Original Research Article

Zone-Specific Patterns and Early Functional Outcomes After Surgical Repair of Extensor Tendon Injuries of the Hand, Wrist, and Forearm: A Prospective Study

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A B S T R A C T

Background; Extensor tendon apparatus injuries of the hand, wrist, and forearm are common in trauma practice, yet early functional recovery differs noticeably across anatomical zones. In many patients, the limiting factor is not tendon continuity alone, but stiffness, adhesions, and subtle imbalance that emerges during the first few weeks after repair.

Objectives; To describe injury patterns by zone, mechanism, and tendon involvement, and to evaluate early post-operative functional outcome using Miller's criteria.

Methods; A longitudinal prospective study was conducted from June 2024 to November 2025 among patients undergoing surgical repair for extensor tendon apparatus injuries involving the hand, wrist, or forearm (n = 85). Recorded variables included demographics, hand dominance, mechanism of injury, anatomical zone (I–IX), tendon(s) involved, time to presentation, and early complications. Functional outcome at post-operative day 14 was graded using Miller's criteria. Associations were tested using chi-square where appropriate with a significance threshold of $p < 0.05$.

Results; Mean age was 32.4 ± 11.6 years; 72.9% were male, and 58.8% involved the dominant hand. The common mechanisms were glass cuts (34.1%), machinery injuries (28.2%), knife injuries (17.6%), and crush injuries (12.9%). Zone VI injuries predominated (31.8%), followed by Zone V (18.8%) and Zone VII (12.9%). The most frequently involved tendon group was extensor digitorum communis (52.9%), followed by extensor pollicis longus (18.8%). At day 14, outcomes were Excellent 21.2%, Good 45.9%, Fair 23.5%, and Poor 9.4%. Distal zones (I–III) showed a higher Fair/Poor proportion than mid-zones (V–VII) (45.0% vs 26.2%, p = 0.03). Presentation after 24 hours was associated with poorer grades (18.2% vs 6.1%, p = 0.04). Early complications included stiffness/adhesions (14.1%), superficial infection (5.9%), and rerupture (2.4%).

Conclusion; Extensor tendon injuries clustered in Zone VI and were predominantly sharp or machinery-related. Distal zones and delayed presentation were associated with poorer early function, supporting zone-stratified counselling and rehabilitation planning from the first follow-up.

Keywords: Extensor Tendon, Hand Injuries, Tendon Repair, Zone Classification, Miller Criteria, Functional Outcome.

INTRODUCTION

Extensor tendon apparatus injuries of the hand, wrist, and forearm are common and often look "simple," yet recovery can still be unpredictable. The extensor system is thin, superficial, and closely linked to skin, periosteum, and dorsal

capsules; small changes in tendon length, tension, glide, and tissue viability can translate into extension lag, loss of composite flexion, or stiffness that dominates function.[1] This vulnerability is not just theoretical. Reviews repeatedly note that tendon continuity alone does not guarantee movement, because adhesions, joint stiffness, and imbalance across MCP/IP joints can quietly decide the final arc of motion even after technically sound repair.[2] Zone-based thinking therefore matters. The extensor zone system (Kleinert–Verdan concept applied to extensor tendons) is not merely descriptive; it reflects zone-specific constraints such as tendon width, retinacular mechanics, synovial environment, and proximity to joints.[3]

Epidemiologic work also reinforces that "pattern" matters: open extensor tendon injuries show non-random distribution across digits, hand, and forearm, and associated injury to bone, capsule, or soft tissue is frequent, with direct implications for rehabilitation potential.[4] Clinical summaries further emphasize structured examination and documentation, since partial lacerations, multi-tendon involvement, and occult joint injuries are not unusual in dorsal trauma.[5]

Rehabilitation is the second hinge point. Evidence syntheses support early active or protected mobilisation in suitable repairs, particularly for Zones V and VI, because immobilisation alone tends to invite stiffness and adhesions.[6] For outcome reporting, Miller's criteria remain a pragmatic early language because extension lag and flexion loss map directly onto what patients experience in daily function.[7] Outcome series also suggest that zone-linked differences persist even with standard repair, supporting the need for zone-anchored counselling and expectations.[8]

