Research Square

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Internal brace augmentation for lateral ulnar collateral ligament repair in terrible triad injury

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Abstract

Background:

To evaluate the clinical and functional outcomes of lateral ulnar collateral ligament (LUCL) repair augmented with the internal brace technique in patients with terrible triad injuries (TTI) of the elbow.

Methods:

We retrospectively reviewed 17 elbows (16 patients) with TTI treated at a single tertiary medical center between 2022 and 2025. Surgical management followed a standardized protocol: coronoid process fixation via the suture lasso technique, radial head reconstruction (ORIF) or replacement, and LUCL repair augmented with high-strength suture tape (internal brace). An accelerated rehabilitation protocol using alternating splints (full extension and 90◦ flexion) was initiated on the first postoperative day (POD 1). Clinical outcomes were assessed using the Mayo Elbow Performance Score (MEPS) and range of motion (ROM) at a minimum follow-up of one year.

Results:

The mean patient age was 47.3 years. At the final follow-up, the average elbow flexion/extension arc was 137.65◦±22.16◦ and the pronation/supination arc was 158.83◦±32.04◦. The mean MEPS was 95.88 ± 10.49, indicating excellent functional results. Complications occurred in 3 elbows (17.6%): two cases of transient posterior interosseous nerve palsy that resolved spontaneously and one case of heterotopic ossification requiring surgical excision. No instances of recurrent instability or hardware failure were observed.

Conclusions:

LUCL repair with internal brace augmentation appears to provide sufficient immediate stability in TTI, facilitating the initiation of an accelerated postoperative rehabilitation protocol. This approach is associated with excellent functional outcomes and high patient-reported scores while minimizing the risk of postoperative stiffness.

Background

Terrible triad injury (TTI) of the elbow is a complex fracture-dislocation characterized by posterior elbow dislocation, a radial head fracture, and a coronoid process fracture. The primary mechanism of injury typically involves a fall onto an outstretched hand, which subjects the elbow to excessive axial compression and valgus stress while the forearm is in a supinated position. Beyond the aforementioned osseous injuries, extensive ligamentous disruption plays a critical role in joint instability, with the lateral ulnar collateral ligament (LUCL) complex being the most frequently compromised structure. Due to the inherent complexity of these injuries, TTI has historically been associated with a high incidence of complications and suboptimal functional outcomes. Achieving a stable joint throughout the range of motion (ROM) is the cornerstone of successful surgical intervention for TTI. A stable elbow allows for early mobilization, which is essential to prevent sequelae such as stiffness and functional deficits. The modern surgical approach to TTI follows a systematic decision-making flow based on the severity of each component. Following closed or open reduction of the joint, osseous components—specifically the coronoid process and radial head—are addressed through internal fixation or replacement. Once bony stability is restored, the injured ligaments are then repaired. Traditionally, LUCL injuries in TTI are managed with suture repair using either transosseous sutures or suture anchors. Postoperatively, patients are typically immobilized in a long-arm splint for approximately two weeks before transitioning to a hinged elbow orthosis. Although this protocol aims to protect the repaired ligaments while gradually restoring mobility, the prolonged protection phase often leads to extended recovery times and residual ROM deficits [5].

In more severe cases, residual joint instability may persist even after ligament repair, often due to poor tissue quality or inadequate suture techniques [3, 4]. To address this, internal joint stabilizers have been utilized to provide temporary mechanical support. While these fully implanted devices permit early rehabilitation and shorten the recovery period, they are not without drawbacks. Implant-related complications, such as breakage, loosening, or migration, are well-documented. Furthermore, a secondary procedure is often required to remove the device after the ligaments have healed to prevent long-term hardware-related issues.

