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Triceps-sparing extra-articular step-cut olecranon osteotomy for distal humeral fractures: an anatomic study

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Background: This anatomic study investigated the distal humeral articular surface exposure achievable through a triceps-sparing oblique extra-articular osteotomy of the olecranon with a step-cut modification compared with the anconeus flap transolecranon apex distal chevron osteotomy. In addition, the bone contact surface areas of the osteotomized surfaces after transolecranon and extra-articular osteotomies were compared.
Methods: Seven pairs of fresh adult cadaveric elbow joints were examined. Each of the right elbows underwent triceps-sparing extra-articular step-cut olecranon osteotomy (SCOOT) with an anconeus flap, and the left elbows underwent the anconeus flap transolecranon apex distal chevron osteotomies (CO). The articular surface exposed by each of the osteotomy techniques was then digitally analyzed using a 3-dimensional measurement system. The bone contact surface area of the osteotomized surfaces was also assessed.
Results: The percentage of total joint exposed by the SCOOT group was less than the CO group (SCOOT: 64% ± 3% vs. CO: 73% ± 3%; $P = .002$). There was significantly greater bone contact surface area of the osteotomized surfaces in the SCOOT group compared with the CO group (SCOOT: 1172 ± 251 mm^2 vs. CO: 457 ± 133 mm^2; $P = .002$).
Conclusion: The triceps SCOOT procedure with an anconeus flap provides excellent distal humeral articular surface exposure with the added benefit of a substantially increased (2.6-times) bone contact surface area of the osteotomized surfaces.
Level of evidence: Basic Science; Anatomy Study; Cadaver Dissection

Keywords: elbow; trauma; distal humeral fracture; olecranon osteotomy; surgical approach; osteosynthesis; open reduction internal fixation

Distal humeral fractures in adults are complex and technically demanding injuries to manage. The fracture pattern in 96% of adult distal humeral fractures is complex, involving both columns and with extension to the articular surface.[15,19] Operative intervention is indicated in most cases.

This study did not require ethical approval.

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Achieving adequate exposure to safely apply stable internal fixation is difficult because of multiple fracture planes, fragmentation of the articular surface, and the intricate anatomy of the elbow.[19] There is controversy regarding a number of issues pertaining to the management of distal humeral fractures, including the best operative approach.

An ideal surgical approach to the distal humerus should provide exposure to allow anatomic reconstruction of the articular surface and the application of stable internal fixation, while protecting neurovascular structures.[21] Numerous operative approaches for the management of distal humeral fractures have been described. With the exception of approaches described for the fixation of coronal shear fractures, these all use a posterior skin incision with various strategies of working through or around the triceps muscle. Described approaches include the paratricipital (Alonso-Llames),[1,31] triceps-reflecting (Bryan-Morrey),[8] triceps-reflecting anconeus pedicle,[27] triceps-splitting,[20,40] and olecranon osteotomy techniques.[2,4,23,28,35,37]

The paratricipital, triceps, and triceps-splitting approaches are generally adequate for extra-articular fractures. The major disadvantage of this approach is limited visualization of the articular surface in complex intra-articular distal humeral fractures; therefore, different extra-articular and intra-articular osteotomy approaches have been described.[23,35,37] An anatomic study by Wilkinson and Stanley[38] found that the percentage of articular surface visible after triceps-splitting, triceps-sparing, and olecranon osteotomy were 35%, 46%, and 57%, respectively. This is one of the major reasons why the transolecranon approach, using the apex distal chevron osteotomy (CO), remains the gold standard for most surgeons.[5,16,38] Because the traditional transolecranon approach causes denervation of the anconeus muscle,[26] variations of the olecranon osteotomy that preserve the anconeus have been described.[2,26]

At the conclusion of the procedure, the osteotomy site is fixed with a tension band construct, an intramedullary screw, or a plate. Depending on the method of fixation of the transolecranon osteotomies, several complications have been reported. The reported union rates are up to 100%,[4,28] but other authors have observed complications, with failure of fixation, delayed unions, or even nonunions.[14,30,33]

A triceps-sparing extra-articular step-cut olecranon osteotomy (SCOOT) with an anconeus flap was developed to address some of the limitations of the classic transolecranon distal apex CO. The adequacy of joint exposure with this extra-articular osteotomy of the olecranon is not known. To our knowledge, median joint surface exposure has been compared between transolecranon osteotomy, triceps-reflecting, and triceps-splitting approaches,[38] but no comparison has been made between exposures achieved through intra- articular and extra-articular osteotomes.