Accordingly, this prospective study (June 2024 to November 2025) maps zone-specific injury patterns after surgical repair and evaluates early functional outcome at post-operative day 14 using Miller's criteria.[7]

MATERIALS AND METHODS

Study Design and Setting
This was a longitudinal prospective hospital-based study conducted in the Department of General Surgery at a tertiary care teaching hospital (East Point Hospital, Bengaluru). The study period was June 2024 to November 2025. All eligible cases presenting through the emergency department and outpatient services were screened consecutively, and those requiring operative management for extensor tendon apparatus injury were enrolled.

Study Population and Sample Size
Patients with extensor tendon apparatus injuries involving the hand, wrist, or forearm who underwent surgical repair during the study period were included. A total of 85 patients constituted the final study sample.

Eligibility Criteria

Inclusion Criteria
- Patients of either sex and any age group with extensor tendon apparatus injury of the hand/wrist/forearm planned for surgical repair.
- Willingness to participate with written informed consent (assent with guardian consent for minors where applicable).

Exclusion Criteria
- Same-limb fractures requiring specialised fixation or complex reconstruction.
- Massive soft-tissue envelope loss where tendon repair could not be evaluated with a standard post-operative pathway.
- Combined flexor and extensor tendon injuries in the same region.

Case evaluation and Baseline Documentation
Each enrolled patient underwent a structured assessment at presentation. The following were documented in a predesigned case record form:

1. **Demographic and Background Variables**
o Age, sex
o Side involved and **hand dominance** (dominant vs non-dominant)
o Occupation grouped pragmatically (manual labour/industrial work, skilled, clerical, student, homemaker, others)
o Comorbidities with a focus on variables that influence wound healing or stiffness (diabetes mellitus, smoking history, alcohol use where relevant)

2. **Injury-Related Variables**
o Time since injury and time to presentation (recorded in hours)
o Mechanism of injury (glass cut, knife cut, machinery-related, crush, avulsion, bite, others)

o   Nature of wound (clean/contaminated, simple/complex)
o   Digit(s) involved and number of tendons involved
o   Neurovascular status (capillary refill, sensory deficit, motor deficit)
o   Associated injuries: suspected/confirmed capsule or joint involvement, bony injury on imaging, skin loss

3. **Zone Classification**

Injuries were classified using the extensor tendon zone system across Zones I to VIII for digits/hand/wrist and Zone IX for forearm injuries. If a wound spanned more than one zone, the primary discontinuity zone was coded for analysis and additional zones were recorded descriptively.

Operative Management and Intra-Operative Recording

All patients underwent operative management under regional or general anaesthesia as clinically appropriate. The following intra-operative details were captured in a uniform format:

*   Tendon(s) involved (e.g., EDC, EPL, EIP, EDM, EPB/APL as applicable)
*   Extent of injury (partial vs complete laceration)
*   Tendon end quality (sharp/clean vs frayed/crush)
*   Associated findings (capsular breach, joint involvement, contamination, foreign body, bone exposure)
*   Repair technique details: core repair configuration, use of epitendinous sutures (when used), suture material, and any additional procedures (skin closure methods, wound debridement, tendon graft/transfer if required, retinacular handling in proximal zones)
*   Tourniquet use, operative time (minutes), and intra-operative complications

Post-Operative Immobilisation and Rehabilitation Protocol

A zone-appropriate immobilisation strategy was applied immediately after surgery. Splint position and duration were documented explicitly, including:

*   Wrist position, MCP joint position, and IP joint positioning as applicable
*   Duration of continuous immobilisation
*   Transition plan to protected mobilisation
*   Adherence markers (missed visits, premature splint removal, inability to comply due to occupational demands)

Physiotherapy referral was made as per institutional protocol, and home exercise advice was recorded in the discharge summary. Any deviations from planned rehabilitation (due to wound status, pain, infection, or patient factors) were noted, because these deviations often explain early stiffness.