In recent years, innovative techniques such as "internal brace augmentation" have emerged to enhance the outcomes of ligament repairs. This technique involves the use of high-strength, ultra-braided suture tape anchored at the anatomical footprints of the ligament. The suture tape acts as a secondary stabilizer (or "brace") that protects and off-loads the repaired native tissue during the healing phase. By providing immediate supplemental stability, this technique offers the potential for earlier mobilization and a shortened rehabilitation period. Internal brace augmentation has already demonstrated clinical success in the knee, thumb, and ankle, as well as promising results in medial ulnar collateral ligament (MUCL) repairs in overhead athletes [10–13].

Consequently, we sought to apply this technique to the management of TTI by incorporating internal brace augmentation into the standard LUCL repair protocol. We hypothesize that this approach can accelerate postoperative recovery and reduce the required duration of joint protection. The

objective of this article is to describe the surgical application of internal brace augmentation for LUCL repair in TTI, provide a detailed technical note and a novel accelerated rehabilitation protocol, and report the subsequent clinical outcomes and complication profiles in a patient cohort.

Methods

Study Design and Setting

This retrospective case series was conducted at a single tertiary medical center between August 2022 and August 2025. We reviewed adult patients (≥ 18 years) diagnosed with TTI, specifically involving posterior dislocation associated with radial head and coronoid process fractures. Patients treated with LUCL repair using internal brace augmentation were enrolled in this study, with a minimum follow-up requirement of one year. The study protocol was approved by the Institutional Review Board (IRB No. 202501577B0), and the requirement for informed consent was waived due to the retrospective nature of the study.

Surgical Technique

All surgical procedures were performed following a standardized institutional protocol for TTI. Patients were positioned supine, and a lateral incision using a Kocher approach was utilized. The coronoid process fracture was addressed first, typically accessed through the window created by the radial head fracture or via the dislocated elbow joint. We routinely employed a suture lasso technique to simultaneously secure the coronoid tip fracture and the anterior joint capsule, ensuring the restoration of anterior stability.

Following coronoid fixation, the radial head fracture was addressed through the same approach. Our primary surgical objective was the anatomical reconstruction and internal fixation of the radial head using screws or a low-profile locking plate. In cases where the fracture was deemed non-salvageable due to extensive comminution or poor bone quality, a radial head arthroplasty was performed to maintain radial length and valgus stability of the forearm.

Despite the restoration of the osseous components, the elbow joint often remains unstable due to significant LUCL disruption. To address this, internal brace augmentation was utilized for LUCL repair (Fig. 1). The procedure began with the insertion of a 3.5-mm polyetheretherketone (PEEK) suture anchor pre-loaded with high-strength suture tape (SwiveLock with FiberTape; Arthrex, Naples, FL) into the ulnar footprint at the supinator crest (Fig. 1A). This represents the anatomical distal insertion of the LUCL complex. The annular ligament was then repaired with sutures (Fig. 1B). The suture tape was subsequently routed proximally, passing lateral to the radial head and superficial to the previously repaired annular ligament (Fig. 1C). A second 3.5-mm PEEK SwiveLock anchor was placed at the anatomical origin of the LUCL on the lateral epicondyle of the humerus (Fig. 1D). During this phase, the tension of the suture tape was meticulously adjusted with the elbow held at 30◦ of flexion and the forearm in full pronation to ensure that no residual joint subluxation occurred throughout a full ROM arc while avoiding over-tensioning. Intraoperative joint stability and smooth tracking were confirmed under live fluoroscopy prior to final knot tying. Once the augmentation was secured, the native LUCL remnants were repaired back to the lateral epicondyle using FiberWire sutures, effectively imbricating the biological tissue over the synthetic brace.

Following the reconstruction of the lateral structures, the MUCL was assessed for functional integrity using a valgus stress test. If persistent medial joint opening or gross instability was observed, an MUCL repair was performed using suture anchors through a medial incision. In such instances, the ulnar nerve was identified, neurolysed, and protected to prevent iatrogenic injury. Final joint stability was confirmed under fluoroscopy and direct visualization before the wound was closed in layers.

