



Total elbow arthroplasty for acute distal humeral fractures with humeral condyle resection or retention: a long-term follow-up study

Andrea Celli, MD*, Chiara Paroni, MD, Pierluigi Bonucci, MD, Luigi Celli, MD

Department of Orthopaedic and Trauma Surgery, Shoulder and Elbow Unit, Hesperia Hospital, Modena, Italy

ARTICLE INFO

Keywords:

Elbow
Articular fracture
Total elbow replacement
Long-term follow-up
Medial and lateral condylar bone fragments
Complications

Level of evidence: Level III; Retrospective Cohort Comparison; Treatment Study

Background: Open reduction and internal fixation is the gold standard for the operative treatment of intra-articular distal humeral fractures. However, in elderly patients the approach involves a high rate of complications. We reviewed the long-term outcomes of 13 primary total elbow arthroplasties (TEAs) performed to treat acute fractures in non-rheumatoid patients who at the time of trauma were aged less than 70 years. The aim of the study was to establish whether condyle retention enhances hinge stability and influences outcomes in these patients, who are younger than those who typically undergo TEA.

Methods: In 13 consecutive patients with acute distal humeral fractures aged 61–67 years, a linked semi-constrained Coonrad-Morrey prosthesis was implanted. The medial and lateral condylar bone fragments were resected (7 patients) or stabilized to the diaphysis using k-wires or plates (6 patients).

Results: At a mean follow-up of 12 years, the mean Mayo Elbow Performance Score was 88 and patient satisfaction was 85%. Nine patients (70%) did not require surgical revision. All revisions involved the group managed by condyle resection.

Discussion: TEA can be considered in elderly subjects with acute distal humeral fracture. In our patients, resection of the medial and lateral condyle fragments did not influence outcomes, although clinical observation suggested that it involves greater mechanical stress on the hinge, heightening the long-term risk of bushing wear. Condyle fixation with plates or k-wires seems to afford longer implant survival and is recommended in younger patients with higher functional demands.

© 2021 The Author(s). Published by Elsevier Inc. on behalf of American Shoulder and Elbow Surgeons.

This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Surgical treatment of intra-articular fractures of the distal humerus involves potentially disabling consequences. Approximately 7% of all adult fractures affect the elbow; of these, 30% involve the distal humerus² and about 10% are displaced and comminuted.³⁹

According to epidemiologic studies, the incidence of distal humeral fractures in women older than 60 years will triple by 2030 due to population aging.³⁰ In Edinburgh (Scotland), the annual incidence of distal humeral fractures in 1988–1997 was 5.7 per 100,000 population;³⁵ although the rate may appear low, cases are rapidly increasing in Scotland, particularly among women aged more than 60 years. From 1970 to 1998 the annual total number of these fractures has increased more than 5-fold from 42 to 224, with a dramatic rise in age-adjusted incidence over the same period.²⁹

These lesions are commonly treated with rigid fixation; however, a review of 13 papers reporting the data of 846 patients with intra-articular fractures managed with open reduction and internal

fixation (ORIF) has found unsatisfactory outcomes in 20% of patients.¹³

Although ORIF with early mobilization is the treatment of choice for distal humeral fractures, elderly patients with marked intra-articular comminution and osteopenia often experience poor outcomes because stable fixation is difficult or impossible to achieve.^{9,14–16,20} Notably, sequelae such as joint stiffness, loss of reduction and early posttraumatic osteoarthritis are not uncommon in these fractures and are particularly common in older patients.^{3,10,12,19,24,34,38}

According to recent studies, ORIF of comminuted distal humeral fractures in patients aged more than 60 years does not consistently yield acceptable outcomes.^{6,33} In a review of their cases managed with internal fixation, Pajarinem et al²⁸ found that excellent and good postoperative results were much more common in patients aged less than 40 years than in those over 50 years of age, who also developed elbow stiffness. The authors attributed the worse outcomes of the older patients to the longer postoperative immobilization due to fracture comminution and lower bone quality. Similarly, Caja et al⁶ noted that patients over 40 years of age had a lower final range of motion (ROM) than those aged less than 40 years. Morrey et al stressed that total elbow arthroplasty (TEA) is a

This study was approved for research involving human participants by Hesperia Institutional Scientific Board.

* Corresponding author: Andrea Celli, MD, Via Emilia Est 380/1, Modena, Italy 41124.

E-mail address: celli.andrea.md@gmail.com (A. Celli).