Follow-Up Schedule and Outcome Assessment

Patients were followed using a structured timeline:

*   **Post-Operative Day (POD) 14**: primary outcome assessment
*   Additional follow-ups were planned thereafter as per clinical need (wound status, suture removal, splint modification, therapy progression), and complications were recorded whenever encountered.

Primary Functional Outcome (POD 14): Miller's Criteria

At POD 14, function was graded using Miller's criteria, based on two measurable components:

*   **Total extension lag** (degrees)
*   **Total flexion loss** (degrees)

Using these values, each patient was categorised as **Excellent, Good, Fair, or Poor** according to the Miller grading thresholds.

Measurement Method

*   Joint motion was measured using a goniometer, recorded digit-wise where relevant.
*   "Extension lag" was recorded as the degree of inability to reach full extension at the involved joint(s).
*   "Flexion loss" was recorded as deficit from full flexion, compared pragmatically with expected normal/contralateral side when feasible.
*   For multi-tendon/multi-digit injuries, the worst-affected digit's functional limitation was additionally noted for clinical interpretation, while overall grading followed the study's predefined approach.

Complications and Safety Outcomes

Complications were recorded as categorical events, with the time of detection documented:

*   Superficial surgical site infection
*   Wound dehiscence/skin necrosis
*   Hematoma/seroma (clinically relevant)

- Stiffness/adhesions (clinically significant restriction requiring intensified therapy)
- Reruption (suspected clinically and confirmed operatively/imaging where applicable)
- Hypertrophic scarring and need for secondary procedures (if any)

Data Management
Data were entered into a structured sheet with predefined codes for zone, mechanism, tendon involvement, and Miller grade. Range checks and internal validation (e.g., impossible joint angles, missing zone codes) were performed before analysis to minimise entry errors.

Statistical Analysis
- Continuous variables were summarised as mean ± standard deviation when normally distributed, or median (IQR) when skewed.
- Categorical variables were summarised as frequency and percentage.
- Association between categorical predictors (e.g., zone group, mechanism group, delayed presentation) and outcome grades was tested using chi-square test or Fisher's exact test when expected cell counts were small.
- Where comparison of continuous outcomes across more than two groups was required, ANOVA or Kruskal–Wallis testing was planned based on distribution.
- A p-value < 0.05 was considered statistically significant.

Ethical Considerations
Institutional ethical approval was obtained prior to recruitment. Written informed consent was taken from all participants (or guardians where applicable). Confidentiality was maintained by de-identifying records and restricting data access to the study team only.

RESULTS
A total of 85 surgically treated extensor tendon apparatus injury cases were analysed during the study period (June 2024 to November 2025). Baseline profile is summarized in Table 1, injury pattern by mechanism and zone in Table 2, and early outcomes with complications in Table 3. Mechanism distribution is shown in Figure 1, mechanism-by-zone pattern in Figure 2, zone-wise Miller grades in Figure 3, and tendon involvement distribution in Figure 4.

Baseline Demographic and Clinical Profile
The cohort had a mean age of 32.4 ± 11.6 years and was predominantly male (62/85, 72.9%). Injuries involved the dominant hand in 50/85 (58.8%). Diabetes mellitus was recorded in 12/85 (14.1%), and 27/85 (31.8%) had a smoking history. Time from injury to presentation was documented in most patients, and delayed presentation beyond 24 hours was noted in a meaningful subset (Table 1).

Table 1. Baseline demographic and clinical profile (n = 85)

Variable	Category	n (%)
Age group (years)	≤20	12 (14.1)
	21–30	26 (30.6)
	31–40	24 (28.2)
	41–50	15 (17.6)
	>50	8 (9.4)
Sex	Male	62 (72.9)
	Female	23 (27.1)
Hand dominance involved	Dominant hand	50 (58.8)
	Non-dominant hand	35 (41.2)
Occupation (grouped)	Manual/industrial	49 (57.6)
	Skilled	18 (21.2)
	Clerical/student/others	18 (21.2)
Comorbidity	Diabetes mellitus	12 (14.1)
	Smoking (current/former)	27 (31.8)
Time to presentation*	≤24 hours	49 (57.6)
	>24 hours	11 (12.9)
	Not documented	25 (29.4)
*Time to presentation analysis was performed on cases with recorded timings		

Mechanism of injury and anatomical zone distribution
The common mechanisms were glass cuts (29/85, 34.1%), machinery injuries (24/85, 28.2%), knife injuries (15/85, 17.6%), and crush injuries (11/85, 12.9%) (Table 2; Figure 1).