Postoperative Rehabilitation and Outcome Assessment

Postoperative mobilization was initiated on the first postoperative day (POD 1). To prevent immobilization-related stiffness, we implemented a novel alternating splint protocol. Each patient was provided with two long-arm splints: one positioned in full elbow extension and the other in 90◦ of elbow flexion. Patients were instructed to alternate between these two splints every two hours during the daytime. The rehabilitation program was therapist-supervised twice weekly in conjunction with a structured home protocol. During each transition, passive stretching without ROM restriction for at least 10 minutes was encouraged. Active-assisted ROM was introduced at postoperative week 2, and full active ROM was permitted at week 4. Forearm rotation was initially restricted to the neutral or pronation position during extension exercises to protect the LUCL construct, and advanced to full rotation only at 90◦ of elbow flexion. At six weeks post-surgery, provided that clinical recovery was satisfactory, patients were allowed to perform overhead movements without a splint and gradually initiate weight-bearing exercises of the affected limb. Compliance with this alternating protocol was monitored via patient-logged diaries and verified at each bi-weekly outpatient follow-up.

Patients were routinely followed up at 2 weeks, 6 weeks, 3 months, 6 months, and annually thereafter. Clinical outcomes were assessed using the Mayo Elbow Performance Score (MEPS) and objective measurements of the elbow's ROM. In addition, any procedure-related complications were

recorded, including joint stiffness, heterotopic ossification (HO), residual instability, hardware failure (e.g., breakage or migration), peripheral neuropathy, wound complications, and the development of post-traumatic arthritis.

Results

Patient Demographics and Injury Characteristics

Between August 2022 and August 2024, a total of 16 patients with 17 affected elbows (including one patient with bilateral injuries) were enrolled in this study. The cohort consisted of 10 males and 6 females, with a mean age of 47.25years (range, 25–78 years). The most common mechanism of injury was motorcycle accidents (n = 7), followed by falls from height (n = 5) and ground-level falls (n = 4). Associated injuries are summarized in Table 1.

Table 1
Patient demographics and injury characteristics

Case	Gender	Age range	Injury mechanism	Comorbidities	Side	Combined injury	Radial head fracture		MCL repair
#	Male/Female				Left/Right		AO/OTA classification	Treatment	
1	M	40–49	motorcycle accident	nil	L	nil	2R1C3	low-profile locking plate	yes
2	M	30–39	fall from height	nil	L	hemopneumothorax left acetabulum fracture traumatic ICH	2R1B3	low-profile locking plate	
3	F	20–29	motorcycle accident	nil	L	left proximal humerus fracture right femoral shaft fracture left 1st metacarpal base fracture	2R1B1	screw fixation	
4	M	40–49	motorcycle accident	nil	R	nil	2R1C1	low-profile locking plate	yes
5	M	50–59	fall from height	colon cancer	R	nil	2R1C3	low-profile locking plate	yes
6	F	30–39	ground-level fall	nil	L	facial bone fracture	2R1A2	low-profile locking plate	yes
7	M	40–49	motorcycle accident	gout	L	nil	2R1B3	low-profile locking plate	
8	F	50–59	ground-level fall	nil	L	nil	2R1C1	low-profile locking plate	
9	M	30–39	ground-level fall	nil	R	nil	2R1B1	low-profile locking plate	yes
10	F	60–69	ground-level fall	nil	R	nil	2R1C3	low-profile locking plate	yes
11	M	30–39	fall from height	nil	L	nil	2R1B3	low-profile locking plate	
12	F	60–69	motorcycle accident	HTN	R	nil	2R1C3	low-profile locking plate	yes
13	M	40–49	fall from height	HTN	R	bilateral injury	2R1B3	low-profile locking plate	
14	(same patient as Case 13)				L	bilateral injury	2R1B3	low-profile locking plate	
15	M	40–49	fall from height	nil	R	pelvic fracture right femoral neck fracture	2R1B3	low-profile locking plate	
16	F	40–49	motorcycle accident	nil	L	nil	2R1C1	low-profile locking plate	

