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What factors can reduce the need for repeated revision for humeral loosening in revision total elbow arthroplasty?

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Background: This study aimed to determine the re-revision rate in a cohort of patients who underwent revision total elbow arthroplasty (rTEA) for humeral loosening (HL) and identify factors contributing to re-revision. We hypothesized that proportional increases in the stem and flange lengths would stabilize the bone-implant interface significantly more than a disproportional increase in stem or flange length alone. Additionally, we hypothesized that the indication for the index arthroplasty would impact the need for repeated revision for HL. The secondary objective was to describe the functional outcomes, complications, and presence of radiographic loosening after rTEA.

Methods: We retrospectively reviewed 181 rTEAs performed from 2000-2021. We included 40 rTEAs for HL performed on 40 elbows that either required a subsequent revision for HL (10 rTEAs) or had a minimum of 2 years of clinical or radiographic follow-up. One hundred thirty-one cases were excluded. Patients were grouped based on stem and flange length to determine the re-revision rate. Patients were divided based on re-revision status into the single-revision group and the re-revision group. The stem–to–flange length (S/F) ratio was calculated for each surgical procedure. The mean length of clinical and radiographic follow-up was 71 months (range, 18-221 months and 3-221 months, respectively).

Results: Rheumatoid arthritis was statistically significant in predicting re-revision total elbow arthroplasty for HL ($P = .024$). The overall re-revision rate for HL was 25% at an average of 4.2 years (range, 1-19 years) from the revision procedure. There was a significant increase in stem and flange lengths from the index procedure to revision, on average by 70 ± 47 mm ($P < .001$) and 28 ± 39 mm ($P < .001$), respectively. In the cases of re-revision (n = 10), 4 patients underwent an excisional procedure; in the remaining 6 cases, the size of the re-revision implant increased on average by 37 ± 40 mm for the stem and 73 ± 70 mm for the flange ($P = .075$ and $P = .046$, respectively). Furthermore, the average flange in these 6 cases was 7 times shorter than the average stem (S/F ratio, 6.7 ± 2.2). This ratio was significantly different from that in cases that were not re-revised ($P = .03$; S/F ratio, 4.2 ± 2). Mean range of moion was 16° (range, 0°-90°; standard deviation, 20°) extension to 119° (range, 0°-160°; standard deviation, 39°) flexion at final follow-up. Complications included ulnar neuropathy (38%), radial neuropathy (10%), infection (14%), ulnar loosening (14%), and fracture (14%). None of the elbows were considered radiographically loose at final follow-up.

Conclusion: We show that a primary diagnosis of rheumatoid arthritis and a humeral stem with a relatively short flange relative to the stem length significantly contribute to re-revision of total elbow arthroplasty. The use of an implant where the flange can be extended beyond one-fourth of the stem length may increase implant longevity.

The University of South Florida Institutional Review Board deemed this study exempt from institutional review board review.

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Total elbow arthroplasty (TEA) remains a viable surgical option for various elbow pathologies. The classic indication for TEA is rheumatoid arthritis (RA).[7,22] However, the indications have been broadened to include post-traumatic arthritis, acute distal humeral fracture, nonunion, or reconstruction in the setting of tumor resection.[8,9,15,28] Historically, TEA has been shown to provide predictable improvements in pain and function.[29] However, TEA is associated with a relatively high complication rate, with potential complications including infection, aseptic loosening, ulnar neuropathy, and weakness or failure of the extensor mechanism.[1,12-14,25]

Currently, the semiconstrained implant is the most commonly used implant for TEA. The semiconstrained design has been shown to have statistically significantly lower rates of complications and re-revisions than unlinked designs.[17] This design allows for out-of-plane motion with around 6°-8° of varus-valgus motion and axial rotation. Lower failure rates have been attributed to lower stress on the bone-cement interface; however, rates of aseptic loosening remain high. Thus, the anterior flange was added to the design, which additionally reduced posterior displacement.[6]

In the evaluation of aseptic loosening, there is evidence that the humeral component fails at a higher rate than the ulnar component (71.7% vs. 28.3%).[4] Among the different failure modalities, humeral loosening (HL) is uniquely challenging because it is often accompanied by humeral bone loss. In this scenario, surgeons have 3 options to address the HL: extend the stem past the point of loosening in the humerus, use a prosthesis with a more extended anterior flange, or extend both the stem and the flange. There is a lack of evidence supporting that revision with a longer humeral stem decreases the chance of future revision surgery for HL, although this is common practice.[20]

To address the problem of HL, manufacturers began to offer a longer anterior flange as an option for their prostheses. For challenging cases of HL, a custom prosthesis with an exceptionally long anterior flange has been designed. The intended purpose of the extended anterior flange is to increase load transfer from the prosthesis to the humerus, thereby decreasing stress shielding and the incidence of HL.[11,21] Additionally, the anterior flange mitigates rotational bending forces, which also serves the purpose of reducing the likelihood of HL.[23] There are no studies evaluating the effectiveness of elbow prostheses based on the combination of stem length and flange length.