<https://doi.org/10.1016/j.jseint.2021.03.006>

2666-6383/© 2021 The Author(s). Published by Elsevier Inc. on behalf of American Shoulder and Elbow Surgeons. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

reliable option in elderly patients when comminution and poor bone quality prevent adequate fixation.^{9,27} According to Robinson et al,³⁵ the difficulty of obtaining stable fixation of type C distal humeral fractures can entail a higher risk of malunion/nonunion and TEA should be the primary treatment option in elderly patients. Indeed, in patients aged more than 60 years, better outcomes have been reported for complex elbow fractures managed directly by TEA than for those converted to TEA after the failure of primary ORIF.^{11,27}

We describe the long-term outcomes of acute comminuted and/or unfixable fractures of the distal humerus managed with TEA by medial and lateral condyle fragment resection or fixation in non-rheumatoid patients who at the time of injury were aged less than 70 years. We report the complications and revision data related to the surgical approach and advance the hypothesis that condyle retention enhanced hinge stability, thus improving outcomes in these patients, who were younger than those typically managed with TEA.

Materials and methods

We reviewed our 1993–2005 records for patients with acute distal humeral fractures aged less than 70 years who were managed by TEA and for whom long-term follow-up data were available.

The study was performed in accordance with the Ethical Standards of the 1964 Declaration of Helsinki as updated in 2004.

Of 39 patients with acute fractures treated with TEA, 13 consecutive patients with at least 12-year follow-up (range, 12–14 years) and no evidence of preexisting elbow joint damage due to rheumatoid arthritis or other inflammatory joint diseases met the inclusion criteria. All had comminuted distal humeral fractures that prevented stable fixation and early mobilization. There were 10 type C3 and 3 type C2 fractures associated with osteopenia according to the Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification of distal humeral fractures.¹² Their preoperative medical history and the latest follow-up data were reviewed.

All patients received a linked semi-constrained implant, the Coonrad-Morrey total elbow replacement (Zimmer-Biomet, Warsaw, IN, USA).

Surgical technique

All procedures were performed at the same institution by the senior author (LC) assisted by the same team. Patients lay in the supine position. A posterior midline skin incision was performed just medial or lateral to the tip of the olecranon. The ulnar nerve was identified and mobilized distally to the first motor branch of the flexor carpi ulnaris; at the end of the procedure it was transposed to an anterior subcutaneous pocket carefully avoiding tension.

The Bryan-Morrey approach⁵ was performed in 9 consecutive elbows. The triceps tendon was reflected laterally from the olecranon in continuity with the ulnar periosteum and the fascia of the forearm including the anconeus. At the end of the procedure the triceps was reattached to the olecranon through drill holes with heavy non-absorbable suture as described by Morrey.⁵

Four patients were managed by the triceps-on (triceps preserving) approach,^{1,36} where the triceps insertion is left intact. The joint was exposed through medial and lateral fascia insertions by releasing the common flexor-pronator muscles from the medial side and the extensor supinator muscles from the lateral side, preserving the bone insertion on the medial and lateral condylar fragments. Once the distal humerus was exposed, the medial and lateral condyle fragments were either resected or fixed. Patients #1–7, who were managed before 1999, underwent release and

resection of the medial and lateral fragments and the medial and lateral muscle-tendon units were sutured directly to the triceps muscle tendon; in particular, the triceps tendon was reflected laterally in 6 elbows and preserved in the seventh (Fig. 1). In the 6 patients treated after 1999, the medial and lateral bone condyle fragments were reduced and stabilized to the diaphysis using k-wires with heavy non-absorbable suture (patients #8–10; Fig. 2) or 2 plates (patients #11–13; Fig. 3). The medial and lateral muscle-tendon units were left attached to the condyles. The triceps preserving approach and the Bryan-Morrey approach⁵ were performed in 3 elbows each.

The linked semi-constrained Coonrad-Morrey prosthesis was implanted in all patients. Its design provides stability also in case of condyle fragment excision.²⁶

No intraoperative complications were recorded.

At the end of the procedure, the limb was placed in a plaster splint with the elbow extended. The edema was controlled with 3 drains, ice, and elevation of the arm for 24–48 hours. The splint was then removed and gentle motion was begun. Patients managed with the triceps preserving approach were allowed active flexion and extension after splint removal, whereas those whose triceps insertion was released and reattached were allowed active flexion with gravity-assisted extension after 5 weeks.

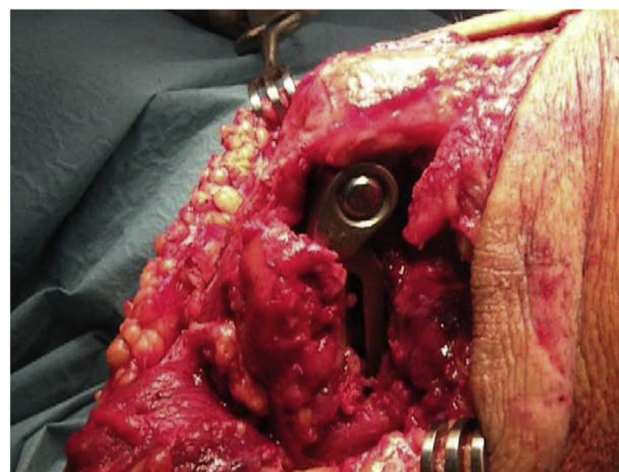


Figure 1 Total elbow arthroplasty with resection of both condyle fragments.