Case	Gender	Age range	Injury mechanism	Comorbidities	Side	Combined injury	Radial head fracture		MCL repair
#	Male/Female				Left/Right		AO/OTA classification	Treatment	
17	M	70–79	motorcycle accident	HTN, DM	R	C-spine injury, traumatic SAH	2R1C3	radial head arthroplasty	

Surgical Findings and Interventions

All patients were treated according to the standardized protocol at a mean of 4.76 days after the initial injury. Regarding the coronoid component, all 17 elbows presented with coronoid tip fractures, classified as Regan-Morrey type I (O'Driscoll type 2, subtype 1), which were fixed using the suture lasso technique with non-absorbable sutures. Radial head fractures were classified according to the AO/OTA system: 2R1A2 (n = 1), 2R1B1 (n = 2), 2R1B3 (n = 6), 2R1C1 (n = 3), and 2R1C3 (n = 5). Surgical management of the radial head included ORIF with low-profile locking plates in 15 elbows, screw fixation in one elbow, and radial head arthroplasty in one geriatric patient with a non-reconstructible fracture.

For ligamentous injuries, all 17 elbows underwent LUCL repair with internal brace augmentation. Intraoperative valgus stress testing following LUCL reconstruction revealed residual medial instability in 7 elbows, which subsequently underwent MUCL repair using suture anchors. The mean operative time was 143.24 ± 34.59 minutes.

Radiographic and Functional Outcomes

Radiographic evaluation during the follow-up period demonstrated successful osseous union in all cases, with no instances of nonunion or hardware failure. The mean time to union was 3.28 ± 1.75 months. Functional outcomes, including ROM and MEPS, were recorded at 6 weeks, 3 months, 6 months, and 1 year postoperatively. At the final follow-up, the average elbow flexion/extension arc was 137.65∘±22.16∘, and the average pronation/supination arc was 158.83∘±32.04∘. The mean MEPS was 95.88 ± 10.49, indicating excellent clinical results (Table 2).

Table 2. Average elbow ROM and MEPS after operation

		6 weeks	3 months	6 months	1 year
Elbow ROM (degree ± SD)	**flexion**	110.88 ± 22.59	130.59 ± 23.48	138.53 ± 21.34	142.06 ± 17.24
	extension	9.71 ± 6.59	7.06 ± 7.92	4.71 ± 6.95	4.41 ± 6.59
	flexion-extension arc	**101.17 ± 28.04**	**123.53 ± 30.35**	**133.82 ± 26.78**	**137.65 ± 22.16**
	pronation	64.35 ± 19.19	80.00 ± 16.49	82.65 ± 16.69	82.65 ± 16.69
	supination	45.88 ± 28.90	66.18 ± 25.03	75.88 ± 16.03	76.18 ± 16.06
	pronation-supination arc	**110.23 ± 47.20**	**146.18 ± 37.52**	**158.53 ± 31.96**	**158.83 ± 32.04**
MEPS (± SD)		83.24 ± 12.62	92.06 ± 13.24	93.82 ± 10.83	95.88 ± 10.49

Complications

Postoperative complications occurred in 3 patients (17.6%) (Table 3). Two patients experienced posterior interosseous nerve (PIN) palsy, both of which resolved spontaneously during the early follow-up period without further surgical intervention. One patient developed HO, which resulted in significant ROM limitations, particularly in supination and pronation. This patient subsequently underwent implant removal and HO excision 1.5 years after the index surgery, after which the ROM improved to near-normal levels. No cases of deep infection, post-traumatic arthritis, or persistent joint instability were observed.