This study aimed to determine the re-revision rate in a cohort of patients who underwent revision total elbow arthroplasty (rTEA) for HL and identify factors contributing to re-revision. We hypothesized that proportional increases in the stem and flange lengths would significantly stabilize the bone-implant interface more than a unilateral increase or uneven increases in revision implant length. Additionally, we hypothesized that the original indication for the index arthroplasty would impact the need for repeated revision for humeral implant loosening. The secondary objective was to describe the functional outcomes, complications, and presence of radiographic loosening.

Materials and methods

Study population

We conducted a retrospective review of the institutional clinical database of a single fellowship-trained surgeon between January 2000 and July 2021. All patients who underwent revision of a failed TEA due to HL were included. Figure 1 summarizes the patient search and Current Procedural Terminology (CPT) codes used. We excluded 131 cases for the following reasons: (1) ulnar loosening (n = 35), (2) infection with no HL (n = 28), (3) failed bushing (n = 19), (4) primary TEA with associated hardware removal (n = 18), (5) hardware failure without HL (n = 16), (6) insufficient follow-up data (n = 12), (7) trauma (n = 2), and (8) excisional arthroplasty as first revision procedure for HL (n = 1). Of the 12 patients with insufficient follow-up, 6 died, 5 had no medical records available, and 1 was lost to follow-up despite multiple contact attempts. A total of 39 patients (25 women and 14 men) and 40 elbows (1 patient underwent bilateral rTEA for HL) were included. The mean age at primary TEA was 60 years (range, 41-79 years). There 20 right and 20 left elbows that underwent surgery. The indication for primary TEA was inflammatory arthritis in 15 of 40 elbows, acute fracture in 7, post-traumatic arthritis in 8, failed open reduction–internal fixation (ORIF) and/or malunion in 3, osteoarthritis in 2, silicone synovitis in 2, and unknown in 3.

Grouping

Radiographs were reviewed and measured to determine the stem and flange lengths used in the revision surgical procedure and every subsequent revision for HL, if applicable. Patients were then grouped based on the lengths of the stem and flange they received. Cutoff values for the stem and flange lengths for the division of patients into groups were based on virtual caliper measurements made on radiographs. The 5 groups were as follows: short stem (100-150 mm) with short flange (25 mm) (SS-SF); short stem with long flange (45 mm) (SS-LF); long stem (200 mm) with short flange (LS-SF); long stem with long flange (LS-LF); and long

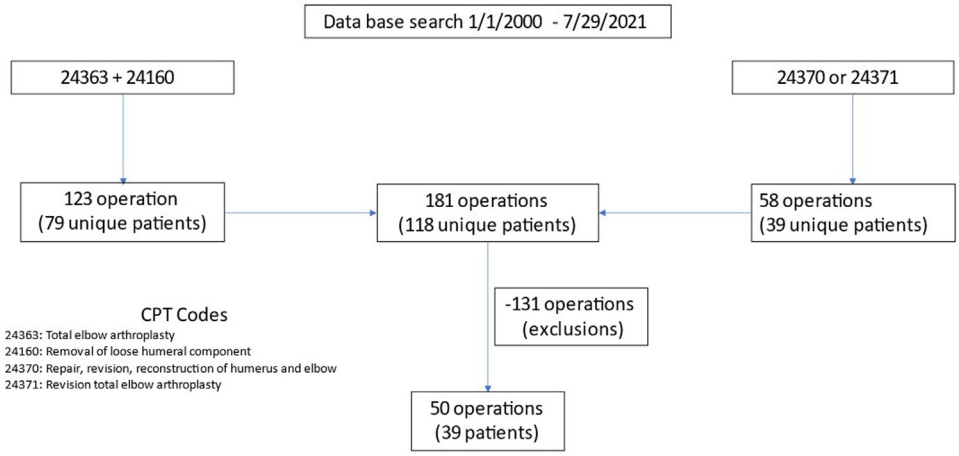

Figure 1 Flowchart of patient selection for inclusion. *CPT*, Current Procedural Terminology.

stem with very long flange (56-176 mm) (LS-vLF). The re-revision rate was calculated for these 5 groups.