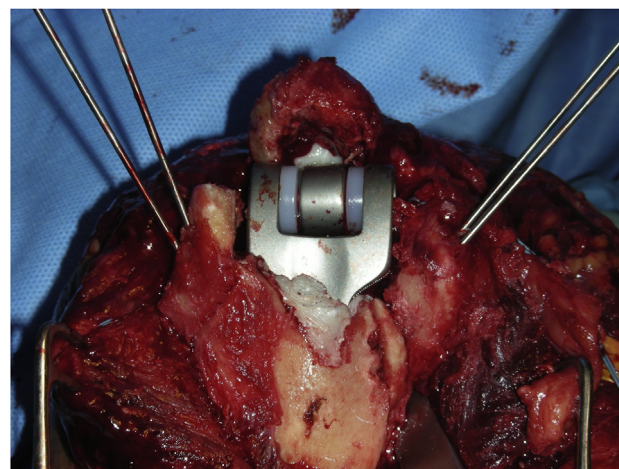


Figure 2 Total elbow arthroplasty with condyle fragment reduction and stabilization to the diaphysis using k-wires and sutures.

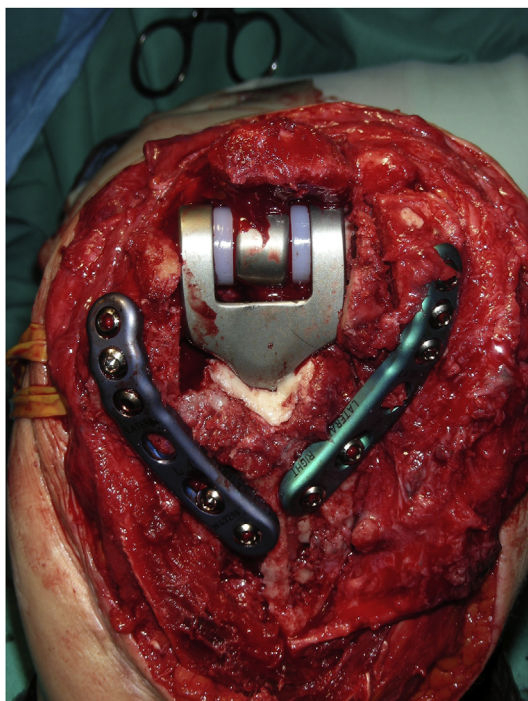


Figure 3 Total elbow arthroplasty with condyle fragment reduction and stabilization to the diaphysis using 2 plates.

Patient demographics

Thirteen consecutive patients, 11 women and 2 men whose mean age was 64 (range, 61-67) years, met our inclusion criteria. The right arm was involved in 9 patients and the left in 4. All patients were retired; none had rheumatoid arthritis, other metabolic or bone disorders, or a history of elbow injury or fracture. The lesion was caused by a fall in 12 patients and by a car accident in 1 (case #5) (Table I).

There were 10 AO type C3 fractures and 3 AO type C2 fractures with osteopenia.¹² The mean interval between the injury and surgical management was 4 (range, 2-8) days. Mean follow-up duration was 12 (range, 12-14) years.

Two patients had other fractures: a femoral fracture (case #5), which required surgical treatment, and a proximal fracture of the contralateral humerus (case #3), which was treated conservatively.

Table I
Patient demographics and operative techniques employed.

Case #	Gender	Age at the time of injury	Side (R, L)	Handedness (R, L)	Articular fracture AO classification	Other fractures	Time to treatment (d)	Triceps approach	Medial and lateral columns
1	F	66	R	R	C3	No	5	Bryan-Morrey	Resection
2	F	65	R	L	C3	No	4	Bryan-Morrey	Resection
3	F	63	R	R	C2	Yes (shoulder)	7	Bryan-Morrey	Resection
4	F	62	L	R	C2	No	3	Bryan-Morrey	Resection
5	M	64	L	R	C3	Yes (hip)	8	Bryan-Morrey	Resection
6	F	65	R	R	C3	No	4	Bryan-Morrey	Resection
7	F	63	R	L	C3	No	2	Preserving	Resection
8	F	64	R	R	C3	No	4	Bryan-Morrey	Repair with k-wires
9	F	61	L	R	C3	No	3	Bryan-Morrey	Repair with k-wires
10	F	65	R	R	C3	No	2	Preserving	Repair with k-wires
11	F	67	L	L	C2	No	3	Bryan-Morrey	Repair with k-wires
12	F	65	R	R	C3	No	6	Preserving	Repair with k-wires
13	M	66	R	R	C3	No	4	Preserving	Repair with k-wires

R, right; L, left; AO, Arbeitsgemeinschaft für Osteosynthesefragen.

Clinical assessments

The latest postoperative clinical evaluations were assessed by the Mayo Elbow Performance Score (MEPS),¹⁸ which rates pain, ROM, stability, and ability to perform basic everyday life activities.

