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Intraoperative modification of total elbow arthroplasty implants

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Background: Modification of total elbow arthroplasty (TEA) implants may be necessary in selected patients with substantial anatomic bone deformity or those undergoing revision surgery. The purpose of this study was to investigate the prevalence and consequences of implant modifications during TEA at our institution. We hypothesized that TEA implant modification would be more common in revisions than in primary replacements, and that it would not be associated with worse clinical outcomes or increased rates of radiographic or surgical complications directly related to the implant modification.

Methods: Elbows that had undergone TEA by any of 3 surgeons at our institution with use of intraoperative implant modification between January 1992 and October 2019 were retrospectively reviewed for the type of modification and complications. Complications were classified as definitely related, probably related, possibly related, or nonrelated to the implant's modification according to the consensus review by the 3 senior surgeons. A survey was sent out to surgeons outside of our institution to investigate whether intraoperative modification to TEA implants is a common clinical practice.

Results: A total of 106 implant components were modified during 94 of 731 TEA procedures (13%) in 84 of 560 patients. Implant modifications were performed in 60 of 285 revision cases (21%) compared with 34 of 446 (8%) primary cases ($P < .0001$). These included shortening the stem in 40 (44%), bending the stem in 16 (15%), notching the stem in 16 (15%), tapering the stem in 9 (9%), and a combination of 2 or more of these modifications in 19 implants (17%). Among the 55 index surgeries available for complication analysis, 40 complications occurred in 28 index surgeries (11 primary and 17 revisions; 25 patients), making the overall complication rate 51%. Of these 40 complications, 23 were considered independent of any implant modification. Of the remaining 17 complications, 9 were considered nonrelated to the implant modification, 6 were possibly related, and 2 were probably related to the implant modification. Therefore, the complication rate possibly related or probably related to implant modification was 15% (8 of 55). No complication was classified as definitely related to the implant modification. No implant breakage or malfunction occurred after any modification. A total of 442 survey responses were received representing 29 countries, of which 144 surgeons (39%) performed modification to implants during TEA procedures.

Discussion: This study confirmed our hypothesis that modification of TEA implants is not uncommon at our institution, particularly in revision arthroplasty. Surgeons should keep in mind that complications possibly related or probably related to implant modification were at minimum 15% and could have been as high as 30% if the patients lost to follow-up had all had complications. Implant modification may be necessary in some cases but should be exercised with thoughtful consideration and caution.

This study was approved by the Mayo Clinic institutional review board (IRB 11-002988).

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Keywords: Implant; Modification; Total Elbow Arthroplasty; Revision; Latitude; Coonrad-Morrey

Total elbow arthroplasty (TEA) has become a common surgical treatment for many degenerative, inflammatory and traumatic elbow conditions. When successful, TEA provides pain relief and restoration of function for otherwise severely disabled patients. Current indications for TEA include inflammatory arthritis, acute trauma, distal humerus nonunion, post-traumatic arthritis, primary osteoarthritis, tumor, and persistent elbow instability.[17,25] Historically, rheumatoid arthritis was the most common indication for TEA, but, with the advent of disease-modifying antirheumatic drugs, the need for TEA in patients with rheumatoid arthritis has decreased (Fig. 1).[22] At the same time, because of studies demonstrating better outcomes in elderly patients with comminuted distal humeral fractures undergoing TEA as opposed to open reduction and internal fixation, the use of TEA for acute distal humerus trauma has increased.[6,15] Additionally, advances in implant design over the past 2 decades have resulted in greater utilization in patients with posttraumatic arthritis. Unfortunately, TEA after post-traumatic conditions has been less durable over time compared with those performed for inflammatory arthropathies. Overall, considering these competing trends, the incidence of TEA and revision TEA has increased in recent years.[10,12,26]

Despite many advances in implant design and surgical technique since its inception, TEA remains notable relative to other joint arthroplasties for higher rates of complications and failures.[21,25] The most common reasons for failure and subsequent revision surgery include aseptic loosening, dislocation, fracture, prosthetic component failure, and triceps tendon failure.[24] Because of the increased utilization of TEA and the relatively high surgical complication and failure rates, revision TEA surgery is often required. Revision TEA is associated with worse clinical outcomes and higher radiographic and surgical failure rates as compared to primary TEA.[8,16]

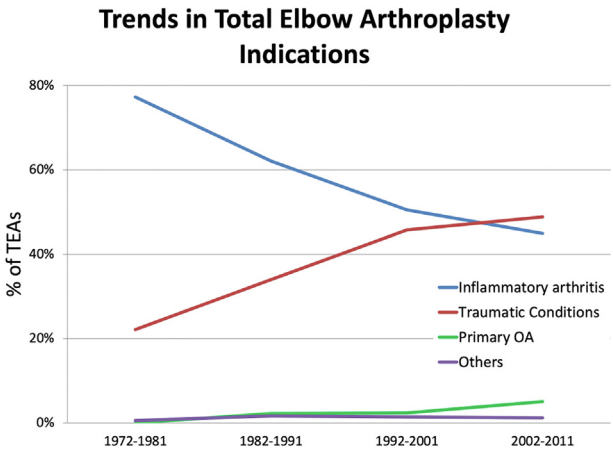

Figure 1 Trends in the indications for total elbow arthroplasty (TEA) at our institution. The percentage of TEAs performed for inflammatory arthritis has decreased over time, whereas the percentage performed for trauma and post-traumatic conditions has increased. Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved.