Patients were divided into the following groups based on re-revision status: successful (single) revision (n = 30), re-revision (n = 6), and excision (n = 4). Stem and flange lengths at the index procedure and at every subsequent revision operation were evaluated. The stem–to–flange length (S/F) ratio was calculated for each surgical procedure as depicted in Figure 2.

Surgical technique

Planning the revision of a loose humeral implant required evaluation of the ulnar component. If the ulnar component was well fixed, then the humeral component selection was limited to the offering of the device that would allow mating with the ulnar component. In cases where the selection of the humeral component to adequately achieve fixation on the humerus was not readily available, an implant with a longer stem and a very long flange (LS-vLF) was developed as a custom implant. Nine of these LS-vLF implants (Biomet Discovery in 7 cases [Zimmer Biomet, Warsaw, IN, USA], DePuy Acclaim in 1 [DePuy, Raynham, MA, USA], and Pritchard-Walker in 1[DePuy, Raynham, MA, USA]) were used in this study's patient population. These LS-vLF implants have limited availability; therefore, if a commercially available implant with a longer stem and/or longer flange was available, it was selected. The number of commercial implant designs in each subgroup were as follows: SS-SF, 5 Discovery and 4 Coonrad-Morrey implants (Zimmer Biomet, Warsaw, IN, USA); SS-LF, 1 Coonrad-Morrey implant and 1 Latitude implant (Wright Medical, Memphis, TN, USA); LS-SF, 4 Discovery and 2 Coonrad-Morrey implants; and LS-LF, 17 Coonrad-Morrey and 3 Latitude implants.

Patients were positioned prone on a radiolucent table so that fluoroscopy could be used to easily visualize the entire humerus. A posterior midline incision was made, and the ulnar and radial nerve were identified. Preservation of the triceps was attempted, but the triceps was elevated from the ulnar insertion in cases of multiple revisions. Removal of the previous implant and an extensive synovectomy were performed. Tissue was submitted for frozen section evaluation and deep tissue cultures. All remaining loose cement and fibrous tissues were carefully removed from the intramedullary humeral canal. Reaming then proceeded to prepare the canal proximal to the length of the previous stem. Trialing subsequently proceeded to ensure that full elbow extension and flexion could be achieved without repositioning the humeral component. The stems were then cemented with the retrograde cement technique.

Radiographic analysis

Final radiographs were reviewed to determine the presence of HL that may have been treated nonoperatively. Radiolucent lines were determined via the modified Gruen zone technique described by Wagener et al.[27]

Outcome measures

Primary outcome measures were the rate of re-revision TEA for HL and factors predictive of future re-revision for HL (demographic characteristics, combination of stem length and flange length, and S/F ratio). Secondary outcome measures were range of motion, complications, and the presence of radiographic loosening at final follow-up.

Re-revision for HL was determined through a retrospective review of clinical notes, operative notes, and radiographs. Range of motion (flexion, extension, pronation, and supination) and complications were retrospectively recorded from clinical notes. Radiographic loosening was determined based on the presence of radiolucent lines on anteroposterior and lateral radiographs.

Statistical analysis

Descriptive statistics were used to describe patient characteristics. Means and standard deviations (SDs) were reported for continuous variables, and percentages were reported for categorical variables. Re-revision rates were determined arithmetically. A Shapiro-Wilk analysis was used to confirm normal distribution among the groups. We used an independent *t* test, the Mann-Whitney test, or analysis of variance with a least significant difference post hoc test for group comparisons. The χ^2 test or Fisher exact test (where appropriate) was used for categorical variables. All statistical analyses were performed with the SPSS program (version 24.0; IBM, Armonk, NY, USA), with the α level set at .05.

