ELBOW

Cost-effectiveness analysis of total elbow arthroplasty versus open reduction–internal fixation for distal humeral fractures

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Background: Total elbow arthroplasty (TEA) and open reduction–internal fixation (ORIF) are 2 viable surgical treatment options for acute, intra-articular distal humeral fractures in elderly patients. Whereas recent systematic reviews and randomized trials have suggested that TEA and ORIF result in similar functional outcome scores, no previous study has assessed the comparative cost-effectiveness between TEA and distal humeral ORIF in this specific demographic.
Methods: A Markov model was created with the highest-level data available from the literature depicting transitioning health states based on treatment strategies. To populate the quality-of-life data points in the model lacking in the literature, a survey was conducted of patients at 2 referral institutions who underwent TEA or ORIF for acute, intra-articular distal humeral fractures via the European Quality of Life, 5 Domains (EQ-5D) questionnaire at least 2 years postoperatively. Cost data from 2016 for each strategy were used to calculate the comparative cost-effectiveness of TEA versus ORIF.
Results: For patients aged 65 years, the total cost of TEA was $19,407 compared with $20,669 for ORIF. The effectiveness of TEA and ORIF was 8.17 and 7.72, respectively. Overall, the incremental cost-effectiveness ratio of TEA ($2375.76/quality-adjusted life-year) was favored more than ORIF ($2677.26/quality-adjusted life-year).
Conclusion: These findings suggest TEA is a slightly more cost-effective procedure than ORIF for most elderly patients who sustain acute, intra-articular distal humeral fractures. Still, the unique limitations, complications, and revision rates for each strategy must be carefully weighed for each patient when making a decision.
Level of evidence: Level II; Economic Analysis Study
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Keywords: Total elbow arthroplasty; open reduction–internal fixation; distal humeral fracture; cost-effectiveness analysis; Markov model; incremental cost-effectiveness ratio

Distal humeral fractures are challenging and relatively common injuries, comprising 30% of all elbow fractures.[1,10,26] A population-based study from Finland showed that the incidence of distal humeral fractures in women older than 60

years was 28 in 100,000 in 1995, with a regression model showing an expected 3-fold increase by 2030.[21] These fractures tend to occur in a bimodal distribution with younger patients sustaining high-energy injuries and elderly patients, typically women, sustaining low-energy falls.[17,25] Although distal humeral fractures in younger patients are almost universally amenable to open reduction–internal fixation (ORIF), treatment of an elderly patient with a displaced, intra-articular fracture generally requires ORIF or total elbow arthroplasty (TEA).

ORIF was once considered the gold standard for intra-articular fractures of the distal humerus in elderly patients. Typically, reduction of the joint surface is followed by instrumentation with "parallel" or orthogonal "90-90" plating to provide bicolumnar buttress support of the articular surface. Both methods of fixation have given acceptable results.[13] The advent of locked plating has yielded similarly favorable results, with potential advantages in the elderly patient with osteoporotic bone.[4,9] Despite these advances, a complication rate after ORIF of over 35% has been reported and complications can include nonunion, heterotopic ossification, ulnar neuropathy, and stiffness.[11,16,20,27]

TEA, the gold standard for treatment of end-stage elbow arthritis in elderly patients, has recently been introduced as a viable acute treatment for traumatic elbow fractures. TEA allows predictable postoperative range of motion (ROM) and pain relief, especially in the patient with pre-existing elbow arthritis. The disadvantages of TEA include surgeon-imposed activity restrictions (often a 2.5 kg weight limit) and several catastrophic complications including infection, aseptic loosening, and periprosthetic fracture. Several recent studies have compared the short- and medium-term results of TEA with those of ORIF and concluded that TEA is a reasonable option for elderly patients with comminuted intra-articular distal humeral fractures.[7,8] A prospective, randomized controlled trial concluded that TEA is the preferred alternative to ORIF in elderly patients with complex distal humeral fractures not amenable to stable fixation.[15]

In today's health care climate, the cost-effectiveness of plausible interventions must be evaluated in conjunction with clinical outcomes. Cost-effectiveness analysis (CEA) is an established and powerful tool for policymakers, insurers, researchers, and clinicians. In the field of orthopedics, CEAs have been applied in multiple diverse situations ranging from bearing surfaces for total joint replacement to fixation of hip fractures and arthroplasty for glenohumeral arthritis.[18,19,28] Disease modeling with decision analysis enables investigators to identify the factors and outcomes most crucial to cost-effectiveness and clinical effectiveness. No study to date has analyzed the quality-of-life outcomes after ORIF and TEA for this fracture pattern in this patient population. Although multiple studies have evaluated disability, ROM, pain, complications, and other relevant clinical parameters,[7,15] assessing quality-of-life metrics that can be converted to quality-adjusted life-years (QALYs) is essential to conducting a CEA of the treatment options for this injury.