In our experience, intraoperative implant modification is sometimes required to properly insert TEA implants, particularly in patients with significant anatomic deformity or in those who undergo revision TEA. Despite this need, there is no information in the literature about the safety and efficacy of intraoperatively modifying TEA implants.

The purpose of this study was to investigate the prevalence and consequences of implant modifications during TEA at our institution. We hypothesized that TEA implant modification would be more common in revisions than primary replacements, and that modification of implants would not be associated with worse clinical outcomes or increased rates of radiographic or surgical complications directly related to the modification.

Materials and methods

This study is a retrospective review of patients who had undergone TEA at our institution with use of intraoperative implant modification between January 1992 and October 2019.

Identification of patients with intraoperative TEA implant modifications

Patients who had undergone TEA by one of 3 senior surgeons with fellowship training in elbow arthroplasty were identified through each surgeon's database. A retrospective chart review was then conducted to evaluate each of these patients' surgeries. Patients who had had an intraoperative implant modification were identified through review of the postoperative radiograph, when available, and the operative note. To ensure adequate follow-up, modified implants with less than 12 months of clinical or radiographic follow-up—unless TEA failure had occurred prior to this time—were excluded from the functional, radiographic, and complication analyses.

For each patient who had an intraoperative modification of a TEA implant, patient information including age, gender, handedness, underlying diagnosis, and number of previous ipsilateral elbow surgeries were recorded. Additionally, details on the

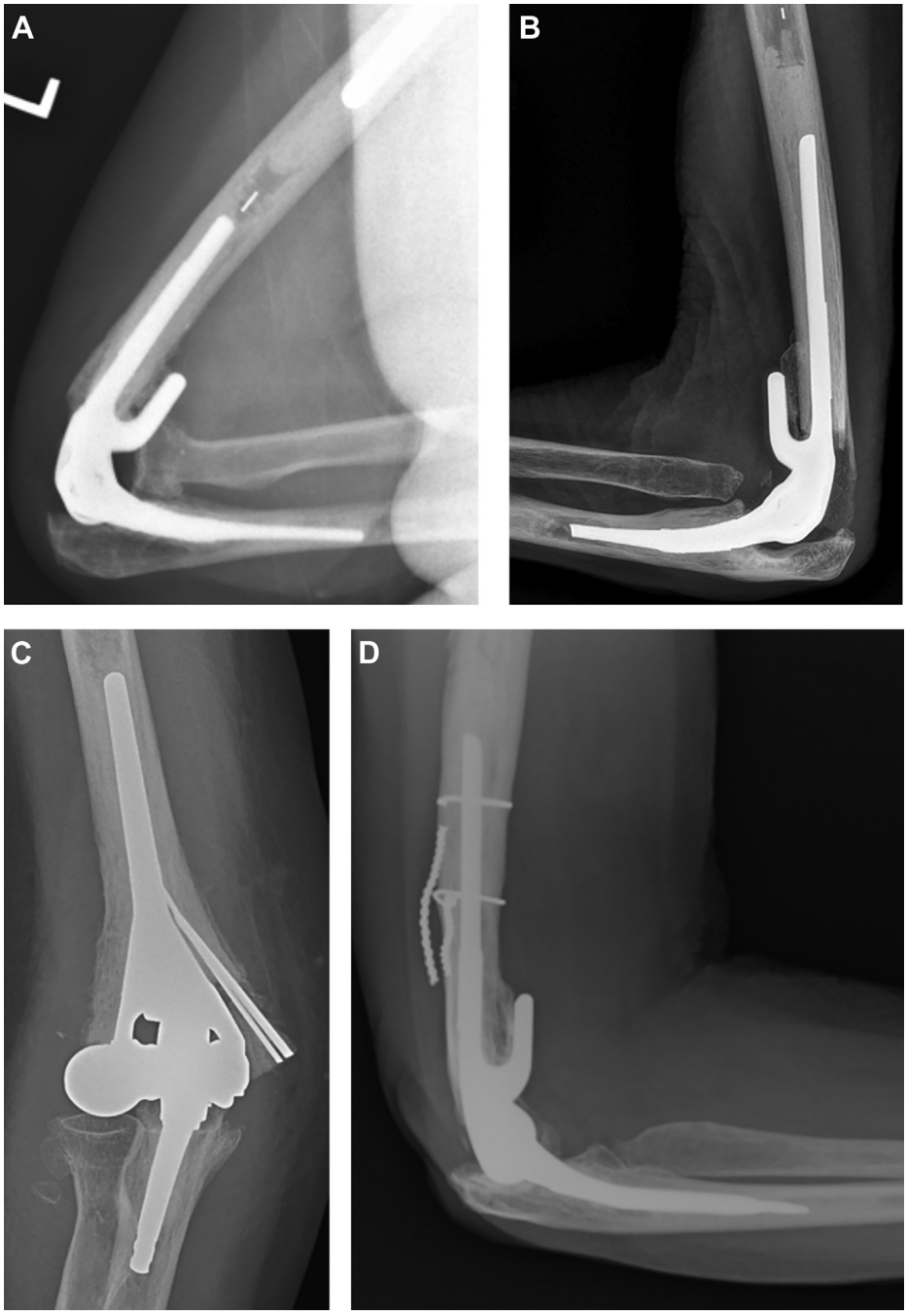

Figure 2 Radiographic examples of intraoperative total elbow arthroplasty (TEA) modifications. (**A**) A humeral stem was shortened to accommodate an ipsilateral total shoulder arthroplasty humeral component. (**B**) An ulnar stem was bent and shortened to fit the ulnar canal. (**C**) An ulnar stem was notched distally to improve fixation. (**D**) An ulnar stem was tapered distally to accommodate a narrow ulnar canal during a revision arthroplasty. Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved.

reason for implant modification as well as the type of modification and modified component (ulnar stem, humeral stem, and/or humeral flange) were recorded. Implant modifications were classified into one of the following 4 descriptive groups: shorten, bend, notch/roughen, and taper (Fig. 2). For implants that underwent more than 1 form of modification, all modifications were recorded.