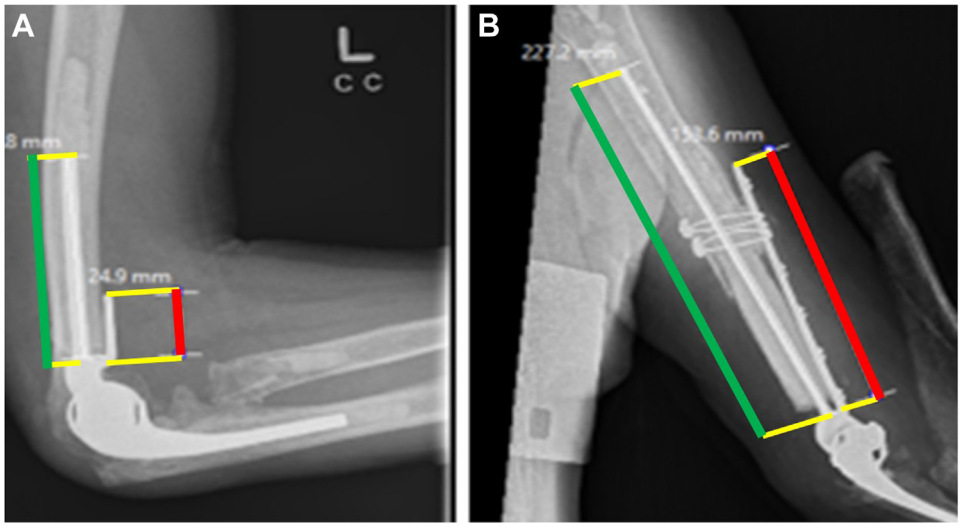

Figure 2 Case example of 1 patient undergoing revision from an implant with a short stem and short flange **(A)** to an implant with a long stem and very long flange **(B)** for humeral loosening. The stem-to-flange ratio decreased from 3.2 (ie, 79.8/24.9) in **A** to 1.5 (ie, 227.2/153.6) in **B**. Humeral stem length (*green line*), flange length (*red line*), endpoints of humeral stem and flange lengths denoted by *yellow lines*.

Results

There were 40 elbow arthroplasties among 39 patients (1 patient with bilateral procedures) who underwent primary TEA followed by revision or re-revision TEA for HL. Of these 40 elbows, 30 (75%) underwent 1 rTEA procedure for HL and 10 (25%) underwent 2 rTEA procedures for HL. The mean length of clinical and radiographic follow-up from last successful rTEA was 71 months (range, 18-221 months) and 71 months (range, 3-221 months), respectively.

Population

Comparisons of basic demographic characteristics and diagnoses are presented in Table I. Among all the demographic characteristics and index diagnoses studied for this population, RA was the only statistically significant factor for predicting re-revision TEA for HL ($P = .024$).

Grouping

Table II displays the number of patients in each group, different implant properties (stem and flange lengths), and manufacturer designs. The 5 groups were determined to be statistically significantly different from each other based on the stem and flange lengths (Figs. 3 and 4).

Re-revision rate

The overall re-revision rate for HL among the 5 groups was 25% at an average of 4.2 years (range, 1-19 years). Table III displays the re-revision rate for HL in each of the 5 groups. Additionally, a lower combined revision rate was observed in the LS-LF and LS-vLF groups (14%) compared with the groups with shorter stems or flanges (SS-SF, SS-LF, and LS-SF) (41%). Tables II and III report on 46 implants despite 50 procedures being included in the study because 4 patients underwent revision to excisional arthroplasty as their second revision procedure for HL.

Time to re-revision

Prosthetic failure was defined as revision surgery for HL. The average time to re-revision for all failures was 46 months (range, 3-221 months). The average time to re-revision for the SS-SF prosthesis was 104 months (range, 33-221 months). The 3 SS-SF failures occurred at 33, 60, and 221 months. The 1 SS-LF failure occurred at 12 months. The average time to re-revision for the LS-SF prosthesis was 31 months (range, 11-43 months). The 3 LS-SF failures occurred at 11, 38, and 43 months. Finally, the average time to re-revision for the LS-LF prosthesis was 22 months (range, 3-38 months). The 3 LS-LF failures occurred at 3, 13, and 38 months. None of the LS-vLF prostheses were revised for HL.

Implant modifications for re-revision

In our cohort, there was a significant increase in stem and flange lengths from the index procedure to revision, on average by 70 ± 47 mm ($P < .001$) and 28 ± 39 mm ($P < .001$), respectively (Table IV, pairs 1 and 2). In cases of re-revision (n = 10), 4 patients underwent an excisional procedure (3 cases of infection and 1 case of progressive RA with severe bone loss). In the remaining 6 cases, the size of the re-revision implant increased on average by an additional 37 ± 40 mm for the stem ($P = .075$) and 73 ± 70

Table I Patient demographic characteristics between patients requiring re-revision and patients not undergoing re-revision

Patient characteristic	No re-revision (n = 30)	Re-revision (n = 10)	*P* value
Sex, n (%)			>.999
Female	19 (76)	6 (24)	
Male	11 (73)	4 (27)	
Laterality, n (%)			.716
Right	14 (70)	6 (30)	
Left	16 (80)	4 (20)	
Age at index procedure, mean (SD), yr	62 (7.1)	58.7 (10.3)	.353
Age at revision, mean (SD), yr	67.6 (4.6)	65.9 (9.5)	.465
Age at re-revision, mean (SD), yr	—	72.3 (6.6)	—
Index diagnosis, n (%)			
Fracture and fracture sequelae	8 (80)	2 (20)	.673
RA	8 (53)	7 (47)	.024*
Post-traumatic arthritis	8 (100)	0 (0)	.165
Other	6 (87)	1 (13)	>.999
Osteoporosis, n (%)			.513
Yes	2 (100)	0 (0)	
No	28 (75)	10 (25)	

SD, standard deviation; *RA*, rheumatoid arthritis.
* Statistically significant ($P < .05$).

