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ORIGINAL ARTICLE

Factors affecting functional outcomes after surgery to repair extensive volar forearm lacerations with nerve injuries identified via quantitative and qualitative methods

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ABSTRACT

Objectives: We aimed to investigate factors affecting the functional outcomes of patients with extensive volar forearm lacerations combined with nerve injuries who underwent surgery.

Patients and methods: Between January 2012 and December 2018, a total of 71 patients (58 males, 13 females; mean age: 41±12.1 years; range, 20 to 66 years) with extensive volar forearm lacerations treated in our center were retrospectively analyzed. Demographic data and injury details of the patients were recorded. The functional results were quantitatively evaluated using the Rosén-Lundborg protocol (RLP) and qualitatively evaluated using the Quick Disability of Arm, Shoulder, and Hand (QuickDASH) scale.

Results: The mean follow-up time 69.8±36.7 (range, 18 to 148) months. The mean final RLP and QuickDASH scores were 2.17±0.4 and 8.03±10.55, respectively. There were no major complications such as infection, necrosis, re-rupture of a structure, or amputation. Patients with combined median and ulnar nerve injuries had poorer RLP scores than the others. Patients with combined median and ulnar nerve injuries, combined radial and ulnar arterial injuries, and who were of low education status, had lower QuickDASH scores than the others.

Conclusion: The main factors affecting long-term functional outcomes are a combined artery or nerve injury and a low education status. Favorable results can be achieved with the cooperation of experienced surgeons and hand rehabilitation specialists for patients with severe hand injuries.

Keywords: Artery repair, intrinsic function, median nerve, sensation, ulnar nerve.

The tendons and neurovascular structures of the volar forearm lie very close to the skin. Thus, these structures are often injured in patients with volar forearm lacerations.[1] During hand surgery, it is challenging to avoid peripheral nerve damage in the volar forearm and wrist areas; such damage typically is associated with poor functional outcomes. Young adults are more prone to hand injuries that usually involve the dominant hands. The incidence is particularly high among the working population.[2] Complex hand injuries may cause lifelong impairment associated with social and economic difficulties.[3,4] Many researchers have sought factors influencing the functional recovery of patients with extensive volar forearm lacerations. Advanced patient age, more proximal injuries, injuries to the ulnar nerve (compared to the median nerve), injuries to multiple nerves, and concomitant injuries to tendons and arteries predispose to poor outcomes.[5-9] Primary repair as soon as possible, close follow-up, and appropriate rehabilitation are of the utmost importance while seeking favorable outcomes.[10,11]

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Given the complexities of such injuries, it is difficult to measure the functional results after treatment. Although there are several assessment tools described in the literature, most are subjective tools.[7-10] Rosén and Lundborg[12] developed a quantitative method for evaluating functional outcomes after wrist and distal forearm nerve injuries. It is also important to evaluate competence in the activities of daily living (ADLs). The short version of the Disability of Arm, Shoulder, and Hand (DASH) questionnaire (QuickDASH) is widely used to evaluate the ADL in those with upper extremity problems.[13]

In the present study, we aimed to investigate factors influencing the outcomes of extensive volar forearm lacerations accompanied by nerve injuries using quantitative tools.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Mersin University Faculty of Medicine, Department of Orthopedics and Traumatology, Division of Hand Surgery. he electronic medical records of all patients with extensive volar forearm lacerations treated in our center between January 2012 and December 2018 were screened. Adults who sustained an acute, complete median and/or ulnar nerve injury after extensive volar forearm laceration, who underwent surgery within 24 h, and for whom at least 12 months of documented follow-up data were available, were included. Patients with osseous pathologies, significant skin defects, crush injuries, prior ipsilateral injuries, and for whom follow-up data were incomplete were excluded. Finally, a total of 96 patients who met the inclusion, but not the exclusion criteria, were telephoned and invited to final follow-up visits. Of them, 71 (58 males, 13 females; mean age: 41±12.1 years; range, 20 to 66 years) who gave consent for the participation in the study were recruited.

