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Original Research Article

Surgical Management of Tendon and Neurovascular Injuries in the Flexor Zones of Upper Limb and Their Outcomes

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Abstract:

Background: In the hand and forearm, there are 12 flexor tendons, including finger, thumb, and wrist flexors, with nine tendons within the carpal tunnel (four FDS, four FDP, and one FPL). Flexor tendons are most complex within finger pulleys. Intrinsic healing involves tenocyte proliferation, while extrinsic healing forms adhesions. Preventative methods include precise surgery and early mobilization. Tendon strength stabilizes initially, then substantially increases after 4 weeks. Open flexor tendon injuries, often caused by sharp cuts or crush injuries, are common. This study aims to assess the outcomes of early repair and rehabilitation for acute cut injuries in the hand and forearm flexor zones.

Methods: This Retrospective study included forty patients operated for hand injuries. Following initial examination and resuscitation, a thorough assessment of the limb was conducted, encompassing neurovascular, musculotendinous, and skeletal examinations. The integrity or damage of each tendon was evaluated. Specific investigations, including arterial Doppler and Nerve Conduction Studies or Electromyograms, were performed for each patient. Subsequently, patients underwent surgery. Exploration was done and injured tendons, vessels, and nerves were repaired. The hand was kept in a splint and the limb elevated. Physiotherapy and rehabilitation were started at the earliest.

Results: In this study, 35% of cases were between the ages of 20 to 30 years. Accidental injury occurred in 35%. The right hand was injured in 50%. Flexor Digitorum Superficialis was injured in 75% and Flexor Digitorum Profundus in 65%. Arterial injuries were at 57.5%. The median nerve was injured in 40% and the ulnar nerve in 35%. 75%of median nerve repairs and 71%of ulnar nerve repairs developed a score of S3 perception. Excellent digital flexion was obtained in 55%. 70% had an active range of flexion of more than 50°. The average grip strength achieved was up to 80% of normal. 87 % of median nerve and 57% of ulnar nerve repairs achieved M4 & M3 function. 70% returned to work by nine months.

Conclusion: Zone V was the most commonly involved. Early repair and postoperative physiotherapy facilitated better outcomes. Injuries of the wrist and forearm showed better functional outcomes and earlier return to work and activities of daily life.

Keywords: Flexor tendons, Flexor zones, Nerve conduction study, modified Kessler's technique, Klinert's protocol.

Introduction

The hand is vital for daily activities, with injuries accounting for 5-10% of emergency cases. [1] Common causes of volar wrist injuries include machine accidents, glass cuts, knife wounds, and suicide attempts. [2] Flexor zone five is particularly vulnerable due to its exposure. Lacerations in this area can be severe, affecting tendons, nerves, and arteries, compromising hand function. [3, 4] Healing of tendons is reliant on the epitendenous vascular network. Postoperative immobilization increases adhesion risk, while early mobility can impede nerve healing. [5]

In the hand and forearm, 12 flexor tendons include finger, thumb, and wrist flexors. The finger flexor tendons are flexor digitorum superficialis (FDS) and flexor digitorum profundus (FDP), with the thumb tendon being flexor pollicis longus (FPL). Wrist flexors include flexor carpi radialis (FCR),

flexor carpi ulnaris (FCU), and palmaris longus (PL). In the carpal tunnel, four FDS, four FDP, and one FPL tendon exist. The most complex portions of the flexor tendons are within the fibro-osseous sheath in the fingers. Annular pulleys maintain tendon paths close to bones and phalangeal joints. Anatomically, hand and forearm flexor tendons are categorized into five zones: 1. From FDS tendon insertion to FDP tendon terminal insertion, 2. From digital synovial sheath proximal reflection to FDS insertion, 3. From distal transverse carpal ligament margin to digital synovial sheath, 4. Area covered by the transverse carpal ligament, 5. Proximal to the transverse carpal ligament. In the thumb: 1. Distal to the interphalangeal (IP) joint, 2. IP joint to A1 pulley, 3. Thenar eminence area. Kleinert and associates introduced a controlled active extension–passive flexion motion protocol for rehabilitation, utilizing a dorsal protective splint with wrist flexion, MCP joint flexion, and IP joint extension. Rubber bands assist in active finger extension, with a modification featuring a palmar bar for increased flexion of PIP and DIP joints. At night, bands are removed, and fingers are splinted in extension to prevent contractures.