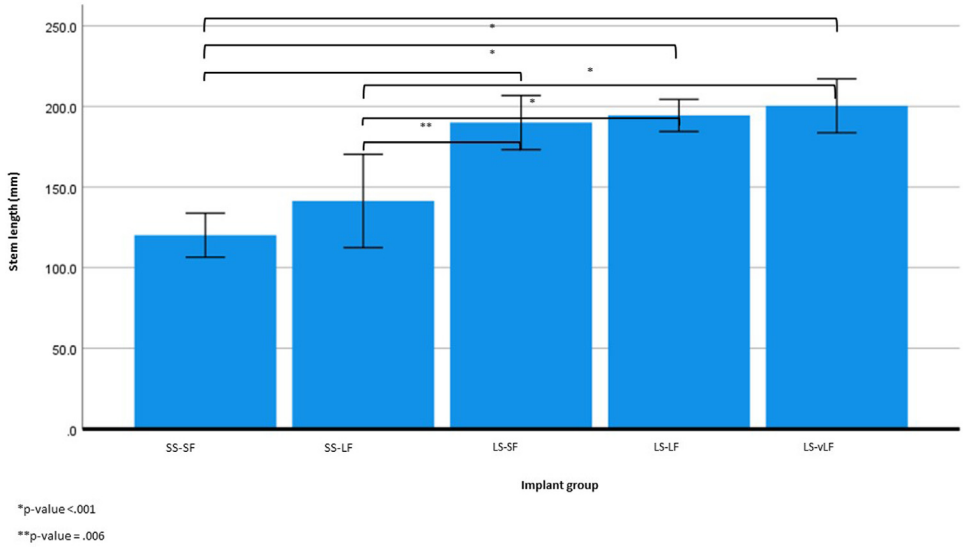

Figure 3 Graphical representation of stem lengths between the 5 groups showing the difference in stem length between short and long stems. Statistically significant differences in stem lengths were observed between the groups. *SS*, short stem; *SF*, short flange; *LF*, long flange; *LS*, long stem; *vLF*, very long flange.

mm for the flange ($P = .046$) (Table IV, pairs 3 and 4). Furthermore, the average flange in these 6 cases was about 7 times shorter than the average stem (S/F ratio, 6.7 ± 2.2). This ratio was significantly different from that in cases that were not re-revised (S/F ratio, 4.2 ± 2; $P = .03$) (Table V).

Clinical outcomes

Of the 40 elbows included in this study, 39 had documented flexion and extension measurements at final follow-up. Seventeen patients had reported pronation and supination measurements at final follow-up. Mean flexion was 134° (range, 100°-160°; SD, 16°) in the single-revision group and 106° (range, 0°-140°; SD, 49°) in the re-revision group; the mean extension deficit was 19° (range, 0°-90°; SD, 21°) in the single-revision group and 9° (range, 0°-40°; SD, 14°) in the re-revision group; mean pronation was 82° (range, 0°-100°; SD, 26°) in the single-revision group; and finally, mean supination was 85° (range, 40°-100°; SD, 15°) in the single-revision group. No data on pronation and supination were available for the re-revision group. Of the 39 elbows