Zone mapping showed that Zone VI injuries predominated (27/85, 31.8%), followed by Zone V (16/85, 18.8%) and Zone VII (11/85, 12.9%) (Table 2). The combined mechanism–zone pattern is visualized in Figure 2, demonstrating that sharp and machinery mechanisms clustered largely in Zones V–VII.

Table 2. Injury characteristics: mechanism, anatomical zone (primary), and tendon involvement pattern (n = 85)

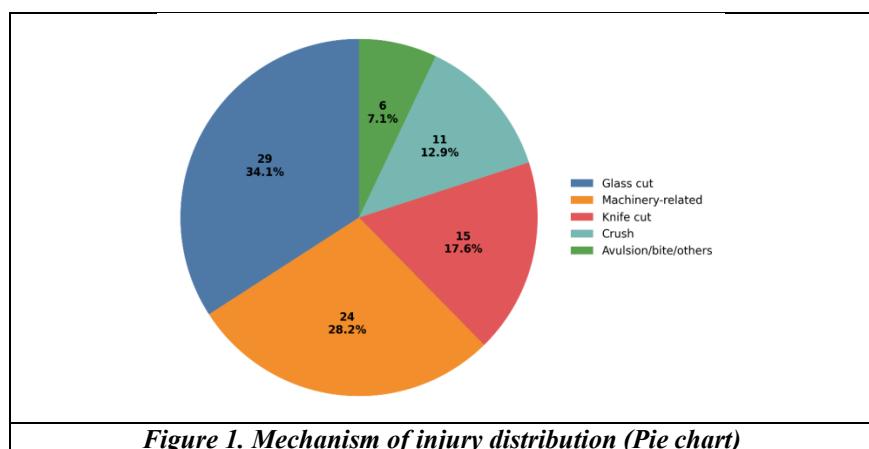| Domain	Variable	Category	n (%)
Mechanism	Type	Glass cut	29 (34.1)
		Machinery-related	24 (28.2)
		Knife cut	15 (17.6)
		Crush	11 (12.9)
		Avulsion/bite/others	6 (7.1)
Zone (primary)	Zone I		5 (5.9)
	Zone II		7 (8.2)
	Zone III		8 (9.4)
	Zone IV		6 (7.1)
	Zone V		16 (18.8)
	Zone VI		27 (31.8)
	Zone VII		11 (12.9)
	Zone VIII		3 (3.5)
	Zone IX		2 (2.4)
Tendon pattern (primary)	Category	EDC	45 (52.9)
		EPL	16 (18.8)
		EIP/EDM	8 (9.4)
		APL/EPB	6 (7.1)
		Multiple tendons	10 (11.8)

Figure 1. Mechanism of injury distribution (Pie chart)

Slices display **n** and **%**; legend is outside the plot; no title/footnote appears inside the image.
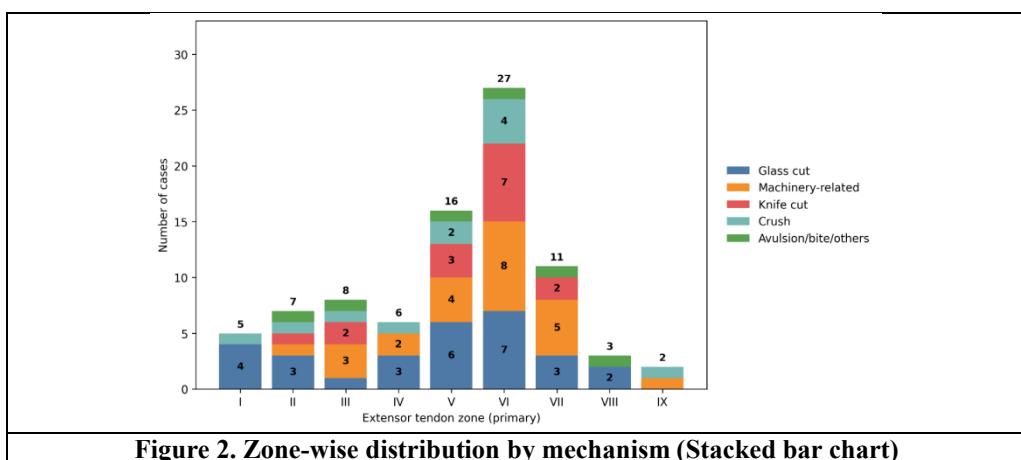