Material and Methods

This retrospective study included 40 patients (36 male, 4 female) with flexor zone injuries who were operated in the Department of Plastic Surgery in a tertiary care hospital. Only those patients in whom plastic surgery was of primary importance were taken into study. Those with other injuries, like head injury, abdominal trauma, multiple traumas, and patients with associated skeletal injuries were excluded from the study. After preliminary examination and resuscitation, a complete and detailed examination of the limb was done which included neurovascular, musculotendinous, and skeletal examination. The intactness or injury of each tendon was assessed. Arterial Doppler and Nerve Conduction Studies, or Electromyogram were the specific investigations done for every patient. After investigations, the patients were operated on at the earliest. All the patients were operated under either general anesthesia or nerve blocks. Electronic tourniquet control was used to control blood loss and keep the operating field clear. The surgeries were done under magnification for clear identification of structures. As the skeletal injury patients were excluded, tendons were repaired first followed by nerves, and lastly vessels.

Tendons were repaired with core and epitendinous sutures. Core suturing was by Modified Kessler's technique with Prolene 3-0 and epitendinous suturing was with Prolene 4-0. Arterial repair was done with Prolene 8-0. Nerves were repaired with epineural suturing using Prolene 8-0. Postoperatively, the hand was kept in a Plaster of Paris splint in universal flexion for the structures repaired, and the limb was kept in elevation. Physiotherapy and rehabilitation were initiated as early as 24 hours of surgery. We followed Kleinert's protocol. In the first three weeks, active extension and passive recoil against rubber band traction were instructed. Passive proximal interphalangeal joint (PIP) and distal interphalangeal joint (DIP) motion were advised within the restraints of the dorsal-blocking splint four times per day. A universal flexion splint was removed at the end of three weeks and a dorsal blocking splint was made to be used. After three weeks and until six weeks, active composite flexion and active extension were made to be done, with the wrist in a neutral position. Between six and nine weeks, gentle passive extensions were allowed with active flexion and extension. Between nine and twelve weeks, passive flexion was added to the previously allowed movements. Firm squeezing was advised against a foam ball. After 12 weeks, the patient is advised to resume normal activities within manageable limits.

Different parameters that were studied and analyzed were:

I. Vascular Patency after repair

II. Sensory and motor assessment of Nerve repair

III. Active range of motion of the fingers and wrist joint

IV. Grip strength was evaluated.

V. Time for return to work was taken as a measure to assess functional recovery

Statistical Analysis: All the available data was refined and uploaded to an MS Excel spreadsheet and analyzed by SPSS version 21 in Windows format. The continuous variables are depicted as mean, standard deviation, and percentages, and categorical variables were analyzed by chi-square test for significance. The value of p (<0.05) was taken as significant.

Results

Patients were instructed to be on regular follow-up to assess their progress and rehabilitation was advised at each visit. At each follow up the patient's progress was noted. There were thirty-six (90%) males and four (10%) females in the study. Six patients (15%) were aged less than 20 years, fourteen patients (35%) were between 20 and 30 years of age, ten patients (25%) were between 31and 40 years, six patients (15%) were between 41 and 50 years and another four patients (5%) were aged above 50 years. The most frequent mode of injury was accidental from machinery at workplaces and was noted in 35% followed by road traffic accidents in 30%. Other modes included cuts due to glass, suicidal attempts, and assault. (Table I)