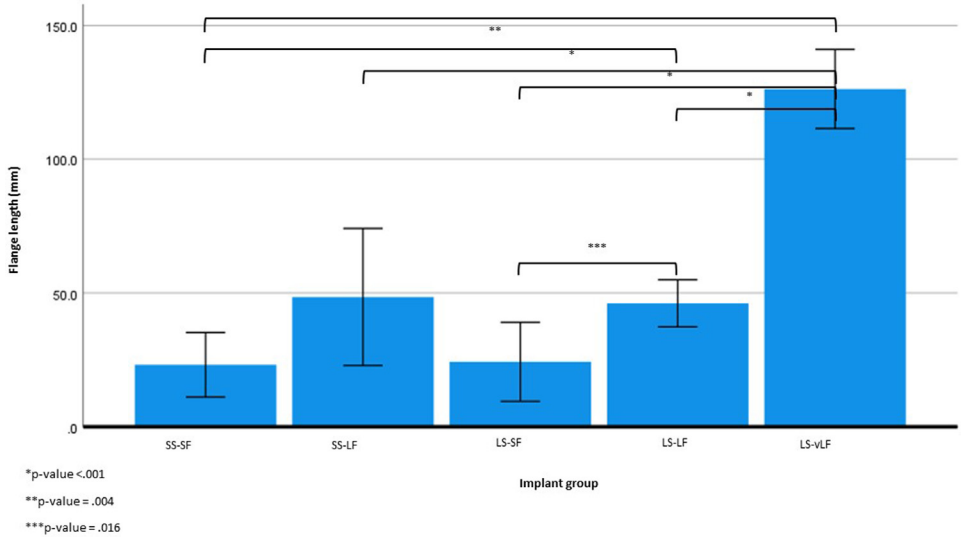

Figure 4 Graphical representation of flange lengths between the 5 groups showing the difference in flange length between short, long, and very long flanges. Statistically significant differences in flange lengths were observed between the groups. *SS*, short stem; *SF*, short flange; *LF*, long flange; *LS*, long stem; *vLF*, very long flange.

Table II Data regarding various implants used in study cohort including average stem and flange lengths within groups

Implant group	No. of implants	Implant design	Stem length, mean ± SD, mm	Flange length, mean ± SD, mm
SS-SF	9	Discovery in 5 and CM in 4	125 ± 26	23 ± 3.5
SS-LF	2	CM in 1 and Latitude in 1	141 ± 2.8	49 ± 1
LS-SF	6	Discovery in 4 and CM in 2	190 ± 15	24 ± 5.5
LS-LF	20	CM in 17 and Latitude in 3	193 ± 10	45 ± 3.8
LS-vLF	9	Discovery in 7, Acclaim in 1, and Pritchard-Walker in 1	214 ± 36	138 ± 42

SD, standard deviation; *SS*, short stem; *SF*, short flange; *CM*, Coonrad-Morrey; *LF*, long flange; *LS*, long stem; *vLF*, very long flange.

Table III Re-revision rates for 5 implant groups

Implant group	Total implanted, n	Failed implants for HL	
		Total, n	%
SS-SF	9	3	33
SS-LF	2	1	50
LS-SF	6	3	50
LS-LF	20	4	20
LS-vLF	9	0	0

HL, humeral loosening; *SS*, short stem; *SF*, short flange; *LF*, long flange; *LS*, long stem; *vLF*, very long flange.

included in this section, 4 ultimately underwent revision to excisional arthroplasty leaving the patients with a flail elbow.

Complications

The most common complication was ulnar neurapraxia, occurring in 27 elbows (68%, 21 in single-revision group and 6 in re-revision group). Of these 27 instances, 12 resolved entirely (9 in single-revision group and 3 in re-revision group), leaving 15 patients (38%, 12 in single-revision group and 3 in re-revision group) with persistent ulnar neuropathy. In addition, there were 8 instances of radial neurapraxia (20%, 5 in single-revision group and 3 in re-revision group). Four of these cases resolved, resulting in 4 persistent neuropathies (10%, 2 in single-revision group and 2 in re-revision group).

Infection occurred in 6 patients (15%). Of these 6 patients, 3 had an infection of the prior prosthesis that was revised. One of these 3 patients was treated with intravenous (IV) antibiotics and a 2-stage revision with irrigation and débridement, as well as insertion of an antibiotic spacer, with a later revision of the bushing and ulnar component. One of these patients received an antibiotic spacer and IV antibiotics, followed by a bushing exchange and irrigation and débridement for infection. This patient was found to have a chronic infection and was treated with excisional arthroplasty. The last of the 3 aforementioned patients underwent treatment of infection with IV antibiotics, polyethylene exchange, and débridement.

Table IV Pair-wise comparisons of stem and flange sizes between primary or preceding TEA and rTEA (pairs 1 and 2) and between rTEA and re-revision TEA (pairs 3 and 4)

Paired comparisons	Mean, mm	SD, mm	*P* value
Pair 1: difference in primary or preceding TEA stem length and first rTEA stem length	70.1	46.7	<.001*
Pair 2: difference in primary or preceding TEA flange length and first rTEA flange length	28.2	39.0	<.001*
Pair 3: difference in first rTEA stem length and second rTEA stem length	36.8	40.3	.075
Pair 4: difference in first rTEA flange length and second rTEA flange length	73.1	69.6	.046*

TEA, total elbow arthroplasty; *rTEA*, revision total elbow arthroplasty; *SD*, standard deviation.
* Statistically significant ($P < .05$).