The aims of this anatomic study were to:

1. investigate the articular surface exposure achievable through the triceps-sparing extra-articular SCOOT with an anconeus flap compared with the anconeus flap transolecranon apex distal CO; and
2. evaluate the bone contact surface area of the osteotomized surfaces after SCOOT and CO.

Materials and methods

Specimens

Seven pairs of fresh adult cadaveric elbow joints were examined (7 left and 7 right). All investigations were performed according to ethical guidelines and recommendations for working with cadavers.[6] To preserve the anonymity of the donors, information such as personal identity and medical history was not disclosed.

Each elbow consisted of an arm segment from midhumerus to midforearm and was completely intact of all fascia as well as skin. All specimens were free from deformity, significant joint degeneration, previous operations, and any previous dissection of deep structures. Each of the right elbows underwent triceps-sparing extra-articular SCOOT with an anconeus flap (Fig. 1, *A*), and the left elbows underwent the anconeus flap transolecranon apex distal CO (Fig. 1, *B*).

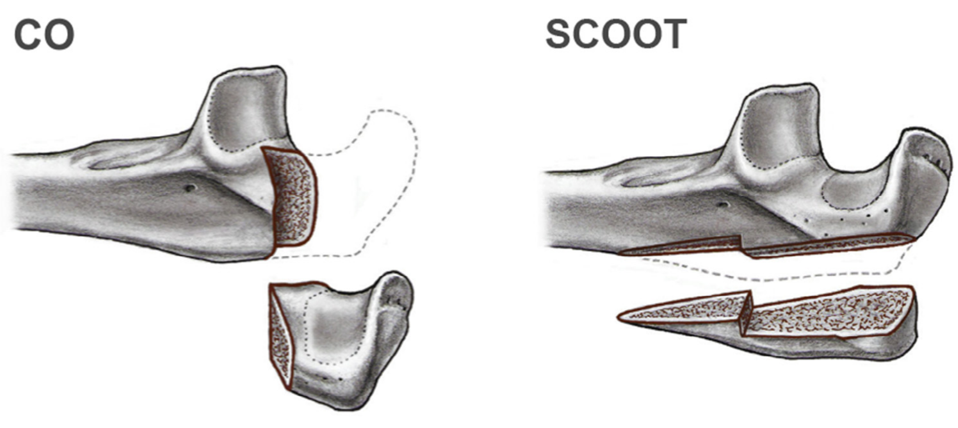


Figure 1 The transolecranon apex distal chevron osteotomy (*CO*) on the right compared with the triceps-sparing extra-articular step-cut olecranon osteotomy (*SCOOT*) with an anconeus flap on the left.

The approach and the soft tissue management

A universal posterior skin incision was used with the elbows in lateral decubitus using a bolster. The surgical approach, with creation of an anconeus flap, was according to Athwal et al[2] in 2006. Medial and lateral full-thickness skin flaps containing the superficial sensory nerves were created. The ulnar nerve was identified, dissected distally, and then released from the cubital tunnel. The nerve was then mobilized until the first motor branch to the flexor carpi ulnaris (FCU) was seen by splitting the fascia of the FCU in line with the nerve for approximately 3 cm.

Because the traditional transolecranon approach causes denervation of the anconeus muscle,[26] variations of the olecranon osteotomy that preserve the anconeus have been described.[2,26] Advantages are that the anconeus provides dynamic stability to the lateral side of the elbow[2] and that an intact muscle also provides a vascularized bed over the osteotomy, which may aid in osteotomy healing.