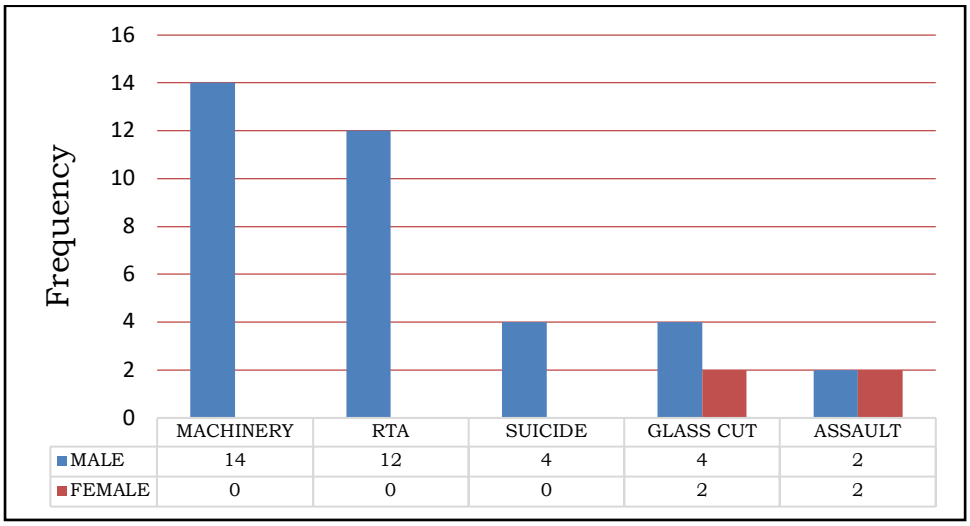

Figure 1: Mode of injury in the cases of the study

Hand Dominance: 80% were right-hand dominant. Of the 40 patients, 20 patients (50%) had a right-hand injury, 18 had left hand (45%), and both hands were involved in 2 patients (5%). **Zones Involved:** The frequently involved zone was Zone V at 60%, followed by Zone IV at 27.5%, and multiple zones were involved at 25%. There was no patient with zone I injury. All four (10%) females had Zone II injury (Table 1)

Table 1: Showing the zones of injury in n=50 cases of the study

Zones	Frequency	Patients with single-zone Injury
I	0	0
II	4	4(10%)
III	7	5(12.5%)
IV	14	12(27.5%)
V	25	21(50%)
Multiple	10(25%)	00(00%)

Timing Of Surgery: 28(70%) patients were operated within three days of injury, n=12(30%) were operated three days later. **Surgery:** Primary exploration with repair of the injured structures and splinting in appropriate position was done in all patients. The incision /injury site was primarily closed in all patients. A flap was not needed to cover repaired tendons, in any.

Table 2: Showing the tendons involved in the cases of the study

Structures	Frequency
FDS	30
FDP	26
FCR	16
PL	12
FCU	8
FPL, BR	4

Tendons: The long Flexors were the most frequently injured. 75% had Flexor Digitorum Superficialis (FDS) and 65% had Flexor Digitorum Profundus (FDP) injured. This was followed by Flexor Carpi Radialis (FCR) in 40% and Palmaris Longus (PL) in 30%. Flexor Carpi Ulnaris (FCU) was injured in 20%. The Flexor Pollicis Longus (FPL) and Brachioradialis were the least involved in 10%. (Table 2) *Arteries;* Of the 40 patients, 23 patients (57.5%) had arterial injuries. The Ulnar artery alone was involved in eight patients (20%), the radial artery alone was injured in fifteen patients (37%) while both ulnar and radial were involved in three patients (7.5%). (Table 3) *Nerves:* Median nerve was involved in 16 (40%) and ulnar nerve was involved in 14 (35%) both structures were injured in 2 (5%). No nerve grafts were needed in any patient. (Table 3) Number of Surgeries: Thirty-six patients (90%) underwent one procedure, while four (10%) underwent two or more procedures. *Complications:* Four patients (10%) had surgical site infections. The other complications included hematoma and

compartment syndrome that occurred in two patients each (5%).

Table 3: Arteries and Nerves Repaired in the cases of the study

	Artery Repaired	Nerve Repaired
Radial	15(37%)	16(40%)
Ulnar	8(20%)	14(35%)
Both	3(7.5%)	2(5%)

Hospital Stay: Twenty-six patients (65%) were discharged within 5 days of surgery. The rest had to stay for a few more days due to complications (Figure 2) *Follow Up:* Thirty-two patients (80%) attended between 5 to 9 follow-up clinics. Six patients (15%) attended more than 10 follow-ups.