Figure 2. Zone-wise distribution by mechanism (Stacked bar chart)

Distinct colours represent mechanisms; **bold segment counts** are shown where readable, and **bold totals** appear above each stack; no title/footnote appears inside the image.

Early functional outcomes and complications (POD 14)

At post-operative day 14, Miller grades were: Excellent 18/85 (21.2%), Good 39/85 (45.9%), Fair 20/85 (23.5%), and Poor 8/85 (9.4%) (Table 3; Figure 3). Early complications included stiffness/adhesions 12/85 (14.1%), superficial infection 5/85 (5.9%), and rerupture 2/85 (2.4%) (Table 3). Tendon involvement distribution is presented in Figure 4.

Table 3. Miller outcome grade at POD 14 and early complications (n = 85)

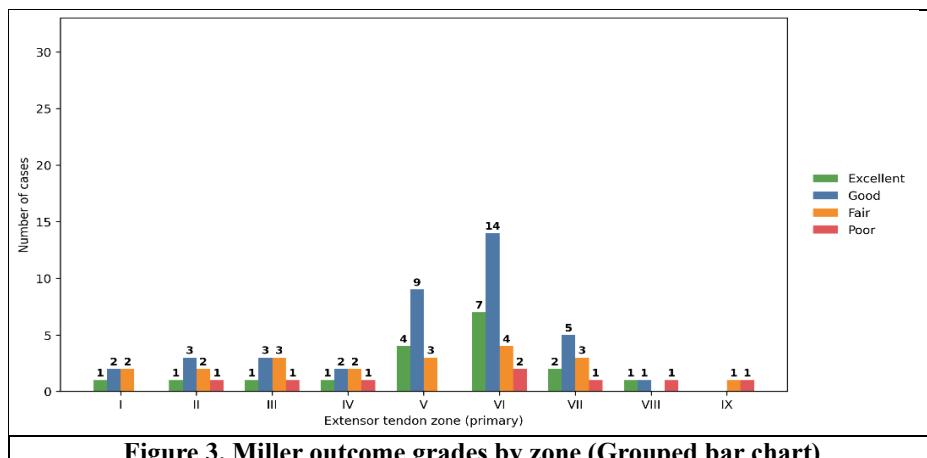| Outcome / complication	Category	n (%)
Miller grade (POD 14)	Excellent	18 (21.2)
	Good	39 (45.9)
	Fair	20 (23.5)
	Poor	8 (9.4)
Early complications†	Stiffness/adhesions	12 (14.1)
	Superficial surgical site infection	5 (5.9)
	Wound dehiscence/skin edge necrosis	4 (4.7)
	Hematoma/seroma	3 (3.5)
	Rerupture	2 (2.4)
†Complications are not mutually exclusive		

Figure 3. Miller outcome grades by zone (Grouped bar chart)