Table 3
Radiologic outcome and complications

Radiologic outcome		
	average bone union time (months ± SD)	**3.28 ± 1.75**
Complications		
	residual instability	0
	post-traumatic arthritis	0
	nonunion	0
	deep infection	0
	PIN palsy	2
	heterotopic ossification	1

Discussion

TTI of the elbow is a challenging fracture-dislocation pattern involving complex osseous and ligamentous disruptions. Within the surgical management of these injuries, the repair of the LUCL is widely regarded as the "keystone" step [1, 2]. Suboptimal LUCL repair or inadequate tensioning can result in residual elbow instability, which may subsequently compromise the internal fixation of osseous components, potentially leading to catastrophic clinical failures and persistent joint subluxation [3, 4].

Historically, concerns regarding LUCL repair failure led to relatively conservative postoperative rehabilitation protocols. Patients were immobilized in a long-arm splint for at least two weeks to protect the repaired ligaments [5]. However, the elbow is a joint notoriously prone to post-traumatic stiffness, and such prolonged immobilization often results in a permanent loss of ROM [6, 7]. For instance, Chemama et al. reported that delaying mobilization until two weeks postoperatively resulted in a mean flexion of 127◦ but a significant extension loss of 18◦ [8]. Existing literature on TTI outcomes shows highly variable results, with mean elbow flexion/extension arcs ranging from 99◦ to 140◦ and pronation/supination arcs between 80◦ and 172◦ [9]. This inconsistency underscores the urgent need for a more robust fixation method that can safely accommodate accelerated rehabilitation.

To address this therapeutic dilemma, we utilized the internal brace augmentation technique for LUCL repair in 17 TTI cases. Our findings suggest that this technique may provide superior mechanical stability, appearing to facilitate very early mobilization initiated as early as the first postoperative day (POD 1). This timeline is substantially more aggressive than traditional protocols. In our cohort, the suture-tape augmentation functioned as a "safety belt" for the native LUCL repair, and was associated with immediate rehabilitation without any observed instances of acute recurrent instability. This biomechanical reinforcement directly translated into favorable clinical outcomes; at the 3-month follow-up, our patients achieved an average elbow flexion/extension arc of 123.53◦ and a pronation/supination arc of 146.18◦. Furthermore, the mean MEPS reached 92.06 at three months, demonstrating excellent early functional recovery that persisted through the final follow-up, with an average elbow flexion/extension arc of 137.65◦ and a pronation/supination arc of 158.83◦ at 1 year. It is critical to note that these excellent outcomes are likely a synergistic effect of both the structural augmentation and our intensive alternating splint protocol, rather than the internal brace alone.

The internal brace technique has a proven track record in various anatomical regions, most notably in ankle deltoid ligament repairs and MUCL reinforcement in athletes [10]. Dugas et al. demonstrated that 93% of overhead athletes returned to their prior level of competition within six months following MUCL repair with internal brace augmentation [11–13]. Regarding the LUCL, Melbourne et al. conducted a cadaveric study comparing LUCL repair and reconstruction with and without internal brace augmentation; the augmented group demonstrated significantly higher load-to-failure and near-normal rotational stiffness [14–16]. Ozdag et al. also reported successful clinical outcomes using LUCL internal bracing [17]. However, their cohort was relatively heterogeneous, including simple dislocations and chronic instability cases. In contrast, our series focused exclusively on acute TTI, further clarifying the role of internal brace augmentation in this complex injury pattern.

Alternative methods to enhance LUCL repair or reconstruction include autologous triceps tendon grafting [18–20]. Although biomechanically comparable to suture-tape augmentation, grafting involves donor-site morbidity and increased operative time. In our experience, suture-tape internal bracing offers a simpler, safer, and more reproducible alternative that avoids the complications associated with graft harvesting while maintaining high structural integrity.

Our complication rate was 17.6% (3 patients), which is comparable to existing literature [2, 4, 9]. Most importantly, we observed no cases of recurrent instability or fixation failure—the most dreaded complications in TTI management. The two cases of PIN palsy resolved spontaneously. The single case of HO occurred in a patient with a concomitant intracranial hemorrhage (ICH), a well-known risk factor for HO. Despite adhering to the early mobilization protocol, this patient required HO excision 1.5 years later. This case suggests that for TTI patients with concurrent traumatic

brain injury, aggressive rehabilitation alone may be insufficient, and the routine administration of HO prophylactic medications (such as NSAIDs or low-dose radiation) should be considered.