TEA and ORIF are 2 viable surgical treatment options for acute, intra-articular distal humeral fractures in patients older than 60 years. Recent systematic reviews and randomized trials have suggested that TEA and ORIF result in similar functional outcome scores, with TEA perhaps having decreased reoperation rates in patients with complex distal humeral fractures not amenable to stable fixation.[7,8,15] This study compared the cost-effectiveness of TEA and distal humeral ORIF in this specific demographic.

Materials and methods

Study design

This study comprised a retrospective chart review of included patients with telephone interviews to collect the most recent patient-recorded outcome scores. An extensive literature search was performed to identify the highest level-of-evidence studies related to the treatment of acute distal humeral fractures in our specific age demographic. Subsequently, outcome and transition state probabilities were obtained using the results of these studies to create a Markov decision model. The QALYs were calculated for each surgical demographic within the model to arrive at the comparative cost-effectiveness of TEA versus ORIF.

Setting

Perioperative database queries were performed at 2 tertiary referral institutions in the eastern United States from December 1998 to November 2013 using the Current Procedural Terminology codes for TEA (24363); open treatment of humeral supracondylar or transcondylar fracture with or without internal or external fixation with intercondylar extension (24546); open treatment of humeral condylar fracture, medial or lateral, with or without internal or external fixation (24579); and open treatment of periarticular fracture and/or dislocation of the elbow (24586).

Participants

The inclusion criteria for the survey portion of the study comprised patients older than 60 years at the time of the operation, surgery performed within the past 15 years at the participating institutions, surgical intervention of either ORIF or TEA for acute (<3 weeks) displaced distal humeral fractures with substantial intra-articular involvement (AO–Orthopaedic Trauma Association classification type 13-C2 and 13-C3 fractures), and adequate postoperative follow-up with a telephone survey at least 24 months after the procedure. Because of the capacity to give legally effective consent, only patients who spoke English were included in the study. The exclusion criteria included patients who underwent TEA or ORIF for any pathology apart from acute fracture, patients with concomitant vascular injury, patients with pathologic fractures, and patients with greater than Gustilo grade I open injuries. Clinical follow-up was performed at 2 and 6 weeks postoperatively and then at standard intervals determined by each institution. Patients undergoing ORIF had constructs and approaches dictated by surgeon discretion, which included both orthogonal and parallel plating with locking plates. The TEA implants used were the semiconstrained Coonrad-Morrey TEA

prosthesis (Zimmer, Warsaw, IN, USA) and the Discovery prosthesis (Biomet, Warsaw, IN, USA). Preoperative antibiotics were given to all patients included in the study. Postoperative therapy protocols were determined by each institution. Combined, 4 primary surgeons were involved in the patients' surgical care.

Variables

The primary outcome for our study was health outcome from each treatment as measured through QALYs. QALYs are determined through a combination of utility assigned to a certain health state multiplied by the number of years living in that state. Scores from the European Quality of Life, 5 Domains (EQ-5D) questionnaire were used to calculate utility and cost data from 2016 for ORIF and TEA and were used in the CEA. Cost data accounted for all aspects of the patients' care from the payer perspective, including implant, professional, surgical, hospital, therapy, and medication fees. Secondary outcomes were complications (malunion or nonunion, refracture, hardware prominence, significant stiffness, loss of mechanical fixation, infection, wound breakdown, ulnar neuropathy, and post-traumatic arthritis); reoperations; ROM; Mayo Elbow Performance Score (MEPS); and Disabilities of the Arm, Shoulder and Hand (DASH) score. These secondary outcomes were used for generalizability of our data in comparison with the literature.

Data sources and measurement

Data for complications, postoperative ROM, and functional scores were collected from the most recent in-person clinic visit and occupational therapy notes through electronic medical records. Final follow-up was performed via telephone questionnaire to gather the most recent patient-reported outcome scores including DASH and EQ-5D scores, as well as portions of the MEPS. The DASH score is a validated disability metric for the upper extremity. The MEPS is a validated metric for elbow disability. EQ-5D is a validated quality-of-life scoring system and was used to determine the utility for the patient in his or her given health state. EQ-5D is one of the most commonly used instruments for CEA.[24]

Bias

To limit bias, phone interviews were conducted by researchers not involved in surgical or clinical care of patients.