Surgical technique and rehabilitation protocol

Our center is a hand trauma center accredited by the Federation of European Societies for Surgery of the Hand in the years 2015 to 2018; all surgeries were performed by an experienced (Level III) operator.[14] After preoperative clinical assessment, broad-spectrum antibiotics and anti-tetanic serum immunoglobulin were administered, if necessary, to all patients. All surgeries were performed with patients under general anesthesia within 24 h of injury. A pneumatic tourniquet was applied. All injured tendons, nerves, and vessels were repaired during surgery. The repair sequence was dictated by the preoperative blood flow in the hand. Arterial repair was performed first, if arterial injuries disrupted blood flow. For such repairs, we employed an interrupted suture technique using 8-0 polypropylene. For tendon repair, we used a four-strand core suture technique employing 3-0 or 4-0 polypropylene sutures reinforced with a 4-0 or 5-0 interlocking epitendinous repair. For nerve repair, we employed an epineural suture technique using 8-0 polypropylene. Arterial and nerve repairs were performed under microscopic magnification. All repairs were primary in nature; there was no need for a vascular or neural graft. Postoperative rehabilitation followed the modified Duran protocol.[15] After surgery, a dorsal, extension block splint was placed for one month with the wrist flexed at 15°, the metacarpal phalangeal joints flexed at 20°, and the interphalangeal joints in full extension. On postoperative Day 3, passive finger flexion and extension to the boundaries of the splint were initiated. Active flexion was not permitted until one month after surgery. At six weeks, the splint was removed, tendon gliding exercises were initiated, and light ADLs were encouraged. At eight weeks, light resistive exercises were initiated and, at 12 weeks, all activities were allowed.

Data collection and clinical assessment

Age, sex, education status, smoking status, the cause of injury, hand dominance, the affected side, the level of injury, and transected structures were recorded. Quantitative assessment of functional outcomes was based on the parameters of Rosén and Lundborg.[12] The Rosén-Lundborg protocol (RLP) model quantifies the functional outcomes of patients after median or ulnar nerve repairs to the wrist or distal forearm. The model includes sensory (sensory innervation, tactile gnosis, and finger dexterity), motor (motor innervation and grip strength), and pain/discomfort (hyperesthesia and cold-intolerance) domains. The sensory domain was evaluated using Semmes-Weinstein monofilaments.[16] and tactile gnosis was assessed via two-point discrimination.[17] and shape/texture identification (STI).[18] Three shapes and three simplified textures were offered for identification in an increasing order of complexity. Finger dexterity was assessed using three tasks from the Sollerman test[19] (No. 4: pick up coins, No. 8: place nuts on bolts, No. 10: fasten a button). The manual muscle strength test,[20] which is scored from 0 to 5, and a Jamar dynamometer (Sammons Preston Rolyan, Nottinghamshire, UK) that measures grip strength, were used to evaluate the motor domain. The average of three consecutive measured values was taken.

TABLE I
The Rosén and Lundborg protocol for functional assessment

Sensory Domain		
Innervation Critical Sites: Median: Tip of first finger, tip and base of second finger Ulnar: Tip and base of fifth finger, proximal hypothenar 	Sammes-Weinstein monofilaments 0=not testable 1=filament 6.65 score range: 0-15 2=filament 4.56 maximum score for the median nerve: 15 3=filament 4.31 maximum score for the ulnar nerve: 15 4=filament 3.61 5=filament=2.83	Score=measured value/maximum score
Tactile Gnosis	Two-point discrimination (s2PD) (Second and fifth finger) 0= ≥ 16 mm score range: 0-3 1=11-15 mm maximum score: 3 2=6-10 mm 3=≤ 5 mm	Score=measured value/maximum score
	Shape/Texture Identification Test (STI) Score range: 0-6 (Second and fifth finger) maximum score: 6	Score=measured value/maximum score
Dexterity	Sollerman test score range: 0-12 (tasks 4, 8, and 10) maximum score: 12	Score=measured value/maximum score
Mean sensory domain score:		The mean value of the sensory subdomains
Motor Domain		
Innervation	Manual muscle test score 0-5 Median: Palmar abduction Ulnar: Abduction of second and fifth finger, adduction of fifth finger Score range for the median nerve: 0-5 Score range for the ulnar nerve: 0-15 Maximum score for the median nerve: 5 Maximum score for the ulnar nerve: 15	Score=measured value /maximum score
Grip strength	Jamar dynamometry (kg) Mean of three consecutive measurements, affected and unaffected hands. Maximum score: Result for the unaffected hand	Score=measured value/maximum score
Mean motor domain score:		The mean value of the motor subdomain scores
Pain/Discomfort Domain		
Cold-intolerance or hyperesthesia	Patient perception 0=Not functional score range: 0-3 1=Disturbing maximum score: 3 2=Moderate 3=Functional; only a minor problem	Score=measured value/maximum score
Mean pain/discomfort score:		Mean cold-intolerance and hyperesthesia values
Total Score:		Sum of the scores on the sensory, motor, and pain/discomfort domains

During the tests, the elbow was flexed at 90°, and the forearm and wrist were held in the neutral positions. Using a scale from 0 to 3, each patient was asked to rate the severity of difficulties attributable to hyperesthesia and cold-sensitivity.[21] The total score of the RLP ranged from 0 to 3, with a maximum of 1 point from each domain (Table I). The QuickDASH questionnaire.[13] was used to evaluate ADL capacity (score from 0 [no disability] to 100 [most severe disability]). High QuickDASH scores or low RLP scores indicate the severity of the injury. The Allen test[22] was used to assess hand circulation the at the final follow-up. All tests were performed by a single researcher with an eight year of surgical experience in the same room using the same equipment.