TEA implant modification survey

To investigate whether intraoperative modifications to TEA implants are also done commonly outside our institution, a 5-question survey was created on Qualtrics XM (Seattle, WA, USA) and was sent out to members of American Shoulder and Elbow Surgeons (n = 1217), Mayo Elbow Club (n = 125), and attendees

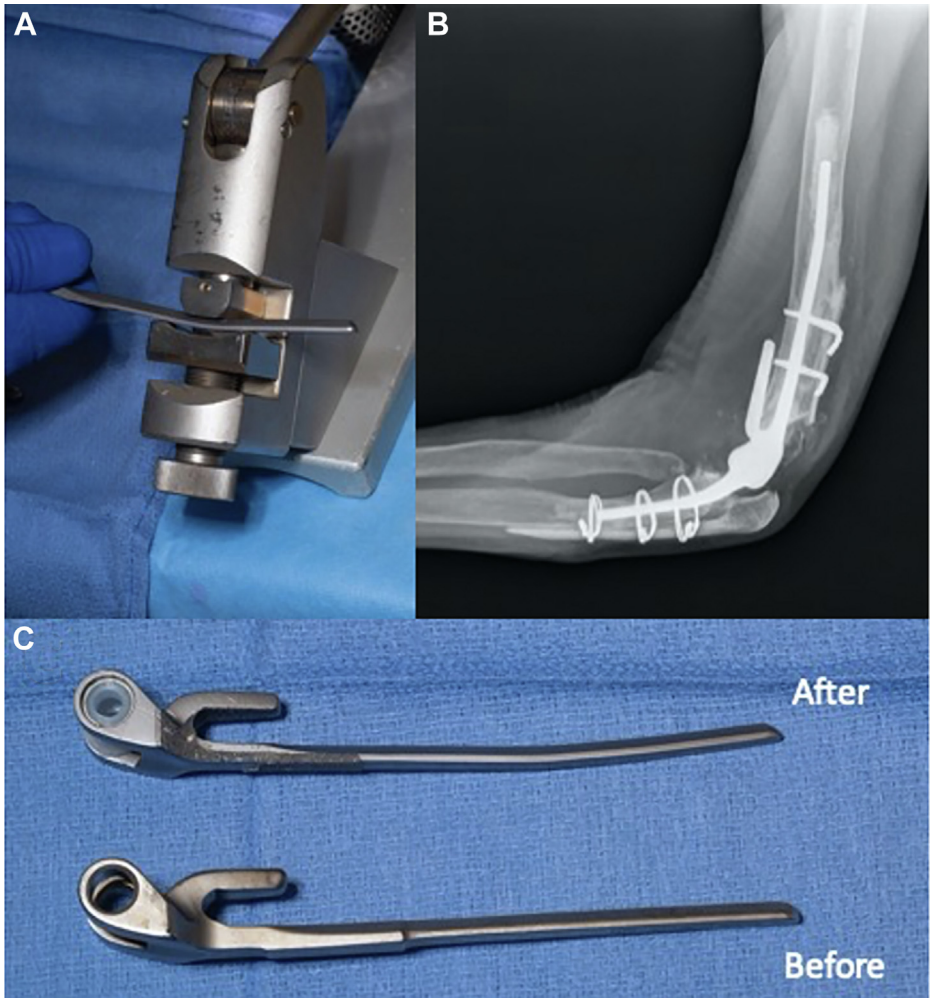

Figure 3 Bending a stem. (**A**) A humeral component prosthesis is positioned in the large plate bender in preparation to bend the stem. (**B**) The bent stem is better able to navigate the humeral canal. (**C**) Before and after images of a bent humeral stem. Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved.

of the annual ''Teach the Teachers'' Advanced Surgical Skills Course (n = 639). The Mayo Elbow Club is composed of alumni shoulder and elbow surgeons who completed fellowship or a significant component of elbow training at our institution. Some individuals belonged to more than 1 group, and in those instances, they were instructed to complete only 1 survey. The questions asked included, Do you perform TEA? Over the last 5 years, how many primary/revision TEA cases have you performed annually? Have you ever modified a TEA implant intraoperatively? How many times do you estimate you have performed the following modifications to a TEA implant intraoperatively in the last 5 years—shortening (cut off stem), tapering the tip of the stem, bending the stem, roughening the stem or creating notches, and other? (Supplementary Material S1). The data were collected from responses received within 3 weeks from the launch of the survey.

Implant modification techniques

All TEAs were performed via a standard posterior midline incision. Triceps tendon management was according to each surgeon's preference and the underlying elbow pathology. TEA instrumentation and implantation was performed according to manufacturer recommendations apart from the implant modifications.