Table V Index implant size and S/F ratio in patients requiring re-revision TEA and patients not requiring re-revision TEA

Surgical characteristic	Single revision (n = 30)	Re-revision (n = 6)	Excision (n = 4)	*P* value
Index implant size, mean (SD)				
Stem size, mm	106.7 (34.6)	97.7 (27.1)	97.7 (26.4)	.795
Flange size, mm	21.2 (5.4)	24.0 (3.8)	19.0 (1.5)	.381
S/F ratio	4.8 (1.4)	4.3 (2.1)	5.2 (1.5)	.720
Time to first rTEA, mean (SD), yr	7.7 (6.4)	4.5 (3.6)	7.3 (8.3)	.519
Revision implant size, mean (SD)				
Stem size, mm	176.3 (41.0)	175.5 (26.5)	167.7 (32.8)	.916
Flange size, mm	55.4 (42.3)	28.2 (10.2)	40.9 (14.3)	.258
S/F ratio	4.2* (2.0)	6.7* (2.2)	4.6 (1.8)	.030*
Primary diagnosis of RA, n (%)	8* (27)	4* (67)	3 (75)	.048*

S/F, stem to flange length; *TEA*, total elbow arthroplasty; *SD*, standard deviation; *RA*, rheumatoid arthritis.
* Statistically significant ($P < .05$).

Three patients had a novel infection of the implanted prosthesis. In one of these patients, the infection resolved with IV antibiotics. One of these patients had a chronic infection treated with excisional arthroplasty. The third patient was ultimately treated with excisional arthroplasty after failure of IV antibiotics.

Ulnar loosening occurred in 6 elbows (13%) (5 in single-revision group and 1 in re-revision group). Three of these elbows were treated conservatively, whereas 3 underwent revision of the ulnar component. In 6 elbows (13%), complications owing to fracture occurred at some point after the final rTEA for HL (4 in single-revision group and 2 in re-revision group). Four patients fell and sustained a fracture of the humerus; treatment was performed with rTEA in 1 case and conservatively in the other 3 cases. One patient experienced a proximal humeral fracture, which was treated with a Sarmiento brace until ORIF could be performed. One patient sustained multiple humeral and lateral flange fractures throughout the clinical course; these were treated with a combination of rTEA and ORIF. There were no instances of radial or ulnar dislocation.

Radiographic assessment

Of the 40 elbows included in this study, 33 had radiographs available for review, with a mean follow-up period of 75 months (range, 18-221 months). Four subjects were excluded from radiographic review because they underwent excisional arthroplasty as their second revision procedure. Two additional subjects were excluded because their radiographs were unable to be retrieved. However, these patients had sufficient clinical follow-up (54 months and 74 months) to rule out clinically relevant HL that would require further revision surgery. In 1 case, the quality of the radiograph was extremely low, making it difficult to confidently define the Gruen zones; however, this patient had 96 months of clinical follow-up without any complications or complaints. None of the implants were found to be radiographically loose. A summary of the radiographic review can be found in Supplementary Table S1.

Discussion

Revision of TEA for HL continues to be a clinical challenge. In our experience, reoperations for repeated loosening and additional complications are common. The overall re-revision rate for HL was 25% at an average of 4.2 years (range, 1-19 years) from the revision procedure. Patients with an index-procedure diagnosis of RA are more likely to require future revision surgery for HL. Complications included ulnar neuropathy (n = 15, 38%), radial neuropathy (n = 4, 10%), infection (n = 6, 14%), ulnar loosening (n = 6, 14%), and fracture (n = 6, 14%). However, the selection of a humeral component with a longer

flange and stem can provide a reduction in the rate of repeated surgery for HL (Tables II and III). Therefore, our hypothesis that proportional increases in the stem and flange lengths would stabilize the bone-implant interface significantly more than a unilateral increase or uneven increases in revision implant length was validated. We found that increasing the flange to about one-fourth of the stem length (S/F ratio of approximately 4) will reduce instances of future revision for HL (Table V).

Comparing our results with those of other reports is difficult because, to our knowledge, no other report has specifically studied this patient population. However, studies have examined the outcomes of rTEA for any indication and reported re-revision rates of 8%-9%.[2] The literature has consistently shown that aseptic loosening is one of the most common indications for rTEA.[4,7,19] However, the most frequently reported location of loosening (ulnar vs. humeral) has varied. DeBernardis et al[5] evaluated 46 patients with a failed rTEA who required a second rTEA. Of the 46 patients evaluated, 17 (37%) underwent re-revision for aseptic loosening. Of these 17 patients who underwent re-revision for aseptic loosening, 7 required revision of the humeral component alone. The authors then explained that these same 7 patients were the only patients to require additional revision surgery among the group of patients with aseptic loosening.[5] Clarkson et al[4] retrospectively evaluated 869 TEA failures and found that the most common mode of failure was aseptic loosening (26.8%). They also found that most aseptic loosening failures occurred at the humeral component as compared with the ulnar component (71.7% vs. 28.3%, $P < .001$). These studies highlight that rTEA in the setting of HL is a difficult problem to clinically manage and a prevalent one.

