views of the fractured ulnar component. (**E**) Burnishing at the fracture site (→) is suggestive of fatigue failure. Used with permission of Mayo Foundation for Education and Research. All rights reserved.

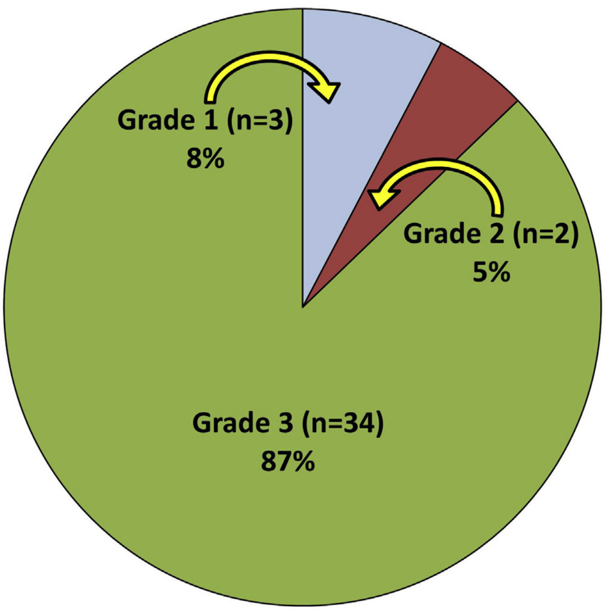

Figure 7 Pie chart showing distribution of bushing wear among patients with component fracture. Of the patients, 34 (87%) had grade 3 bushing wear at the time of component fracture. Used with permission of Mayo Foundation for Education and Research. All rights reserved.

occurred at the junction between the well-fixed stem and unsupported stem. Overall, the stems fractured at a median distance of 0 mm (interquartile range, 0-5 mm) from the junction between the unsupported and well-fixed regions of the stems. Pre-revision radiographic measurements for bushing wear revealed that 21 cases had a midline deviation of more than 7°, consistent with at least partial wear.

Discussion

The findings in this study support the hypothesis that a component stem fracture is a consequence of periarticular osteolysis due to wear of the bushings in the hinge mechanism of a TEA. This osteolysis creates a region of unsupported stem adjacent to a region in which the remainder of the stem is well fixed. At the junction, a stress riser is created and subjected to cyclic loading that places the implant at risk of fatigue failure. All of the elbows in which bushing wear was able to be quantitated did indeed show evidence of wear, which was severe in 34 of 39, and all 47 elbows with radiographs available at final follow-up had periarticular osteolysis. This created a stress riser between the unsupported section of the stem and the well-fixed portion. Component fractures at this junction occurred at a median distance of 0 mm (interquartile range, 0-5 mm) from the junction. This indicates that stress is concentrated at the junction of the well-supported stem and the unsupported area owing to osteolysis. The osteolysis was limited to zones 1 and 2 except in 1 case. This finding suggests that osteolysis occurred because of bushing wear.

Polyethylene bushing wear, which can lead to metal-on-metal contact and titanium particulate debris, can produce serious complications after TEA.[8,25] The majority of components in this series were Coonrad-Morrey linked TEAs. Lee et al[14] reported that revision for bushing wear alone with the Coonrad-Morrey prosthesis is uncommon (1.3%). This has been misunderstood by many individuals to suggest that bushing wear is not much of a problem with this prosthesis. However, our study shows that bushing wear is ultimately responsible for periarticular osteolysis leading to stress concentration and fatigue fracture of the ulnar and humeral stems. Furthermore, osteolysis is responsible for most periprosthetic elbow fractures as well, raising the likelihood that bushing wear is a much more serious concern than some individuals may have realized or indicated.

Sanchez-Sotelo et al[21] reported component fractures in 9 cases (8 ulnar component fractures and 1 humeral component fracture) among 461 primary TEAs (2.0%) using Coonrad-Morrey prostheses. Aldridge et al[1] reported 1 humeral and 1 ulnar component fracture among 41 Coonrad-Morrey prostheses. Athwal and Morrey,[2] in their case series of 927 total elbow prostheses, reported 11 ulnar component fractures (1.2%) and 6 humeral component fractures (0.7%). Toulemonde et al[23] reported 1 component fracture in 100 semiconstrained TEAs. The results of these studies are comparable to those in our study, which showed an incidence of TEA component fracture of about 2.2% (57 of 2637 cases).

We believe that the time taken for a stem to fail by fatigue fracture is related to the time course of osteolysis. Not much literature exists on osteolysis due to metallosis in the elbow. However, Bonnheim et al[3] estimated that, on the basis of the conservative assumption of 1 million steps per year, a fatigue fracture of a femoral stem could occur after 28 years in the case of proximal bone support and after 7.3 years in the case of purely distal fixation. However, our study showed that 13 component fractures occurred within 4 years. In 9 of the 13 cases with component fractures within 4 years, the initial TEA was performed for distal humeral fracture or nonunion, with loss of condylar support for the distal part of the prosthesis. This exposes the TEA to much greater stresses than occur when the entire prosthesis is supported by bone.

Grade II bone loss of the distal humerus was found in 11 of 14 patients. Of these 11 patients, 2 also had grade II bone loss of the proximal ulna and 1 had grade Ib bone loss of proximal ulna, whereas 8 had no proximal ulnar bone loss. Grade I bone loss of the distal humerus was noted in 3 patients. None of these 3 patients had bone loss of the proximal ulna. Wright and Hastings[25] reported that bushing wear could worsen if there was no condyle in the distal humerus. The flexor pronator mass and extensor origin muscles can reduce the end-range varus-valgus loading of the implant. They also dynamically stabilize the elbow. Repetitive varus-valgus and rotational loads cause polyethylene wear, allowing for greater varus and valgus deformation. The loss of bone in the distal humerus predisposes to bushing wear, which may lead to more bone loss and may result in fractures due to persistent loading on the unsupported stem. In this same study, initial bushing wear and failure proved to be another cause of loosening or fracture of Coonrad-Morrey ulnar implants.[25] Of 13 cases with stem component fractures within 4 years, 11 had either distal humeral or proximal ulnar bone loss after the previous operation. Failure to properly support the component appears to have precipitated faster component fractures.

We made the observation that the operative notes frequently made no specific mention of bushing wear despite clear radiographic evidence. All 11 operative records of the senior author described the degree of bushing wear. However, no mention of bushing wear was made in 13 of the remaining 33 cases operated on by other surgeons. Of the 13 cases with no mention of bushing wear, 3 underwent bushing-exchange surgery before fracture. Metallosis or black staining was confirmed in 5 cases, and these characteristics were associated with bushing wear. This finding should be considered in interpreting other reports on bushing wear in TEA because the operative records clearly under-documented bushing wear. Varus and valgus radiographic views were unavailable for bushing wear analysis. This is a limitation as these views may help to assess bushing wear more accurately; however, we were still able to assess bushing wear sufficiently with the lateral and anteroposterior views.

Conclusion

On the basis of our findings, a component stem fracture after TEA seems to occur by fatigue failure at or near the junction between an unsupported stem and well-fixed stem. This area of unsupported stem occurs owing to osteolysis caused by bushing wear. The solution for component fractures requires a solution for bushing wear.

Disclaimer

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