Statistical analysis

Statistical analysis was performed using the SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive data were expressed in mean ± standard deviation (SD), median (min-max) or number and frequency, where applicable. After confirming the normality of all relevant variables, relationships among the variables were explored, as appropriate, using Pearson correlation analysis, cross-table chi-square statistics, the t-test for the independent groups of pairwise group comparisons, and one-way analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA) for the comparison of more than two groups. The least significant difference post-hoc test was used to identify groups that differed significantly in the ANOVA. A p value of <0.05 was considered statistically significant.

RESULTS

The mean follow-up time 69.8±36.7 (range, 18 to 148 months). Of all patients, 27 (38%) were graduated from primary school, 17 (23.9%) from secondary school, 17 (23.9%) from high school, and 10 (14.1%) from university. Thirty-two (45.1%) were smokers and 39 (54.9%) were non-smokers. Sixty-two (87.3%) were right-handed and nine (12.7%) were left-handed. The dominant extremity was injured in 36 (51%) and the non-dominant extremity in 35 (49.9%). The levels of injury were the proximal third in seven (9.9%), the middle third in 12 (16.9%), and the distal third in 52 (73.2%). The causes of injury were punching glass in 25 (35.2%), saw lacerations in 20 (28.2%), knife lacerations in 10 (14.1%), and a variety of other rare causes in 16 (22.5%). Twenty-seven patients (38%) had median, 31 (43.7%) had ulnar, and 13 (18.3%) had combined median and ulnar nerve lacerations. Forty-nine patients (69%) had associated vascular injuries, thus ulnar artery injuries in 38 (53.5%), radial artery injuries in five (7%), and combined radial and ulnar artery injuries in six (8.5%). All patients had tendon injuries; a mean of 5.36±3.59 (range, 1 to 11) tendons were lacerated.

The mean RLP and QuickDASH scores for all patients were 2.17±0.4 (range, 1.2 to 2.9) and 8.03±10.55 (range, 0 to 65.9), respectively (Figure 1 and 2). At

FIGURE 1. A 45-year-old male patient. The cause of injury was saw laceration. Clinical photographs of 31 months after surgery.

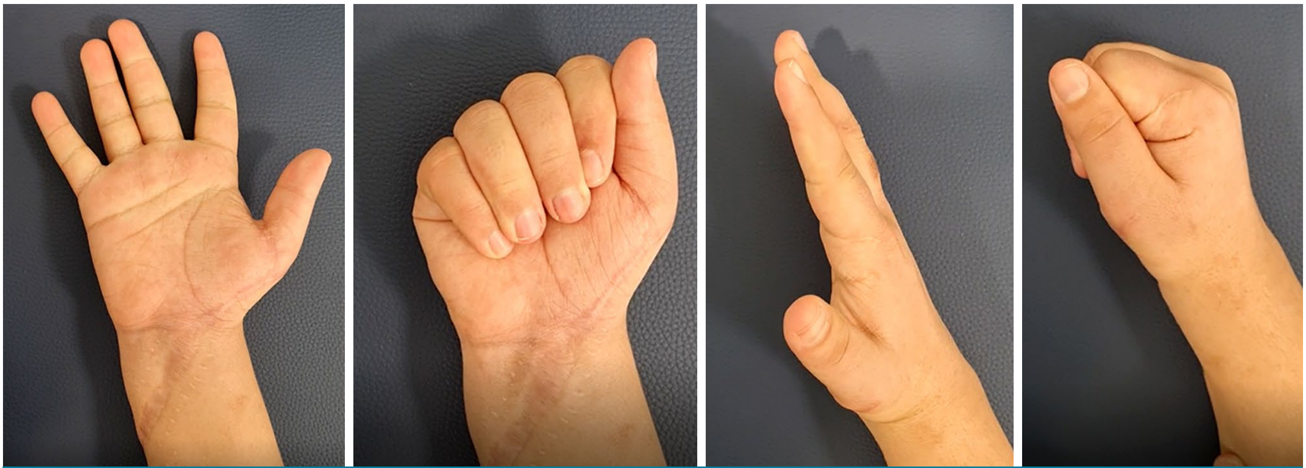

FIGURE 2. A 22-year-old male patient. The cause of injury was punching glass. Clinical photographs of 47 months after surgery.