Implant modifications were performed on a back table with sterile draping. To bend an implant at the stem or flange, a large tabletop plate bender was used (Figs. 3 and 4). Care was taken to bend the implant in small increments to not require unbending and therefore place the implant at increased risk for a fatigue fracture. To shorten, taper, or notch an implant, the preferred instrument was a metal-cutting carbide burr, generally a helicoidal burr (Fig. 5). When using the burr, a gentle and continuous irrigation with saline was applied to prevent heating of the implant. In addition, when an ulnar component with polyethylene was modified, the polyethylene bearing was carefully covered and protected with sterile surgical gauze to avoid any metal debris landing on the polyethylene surface. Likewise, care was taken to minimize airborne metal debris while the implants were burred. If notches were being made, they were staggered to avoid a substantial stress riser that could lead to fracture of the implant. When shortening the implant's stem or flange, a sharp edge would potentially be an abrasive surface and a stress riser and, therefore,

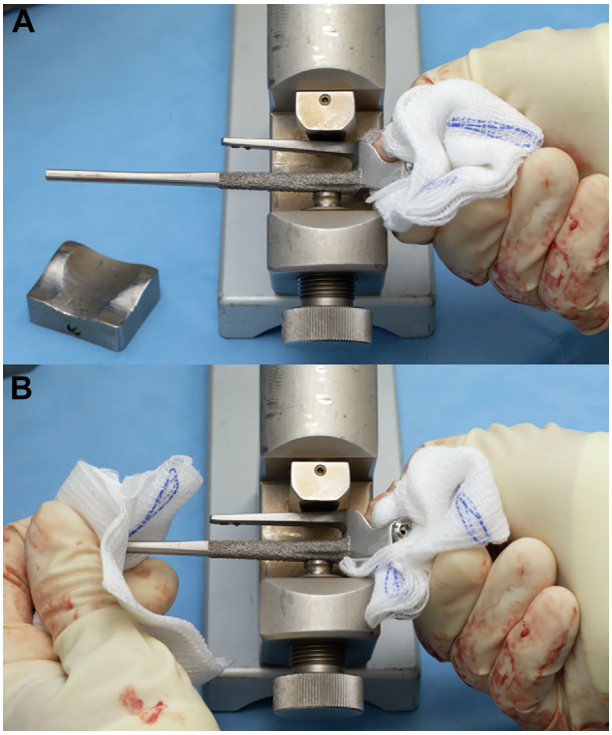

Figure 4 Bending a humeral component's extended flange. (**A**) A humeral component prosthesis is positioned in the large plate bender in preparation to bend the flange. (**B**) The flange is bent down to the desired position as required to accommodate patient anatomy. Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved.

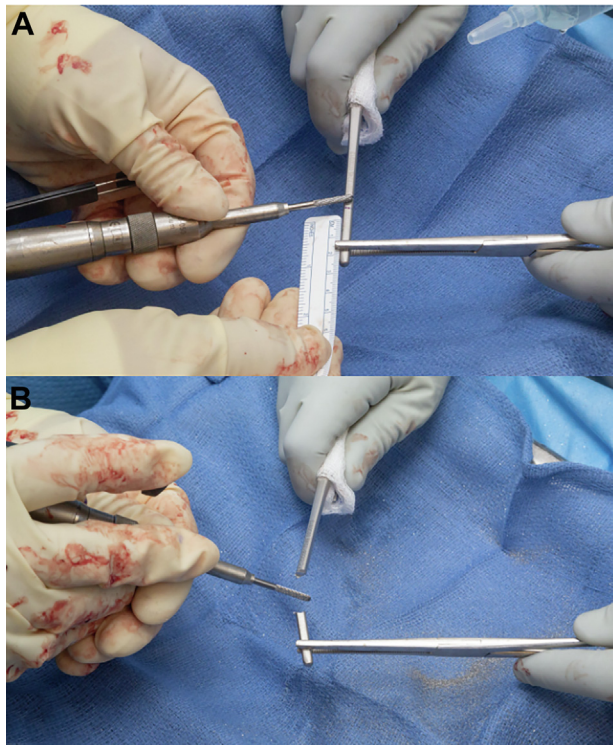

Figure 5 Shortening a stem with a helicoidal burr. (**A**) A humeral stem is marked at the desired level of shortening and a carbide helicoidal burr is used to cut the stem. (**B**) Continuous irrigation prevents thermal modification of the metal and reduces airborne metallic debris. Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved.

cut edges were smoothed again with a burr. Gloves were changed after burring metal.

Clinical outcomes

For each patient, postoperative clinical outcomes were recorded from the medical record and our Institutional Total Joint Registry Database. This registry prospectively requests all patients to return at 1 year, 3 years, and every 5 years postoperatively or to fill out follow-up questionnaires and requests for radiographs. Not all patients respond, so some are lost to follow-up. Clinical outcome evaluation was performed using the Mayo Elbow Performance Score (MEPS) at the patient's most recent assessment. The MEPS is a performance index based on elbow pain, motion, stability, and daily function.[17] Outcomes are considered excellent if the MEPS is $\geq$90 points, good if between 75 and 89 points, fair if between 60 and 74, and poor if the MEPS is $<$60 points.