This study has several limitations. First, as a retrospective case series, it lacks a control group; a prospective randomized controlled trial (RCT) comparing LUCL repair with and without augmentation would provide higher-level evidence. Second, TTI management involves multiple variables, including the treatment of the radial head. Most of our patients underwent ORIF rather than arthroplasty for radial head fracture, which may have influenced the speed of recovery. Third, associated injuries can confound outcomes. In our series, the two patients with the slowest recovery times had concurrent head and neck injuries, which hindered their compliance with the rehabilitation protocol.

Fourth, recent literature has raised concerns regarding long-term osteolysis associated with PEEK suture anchors in the upper extremity. Although no significant bone resorption or implant loosening was observed radiographically in our series, our minimum one-year follow-up is insufficient to rule out late-onset osteolysis or implant-related biological complications. Fifth, because the FiberTape construct is highly rigid, any microscopic deviation from the true anatomic isometric points could theoretically introduce abnormal friction or constraint on the joint surfaces over time, potentially accelerating cartilage wear. Consequently, our short-term finding of 'no post-traumatic arthritis' must be interpreted with extreme caution. Longer follow-up with advanced imaging is mandatory to fully evaluate the long-term cartilage durability and biological safety of this rigid construct.

Conclusions

LUCL repair with internal brace augmentation is a safe and effective technique for managing TTI. By providing robust immediate stability, this method allows for a more aggressive rehabilitation program, effectively minimizing the risk of long-term functional deficits. Further large-scale RCTs are warranted to confirm the long-term advantages of this approach over traditional techniques.

Abbreviations

• **TTI**
Terrible triad injury
• **LUCL**
Lateral ulnar collateral ligament
• **ROM**
Range of motion
• **MUCL**
Medial ulnar collateral ligament
• **MEPS**
Mayo Elbow Performance Score
• **HO**
Heterotopic ossification
• **PIN**
Posterior interosseous nerve
• **ICH**
Intracranial hemorrhage
• **RCT**
Randomized controlled trial
• **IRB**
Institutional Review Board
• **POD**
Postoperative day
• **ORIF**
Open reduction and internal fixation

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Review Board (IRB) of Linkou Chang-Gung Memorial Hospital on December 26, 2025 (IRB No. 202501577B0). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The

requirement for informed consent was waived by the Institutional Review Board of Linkou Chang-Gung Memorial Hospital due to the retrospective nature of the study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

Yu-Kai Lin (Y.K.L.) wrote the main manuscript text. Chih Yang Lai (C.Y.L.) and Ying Chao Chou (Y.C.C.) contributed to data collection and patient data curation. Ying Chao Chou (Y.C.C.) and Yung Heng Hsu (Y.H.H.) provided clinical cases and managed patient coordination. Yi-Hsun Yu (Y.H.Y.) performed the statistical analysis and evaluated functional outcomes. Po Ju Lai (P.J.L.) prepared the figures and illustrations and supervised the study design. All authors reviewed, revised, and approved the final manuscript.

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Availability of data and materials