The triangular anconeus muscle with its base in between the subcutaneous tip of the olecranon and the lateral epicondyle was then identified. Its apex lies 9 to 10 cm distal to the olecranon tip on the subcutaneous border of the ulna.[2] The Kocher interval was then used to raise a proximally based anconeus flap between the anconeus and the extensor carpi ulnaris (ECU). Clearance of all soft tissue from the overlying fascia allows visualization of a fat stripe that marks the Kocher interval. The recurrent posterior interosseous artery that lies in this interval usually requires ligature.

The anconeus is then elevated off the medial fascia of ECU and subperiosteally off the ulna to the level of the planned osteotomy from distal–to-proximal direction. With gradual proximal elevation of this flap, care is taken to preserve the radiocapitellar joint capsule, the annular ligament, the lateral collateral ligament, and the proximally based neurovascular pedicle containing the medial collateral artery and the nerve to anconeus.

Triceps-sparing extra-articular SCOOT with an anconeus flap

The osteotomy was strictly extra-articular, as described by Müller et al[23] in 1970. The oblique cut was modified with a 2-mm step at the middle third of the osteotomy (Fig. 2).

The distance from the olecranon tip to the proximal insertion of the triceps has been shown to be approximately 12 mm.[39] This point also determines the starting point of our extra-articular osteotomy with step-cut modification. To make the SCOOT standardized and reproducible, we developed a special cutting guide (Fig. 3). This cutting guide was placed on the medial side of the olecranon and of the proximal ulna, taking care to protect the previously mobilized ulnar nerve and reflected FCU (Fig. 4, *A* and *B*). Because the triceps insertion is on the dorsal and not on the proximal aspect of the proximal ulna, this area was split into three thirds.[17,39]

The osteotomy was planned under fluoroscopic guidance (Fig. 4, *C*). The starting point of the osteotomy was chosen 12 mm from the tip of the olecranon, from the intersection of the dorsal to the middle third of the proximal area of the proximal ulna in a posterodistal direction with a 20° angle with respect to the posterior cortex of the proximal ulna.[29] The osteotomy is started with an oscillating saw and completed by 2 straight osteotomes placed within each arm of the extra-articular osteotomy with the 2-mm step-cut modification to crack the remaining subchondral bone (Fig. 4, *D* and *E*). This exercise facilitates anatomic reduction of the osteotomy during closure by the interdigitation of fragments. The olecranon fragment with the anconeus muscle flap is then elevated off the posterior aspect of the humerus, in continuity with the triceps muscle, allowing exposure of the distal humeral articular surface (Fig. 4, *F* and *G*).

Figure 2 The planned oblique extra-articular osteotomy of the olecranon with 2-mm step-cut modification (*dashed line*).

Figure 3 Customized cutting guide used to create the oblique extra-articular osteotomy of the olecranon with step-cut modification.

Anconeus flap transolecranon apex distal CO

This osteotomy was also performed as previously described by Müller et al[23] and Weber et al,[37] including a standardized anconeus flap.[2]

Assessment of articular surface exposure

Distal humeral articular surface exposure was assessed in maximal elbow flexion (Fig. 4, *F* and *G*). The articular surface exposed by each surgical approach was then marked with multiple points using a sharp needle and a scalpel. Once the borders of the exposed articular surfaces were carefully marked, the elbow was disarticulated and the cartilage beyond the marked area was removed. In this way,