Radiographic outcomes

For all patients with immediate postoperative radiographs and those performed at final follow-up, the bone-cement interface and the presence of bushing wear were evaluated. The bone-cement interfaces were evaluated for radiolucency on lateral radiographs according to the system used by Athwal et al.[1] Grade 0 indicated no radiolucency at the bone-cement interface; grade 1 a nonprogressive radiolucent line involving $<$50% of the interface; grade 2 a nonprogressive radiolucent line involving $>$50% of the interface; grade 3 a progressive radiolucent line involving $<$50% of the interface; grade 4 a progressive radiolucent line involving $>$50% of the interface; and grade 5 gross radiographic loosening of the implant.

Postoperative bushing wear was scored on anteroposterior radiographs using the system proposed by Gill and Morrey for the Coonrad-Morrey implant (Zimmer-Biomet, Warsaw, IN, USA).[9] This grading system is based on the varus-valgus angulation in the anteroposterior plane on radiograph. Because the Coonrad-Morrey implant has 7° of normal varus-valgus laxity, any varus or valgus angulation greater than 3.5° must involve bushing wear. Therefore, $<$3.5° of ulnohumeral varus or valgus angulation is considered normal, 3.5°-5° is considered partial bushing wear, and $>$5° is considered complete bushing wear. As the Nexel (Zimmer-Biomet), Latitude (Wright Medical Group, Bloomington, IN, USA), and Discovery (DJO Global, Vista, CA, USA) TEA implants also have 7° of normal varus-valgus laxity, we extended the same scoring system to these implants as well.

Complications

For each patient, postoperative complications were recorded from the surgeons' databases and through a retrospective review of the medical records. We considered a fracture of the modified

component, a periprosthetic fracture, an implant loosening, or nonunion of an allograft-prosthetic composite (APC) as potentially related to the implant's modification. When one of these complications were identified, the 3 senior surgeons each independently classified these complications as either related, probably related, possibly related, or nonrelated to the implant's modification. When a disagreement occurred among the 3, they re-evaluated the case together to come to a consensus. Other perioperative complications not considered to be related to implant modification included triceps insufficiency, deep infection, nerve palsy, bushing wear, and radial head dissociation.

A total of 106 implants were modified during 94 index surgeries (13%) in 84 patients. We defined an index surgery as a procedure during which at least 1 implant was modified. For example, a patient who had had an ulnar component notched sustained a radial head dissociation 2 months later and the radial head was removed. Then he had a triceps insufficiency that was managed nonoperatively. He finally had loosening of his humeral component 8.5 years after the first surgery for the TEA. During the revision surgery, both the humerus and ulna were revised, and the new ulnar component was notched. We consider this case as 3 complications during 2 index surgeries in 1 patient.

Statistical methods

The Fisher exact test was used to compare incidents between 2 groups, and a P value of $<.05$ was considered statistically significant.

Results

Patient demographics

Between January 1992 and October 2019, 731 TEAs in 560 patients were performed by one of the 3 surgeons. Among them, 302 were performed for the post-traumatic conditions (acute fracture, nonunion, or post-traumatic arthritis), 171 for rheumatoid or inflammatory arthritis, 36 for osteoarthritis, and 51 for other causes (neurologic, oncology, undetermined). Primary replacement was performed in 446 of 731 cases (61%), whereas 285 of 731 (39%) were revisions. The preoperative demographics of these patients are detailed in Table I.

A total of 106 implants were modified during 94 index surgeries (13%) in 84 patients. Implant modifications were performed in 60 of 285 revision TEAs (21%) compared with 34 of 446 (8%) primary TEAs ($P < .0001$; Table II).

TEA implant modification survey responses

Responses were received from a total of 442 surgeons, representing 29 countries (ASES n = 210, Mayo Elbow Club n = 124, "Teach the Teachers" Advanced Surgical Skills Course n = 108). Among these 442 respondents, 373 (84%) performed TEA, of whom at least 185 (50%) performed more than 5 TEAs annually and at least 85 (23%) performed more than 10 annually. In addition, 144 surgeons (39%) (ASES: 60/163 = 37%; Mayo Elbow Club: 49/108 = 45%; "Teach the Teachers" Advanced Surgical Skills Course: 35/102 = 34%) performed 1 or more modifications to an implant during TEA operation (Fig. 6). Regarding modes of modification, 110 surgeons (29%) had cut off a stem (1-4 times: 100; 5-9 times: 8; 10-19 times: 1; >20 times: 1); 29 (8%) tapered the tip of the stem (1-4 times: 28; 10-19 times: 1); 78 (21%) bent the stem (1-4 times: 66; 5-9 times: 6; 10-19 times: 5; >20 times: 1); and 9 (4%) roughened the stem or created notches (1-4 times: 11; 5-9 times: 1; 10-19 times: 1; >20 times: 2). Surgeons who performed revision TEA were more likely to have experience in modification (128/281; 46%) than those performing only primary TEA (16/92; 17%).

Prevalence and type of modifications

The implants that were modified included 64 Latitude (28 humeral components and 36 ulnar components), 38 Coonrad-Morrey (24 humeral component and 14 ulnar components), 3 Nexel (1 humeral component and 2 ulnar components), and 1 Discovery (1 humeral component). The most frequently performed modification was shortening, which accounted for almost half of the modifications, followed by bending, notching or roughening, and tapering (Table III).

A total of 23 APCs had been performed in the 34 revision TEA procedures included in this study: in 9 cases to reconstruct a distal humerus; in 9 cases for a proximal ulna; in 2 cases to reconstruct both the ulna and triceps; in 2 cases for the humerus, ulna, and triceps; and in 1 case for both the ulna and the humerus.