Study size

The study size was dictated by the number of patients who fit the inclusion criteria for this specific injury and were not lost to follow-up. Fifty-four patients fit all of the inclusion criteria. Of these patients, 23 were able to be contacted for quality-of-life assessment at least 2 years after surgery.

Study and statistical methods

All patients who fit the inclusion criteria at the 2 participating institutions were contacted via an invitation letter and subsequently by telephone to provide verbal consent if interested in participation. Subjects were administered a survey with 3 scoring instruments (MEPS, DASH, and EQ-5D) to assess joint-specific function, limb-specific function, and quality of life.

A Markov decision model and analysis were constructed according to the guidelines set forth by the Panel on Cost-Effectiveness in Health and Medicine of the US Public Health Service in 1996 (Fig. 1).[31] DASH and EQ-5D scores were converted to utility scores, which were then used in conjunction with procedural costs to derive a cost-effectiveness ratio. Decision-model analysis was then performed (TreeAge Pro 2008; TreeAge Software, Williamstown, MA, USA).

Data for the Markov model were derived from the highest-level published research on this specific elderly demographic (Table I). The probabilities for a patient to transition into a given health state were weighted based on the number of subjects included in the studies. These weighted percentages were then added to the model at each branch point to determine the relative likelihood of the patient progressing into one state versus another. After the model was completed, the QALYs were combined with the data to determine the relative utility of each disease state. The cost of any subsequent surgical procedure was then factored into the model based on 2016 US dollars to determine the relative cost. Demographic and outcome data were compared with the literature to show applicability and generalizability of the data (Table II).

Cost-effectiveness analysis

The principal outcome calculated was the incremental cost-effectiveness ratio (ICER), which is the ratio of the difference in costs to the difference in QALYs between the 2 treatment strategies. ICERs of less than $100,000/QALY gained were considered cost-effective. In this CEA, the preferred treatment strategy was the most effective strategy with an ICER lower than "willingness to pay." A strategy is termed "dominant" when it is both less costly and more effective.

One- and two-way sensitivity analyses were performed on all variables in the model. Variables deemed sensitive are those that, when varied across a reasonable range, change the preferred strategy. If the preferred strategy does not change, then the variable is termed "robust." Monte Carlo analysis was used to evaluate (1) the impact of uncertainty in the model assumptions using probabilistic sensitivity analysis and (2) the impact of individual patient variability using microsimulation (Fig. 2).