The clinical evaluation included elbow stability under varus and valgus stress and measurement of the elbow flexion-extension and supination-pronation arcs.

Radiographic assessments

Anterior-posterior and lateral X-rays were examined for radiolucent lines around the implant¹⁹ and for periarticular heterotopic ossification according to the Hastings and Graham classification.¹³

Radiologic loosening was graded from I (mild radiolucency) to IV (gross loosening) according to the criteria of Kamineni and Morrey.¹⁹

Bushing wear was assessed on the latest anterior-posterior X-rays and graded as none, partial, or complete.³⁷

Triceps assessment

The extensor mechanism was assessed as the ability to hold the elbow in extension against gravity with the forearm above the head and by the Medical Research Council scale as modified by Paternostro-Sluga et al.^{25,31}

Statistical analysis

Data are reported as mean (± standard deviation [SD]). The normal distribution of data was tested with the Shapiro-Wilk test and homoscedasticity with the F test for homogeneity of variances. The Wilcoxon signed-rank test was used to compare variables between the condyle resection and retention groups. A P-value < .05 (2-tailed) was considered significant. Analyses were performed using the STATA software package (2009, release 11; Stata Corp, College Station, TX, USA).

Results

The mean follow-up was 153 (range, 144-170) months. Mean patient age at the time of the latest follow-up was 76 (range, 74-79) years.

Elbow function

The mean flexion-extension ROM was 111° (range, 100°-120°), mean extension was 15° (range, 10°-30°), and mean flexion was 126° (range, 110°-140°). The mean arc of motion was 112° (SD 7.5) in the condyle resection group and 110° (SD 6.3) in the condyle retention group ($P = .23$). The mean supination-pronation ROM was 173° (range, 140°-180°). The mean arc of motion was 168° (SD 19.5) in the resection group and 180° (SD 0) in the retention group ($P = .08$). The mean MEPS was 88/100 points (range, 70-100), indicating that outcomes were excellent in 7 patients (54%), good in 5 (38%), and fair in 1 (Table II). The mean MEPS was 85/100 points (SD 8.8) in the resection group and 90/100 points (SD 10.6) in the retention group ($P = .18$).

Altogether, 85% of patients were satisfied with their outcome (Table III).

Radiographic outcomes

The X-rays demonstrated radiolucent lines in 4 elbows. One elbow (case #8) had type 1 radiolucent lines on the ulnar side (1-mm thick lines involving < 50% of the interface) that were detected on the immediate postoperative radiographs and did not change thereafter. Three elbows (cases #1, 3, and 4) had type 2

radiolucent lines on the ulnar and humeral sides (< 1-mm thick lines involving > 50% of the interface), most of which were detected at the latest follow-up, since on the early X-rays they were slight or absent (type 1). However, all 4 patients were asymptomatic and the radiolucent lines did not exhibit a rapid progression. Partial wear of the bushings was detected at the latest follow-up in 5 patients (Table III).

Complications

At the latest follow-up all elbows were stable without infection or wound problems. Four patients reported postoperative numbness in the fourth and fifth fingers (cases #3, 4, 7, and 8).

Complete or partial bushing wear according to Kamineni and Morrey¹⁹ required revision surgery, respectively, in 2 and 1 elbow. The former 2 patients (cases #1 and 4) had clinical symptoms (increased valgus-varus instability), whereas the latter patient (case #7) had no clinical symptoms.

At the latest follow-up, heterotopic ossification around the implant was observed in 6 elbows. Based on the Hastings and Graham classification,¹³ 3 elbows (cases #8, 10, and 12) had class I subclinical lesions and 3 elbows (cases #1, 5, and 9) had class IIA lesions that involved flexion-extension limitation.

Table II
Postoperative clinical data (range of motion; MEPS; MRC scale as modified by Paternostro-Sluga et al³¹).

Case #	Age at the time of follow-up	Follow-up (mo)	Follow-up (yr)	Range of motion						Mayo Elbow Performance Score				Triceps function: extension against gravity (MRC scale as modified by Paternostro-Sluga et al ³¹)	
				Extension (degrees)	Flexion (degrees)	Arc of motion (degrees)	Pronation (degrees)	Supination (degrees)	Arc of motion (degrees)	Pain	Stability	Motion	Daily activities		Total MEPS
1	79	162	13.5	20	130	110	60	80	140	30	10	20	20	80	Yes (4)
2	77	146	12.2	10	120	110	90	90	180	45	10	20	25	100	Yes (5)
3	75	152	12.6	20	140	120	90	90	180	30	10	20	25	85	Yes (4)
4	74	148	12.3	10	130	120	90	90	180	30	10	20	20	80	Yes (4)
5	76	145	12.1	10	130	120	60	80	140	30	10	20	15	75	Yes (4)
6	77	151	12.5	30	130	100	90	90	180	45	10	15	25	95	Yes (4)
7	76	157	13.1	10	120	110	90	90	180	30	10	20	25	85	Yes (3)
8	76	148	12.3	20	130	110	90	90	180	45	10	20	20	95	Yes (5)
9	75	170	14.1	10	110	100	90	90	180	30	10	15	15	70	Yes (5)
10	77	144	12	10	130	120	90	90	180	45	10	20	25	100	Yes (4)
11	79	146	12.2	20	130	110	90	90	180	45	10	20	20	95	Yes (5)
12	77	150	12.5	10	120	110	90	90	180	45	10	20	15	90	Yes (5)
13	79	166	13.8	20	130	110	90	90	180	45	10	20	20	95	Yes (5)

MEPS, Mayo Elbow Performance Score; MRC, Medical Research Council.