When evaluating operative decision making, we found that modification types clustered according to specific intraoperative indications (Table IV). For instance, we found that implant stems were frequently bent to accommodate abnormal canal geometries, whereas notching of the ulnar stem was frequently performed to prevent the pistoning phenomenon that can lead to loosening due to ulnohumeral impingement when certain implants with limited or no surface treatment are implanted.[3] This led to implant modifications by the manufacturer to avoid a completely smooth stem. However, we still use it when we think the fixation of an off-the-shelf implant will not be sufficient. For example, when the porous coat of the stem was not in the native bone in cases of APC, or when the porous coat was not in the canal because of bone loss.

Clinical assessment

Of the abovementioned 106 implants modified during 94 index surgeries (13%) in 84 patients, 48 implants had less than 12 months' follow-up and were excluded for outcome analysis. Thus, outcomes were analyzed for 58 implants (26

Table I Demographics of patients requiring implant modifications

Description	n (%) or mean (range)
Male	57 (61)
Age at surgery, yr	59 (20-86)
Dominant arm	45 (47)
Previous elbow surgeries	3 (0-4)
Previous elbow arthroplasty surgeries	2 (0-13)
Previous nerve impairment	38 (40)
Previous elbow infection	31 (33)
Previous triceps impairment	18 (19)

Table II Implant modifications by surgical indication and primary vs. revision status

	Primary	Revision	Total
Total TEAs	446	285	731
TEAs with ≥1 modification	34 (8)	60 (21)	94 (13)
Surgical indication			
Post-traumatic arthritis	18	37	55 (59)
Inflammatory arthritis	12	16	28 (30)
Primary osteoarthritis	2	4	6 (6)
Other	2	3	5 (5)

TEA, total elbow arthroplasty.
Values are n or n (%).

humeral and 32 ulnar) modified during 55 index surgeries in 50 patients. This cohort had a mean follow-up of 6 years (range, 1-24 years).

At the time of final follow-up, the mean MEPS was 80 points (range, 25-100 points), and it was considered excellent for 16 elbows, good for 11, fair for 8, and poor for 3. The average flexion-extension arc of motion at the most recent follow-up was 107° (range, 30°-150°), with a mean extension of 25° (range, −10° to 90°) and a mean flexion of 132° (range, 60°-150°). The pain component of the MEPS score averaged 34 points (range, 0-45 points). The functional component of the MEPS averaged 18 points (range, 0-25 points).

Radiographic assessment

Radiographs obtained at final follow-up were available for 27 of the 58 cohort implants (47%) (13 humeral and 14 ulnar) modified in 27 index surgeries in 27 patients. The distributions of bone-cement interface radiolucencies at the immediate postoperative time and at final follow-up for the humeral and ulnar component are listed in Table V. There were 5 cases of radiolucency progression on the humeral side: 1 instance each of an increase from grade 0 to 3, from grade 1 to 2, from grade 1 to 3, from grade 1 to 4, and from grade 2 to 3. There were 7 cases of radiolucency

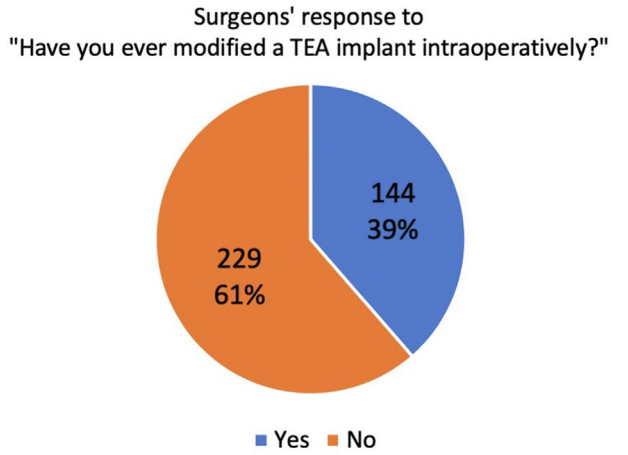

Figure 6 Survey results. Questions 3 and 7 of the survey (attached in Supplementary Material S1) revealed that 39% (144 of 373) surgeons who perform total elbow arthroplasty modified implants intraoperatively, and that modifications are much more common during revisions than primary procedures. Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved.

progression on the ulnar side: 5 from grade 0 to 1, 1 from grade 0 to 3, and 1 from grade 1 to 2.

At final radiographic analysis, bushing wear was graded as none in 21 cases (78%), partial in 4 cases (15%), and complete (requiring bushing exchange) in 2 cases (7%).

Complications

Among the 55 index surgeries, 40 complications occurred after 28 index surgeries (11 primary and 17 revision TEA) during which 31 implants were modified (humerus and ulna were both modified in 3 cases). Therefore, the complication rate after an implant modification was 51%. Seven index surgeries sustained 2 complications, 1 sustained 3 complications, and 1 sustained 4 complications. Of these 40 complications, 23 were independent to the implant modification. This included 7 deep infections, 6 triceps impairments, 4 nerve complications, 2 superficial wound dehiscences, 2 cases of bushing wear, 1 radial head dissociation, and 1 case a clinically significant heterotopic ossification. The 17 complications that might or might not have been related to the implant modifications included loosening in 11 implants, 5 periprosthetic fractures, and 1 failed APC. Of the 40 complications overall, 7 were treated nonoperatively, 17 needed a revision surgery, 6 were treated with a resection arthroplasty, and 10 needed another surgery (4 triceps repair or reconstruction, 2 bushing exchange, 1 irrigation and débridement, 1 prosthetic radial head removal, 1 tendon transfer, and 1 heterotopic ossification removal).