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

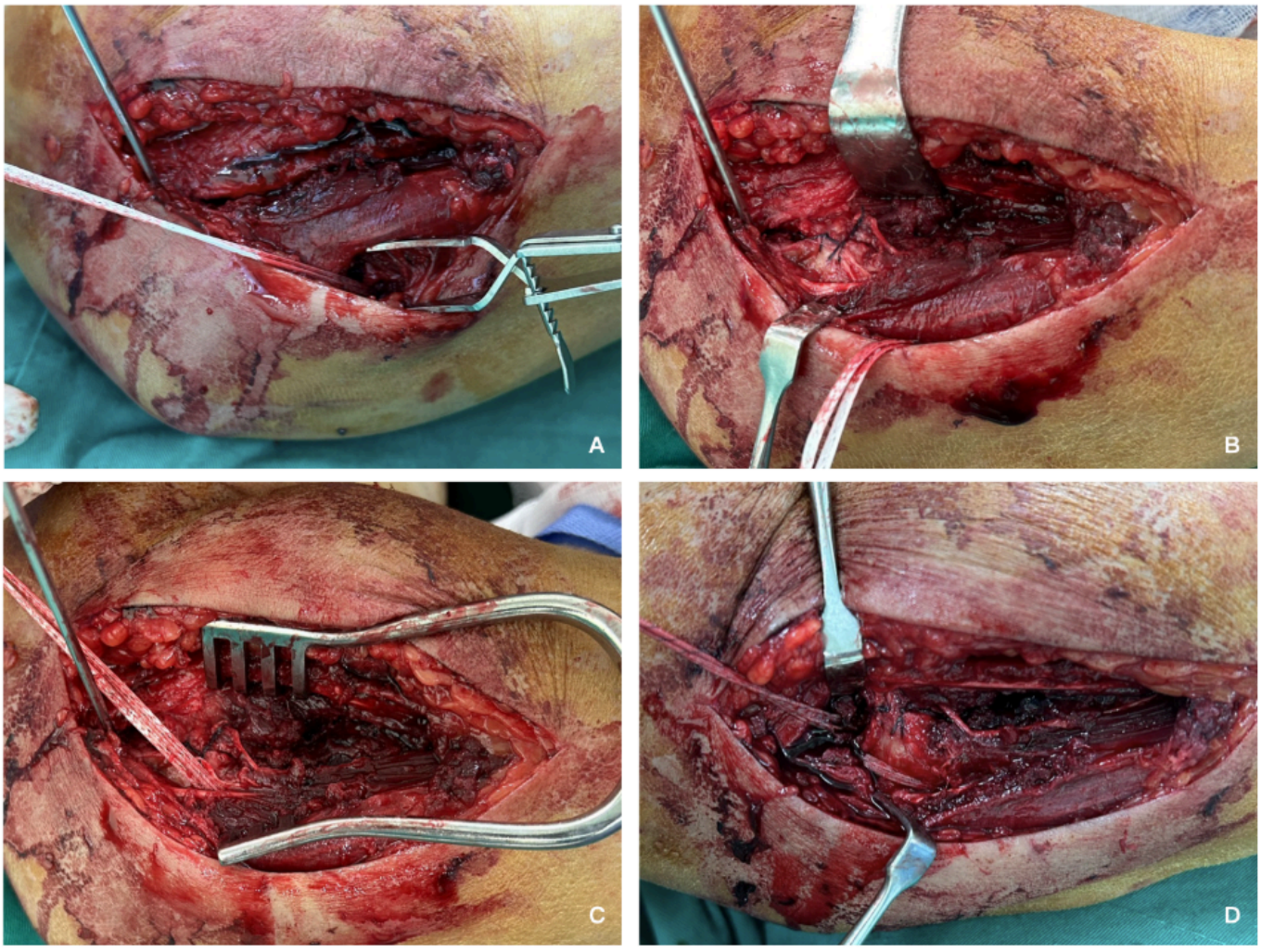


Figure 1

Intraoperative surgical steps of LUCL repair with internal brace augmentation.

(A) Insertion of a 3.5-mm PEEK suture anchor pre-loaded with high-strength suture tape into the ulnar footprint of the LUCL at the supinator crest.

(B) Direct repair of the annular ligament using sutures.

(C) Routing of the suture tape proximally, passing lateral to the radial head and superficial to the repaired annular ligament.

(D) Placement of a second footprint anchor at the anatomical origin of the LUCL on the lateral epicondyle of the humerus under proper tensioning.