Results

Participants

Our initial perioperative data query yielded 129 patients who underwent either TEA or ORIF of acute, intra-articular distal humeral fractures within the specified time range. After chart review applying the exclusion and inclusion criteria regarding the minimum age at the time of surgery, specific AO type C2 or C3 fracture pattern, pre-existing elbow osteoarthritis, and at least 3 months' postoperative clinical follow-up, 54 patients remained. Of these, 23 patients, 11 who underwent TEA and 12 who underwent ORIF, were able to be contacted for consent and a telephone interview with questionnaire completion. The reasons for being unable to contact patients for telephone follow-up include change in phone number, having moved (landline telephone number in chart), and
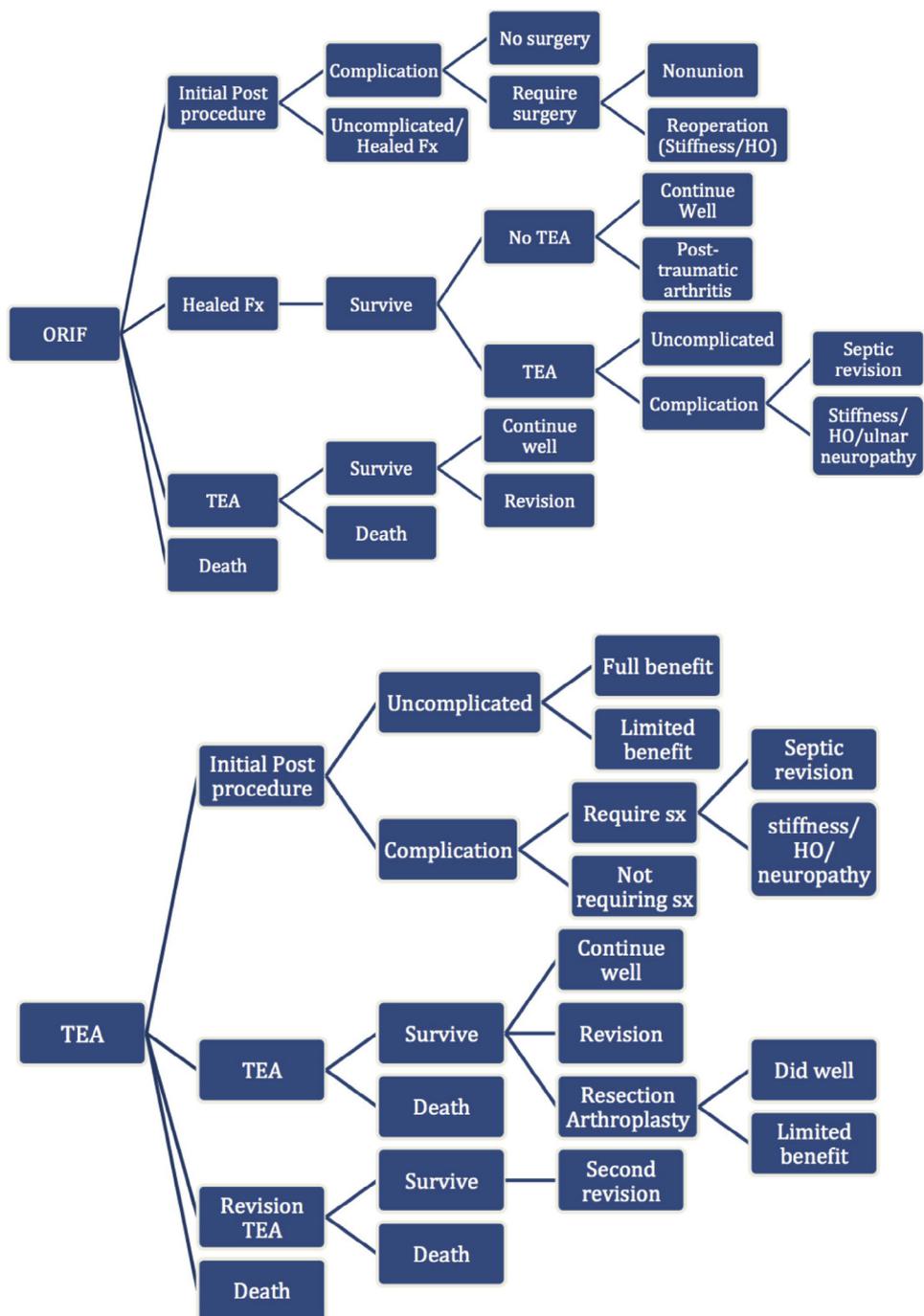
Figure 1 Markov decision model of possible transitioning health states for patients undergoing open reduction–internal fixation (*ORIF*) or total elbow arthroplasty (*TEA*). Probabilities for transition were obtained from the literature (Table I). *Fx*, fracture; *HO*, heterotopic ossification; *sx*, surgery.

unrelated dementia or death as reported by family members. The mechanism of action for all patients included in this study was a ground-level fall onto an outstretched hand.

Descriptive data

The average age of the TEA and ORIF patients was 72.8 years (range, 64-85 years) and 67.2 years (range, 60-82 years), re-

spectively ($P = .061$) (Table II). Women comprised 91% and 83% of the TEA and ORIF populations, respectively ($P = .61$). The average clinic follow-up period was 39.9 months (range, 10-98 months) for TEA patients compared with 15.4 months (range, 3-42 months) for ORIF patients ($P = .016$). The average time from surgery to final follow-up via telephone interview was 60.9 months (range, 26-102 months) for TEA patients and 69 months (range, 25-144 months) for ORIF patients ($P = .51$).