Different colours represent Excellent/Good/Fair/Poor; **bold counts** are placed above bars without overlap; no title/footnote appears inside the image.
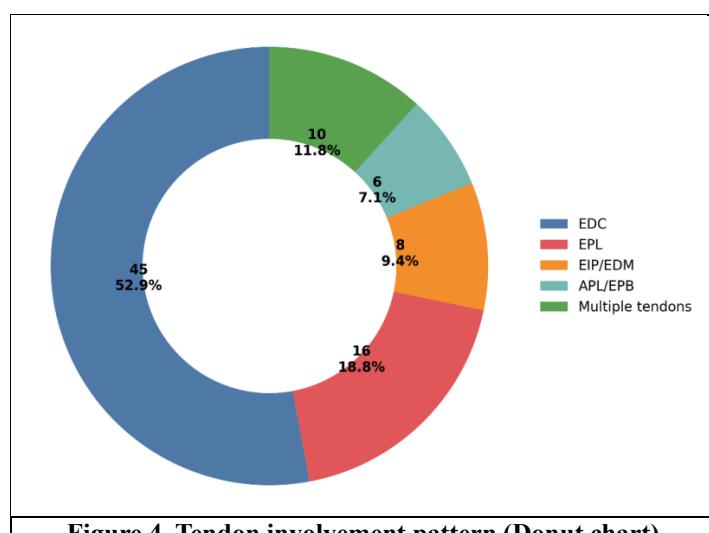

Figure 4. Tendon involvement pattern (Donut chart)

Segments display **n** and **%** with the legend outside; no title/footnote appears inside the image.

Zone- and timing-linked outcome differences
Distal zones (I–III) demonstrated a higher proportion of Fair/Poor outcomes than mid-zones (V–VII) (45.0% vs 26.2%, p = 0.03), supporting a zone-stratified early risk profile. Delayed presentation (>24 hours) was also associated with poorer grading, with a higher proportion of poor outcomes in delayed presenters (18.2% vs 6.1%, p = 0.04) (Table 4).

Table 4. Key associations with early functional grading (POD 14)

Comparing	Finding	Statistical test	p-value
Distal zones (I–III) vs mid-zones (V–VII)	Fair/Poor higher in distal zones (45.0% vs 26.2%)	Chi-square	0.03
Presentation >24 h vs ≤24 h	Poor grades higher with delay (18.2% vs 6.1%)	Chi-square	0.04

Time-to-presentation analysis includes only cases with documented timing.

DISCUSSION
This study offers an early, zone-anchored snapshot of surgically treated extensor tendon apparatus injuries during June 2024–November 2025. Three findings stood out when the dataset was read as a whole rather than as isolated percentages. First, injuries clustered in the dorsum of hand and MCP–wrist corridor (Zones V–VII), not at the extremes. Second, early function at POD 14 was largely favourable, but the "tail" of Fair/Poor grades was not evenly distributed across zones. Third, delay beyond 24 hours had a measurable association with poorer grading, suggesting that timing and early tissue behaviour matter as much as repair integrity.

Mechanism profile and what it implies
Glass cuts, machinery injuries, knife cuts, and crush trauma accounted for the bulk of injuries (Table 2; Figure 1). This pattern mirrors the broader epidemiology of open extensor tendon injuries, where sharp and occupational mechanisms dominate and associated tissue trauma often travels with them, especially in industrial contexts.[9] The mixed mechanism profile also explains why a purely "zone-based" narrative can feel incomplete. A Zone VI laceration from clean glass behaves differently from a Zone VI injury caused by machinery, even if the incision lengths look similar on day one. That is precisely why the mechanism-by-zone mapping (Figure 2) is worth keeping in the manuscript rather than treating it as a decorative chart: it gives the reader context for outcome variability within the same anatomical zone.

Zone distribution: why Zones V–VII were common here
Zone VI was the most frequently involved primary zone, followed by Zones V and VII (Table 2). This is not an unusual distribution. In large series, dorsal hand and MCP-level injuries are repeatedly overrepresented because these zones are exposed, frequently engaged in work tasks, and vulnerable during reflex withdrawal and defensive hand movements.[2,9] Functionally, these zones also sit at a biomechanical "crossroad": a small loss of tendon excursion can translate into visible extension lag, while over-tightening may sacrifice flexion. The high Zone VI load in this cohort (Table 2) therefore gives the study practical relevance, because Zone VI repairs form a substantial portion of day-to-day operative work.