Table III
Postoperative complications, revisions, and patient satisfaction.

Bushing wear at latest follow-up (none, partial, complete)	Ulnar nerve symptoms	Grade of radiographic loosening according to Kamineni and Morrey ¹⁹	Heterotopic ossification according to the Hastings and Graham classification ¹³	Complication: BW, AL, CNU, TI	Revision: BC, IR, TR (mo)	Patient satisfaction
Partial	Normal	2-humerus	IIA	BW complete	BC (98)	Yes
None	Normal					Yes
Partial	Paresthesia	2-ulna		AL	IR-humeral (80)	No
None	Paresthesia	2-ulna		BW complete	BC (110)	Yes
Partial	Normal		IIA			Yes
None	Normal					Yes
Partial	Paresthesia			TI/BW partial	TR-BC (46)	No
Partial	Paresthesia	1-ulna	I	CNU		Yes
None	Normal		IIA			Yes
None	Normal		I			Yes
None	Normal					Yes
None	Normal		I			Yes
None	Normal					Yes

BW, bushing wear; AL, aseptic loosening; CNU, condyle nonunion; TI, triceps insufficiency; BC, bushing change; IR, implant revision; TR, triceps reconstruction.

Nonunion of the lateral condyle was detected in 1 patient (case #8), who showed no clinical symptoms and did not require revision surgery.

One patient (case #7) had grade 3 triceps insufficiency according to the Medical Research Council scale,^{25,31} that is active movement was possible against gravity without resistance in less than 50% of the feasible ROM. The triceps insufficiency was managed at 46 months with an anconeus rotational flap.^{7,8} In all the other patients the functional extensor mechanism enabled elbow extension against gravity. All patients had grade 4 (elbow motion exceeds 50% of the ROM but is weaker than the contralateral side) or 5 (the 2 sides show a similar resistance over the entire ROM and against resistance).^{25,31}

Revision surgery

Revision surgery was required in 4 patients, all belonging to the resection group; in particular, 2 patients (cases #1 and 4) underwent bushing change at 98 and 110 months, respectively (Fig. 4); 1 (case #3) developed aseptic loosening of the humeral component at 80 months; and 1 (case #7) was provided an anconeus rotational flap⁸ for triceps insufficiency and bushing change due to asymptomatic partial wear at 46 months (Table III).

Discussion

Over the past 2 decades, indications for TEA have expanded to elderly trauma patients, to whom it can provide a stable, painless ROM in everyday life activities.^{9,17-19}

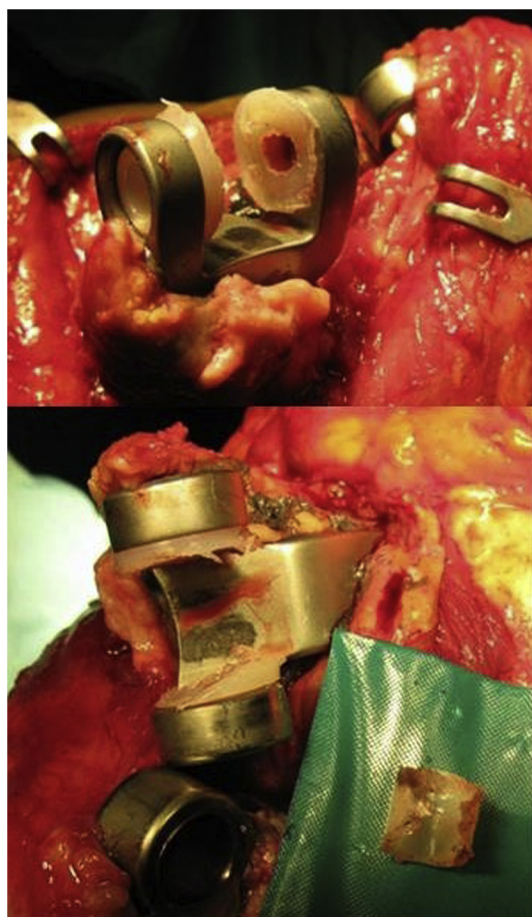


Figure 4 Revision surgery for bushing change (case #4).

The first aim of our retrospective study was to analyze the 12-year clinical results, complications, and revision rates of 13 patients who at the time of TEA were aged less than 70 years.