Table I Model parameter inputs

Transition health state	Transition probability*	Source
ORIF		
Initial post procedure		
Uncomplicated/healed fracture	0.53	McKee et al[15]
Complication	0.32-0.53	McKee et al, Githens et al[8]
No surgery	0.50-0.61	McKee et al, Githens et al
Require surgery	0.28-0.50	McKee et al, Githens et al
Nonunion	0.25	McKee et al
Reoperation (stiffness/HO/ulnar palsy)	0.75	McKee et al
Healed fracture	0.93-0.96	McKee et al, Githens et al
No TEA	1.00 (at 2 yr)	McKee et al
Continue well	0.57	McKee et al
Post-traumatic arthritis	0.29	McKee et al
TEA		
Uncomplicated	0.20-0.62	Voloshin et al,[30] Toulemonde et al[29]
Complication	0.37-0.80	Levy et al,[14] Voloshin et al, Toulemonde et al
Stiffness/HO/neuropathy	0.07	McKee et al
Revision to TEA	0.03-0.25	McKee et al, Githens et al, Frankle et al[7]
Death	0.17	Prasad and Dent[22]
Survive	0.82	Prasad and Dent
Continue well	0.78	Prasad and Dent
Limited benefit	0.21	Prasad and Dent
Revision	0.34-0.67	Frankle et al, Cil et al[6]
Death	0.06 (at 2 yr)	McKee et al
TEA		
Initial post procedure		
Uncomplicated	0.60-0.67	McKee et al, Githens et al
Full benefit	0.80	McKee et al
Limited benefit	0.20	McKee et al
Complication	0.33-0.40	McKee et al, Githens et al
Requiring surgery	0.17-0.30	
Septic revision	0.20-0.33	McKee et al, Githens et al
Stiffness/HO/neuropathy	0.14-0.67	McKee et al, Githens et al
No surgery	0.70-0.79	McKee et al, Githens et al
TEA		
Survive	0.95	McKee et al
Continue well	0.60	McKee et al
Revision	0.04-0.30	Barco et al,[3] McKee et al, Levy et al
Resection arthroplasty	0.05	Levy et al
Did well	0.60	Rhee et al[23]
Limited benefit	0.40	Rhee et al
Revision TEA	0.30	Levy et al
Second revision	0.38	Levy et al
Death	0.10 (per yr)	Barco et al

ORIF, open reduction–internal fixation; *TEA*, total elbow arthroplasty; *HO*, heterotopic ossification.

* Probability of transitioning health states for Markov model obtained from literature.

Outcome data

The reoperation rates were very similar between the 2 treatments, with revision procedures in 41.6% of patients who underwent ORIF and 45.4% of patients who underwent TEA ($P = .86$). However, the average time from primary surgery to the revision procedure was 5.4 months for ORIF patients and 36.9 months for TEA patients ($P = .03$). Two patients from the TEA group did not have DASH scores calculated because they had more than 3 items missing from the questionnaire. DASH scores were nearly identical, at 26.4 and 26.6 for ORIF and TEA, respectively ($P = .98$). However, there was a trend toward a difference in the MEPS, at 78.3 for ORIF and 91.8 for TEA ($P = .075$). EQ-5D scores were similar between the treatments. When grouped by average age of 65 years, the utility was 7.72 for ORIF versus 8.17 for TEA. At an average

Table II Demographic characteristics, outcomes, and reoperation rates from the literature compared with the current study

	Current study			McKee et al[15]		Githens et al[8]		Frankle et al[7]		Barco et al[3]
	ORIF	TEA	P value	ORIF	TEA	ORIF	TEA	ORIF	TEA	TEA
No. of patients	12	11		15	25	NA	NA	12	12	29
Mean age, yr	67.2 ± 7.7	72.8 ± 6.4	.07	77	78	75.1	73.7	74	72	74.8 ± 12
M:F (ITT)	2:11	1:10		4:16	1:19	NA	NA	0:12	0:12	4:25
Female, %	83.3	90.9	.61	80	95	NA	NA	100	100	86
Motion arc, °	100.2 ± 39	114.5 ± 31	.35	95	107	100	101	100	113	93
MEPS	78.3 ± 18	91.8 ± 15	.074	73	86	87.5	90	81	95	91.7 ± 9.9
DASH score	26.4 ± 26	26.6 ± 18	.98	43	32	35.2	38.5	NA	NA	NA
Follow-up, mo	69 ± 34	60.9 ± 21	.51	24	24	43	45.9	57	45	120
Reoperations	0.42	0.45	.86	0.27	0.12	9.4	5.7	0.33	0	7.8
EQ-5D score	0.788 ± 0.13	0.779 ± 0.13	.87	NA	NA	NA	NA	NA	NA	NA