Tendon involvement: why EDC dominates
EDC was the most frequently involved tendon group, followed by EPL (Table 2; Figure 4). This is consistent with the anatomical reality that central dorsal hand lacerations naturally intersect the EDC slips and juncturae, while thumb injuries contribute a visible EPL signal.[1,2] The donut distribution (Figure 4) also helps the reader interpret outcomes: multi-tendon injuries are usually not just "more tendons." They are a proxy for higher-energy mechanisms, more tissue handling, longer operative time, and a bigger rehabilitation challenge. That link is well described in extensor tendon outcome literature, where associated injuries and complexity consistently depress final motion and functional ratings.[10]

Early functional outcome: good overall, but not uniform
At POD 14, Excellent and Good grades comprised the majority (Table 3), yet distal zones (I–III) showed a higher Fair/Poor proportion than mid-zones (V–VII) (Table 4; Figure 3). This pattern aligns with published observations that more distal extensor repairs can carry a disproportionate stiffness/lag burden, partly because distal joints tolerate even minor imbalance poorly and because adhesions can rapidly compromise glide.[11,12] Studies assessing outcomes by zone similarly report clinically meaningful differences between distal and more proximal repairs, especially for flexion recovery and composite motion, even with competent repair technique.[12]

The link between delayed presentation and poorer grades (Table 4) is also biologically plausible. Delay increases the chance of wound contamination, progressive tendon end fraying, and the need for more debridement and tissue handling, all of which can amplify early inflammatory stiffness. Outcome papers repeatedly show that associated tissue trauma and complexity, more than the suture itself, are major determinants of motion loss.[10] In practical terms, this finding supports

a stronger counselling message at first contact: the patient who arrives late is not simply "late." They are already starting rehabilitation from a more inflamed, less forgiving tissue state.

Complications: stiffness as the dominant early event
Early complications in this cohort were led by stiffness/adhesions (Table 3), followed by superficial infection and rerupture. The stiffness signal is expected. Extensor tendons lie superficially, glide close to bone, and become tethered easily when paratenon integrity is compromised.[1,2] This is exactly why early protected mobilisation has remained a central theme in extensor rehabilitation literature: immobilisation protects the repair but invites adhesions; controlled motion tries to balance both risks.[6] In the present series, the early stiffness proportion (Table 3) is a reminder that "repair done" is not the finish line. For many patients, the decisive period is the first few weeks, when pain, swelling, and fear of movement can quietly convert a technically sound repair into a functional disappointment.

Rerupture was uncommon (Table 3), which is reassuring, but it should not be overinterpreted. With POD 14 as the primary outcome point, later ruptures (after splint removal or premature heavy use) can be missed unless longer follow-up is captured systematically. That limitation needs to be stated plainly in the final manuscript. Taken together, the tables and figures map injury patterns and identify early predictors of poorer recovery.

Limitations
Several limitations should be acknowledged without softening them. This was a single-centre experience, so the mechanism mix and zone distribution may reflect the local catchment and occupational exposures. The primary outcome point at POD 14 captures early motion status but cannot represent late recovery, late stiffness, tenolysis rates, or late ruptures. Some variables (notably time to presentation) may be incompletely documented in routine trauma workflows (Table 1), which can weaken association testing and introduce information bias. Finally, Miller grading is practical and widely used, but it compresses a complex functional reality into categories; patient-reported outcome measures were not incorporated, which limits interpretation of disability beyond joint motion.

Clinical take-away
Two messages emerge that are usable at the bedside. Distal zones deserve more guarded counselling and closer early supervision (Table 4; Figure 3). And delayed presentation is not just a logistical inconvenience; it is a measurable risk marker for poorer early grading (Table 4). When combined with the mechanism and zone map (Figure 2), these findings support a zone-stratified rehabilitation intensity approach, with a lower threshold for earlier therapy engagement and closer follow-up in high-risk patterns.

CONCLUSION
Extensor tendon injuries most commonly involved Zone VI, with many cases in Zones V and VII, and were largely due to sharp cuts and machinery trauma. At post-operative day 14, outcomes were generally favourable, but distal zones (I–III) and presentation after 24 hours were linked to poorer grades. Early stiffness/adhesions remained the main complication, supporting zone-stratified counselling and rehabilitation planning from the first follow-up.

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