Regarding the complications that might or might not have been related to the implant modifications, 9 were

Table III Implant modification class distribution

Modification class	Component modified			Percentage
	Ulnar system, n	Humeral system, n	Flange, n	
Shorten	13	33	0	44
Bend	11	2	3	15
Notch and roughen	12	3	1	15
Taper	7	2	0	9
Implants with $\geq$2 modifications, n	9	10		
Combination of:			n/a	17
Notch, n	7	5		
Bend, n	4	5		
Shorten, n	4	5		
Taper, n	3	4		
Total	52	50	4	

Table IV Reason for implant modifications according to modification class

Problem	Modification class			
	Shorten	Bend	Taper	Notch and roughen
Canal was blocked, eg, cement plug, shoulder arthroplasty	+++			
Canal was too narrow, eg, cement within cement technique	++		+++	
Canal shape was altered, eg, APC	+++	++++		
Bone stock was compromised, eg, shorten a revision long-stem with extended flange	+++			
Avoid pistoning and loosening, eg, anterior ulnohumeral impingement	+	+		++++
Avoid stress riser at implant tip, eg, cortical perforation	++			
Available stem was too long, eg, inadequate intraoperative extension	++			

APC, allograft-prosthetic composite.
Numbers of modifications: + = <5; ++ = 5-10; +++ = 10-20; ++++ = >20.

considered not related to the implant modification, 6 were possibly related, and 2 were probably related to the implant modification following review by the 3 senior surgeons. Therefore, the complication rate possibly related or probably related to implant modification is 15%. The initial agreement among the 3 senior surgeons, prior to re-evaluation, when necessary, was 61%. The 6 possibly related complications were 3 aseptic loosening (2 notched ulnar stems, and 1 shortened humeral stem) and 3 periprosthetic fractures (1 humeral shaft fracture in proximity to a bent humeral stem, 1 ulnar shaft fracture in proximity to a bent ulnar stem, and 1 ulnar shaft fracture in proximity to a shortened ulnar stem). The 2 complications classified as probably related to the implant modification were aseptic loosening: 1 shortened humeral stem and 1 shortened ulnar stem.

No complication was classified as definitely related to the implant modification, and there was no implant fracture after any modification. All the prosthesis were made with titanium or a titanium alloy. We did not find any relation between the size of the stem and the complications observed.

Discussion

This study confirmed our hypothesis that modifying total elbow prosthesis implants is not uncommon at our institution, particularly in revision arthroplasty. The overall complication rate was high in our series (51%), but this was principally related to the nature of revision elbow replacement surgery including allograft prosthetic composites. No complications were definitely related to implant modification, and no implant fractures occurred after any modification. The complication rate for cases that were possibly related or probably related to an implant modification was 15%. However, because only 27 of the implants modified during 27 index surgeries had more than 12 months' radiographic follow-up available for analysis, this complication rate could have been as high as 30% if the patients lost to follow-up all had complications possibly related to the implant modification.

Implants are approved before clinical use, but not the method of their use. Therefore, a modification of a device to an individual patient would fall within the domain of surgical decision making to best meet the needs of that

Table V Progression of bone-cement interface radiolucencies in modified total elbow arthroplasty implants

Bone-cement interface radiolucency grade	Humeral interface		Ulnar interface	
	Immediate postoperation, n (%)	Final follow-up, n (%)	Immediate postoperation, n (%)	Final follow-up, n (%)
0	17 (61)	16 (57)	20 (74)	14 (52)
1	8 (29)	5 (18)	7 (26)	11 (41)
2	3 (11)	3 (11)		1 (4)
3		3 (11)		1 (4)
4		1 (4)		
5				

individual patient, similar to bending a plate that does not quite fit. The choice of implant(s) was based on what was thought to be in the best interest of the patient under the circumstances at the time. The 3 coauthors who are consulting staff sit next to each other in the clinic and operate in the same area. This permitted the development of a team approach to the decision-making process, discussion of the advantages and disadvantages of strategies and implant options, and intraoperative consultation as well as postoperative discussion of complicated cases such as those in which modifications of an implant were performed.

A major concern with modifying these implants is that the modified implants may not be as reliable as the original, because rigorous implant testing of modified implants have not been investigated in the laboratory. However, although we do report cases of complications that are possibly or probably related to implant modifications, we did not find any cases with a complication definitively related to an implant modification. This is an encouraging finding, as implant modifications are frequently required during complex primary and revision elbow arthroplasty surgeries.

We report a 51% complication rate and a 42% revision rate (revision or resection arthroplasties) in our series. In the literature, the reported complication rate varies from 5.2% to 50%, and the revision rate varies from 10% to 30%.[2,7,11,13,19,20,23] However, the revision rate may be as high as 54% when the series includes only revision TEA.[4] Our high complication rate is likely related to selection bias, because implant modification is mostly required in the most complex reconstructions and revisions. Thus, this study included a majority of trauma patients (59%, post-traumatic osteoarthritis, trauma sequelae, and acute fracture), whereas the inflammatory arthritis only represented 30% of our cases. This is in contrast with other reported series in the literature, reflecting the shift in indications for TEA from inflammatory arthritis to trauma and post-traumatic conditions and also the nature of the procedures with the potential to require implant modification.[7,11,13,18,19,23] Moreover, in our series, most of our patients (89%) had at least 1 previous elbow surgery, a majority of our patients were revision TEA (64%), and 64% had at least 1 major elbow impairment (triceps insufficiency, ulnar nerve impairment, or infection) prior to the procedure. Overall, these data indicate that our population was more at risk of complications.