the final follow-up, the Allen test revealed that only the radial artery in 28 (39%), only the ulnar artery in five (7%), and both arteries in 38 (54%) patients were intact. There was no major complication such as an infection, necrosis, re-rupture of a structure, or amputation. None of age, sex, smoking status, injury side, the level or mechanism of injury, or the associated tendon injuries significantly affected nerve recovery (Table II). The nature of the artery providing blood to the hand did not affect the functional scores at the final follow-up (Table II). Education status did not affect the RLP scores, but the mean QuickDASH score of primary school graduates was significantly poorer than those of others. The mean QuickDASH and RLP scores of patients with combined median and ulnar nerve injuries were significantly poorer than those of patients with single nerve injuries (ulnar or median). The mean QuickDASH score of patients with combined ulnar and radial artery injuries was significantly poorer than those of others (Table II).

DISCUSSION

Extensive volar forearm lacerations may have lifelong consequences, if not treated appropriately. Even minor tendon lacerations with nerve involvement can be catastrophic.[23] Assessment of functional outcomes after forearm nerve repair is challenging. An optimal tool should assess the motor, sensory, and pain domains. In addition, the test should be easy to understand, simple to perform in a standardized manner, not induce patient fatigue or pain, and be rapid and inexpensive.[12,24] We used the QuickDASH questionnaire to assess ADL but also the RLP, which is valid, reliable,[5,12] and evaluates functional outcomes objectively.

Long-term follow-up is essential while evaluating the functional outcomes of nerve repair. Previous studies have reported relatively short follow-up periods.[4,9-11] In the present study, the mean follow-up period was 69.8±36.7 months. Therefore, our results more reliably reveal the functional outcomes after surgery to treat extensive volar forearm lacerations with nerve injuries.

Several studies assessing the functional outcomes of extensive volar forearm lacerations have reported controversial outcomes, with excellent results in 46%,[25] 48%,[10] and 63%[9] of patients. All functional evaluations featured subjective assessments. Very few studies used the RLP. Galanakos et al.,[5] reported that the mean RLP score of 73 patients was 2.48. Vordemmenne et al.,[26] reported that the median RLP and DASH scores were 2.12 and 21.98, respectively. In the present study, the mean RLP and QuickDASH scores were 2.17 and 8.03, respectively, indicating satisfactory long-term functional outcomes (Figure 1 and 2).

Although the repair sequence of damaged structures is usually from deep to superficial, no consensus has emerged on the optimal repair of tendon, nerve, and arterial injuries in the volar forearm. The most common tendon repair strategy is the modified Kessler method. Repairs of neurovascular structures require microsurgery performed by an experienced surgeon.[23,27] Early postoperative rehabilitation is recommended, but an optimal protocol remains unclear.[28] In our study, the surgical technique and postoperative rehabilitation were standardized, and all surgeries were performed by experienced hand surgeons in a tertiary referral center.[29]

TABLE II
Summary of statistical analyses

		QuickDASH score		RLP score	
Variables	n	Mean±SD	*p*	Mean±SD	*p*
Age (years)			0.330		0.396
20-29	16	3.55±3.98		2.28±0.34	
30-39	17	10.55±16.04		2.16±0.48	
40-49	20	8.89±10.1		2.14±0.38	
50-59	13	7.74±7.31		2.04±0.4	
≥60	5	11.08±9.25		2.38±0.29	
Sex			0.596		0.731
Male	58	8.26±11.55		2.14±0.52	
Female	13	7±4.44		2.3±0.52	
Level of education			**0.010**		0.095
Primary school	27	12.8±14.6		2.12±0.47	
Secondary school	17	6.19±4.66		2.08±0.3	
High school	17	3.7±4.94		2.37±0.37	
University	10	4.56±6.7		2.2±0.33	
Smoking status			0.543		0.533
Smoker	32	8.79±8.99		2.03±0.53	
Non-smoker	39	7.4±11.83		2.24±0.51	
Injury side			0.117		0.047
Dominant	36	5.99±11.93		2.15±0.47	
Non-dominant	35	10.1±8.76		2.19±0.56	
Level of injury			0.396		0.995
Proximal third	7	8.12±6.94		2.23±0.48	
Middle third	12	11.7±18.5		2.1±0.42	
Distal third	52	7.14±8.43		2.17±0.3	
Mechanism of injury			0.906		0.147
Punching glass	25	6.44±13.5		2.2±0.41	
Saw laceration	20	6.69±7.2		2.16±0.42	
Knife injury	10	13.9±8.28		2.08±0.46	
Others	16	8.46±9.32		2.2±0.32	
Nerve injury			**0.011**		**0.020**
Median nerve	27	6.77±7.06		2.37±0.33	
Ulnar nerve	31	4.72±6.6		2.14±0.34	
Combined	13	18.5±16.77		1.84±0.44	
Associated vascular injury			**0.025**		0.659
None	22	7.26±8.08		2.27±0.31	
Radial artery	5	4.18±4.68		2.31±0.26	
Ulnar artery	38	7.97±8.54		2.1±0.42	
Combined	6	14.3±25.7		2.14±0.58	
Associated tendon injury			0.066		0.575
0-4 tendons	31	6.33±8.16		2.2±0.37	
5-9 tendons	26	7.03±6.84		2.13±0.37	
≥10 tendons	14	13.6±17.7		2.18±0.52	
Arterial flow at the final follow-up			0.582		0.281
Radial only	28	6.95±6.24		2.19±0.38	
Ulnar only	5	4.18±4.68		2.38±0.36	
Both intact	38	9.32±13.2		2.13±0.4	