Cobb and Morrey⁹ have been the first to review a series of acute fractures managed with TEA. Their 20 patients (21 elbows; age range, 48-92 years) underwent TEA to treat a comminuted fracture of the articular surface, which in 10 patients was associated with degenerative changes of the articular surface secondary to rheumatoid arthritis. Twenty implants were without implant revision at the latest follow-up examination. According to the MEPS, 15 elbows had excellent results and 5 had good results.

In 1999, Frankle et al¹¹ retrospectively compared the outcomes of intra-articular distal humeral fractures managed by ORIF or TEA in women aged more than 65 years. The group managed by primary TEA achieved better outcomes according to the MEPS, with 11 excellent results, 1 good result, and no fair or poor outcomes, whereas patients wherein ORIF was converted to TEA showed significantly worse outcomes.

In a multicentric, prospective, randomized controlled trial, where 40 elderly patients with displaced intra-articular distal humeral fractures underwent ORIF or TEA, the MEPS indicated that TEA afforded more predictable functional outcomes compared to ORIF.²³

A recent systematic review of 6 studies that included 79 TEA procedures performed to treat acute distal humeral fractures²¹ has found excellent and good results in 99% of patients, despite the limited number of procedures and follow-up duration.

In our study, 85% of the 13 patients, whose mean age at 12-year follow-up was 76 years, were satisfied with their outcome and 70% of procedures did not require revision. These results are comparable to those of a study involving 41 patients and a follow-up of 7.5 years performed at the Mayo Clinic, where 83% of patients were satisfied and 75% of implants did not require revision.¹⁸ A very recent study by the Mayo Clinic,⁴ where 44 patients with a distal humeral fracture received a Coonrad-Morrey implant and were evaluated at 10 years, has reported 23 complications, 8 implant revisions or resections, and 4 reoperations, mostly due to infection. The authors concluded that TEA is an effective approach for unreconstructible distal humeral fractures in the elderly population but that it involves a high rate of complications.

A study by Prasad et al³² reported on 19 patients with a follow-up of at least 10 years and a mean MEPS of 90 (range, 50-95) points. Six patients (31.5%) had radiologic evidence of prosthesis loosening or bushing wear and 2 required implant revision (10.5%). The authors concluded that TEA is an appropriate treatment option with an acceptable 10-year survival.

The second aim of our study was to establish whether resection of the medial and lateral condyle fragments influences long-term outcomes, an issue which to the best of our knowledge has never been investigated.

In a study comparing TEA patients with and without condyle resection, McKee et al²² concluded that resection did not exert an adverse effect on functional strength, although they did not examine the influence of resection on prosthesis survival in terms of aseptic loosening or bushing wear. In our study, the 2 groups had similar clinical outcomes, but a different incidence of bushing wear ($P = .07$, $F 0.02$), since all 3 patients (23%) requiring revision for this reason belonged to the resection group. The percentage seems to be higher than the short- and middle-term incidence reported in the literature.^{4,37}

Aseptic loosening of the humeral component was seen in a patient of the resection group (case #3), who underwent revision at 80 months. At the latest radiographic follow-up, partial bushing wear was detected in 5 patients (38%), of whom 4 belonged to the resection group (57%).

Our results suggest that in the long term condyle resection can influence the mechanical stress on the hinge, increasing varus-valgus motion, the rate of bushing wear, and the incidence of aseptic loosening. Clearly, ORIF involves a risk of fixation loosening with or without fracture nonunion. In our study, only 1, clinically asymptomatic, patient (case #8) showed nonunion of the lateral condyle but did not require revision surgery.

Another consideration regarding condyle resection concerns operating time. Although we have not specifically recorded data on this aspect, ORIF involves longer procedures and a greater risk of intraoperative complications. Condyle fixation is recommended in younger and active subjects, where the risk of mechanical stress on the implant is theoretically higher than in older patients. Based on our data, ORIF seems to reduce hinge stress through a greater alignment of the ulnar and humeral components, which goes some way toward explaining the different incidence of bushing wear and aseptic loosening seen in the 2 groups. Nonunion of the column is obviously a possible complication; the clinical symptoms are often related to hardware loosening or prominence and require surgical removal without revision of the implant or of the nonunion.

The outcomes of our patients suggest that condyle fixation is not necessary but is useful, particularly in patients aged between 60 and 70 years with comminuted articular distal humeral fractures, who can expect long implant survival.

The main limitation of our study is the small patient sample.

Further work on a larger number of patients is required to gain a clearer understanding of the influence of condyle fixation on elbow replacement and its long-term complications.

Conclusion

In patients aged more than 60 years, distal humeral fractures can be treated with ORIF; however, TEA should be considered in those with poor bone quality and fracture comminution. In the latter patients, TEA affords better results than internal fixation. At a mean follow-up of 153 months, our 13 patients had a mean MEPS of 88 points, 9 did not require surgical revision, and 85% were satisfied with the results of the procedure.