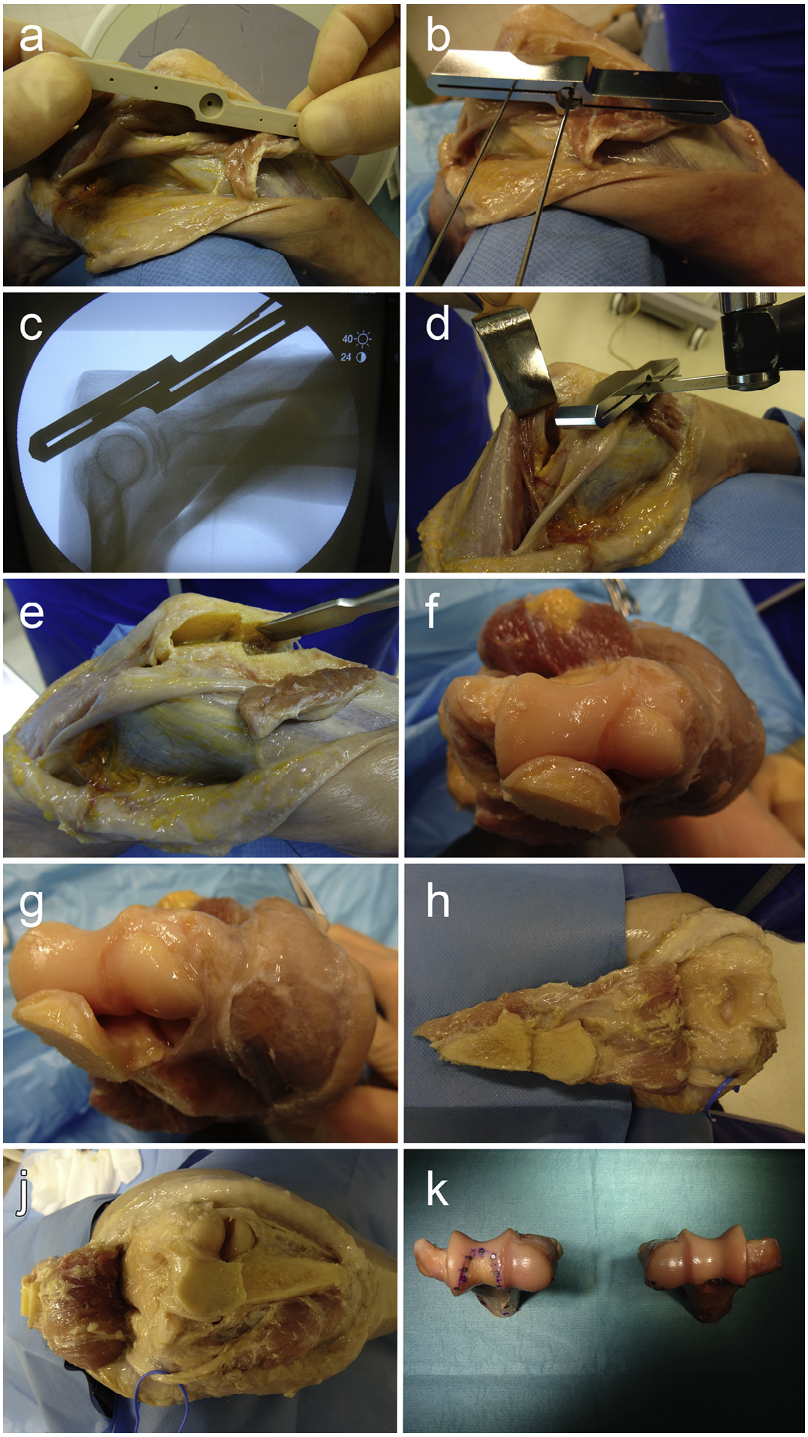


Figure 4 The triceps-sparing extra-articular step-cut olecranon osteotomy (SCOOT) with an anconeus flap was created in a standardized fashion with a cutting guide. (**A** and **B**) This cutting guide was placed on the medial side of the olecranon and proximal ulnar, taking care to protect the previously mobilized ulnar nerve and reflected flexor carpi ulnaris. (**C**) The osteotomy was planned under fluoroscopic guidance. The starting point of the osteotomy was chosen 12 mm from the tip of the olecranon, from the intersection of the dorsal to the middle third of the proximal area of the proximal ulna in a posterodistal direction, with a 20° angle with respect to the posterior cortex of the proximal ulna.[29] (**D** and **E**) The osteotomy is started with an oscillating saw and completed by 2 straight osteotomes placed within each arm of the extra-articular osteotomy with the 2-mm step-cut modification to crack the remaining subchondral bone. (**F, G, H,** and **J**) The olecranon fragment with the anconeus muscle flap is then elevated off the posterior aspect of the humerus, in continuity with the triceps muscle, allowing exposure of the distal humeral articular surface. (**K**) The articular surface exposure achievable through the oblique extra-articular osteotomy of the olecranon with a step-cut modification (left) compared with the anconeus flap transolecranon apex distal chevron osteotomy (right).

the area of cartilage exposed by the surgical approach (ES) was separated from the nonexposed cartilage surface (NES), which was only visible after disarticulation of the elbow joint (Fig. 4, *K*).