ORIF, open reduction–internal fixation; *TEA*, total elbow arthroplasty; *NA*, not available; *M*, male; *F*, female; *ITT*, intention to treat analysis; *MEPS*, Mayo Elbow Performance Score; *DASH*, Disabilities of the Arm, Shoulder and Hand; *EQ-5D*, European Quality of Life, 5 Domains.
Demographic and outcome data are compared with the high-level literature to show the applicability and generalizability of the data. P values refer to the differences between ORIF and TEA in our study.
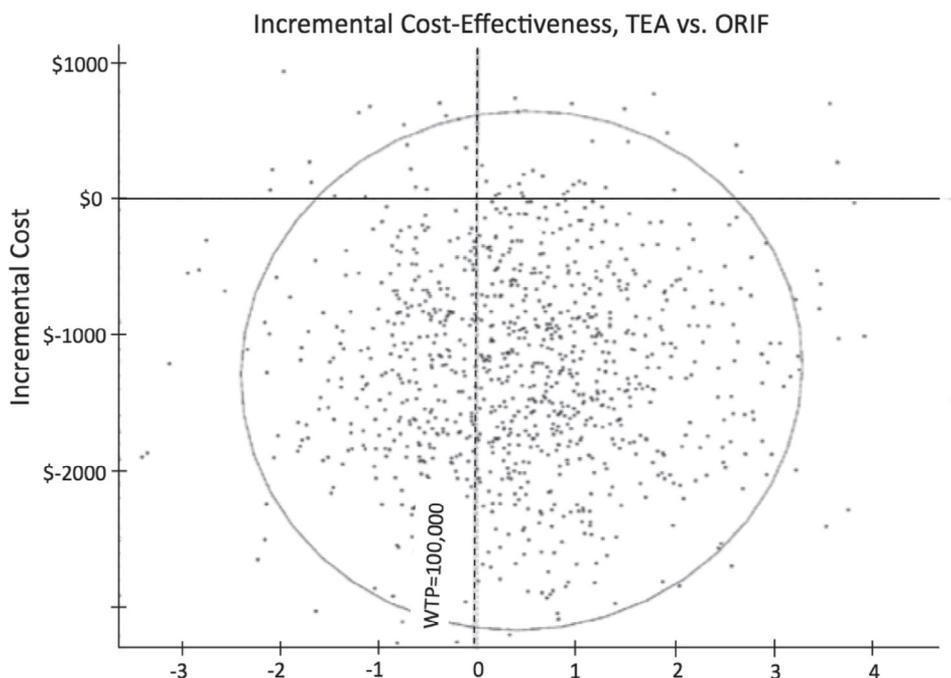

Figure 2 Incremental cost-effectiveness of total elbow arthroplasty (*TEA*) compared with open reduction–internal fixation (*ORIF*) in a Monte Carlo simulation. Each *dot* represents 1 trial simulation, and the dispersion illustrates the effect of parameter uncertainty. There is an increase in cost-effectiveness of TEA over ORIF at age 75 years. *WTP*, willingness to pay.

age of 75 years, the utility was 6.51 for ORIF compared with 6.92 for TEA (Table III). The average patient-rated current overall health score for ORIF was 79.5 compared with 70 for patients who underwent TEA (*P* = .28).

The main objective in measuring objective, non–patient-scored data was to compare with the literature. Table II shows the comparison of this study's data in correlation with several high-level studies' data. Compared with other studies, our patient population was slightly younger at the time of surgery, specifically for ORIF (mean, 67.2 years). As the average time

to final telephone follow-up was greater than 5 years postoperatively, there was a longer period for the more elderly patients to be lost to follow-up for multiple reasons including unrelated death. This study had a comparable MEPS (78.3) to that in the study by McKee et al[15] (73). In the randomized controlled trial of McKee et al, patients' final DASH scores were obtained at 2 years and showed continued improvement from 6 months to 2 years, which may explain the improved DASH scores in our cohort obtained at an average of over 5 years (Table II). Comparing our data with those of

Table III   Cost-effectiveness of TEA versus ORIF by age

Mean age	Strategy	Cost, $	Effectiveness	Incr C/E ($/QALY)	NMB ($)	ICER
65 yr	TEA	19,407	8.17		797,486.03	
	ORIF	20,669	7.72	−2813	751,367.42	Dominated
75 yr	TEA	19,205	6.92		673,044.19	
	ORIF	20,270	6.51	−2583	630,752.07	Dominated

TEA, total elbow arthroplasty; *ORIF*, open reduction–internal fixation; *Incr C/E*, incremental cost-effectiveness; *QALY*, quality adjusted life year; *NMB*, net monetary benefit; *ICER*, incremental cost-effectiveness ratio.
Cost-effectiveness sensitivity analysis data from ORIF and TEA broken up by average ages of 65 and 75 years are shown. Cost refers to the average total cost of a particular strategy to the payer, including reoperations.

studies by McKee et al,[15] Githens et al,[8] Frankle et al,[7] and Barco and Antuña,[2] mean arc of motion and MEPS were similar.

The patients in this study did show higher rates of reoperation (42% in ORIF patients and 45% in TEA patients). However, in comparison with the study by McKee et al,[15] if the intraoperative conversions from ORIF to TEA were considered reoperations, the ORIF group would have a 45% reoperation rate. Moreover, the average time to reoperation for TEA in our study was over 3 years, compared with the 2-year follow-up by McKee et al. Of the 5 revision surgical procedures for TEA patients, only 1 occurred earlier than 39 months postoperatively and it was performed at 2 weeks because of an infection.