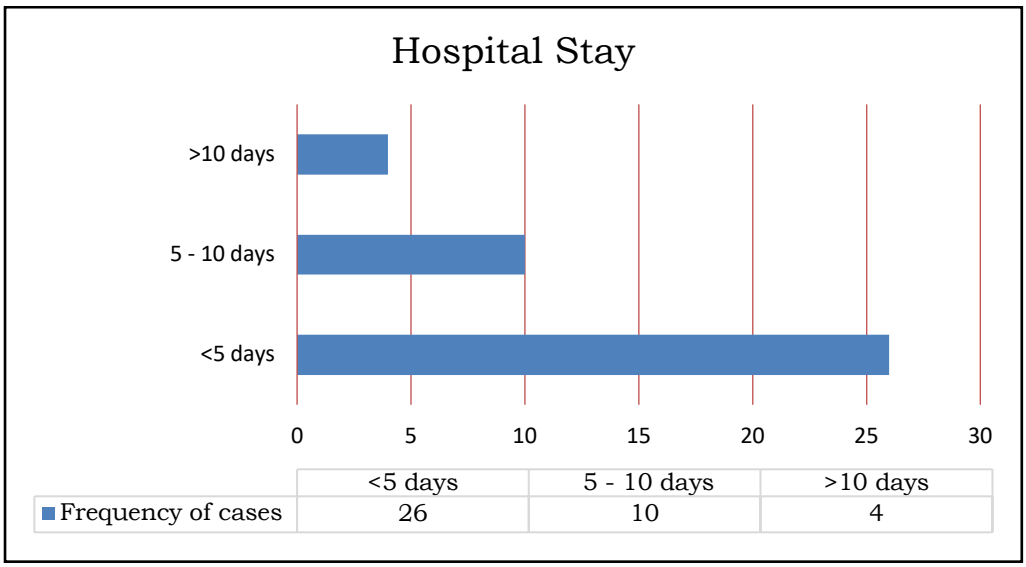

Figure 2: Showing the duration of hospital stay in cases of the study

Nerve Assessment: Sensory: Recovery was assessed by evaluating Tinel's sign and its advancement during recovery. Electrophysiological studies like the Nerve Conduction Study (NCS) and Electromyography(EMG) are done. The study results were given scoring for sensory perception as (S0 to S4). Twelve patients (75%) with median nerve repair had S3 perception and 10 patients (71%) with ulnar nerve repair also had a score of S3 perception. (Table 4) In 2-point discrimination testing, 30 patients (75%) could discriminate <15mm stimuli and 10 other patients (25%) required stimuli to be at least 15mm apart to be discriminated.

Table 4: Depicting the sensory nerve assessment following the surgery

Nerve	Frequency	Sensory Perception (S 0-4)	
Median	16	12(75%)	S3
		4(25%)	S2
Ulnar	14	10(71.2%)	S3
		4(28.5%)	S2

Motor: Strickland's formula for Active range of motion for fingers and wrist joints was used to evaluate the motor recovery. *Strickland's Adjusted Formula = [(DIP + PIP) flexion-extension deficit x 100/175 degrees = % normal]* The results were analyzed after 12 weeks of injury and also later at three months and six months. Of the total 40 patients in whom primary tendon repair was done, excellent digital flexion was achieved in 22 (55%) patients. In 10 patients (40%), the result was good. And fair amount of digital flexion could be achieved in eight (5%) patients. Of the four patients in whom Flexor Pollicis Longus was repaired, thumb flexion was graded excellent in three (75%) patients and good in one (25%) patient. Motor assessment was done at every follow-up and the recovery was graded from M0-M4. Test for active range of flexion at the joints also was assessed. Of 16 median nerves repaired, 14 (87.5%) had a score of M4, and two had M3 power. Of 14 ulnar nerve repairs, eight (57.1%) could get a power of M3, and six (42.9%) had a power of M2**.** (Table 5). *Range of motion;* N=28 patients (70%) had an active range of flexion of more than 50^{o} at the joints after surgery. In 12(30%) patients, the

range of movements was less than 50º of flexion which improved with physiotherapy.