Both articular surface exposures were then examined using a 3-dimensional (3D) measurement system (ATOS III Rev. 1; GOM GmbH, Braunschweig, Germany). The scanner itself consists of a projector unit in the middle and 2 camera lenses on either side. It was calibrated to a virtual cube with a volume of 150 mm^3, at a mean distance of 760 mm from the cameras. When triggered, the projector projects a stripe pattern of light on the object to be scanned, and both cameras capture this using the ATOS software. The software then calculates for every pixel (total amount of 4 million pixels) of the charge-coupled device sensor 3D coordinates of the points on the surface. With the first scan, fixed reference markers on the bone were determined. The object is then scanned from different perspectives, and all individual scans are automatically linked using the reference points. After scanning from at least 4 different projections, the desired surfaces are fully captured, and all scans are additionally matched via their geometry with a "best-fit method." With this "poligonization" method all the scans were meshed together to get one single cumulative mesh. The final mesh can then be exported as an STL file in mm for analysis. The values for total joint exposure (ES + NES) and for exposed cartilage surface (ES) were extracted, and the resultant percentage of joint exposure was calculated (ES/[ES + NES]).

Assessment of bone contact surface area of osteotomized surfaces

The bone contact surface area of each of the osteotomized surfaces after the SCOOT and CO approaches (Fig. 4, *H* and *J*) were also assessed using the same 3D measurement technique described above.

Assessment of interobserver and intraobserver reliability

To assess interobserver reliability, an orthopedic surgeon (B.K.M.) and an MD from the Institute of Forensic Medicine (L.C.) performed the surface measurements as described above. To assess intraobserver reliability, one examiner (B.K.M.) assessed the measurements twice within an interval of 2 weeks while being blinded to the findings of the first set of measurements.

Statistical analysis

Results are expressed as the mean with the standard deviation. The Mann-Whitney test was used for unpaired groups. The intraobserver and interobserver reliabilities were evaluated with the intraclass correlation coefficient (ICC; 2,1), a 2-way random model with single measurement and absolute agreement, for each surface scan of both techniques.[25] The interpretation of the ICC values was graded using the classification scheme of Munro,[24] as low (0.26-0.49), moderate (0.50-0.69), high (0.70-0.89), and very high (0.90-1.00). The data are presented as the estimate and the accompanying 95% confidence interval (CI). All analyses were performed using SPSS 22.0 software (IBM Corp., Armonk, NY, USA). The level of statistical significance was set at $P = .05$.

Results

Interobserver and intraobserver reliability

Overall interobserver and intraobserver reliability between both assessors was extremely high, with an ICC of 0.978 (95% CI, 0.945-0.990) for interobserver and 0.986 (95% CI, 0.970-0.993) for intraobserver reliability. Details of the ICC in the articular surface exposure are presented in Table I.

Articular surface exposure

There was no significant difference between the right and left elbows with respect to the total elbow joint surface area (ES + NES; Table I), nor was there any significant difference in the absolute articular ES (mm^2) achieved by the SCOOT group compared with the CO group. However, the percentage of the total joint exposed in the SCOOT group was significantly lower than in the CO group (SCOOT: 64% ± 3% vs. CO: 73% ± 3%; $P = .002$). The joint exposure achievable by the SCOOT technique was deficient in the anteromedial aspect of the trochlea (Figs. 5 and 4, *K*).

Bone contact surface area of osteotomized surfaces

There was significantly greater bone contact surface area of the osteotomized surfaces in the SCOOT group than in the CO group (SCOOT: 1172 ± 251 mm^2 vs. CO: 457 ± 133 mm^2; $P = .002$; Table II).

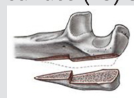
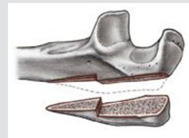
Discussion

Our anatomic study revealed that the transolecranon apex distal CO with an anconeus flap provides the greatest exposure to the distal humeral articular surface, a finding which is consistent with previous studies.[5,38] However, the triceps-sparing extra-articular SCOOT with an anconeus flap also provides excellent articular surface exposure (SCOOT: 64% ± 3% vs. CO: 73% ± 3%; $P = .002$).