Sensitivity and CEA

Although the minimum age at the time of surgery of patients included in our study was 60 years, most of the patients in this study and in the literature were older. As such, sensitivity analyses were performed at ages 65 and 75 years to assess the effect of age on cost-effectiveness. The age of 75 years was used because it more closely approximated the ages incorporated in the only level I study[15] and the longest-term follow-up study.[3] Although the results were similar, TEA was slightly more favored at age 65 years than at age 75 years in terms of cost-effectiveness.

For patients aged 65 years, the total cost of TEA was $19,407 and that of ORIF was $20,669 (increase of $1262). When the analysis was performed at an average age of 75 years, the total cost of TEA was $19,205 and that of ORIF was $20,270 (increase of $1064) (Table III). The upfront cost of the primary procedure for TEA is greater than that for ORIF, but this was balanced by the rate and cost of reoperation within the analysis. On average, there were higher rates of reoperation for ORIF, specifically within the first year postoperatively. Moreover, although the average ORIF procedure was less expensive than the average TEA procedure, the costs of ORIF were skewed right, correlating to a percentage of ORIF procedures that were significantly more expensive than the mean. In the microsimulation model, the cost data used were drawn from the distribution, not merely from the mean; therefore,

when the average total costs were calculated, TEA ($19,407) and ORIF ($20,669) became nearly equal (Table III).

In comparison with ORIF, TEA has increased utility and QALYs. Similarly to the cost data, the increased rate of early reoperation resulted in limited utility and decreased health states within the Markov model. This allowed TEA to have a relatively increased utility, specifically in the initial years after the procedure. Although TEA also had a high rate of reoperation in our cohort, the mean time to reoperation was 36.8 months and was associated with less of a decrease in utility. Overall, the ICER of TEA ($2375.76/QALY) was favored more than ORIF ($2677.26/QALY).

Discussion

The distal humerus and the proximal radius and ulna form the complex triarthrodal joint of the elbow. Fractures of the distal humerus, especially fractures with intra-articular extension, create a challenge for fixation. Moreover, in the elderly population, especially in geriatric women, osteoporosis is an extremely common finding. The fracture patterns often become exceedingly complex, and fixation with traditional plates and screws can at times be less than optimal. TEA can often serve as an alternative treatment; however, arthroplasty is not without its shortcomings. The risk of component loosening, risk of component failure, and limitation regarding weight-bearing status are serious concerns.

TEA is used for multiple indications, including rheumatoid arthritis, post-traumatic arthritis, primary osteoarthritis, and acute fractures. The midterm and long-term results from its use in the rheumatoid arthritis population are very encouraging, but it is thought that this may be because of the low demand in this population.[5,12] Although the functional benefits from TEA and ORIF may be similar, quality of life and subsequent cost-effectiveness must be considered when evaluating the best choice for the patient.

Key results

The upfront cost (implant and professional fees) of TEA is greater than that of ORIF; however, the reoperation rate after ORIF is higher, specifically within the first year. This

increase in reoperation rate not only increases the total cost of that strategy but also results in decreased utility and health states of limited benefit. Therefore, although the total cost of each procedure is nearly the same, there is an average overall improvement in the utility of TEA with respect to ORIF. In the model, the largest driver of the difference in utility is the number of persons living in a limited-benefit state after ORIF, frequently owing to the number of reoperations, as well as the suboptimal results after revision surgery for nonunion, stiffness, and other postoperative complications.

Within the Monte Carlo incremental cost-effectiveness graph (Fig. 2), TEA was favored for a majority of the simulations. However, if chosen for all simulations, a large proportion would not have the optimal strategy. For a significant number of simulations, TEA is the dominant strategy, meaning it is both more effective and less costly (as shown in the simulation points in the bottom right quadrant compared with the top left quadrant in Fig. 2). When neither strategy was dominant but ORIF was favored (bottom left quadrant), TEA was still a less expensive strategy in most cases but had decreased relative utility compared with ORIF. For this reason, despite the perceived increase in the cost of TEA, its cost should not weigh against it during the decision-making process. Although the costs were ultimately similar between the 2 strategies, there was significant variability in utility within each strategy. For these reasons, factors affecting utility had a significant effect on the CEA.

For TEA, one of the most significant factors affecting utility is the lifelong surgeon-imposed activity restriction, commonly 1-2.5 kg. For patients with active lifestyles, this restriction can have a significant effect on their postoperative utility, placing them in a limited-benefit state. In these instances, ORIF may be a more cost-effective strategy. Similarly, ORIF has an increased revision rate, specifically within the first year. For patients whose primary goal is to avoid another operation, they would have a significant decrease in utility if they were to undergo ORIF. TEA may be more cost-effective for these patients. The sensitivity analysis showed there was not a significant difference in cost-effectiveness based on age (65 years vs 75 years). For this reason, there is not a specific age threshold at which one strategy would be absolutely favored over the other. Because patients' preferences and goals appear to affect their utility more than age alone, clinician judgment is crucial in the decision-making process.