The cement-within-cement technique was previously reported as an efficient and effective technique to revise TEAs.[14] This technique may be improved by shortening or tapering the implant when cement narrows the residual canal. We started to notch certain stems after realizing that a smooth stem has a high early loosening rate. This emphasizes the importance of analyzing the complications of the implant in order to improve the design of the implants.[5] We did not observe any fracture of the implant. This was a concern prior to initiation of this study because it was previously reported that implant fracture can occur because of fatigue failure of a stem.[1,14] Therefore, notching the stem could potentially predispose an implant to sustaining a fatigue failure. To prevent this phenomenon, we created the notches closer to the tips of the stems rather than at the metaphyseal region, where the stress concentration would be higher.

Notching of the stem was indicated in 2 differing situations. Although 3 of the 4 prosthetic designs had porous coated stems, 1 of the prostheses was only available with smooth stems without porous coating. Once we recognized that pistoning can cause stem loosening,[3] and that this loosening was fostered by a smooth stem, precautions were taken to minimize the likelihood of that happening. Implant fractures reported in previous literature are due to fatigue failure in the metaphyseal region due to a stress riser between a section of well-supported stem and a section of unsupported stem. In elbow implants, this is typically due to loss of bony support, such as occurs in distal humeral nonunions or secondary to osteolysis. For this reason, we placed notches as close to the tip of the stems as possible. This previous literature is in agreement with our series as we did not observe implant fractures after notching the stem, or with any implant modification. Porous coated stems were also notched closer to their tips if the interface between the patient's bone and the porous coated portion of the stem was compromised because of bone loss or when the porous coated region is only inside allograft bone such as with an APC. Roughening of the stem was sometimes used instead of, or in addition to, notching.

One of the complications that was considered to be probably related to the implant modification was aseptic loosening if the stem had been shortened. We reasoned that if a stem was shortened solely to permit the use of a longer revision implant, then any subsequent loosening of that stem was thought to be no more likely to have occurred than had we used a shorter, conventional stem. On the humeral side, there were times when a longer stem was used (and cut short) solely for the purpose of providing an extended flange, which is only available on the longer stems. In such cases, it is possible that the extended flange may have failed to adequately compensate for any need for additional humeral stem length, and therefore the decision to shorten the stem may have indirectly contributed to loosening, if loosening did occur. Consequently, shortening of a long humeral stem in a patient who eventually experienced humeral stem loosening was considered to have possibly or probably contributed to stem loosening if the stem would not have been cut short had there not been an extended flange on that stem in the first place.

The TEA implant modification survey represented a population of surgeons with a high ratio of experience in TEA. The data from this subset revealed that intraoperative modification is being done around the world, with 39% of 373 surgeons who perform TEA having modified implants intraoperatively, and that modifications are much more common during revisions than primary procedures. The trend of modification modes was similar to our institution, with shortening and bending being the more frequently performed procedures.

To our knowledge, no prior study described the techniques and results of modifying implants. The frequency with which we perform this in our institution is an indicator of the complexity of elbow arthroplasty we see in our practice, particularly revisions. Implant modification may be necessary in some cases but should be exercised with thoughtful consideration and caution.

Limitations

Limitations of this study include its retrospective nature, the lack of a control group, and the relatively small number of cases with some of the modifications described. Another limitation is the small number of patients with radiographic follow-up. This limitation could lead us to underestimate the complication rate related to implant modification. However, because we are a tertiary care institution and a referral center for elbow replacement, it is likely that a patient who would have had a complication with their total elbow prosthesis would have returned to us for treatment.

Limitations related to the TEA implant modification survey included that no patient-related data were available such as background, pathology, clinical outcome, and complications. Additionally, the selected groups do not represent the whole TEA-performing global population; there may be selection bias that surgeons performing TEA were more willing to respond, and those too busy, uninterested, or are infrequent email responders may have tended to not respond. For these reasons, the data are limited to the people who answered the survey, and those may be only a subset of those that would likely modify. Finally, it is important to note that although individuals who belonged to more than 1 group were instructed to only complete 1 survey, there exists the possibility of duplicate responses. However, maintaining the anonymity of the respondents was our main focus. The data support this proposal that implant modification is something done commonly and should be considered part of clinical practice.

Conclusion

The modification of TEA implants is frequently performed in our practice for a variety of indications. Shortening of an implant's stem was the most commonly performed intraoperative modification type, and modifications were more frequently performed during revision surgeries than in primary surgeries. Surgeons should keep in mind that the complication rate for cases that were possibly related or probably related to an implant modification was 15%. However, because only 27 of the implants modified during 27 index surgeries had more than 12 months' radiographic follow-up available for analysis, this complication rate could have been as high as 30% if the patients lost to follow-up all had complications possibly related to the implant modification. As previously stated, implant modification may be necessary in some cases but should be exercised with extreme caution. TEA implant designs should evolve to more modular designs to avoid the need for intraoperative modification.

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Supplementary data

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