Table 5: Depicting the motor nerve assessment following the surgery

Nerve	Frequency	Motor Function (M 0-4)	
Median	16	14(87.5%)	M4
		2(12.5%)	M3
Ulnar	14	8(57%)	M3
		6(42%)	M2

Table 6: Zone-wise assessment of the outcome following the surgery

Zone	Total Patients	Structures Involved				Arterial-Patency	Nerve Function		Tendon (TAM)
		Tendon	T+N	T+A	T+A+N		Sensory	Motor	
II	4	4	-	-	-	-	S4	M3	Fair
III	7	5	2	-	-	-	S3	M3	Good
IV	14	1	5	2	6	Patent	S3	M4	Good
V	25	3	6	5	11	Patent	S4	M4	Excellent

Grip Strength: The power of grip strength was evaluated by using a Dynamometer. This was compared to the normal side. The average grip strength achieved was 80% of the normal side.
Nerve Conduction Studies: Despite axonopathy, 87 % of patients of median nerve, and 57% of ulnar nerve repairs, achieved M4 & M3 motor function.
Arterial Patency: Handheld Doppler was used to test the vascular patency. No patient in this study had to undergo re-exploration for ischemia of the distal limb. Arterial patency was tested at one, two, four, and six-month follow-ups. The radial artery was repaired in 16 patients and the ulnar artery was repaired in eight patients. All patients had patent arteries during these follow-ups.
Average Return to Work: patients who were operated on within three days of injury, returned to work by nine months. Those operated three days after injury had delayed recovery. The average time of return to work was 13 months. Overall functional outcome (Table XII) and Zone wise assessment shown in (Table 6)

Discussion

Injuries to the distal forearm, wrist, and hand on the volar surface are common and debilitating. This is mainly due to the superficial location and high density of the tendons, nerves, and arteries in that area. [6] A balanced postoperative care and rehabilitation customized for each patient is necessary because prolonged immobilization during the recovery period increases the propensity for adhesions in tendons, while early mobility impairs nerve healing. Tuncali et al. [2] studied a total of 228 patients with various types of upper extremity structure injuries. They concluded that tendon and nerve repairs had good results in younger patients. In this study, 35% of patients with volar wrist injuries were aged 20-30 years age. Most of the patients in this study had accidental injuries rather than suicidal or homicidal injuries. All patients were cooperative and motivated to undergo surgery and were willing to undergo physiotherapy and rehabilitation in the postoperative period. Strickland et al. [7] is a proponent of early flexor tendon repairs. In this study, early intervention was done within three days of injury in 70% of the patients. Yiltok et al. [8] reported that primary nerve repair has a superior outcome. In this study, 87 % of patients with median nerve and 57% with ulnar nerve repairs achieved M4 and M3 motor function because of early intervention in the repair of cut ends. In our study, median nerve repair had better outcomes than ulnar nerve repair did. Nerve conduction studies have shown regenerative changes in all repaired nerves, but the results of these studies did not always correlate with clinical findings. All arterial repairs were patent during the follow-up. It has been proposed that controlled early stress promotes the healing process of tendons. Prolonged rest after tendon injury repair may be responsible for the adhesion formation. [9] This is an important limiting factor for the final recovery and return of function after tendon repair. This was also demonstrated in an elaborate study by Hung et al. [10] In this study, 24 patients (60%) underwent arterial repair, and 30 patients (75%) underwent nerve repair. Combined nerve, artery, and tendon repair was performed in 17 patients (42%). Tendon and artery repairs were done in seven patients (17.5%). Isolated tendon repair was performed in 13 patients (32.5%). Most patients achieved average M4 motor recovery and S3 sensory recovery. 78% of Zone IV and V injury patients returned to work by nine months. In comparison, zone II and III patients had a prolonged recovery period and had to undergo prolonged physiotherapy and multiple follow-ups.

Conclusion

Hand injuries require a focused, multidisciplinary approach. In this study, Zone V was the most

commonly involved area. Early repair and good postoperative physiotherapy have resulted in better outcomes. Sensory recovery of the median and ulnar nerves was similar. Assessment of motor function showed that the ulnar nerve lagged behind the median nerve in terms of motor recovery. Most patients could return to work within nine months. Early mobilization and involvement of physiotherapists in the team helped in the better management of acute volar wrist injuries and decreased postoperative functional disability. Injuries to the wrist and forearm provide better functional outcomes and earlier return to work and activities of daily life than patients who presented with injuries to the hand.

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