Limitations

Despite the attempts this study makes to help understand the cost-effectiveness of TEA and ORIF, it is not without its limitations. The retrospective design of the study and its basis on chart review are 2 weaknesses. Electronic medical record chart review allows for reporting bias and possible underestimation of complications. Still, the primary outcome of our study was based on patient-reported outcomes. Despite using data from 2 institutions over a 15-year period, the specific demo-

graphic of patients, injury, and follow-up of this study resulted in a relatively small cohort. As this study deals with an elderly population with an extended period of follow-up, there was difficulty achieving a high rate of patient follow-up because of unrelated patient deaths and, in certain cases, memory deficits. This seemingly higher rate of death in patients sustaining low-energy distal humeral fractures was appreciated in other studies as well.[3] Within the model, utilities were supplied from our cohort population. As such, the simulations were run with a relatively small population of our study, making the distributions wider as a result. It is possible that a larger cohort could affect the mean and range of the utility. With a larger cohort, the study could potentially be powered to delineate significant differences in the cost-effectiveness between the 2 treatment strategies. The Markov model was created with the highest level of evidence available; still, there was only 1 study with level I evidence available and level II, III, and IV data were included as they represented the best evidence available.

Multiple surgeons with varying experience at the 2 participating institutions took part in the patients' surgical care. Postoperative therapy protocols were determined by each institution. This allows for variability in patients' surgery and therapy experiences with possible effects on outcome. Statistical analysis of varying ORIF techniques and different TEA implants was not performed because of the small numbers in the study.

Interpretation

Both TEA and ORIF result in comparable functional scores after surgery.[8] However, ORIF results in more postoperative revision surgical procedures, especially within the immediate postoperative period. It appears that this revision operation rate decreases the patients' utilities owing to living in a limited-benefit state. Moreover, this increased rate of revision within the immediate postoperative period increases the cost of ORIF, balancing it with the increased upfront cost of a primary TEA. Owing to the average decreased costs and increased utility with TEA, it is a slightly more cost-effective procedure within this model.

Generalizability

Demographic and functional outcome data were obtained from our cohort for comparison with the literature (Table II). Our results show that our study population was similar to populations in previously published literature, making our CEA relevant to this demographic as a whole.

The vast majority of our patients were elderly women. This is similar to the patient populations seen in similar studies by McKee et al,[15] Githens et al,[8] and Frankle et al,[7] with women accounting for 80%-95% of the populations, likely because of an increased risk of osteoporosis in this demographic. Although there may be indications for both ORIF

and TEA in younger patients, this elderly demographic was chosen as it is less controversial and more applicable to both strategies currently used. The utilities for our Markov model were derived from 2 tertiary referral centers in the eastern United States.

Future directions

Future studies should focus on determining the specific utility assigned to each complication associated with TEA and ORIF as well as predicting the risk of each complication. Ultimately, these data could answer questions of which complications associated with ORIF or TEA would affect the patients' utilities the least. Moreover, this study emphasizes the importance of patient preference as this could affect relative postoperative utility. Therefore, there would be significant benefit to understanding this population's preferences, thereby making it possible to develop a decision model to determine which operative strategy best capitalizes on these preferences.

Conclusion

These findings suggest TEA is a slightly more cost-effective procedure than ORIF for most elderly patients who sustain acute, intra-articular distal humeral fractures. Still, owing to the relative similarity in cost and wide variability in utility between the 2 strategies, the unique limitations, complications, and revision rates for each strategy must be carefully weighed for each patient when making a decision. For this reason, future studies should focus on understanding the relative utilities assigned to each complication and determining patient preferences within this specific demographic to achieve optimal results. This study suggests that there is not an age threshold at which one strategy would be significantly less cost-effective based on age alone. Moreover, the findings suggest that cost should not be a primary factor in determining treatment strategy. This is currently the only study to have performed a CEA of these 2 treatment strategies for elderly patients with acute, intra-articular distal humeral fractures.

Disclaimer

Matthew L. Ramsey or his immediate family receives financial payments or other benefits from Zimmer Biomet, Integra LifeSciences, and Trice Medical.

Grant E. Garrigues or his immediate family receives financial payments or other benefits from DJO Global.

The other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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