The literature comparing re-revision in the setting of specific index-procedure indications is mixed.[18,24,26] TEA in patients with RA has been shown to be associated with high implant failure, complication, and revision rates.[3,19] Toulemonde et al[26] prospectively evaluated 100 semiconstrained TEAs with minimum 2-year follow-up. They found that patients who received TEA for RA experienced a higher re-revision rate than those whose index-procedure diagnosis was posttraumatic (15% vs. 6%). However, Perretta et al[18] retrospectively reviewed 102 primary TEAs and found the rate of revision to be 27% in patients with inflammatory arthritis and 57% after trauma. Additionally, they found that patients with trauma-related TEAs were more likely to undergo additional reoperations ($P = .008$) and implant revisions ($P = .031$). Similarly, Schöni et al[24] retrospectively evaluated 253 patients treated with the GSB III elbow prosthesis (Zimmer, Winterthur, Switzerland) and found that post-traumatic arthritis was a significant factor contributing to re-revision and RA was not. They observed that 22 of 56 implants in patients with post-traumatic joint replacements had to be revised vs. 32 of 203 implants in patients with RA (10-year survival rate, 0.56 vs. 0.87; $P < .001$).

One of the main mechanisms proposed for aseptic loosening is long-term overloading.[16] In response, extended anterior flanges have been designed to improve implant stability by reducing stress shielding and protecting the bone-cement-implant interface.[21] The clinical significance of a long anterior flange for rTEA in the setting of HL is a sparsely studied topic. Quenneville et al[21] examined the effect of an extended anterior flange on cortical strains in 5 cadaveric distal humeri by use of a Latitude prosthesis. They observed no difference in load transfer between the standard-flange and extended-flange groups. They hypothesized that the supporting collar effect of the Latitude prosthesis may have influenced the axial compression. They concluded that a flange might influence cortical strains using another implant with a different shape and different material properties than the prosthesis they studied. The implants used in our series that had the lowest recurrence of HL had an average anterior flange length of 124 mm (Fig. 3), significantly longer than the flange evaluated by Quenneville et al. It could be postulated that this increased length could have amplified any small amount of stress shielding that Quenneville et al may have observed, resulting in a clinical benefit to the patient. However, this is only speculative as no large biomechanical or clinical studies have evaluated the aforementioned custom prosthesis with a very long anterior flange.

The most common complication experienced in our series was ulnar neurapraxia, with persistent ulnar neurapraxia in 15 patients (38%). In addition, we reported 4 instances (10%) of persistent radial neuropathy. Rates of ulnar and radial neuropathy after rTEA vary in the literature. We reported a higher rate of ulnar neuropathy but a lower rate of radial neuropathy compared with the findings of Barret et al[2]: They reported complications after 19 rTEAs with rates of ulnar neuropathy and radial neuropathy (including triceps weakness) of 21% and 42%, respectively.

We also reported higher rates than Geurts et al,[10] who performed a systematic review of rTEA cases and reported on complications. Their search yielded 21 articles containing 532 cases and found transient ulnar and radial neuropathy in 21% of patients.[10] The higher neuropathy complication rate that we report can be explained by several factors inherent to our patient population. RA was the indication for primary TEA in 16 of the elbows evaluated in this series (35%). Because of this, many patients in our population underwent multiple surgical procedures, possibly owing to the higher incidences of neuropathy that are present after subsequent operations.

This study has several limitations. Our sample size was small, and some patients were lost to follow-up, including several who died. This may have impacted our results; however, this is a common limitation in studies such as this. This was a retrospective review, so our study is subject to all the limitations consistent with a retrospective review, such as limitations in clinical and radiographic data. We included 2 patients with minimal radiographic follow-up

and substantial clinical follow-up. Given the low sample size of our study, we believed that any clinically relevant HL would be manifested by the available follow-up points (54 and 74 months). The findings of this preliminary study should be a catalyst for further research on HL in rTEA including biomechanical studies evaluating custom prostheses with very long flanges.

Conclusion

Revision TEA for HL is a challenging procedure with high complication and re-revision rates. In this study, 2 factors have been identified that significantly contribute to re-revision of TEA. The first factor is if the primary TEA was performed for RA. The second factor is a humeral stem with a relatively short flange relative to the stem length. The use of an implant where the flange can be extended beyond one-fourth of the stem length may increase implant longevity.

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