We feel that TEA is a valuable approach for distal humeral fractures in selected patients and that it can achieve a high percentage of satisfactory results also in the long term. Medial and lateral condyle fragment reconstruction improves hinge stability and alignment of the ulnar and humeral components, reducing the risk of bushing wear. Further work is clearly needed to establish whether condyle reconstruction affects TEA outcomes in large groups of younger patients who have greater functional demands than the patients who are typically managed with TEA.

Disclaimers:

Funding: No funding was disclosed by the author(s).

Conflicts of interest: The authors, their immediate family, and any research foundation 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.

References

- Alonso-Llames M. Bilateral tricipital approach to the elbow. Its application in the osteosynthesis of the supracondylar fractures of the humerus in children. *Acta Orthop Scand* 1972;43:479-90.
- Anglen J. Distal humerus fractures. *J Am Acad Orthop Surg* 2005;13:291-7. <https://doi.org/10.5435/00124635-200509000-00001>.
- Aslam N, Willett K. Functional outcome following internal fixation of intra-articular fractures of the distal humerus (AO type C). *Acta Orthop Belg* 2004;70:118-22. No doi.
- Barco R, Streubel PN, Morrey BF, Sanchez-Sotelo J. Total elbow arthroplasty for distal humeral fractures: a ten-year-minimum follow-up study. *J Bone Joint Surg Am* 2017;99:1524-31. <https://doi.org/10.2106/JBJS.16.01222>.
- Bryan RS, Morrey BF. Extensive posterior exposure of the elbow: A triceps-sparing approach. *Clinic Orthop Relat Res* 1982;188-92.
- Caja VL, Moroni A, Vendemia V, Sabato G, Zinghi G. Surgical treatment of bicondylar fractures of the distal humerus. *Injury* 1994;25:433-8.
- Celli A. Triceps tendon rupture: the knowledge acquired from the anatomy to the surgical repair. *Musculoskelet Surg* 2015;99:S57-66. <https://doi.org/10.1007/s12306-015-0359-y>.
- Celli A, Arash A, Adams RA, Morrey BF. Triceps insufficiency following total elbow arthroplasty. *J Bone Joint Surg* 2005;87A:1957-64. <https://doi.org/10.2106/JBJS.D.02423>.
- Cobb TK, Morrey BF. Total elbow arthroplasty as primary treatment for distal humeral fractures in elderly patients. *J Bone Joint Surg Am* 1997;79:826-32.
- Dubberley JH, Faber KJ, Macdermid JC, Patterson SD, King GJ. Outcome after open reduction and internal fixation of capitellar and trochlear fractures. *J Bone Joint Surg Am* 2006;88:46-54. <https://doi.org/10.2106/JBJS.D.02954>.
- Frankle MA, Herscovici D Jr, DiPasquale TG, Vasey MB, Sanders RW. A comparison of open reduction and internal fixation and primary total elbow arthroplasty in the treatment of intra-articular distal humerus fractures in women older than age 65. *J Orthop Trauma* 2003;17:473-80. <https://doi.org/10.1097/00005131-200308000-00001>.
- Gofton WT, Macdermid JC, Patterson SD, Faber KJ, King GJ. Functional outcome of AO type C distal humeral fractures. *J Hand Surg Am* 2003;28:294-308. <https://doi.org/10.1053/jhsu.2003.50038>.
- Hastings H II, Graham TJ. The classification and treatment of heterotopic ossification about the elbow and forearm. *Hand Clin* 1994;10:417-37.
- Helfet DL, Schermering GJ. Bicondylar intra-articular fractures of the distal humerus in adults. *Clin Orthop* 1993;26-36.
- Huang TL, Chiu FY, Chuang TY, Chen TH. The results of open reduction and internal fixation in elderly patients with severe fractures of the distal humerus: a critical analysis of the results. *J Trauma* 2005;58:62-9. <https://doi.org/10.1097/01.ta.0000154058.20429.9c>.
- John H, Rosso R, Meff V. Operative treatment of the distal humerus fractures in the elderly. *J Bone Joint Surg Br* 1994;793-6.
- Jupiter J, Morrey BF. Fractures of the distal humerus in adult. In: Morrey BF, editor. *The Elbow and its disorders*. 2 Ed. Philadelphia: WB Saunders; 1993.
- Kamineni S, Morrey BF. Distal humeral fractures treated with noncustom total elbow replacement. Surgical technique. *J Bone Joint Surg Am* 2005;87:41-50. <https://doi.org/10.2106/JBJS.D.02871>.
- Kamineni S, Morrey BF. Distal humeral fractures treated with noncustom total elbow replacement. *J Bone Joint Surg Am* 2004;86-A:940-7. <https://doi.org/10.2106/00004623-200405000-00009>.
- Korner J, Lill H, Muller LP, Hessmann M, Kopf K, Goldhahn J, et al. Distal humerus fractures in elderly patients: results after open reduction and internal fixation. *Osteoporos Int* 2005;16:S73-9. <https://doi.org/10.1007/s00198-004-1764-5>.
- Little CP, Graham AJ, Carr AJ. Total elbow arthroplasty: a systematic review of the literature in the English language until the end of 2003. *J Bone Joint Surg Br* 2005;87B:437-44. <https://doi.org/10.1302/0301-620X.87B4.15692>.
- McKee MD, Pugh DM, Richards RR, Pedersen E, Jones C, Schemitsch EH. Effect of humeral condylar resection on strength and functional outcome after semiconstrained total elbow arthroplasty. *J Bone Joint Surg Am* 2003;85-A:802-7. <https://doi.org/10.2106/00004623-200305000-00005>.
- McKee MD, Veillette CJ, Hall JA, Schemitsch EH, Wild LM, McCormack R, et al. A multicenter, prospective, randomized, controlled trial of open reduction – internal fixation versus total elbow arthroplasty for displaced intra-articular distal humeral fractures in elderly patients. *J Shoulder Elbow Surg* 2009;18:3-12. <https://doi.org/10.1016/j.jse.2008.06.005>.
- McKee MD, Wilson TL, Winston L, Schemitsch EH, Richards RR. Functional outcome following surgical treatment of intra-articular distal humeral fractures through a posterior approach. *J Bone Joint Surg Am* 2000;82-A:1701-7.
- Medical Research Council. Aids to the examination of the peripheral nervous system, Memorandum no. 45. London: Her Majesty's Stationery Office; 1981.
- Moro JK, King GJW. Total elbow arthroplasty in the treatment of post-traumatic condition of the elbow. *Clinic Orthop Relat Res* 2000;370:102-14.
- Morrey BF. Fractures of the distal humerus: role of the elbow replacement. *Orthop Clin North Am* 2000;31:145-54.
- Pajarinen J, Bjorkemheim JM. Operative treatment of type C intercondylar fractures of the distal humerus: result after a mean follow-up of 2 years in a series of 18 patients. *J Shoulder Elbow Surg* 2002;11:48-52. <https://doi.org/10.1067/mse.2002.119390>.
- Palvanen M, Kannus P, Niemi S, Parkkari J. Secular trends in distal humeral fractures of elderly women: nationwide statistics in Finland between 1970 and 2007. *Bone* 2010;46:1355-8. <https://doi.org/10.1016/j.bone.2009.11.025>.
- Palvanen M, Kannus P, Niemi S, Parkkari J. Secular trends in the osteoporotic fractures of the distal humerus. *Eur J Epidemiol* 1998;14:159-64.
- Paternostro-Sluga T, Grim-Stieger M, Posch M, Schuhfried O, Vacariu G, Mittermaier C. Reliability and validity of the Medical Research Council (MRC) scale and a modified scale for testing muscle strength in patients with radial palsy. *J Rehabil Med* 2008;40:665-71. <https://doi.org/10.2340/16501977-0235>.
- Prasad N, Ali A, Stanley D. Total elbow arthroplasty for non-rheumatoid Patients with a fracture of the distal humerus: a minimum ten-year follow-