The anteromedial facet of the trochlear is not completely visible with the SCOOT. Hence, in Bryan and Morrey type 3[3] coronal shear fractures involving this region,[7] the CO would provide better access to the involved articular segment. But, if the surgeon prefers an extra-articular osteotomy, the anteromedial facet of the trochlear can be exposed by releasing the anterior band of the medial collateral ligament at its humeral insertion. This can then be repaired at the end of the procedure.

It must be noted that the degree of articular surface exposed with the extra-articular osteotomy was made possible by the ability to achieve high degrees of flexion of the cadaveric elbow specimens. This may not be possible in elbows with contractures and other concomitant intra-articular elbow pathology that may restrict flexion. If additional visibility of the

Table I Articular surface exposure in anconeus flap transolecranon apex distal chevron osteotomy (*CO*) vs triceps-sparing extra-articular step-cut olecranon osteotomy (*SCOOT*)

Cadaveric elbow specimens	Left elbow total joint exposure (ES + NES)	Left elbow exposed cartilage surface (ES) CO 	Joint exposure CO 	Right elbow total joint exposure (ES + NES)	Right elbow exposed cartilage surface (ES) SCOOT 	Joint exposure SCOOT 
	(mm^2)	(mm^2)	(%)	(mm^2)	(mm^2)	(%)
1	1699	1245	73	1667	1062	64
2	2420	1824	75	2563	1702	66
3	1949	1464	75	1982	1315	66
4	2568	1840	72	2508	1642	65
5	1695	1293	76	1757	1169	67
6	2048	1446	71	1952	1178	60
7	3413	2272	67	2857	1697	59
Mean ± SD	2256 ± 609	1626 ± 369	73 ± 3	2184 ± 456	1395 ± 277	64 ± 3
P values				.949	.180	.002
Interobserver reliability ICC (95% CI)	0.973 (0.870-0.995)	0.947 (0.744-0.991)		0.973 (0.586-0.996)	0.943 (0.739-0.990)	
Intraobserver reliability ICC (95% CI)	0.977 (0.880-0.988)	0.982 (0.903-0.997)		0.979 (0.884-0.996)	0.969 (0.838-0.995)	

CI, confidence interval; *ICC*, intraclass correlation coefficient; *SD*, standard deviation.

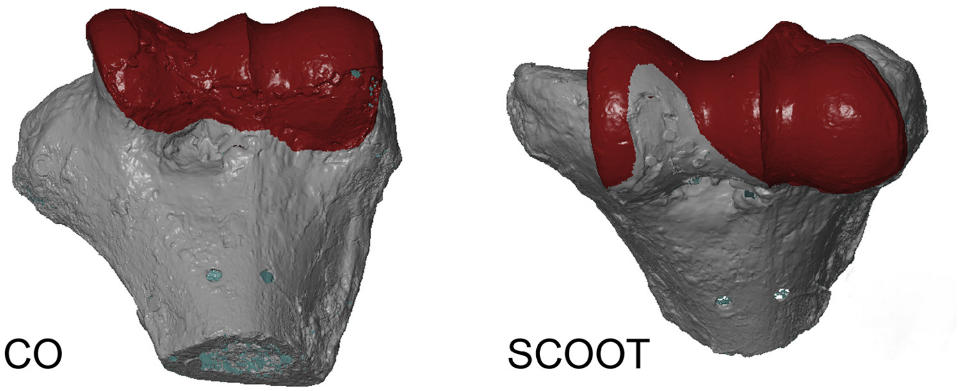


Figure 5 Articular surface exposed with the transolecranon osteotomy (*CO*) compared with the extra-articular osteotomy with step-cut modification (*SCOOT*). The lack of exposure of the anteromedial aspect of the trochlear with the SCOOT technique is evident.