DASH: Disability of Arm, Shoulder, and Hand; SD: Standard deviation; RLP: Rosén-Lundborg protocol.

As in previous studies, punching glass caused most injuries (35.2%), particularly in young men.[4,9,10] The frequencies of median and ulnar nerve involvement (38% and 43.7%, respectively) were comparable. The mean number of tendon injuries accompanying a nerve injury was 5.36. Ulnar artery injury (53.5%) was the most common concomitant artery injury. The median nerve and the ulnar artery are injured more frequently than are the ulnar nerve and the radial artery.[30,31] The reason for the high incidence of ulnar nerve injury in our study is that most injuries were large lacerations extending to the ulnar side.

Given the complexities of the injuries, it is difficult to accurately assess prognosis after an extensive volar forearm laceration with a nerve injury. It has been suggested that younger age, not smoking, a shorter time between injury and repair, a distal injury, a clean-cut injury, a single (not two) injured nerve(s), a median (not an ulnar) nerve injury, and the lack of a concomitant artery and/or tendinous injury are associated better functional outcomes.[1,8,12,26,32] Leclercq et al.[33] found that ulnar nerve repair afforded better functional outcomes, when concomitant artery repair was successful. Keleş et al.[34] reported that patients with patent arteries showed better functional outcomes. De et al.[35] suggested that a low education status was negatively prognostic of spaghetti wrist injury outcomes. We considered more possible prognostic factors than previous studies. The mean RLP and QuickDASH scores of patients with combined nerve injuries were poorer than those of patients with single nerve injuries. A lower QuickDASH score was associated with a low education status and combined radial and ulnar artery injuries. The functional outcomes were unaffected by age, sex, smoking, dominant or non-dominant extremity injury, injury level, injury mechanism, number of concomitant tendon injuries, and arterial flow status at the final follow-up.

Vordemvenne et al.[26] reported that DASH and RLP scores were significantly correlated, although there was a discrepancy in some variables, and they recommended to use combined DASH and RLP scores for the functional assessment of nerve injuries. Likewise, there was a discrepancy between the QuickDASH and RLP scores for some variables in the present study. The reason of this is the different aims of the assessment tools. The primary aim of the QuickDASH evaluation is to determine the impact of the injury on the patient's ADLs, while the aim of the RLP evaluation is to reach a more comprehensive quantitative conclusion with sensory, motor and pain/discomfort domains. We believe that both QuickDASH and RLP tests are reliable and usable, but quantitative tests such as RLP provide more objective and accurate information about prognosis.

Nonetheless, there are some limitations to this study. First, the study has a single-center, retrospective design. Second, patients with extensive skin defects and crush injuries were not included. Of note, the RLP protocol, which is extremely difficult to perform, and the long follow-up period, distinguish our study from previous works.

In conclusion, our study results suggest that many factors associated with poor prognoses in previous studies do not affect the results of long-term follow-up. The main factors affecting long-term functional outcomes are a combined artery or nerve injury and a low education status. Favorable results can be achieved with the cooperation of experienced surgeons and hand rehabilitation specialists for patients with severe hand injuries.

Ethics Committee Approval: The study protocol was approved by the Mersin University Faculty of Medicine Ethics Committee (date: 08.11.2019, no: 1221548). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea/Concept, data collection, analysis, literature review: K.G.; Data collection, analysis, literatüre review: E.A.; Design, control/supervision, writing the article: Z.M.A.

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