- up. *J Bone Joint Surg* 2016;98-B:381-6. <https://doi.org/10.1302/0301-620X.98B3.35508>.
33. Ray PS, Kakarlapudi K, Rajsekhar C, Bhamra MS. Total elbow arthroplasty as primary treatment for distal humeral fractures in elderly patients. *Injury* 2000;31:687-92.
 34. Ring D, Jupiter JB, Gulotta L. Articular fractures of the distal part of the humerus. *J Bone Joint Surg Am* 2003;85-A:232-8. <https://doi.org/10.2106/0004623-200302000-00008>.
 35. Robinson CM, Hill RMF, Jacobs N, Dall G, Court-Brown CM. Adult distal humerus metaphyseal fractures: epidemiology and results of treatment. *J Orthopaedic Trauma* 2003;17:38-47. <https://doi.org/10.1097/00005131-200301000-00006>.
 36. Schildhauer T, Nork SE, Mills WJ, Henley MB. Extensor mechanism-sparing paratricipital posterior approach to the distal humerus. *J Orthop Trauma* 2003;17:374-8. <https://doi.org/10.1097/00005131-200305000-00009>.
 37. Schneeberger AG, Adams R, Morrey BF. Semiconstrained total elbow replacement for the treatment of post-traumatic osteoarthritis. *J Bone Joint Surg Am* 1997;79:1211-22.
 38. Tyllianakis M, Panagopoulos A, Papadopoulos AX, Kaisidis A, Zouboulis P. Functional evaluation of comminuted intra-articular fractures of the distal humerus (AO type C). Long term results in twenty-six patients. *Acta Orthop Belg* 2004;70:123-30. No doi.
 39. Watson-Jones R. *Fractures and joint injuries*. 4th Ed, 2. Baltimore Williams and Wilkins; 1960.