Table II Bone contact surface area of the osteotomized surfaces

Cadaveric elbow specimens	Bone contact surface area	
	CO 	SCOOT 
	(mm²)	(mm²)
1	373	867
2	462	1316
3	442	1172
4	478	1568
5	346	1224
6	361	849
7	734	1205
Mean ± SD	457 ± 133	1172 ± 251 (P = .002)

CO, chevron osteotomy; *SCOOT*, step-cut olecranon osteotomy; *SD*, standard deviation.

joint surface is needed, a limited resection of the olecranon tip to further increase exposure without compromising joint stability is an intraoperative option.[22]

Undoubtedly, the greatest distal humeral articular exposure is provided by the transolecranon approach.[5,38] This technique was originally described by MacAusland[18] in 1915 as a simple transverse osteotomy. To make anatomic reduction easier and increase rotational stability, several modifications, including the use of a CO, have been proposed.[10,11,16] However, the creation and then fixation of the transolecranon osteotomy can lead to several complications, including violation of the articular surface, secondary loss of reduction, as well as delayed unions and nonunions.[9,12,14,16,30,33] Varying methods have been proposed to improve the fixation of such osteotomies.[13,32,36]

Although most of these studies focus on different implants, only one other investigation evaluated the effect of the actual osteotomy technique on the stability of the final construct after fixation.[35] Voor et al[35] demonstrated that oblique extra-articular osteotomies have superior biomechanical characteristics compared with intra-articular osteotomies that pass through the joint contact point where the shear forces reverse and the bending moments peak.

Our recent biomechanical investigation confirmed the findings of Voor et al.[35] We observed that the extra-articular osteotomies have a consistently higher load to failure than classical apex distal intra-articular COs after fixation with a traditional tension band wiring technique.[41] We measured significant increased load to failure of up to 80% of these extra-articular osteotomies compared with the traditional transolecranon technique.

Furthermore, the study demonstrated that the step-cut modification increases the stability by augmenting the resistance of the extra-articular oblique osteotomy against tensile forces. This modification converts some of the tensile forces into compression forces across the step with triceps contraction after tension band fixation. Interestingly, this improvement was only evident near full extension in 20° of flexion, where the triceps contraction leads to higher tensile stresses between the bony fragments. Although, the step-cut configuration would theoretically increase the rotational stability of the tension band reconstruction, this was not analyzed in the biomechanical study.

Besides the impressive inherent stability with up to 1500 N load—which approximates the triceps load during push-ups of an individual of 50-kg body weight[34]—there may also be potential advantages on bone healing. We found that the SCOOT provided a significantly larger bone contact surface area of the osteotomized surface compared with the CO (SCOOT: 1172 ± 251 mm^2 vs. CO: 457 ± 133 mm^2; P = .002). The long oblique triceps-sparing extra-articular SCOOT increases the bone contact surface area by 2.6 times compared with the transolecranon approach, which not only improves static friction and thus resistance against tensile forces, as demonstrated by our biomechanical evaluation, but may also enhance healing potential.

Compared with the mode of failure of the classic CO with progressive intra-articular gap formation, any secondary displacement of the triceps-sparing extra-articular SCOOT will not lead to step or gap formation of the distal humeral articular surface. This step-cut augmentation may actually increase bony abutment, which may aid for bony union.

It must be noted that this is a cadaveric study with several limitations. Only 7 paired cadaveric elbows were available for testing. Although all specimens were free from deformity, significant joint degeneration, previous operations, and any previous dissection of deep structures, subtle deformities and contractures may influence the exposure achieved. As noted above, the degree of articular surface exposed with the extra-articular osteotomy was made possible by the ability to achieve high degrees of flexion of the cadaveric elbow specimens. This may not be possible in elbows with contractures and other concomitant intra-articular elbow pathology that may restrict flexion in patients.

Conclusion

The transolecranon apex distal CO with an anconeus flap provides the greatest exposure of the distal humeral articular surface for complex intra-articular distal humeral fractures. The triceps-sparing extra-articular SCOOT with an anconeus flap provides excellent articular surface exposure with the added benefit of a substantially increased (2.6 times) bone contact surface area of the osteotomized surfaces. This significant increase in the bone contact surface area with the step-cut modification confers a greater inherent stability after fixation with a traditional tension band wiring technique[41] and may potentially enhance healing.

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