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Factors associated with limited hand motion after hand trauma

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Abstract

Hand injuries are common and have a significant impact on daily life. However, the factors associated with functional outcome after hand injuries are not well established. The purpose of this study was to identify factors that are independently associated with hand total active motion (TAM).

A total of 50 patients with unilateral complex hand injury were included in this study. The associations between various demographic, injury-related, and clinical assessment factors and TAM were determined by univariate and multivariate linear regression analyses. Nerve injuries recognized during surgery and diagnosed with electrodiagnostic (EDX) studies were compared using Pearson chi-squared test.

Among multiple injury-related and initial clinical assessment factors, nerve injury diagnosed with EDX studies, hospital stay length, elevated C-reactive protein, and skeletal injury were independently associated with TAM in the affected hand after adjusting for covariates. Nerve injuries diagnosed with EDX studies were not consistent with those recognized during surgery.

Our results suggest that high-energy trauma leading to skeletal and nerve injury with inflammation is associated with limited hand motion after surgery and postoperative immobilization. A comprehensive EDX study may enable identifying occult or recovered nerve injuries, which would be helpful in understanding limitations in finger movements.

Abbreviations: ATO = the time interval from accident time to operation start time, CRP = C-reactive protein, EDX = electrodiagnostic, TAM = total active motion.

Keywords: articular, electrodiagnosis, hand injuries, peripheral nerve injuries, range of motion

1. Introduction

Hand injuries are very common and usually occur in young adults.[1] In the United States, injuries to the hand and arm (28.3%) are the second most common after head and neck injuries (29.5%).[2] They are characterized by a great variability in the extent and distribution of injury. Hand injuries have a significant impact on activities of daily life as well as physical function, which affect socioeconomic aspects of life.[3]

Many patients with hand injuries experience limited motion, stiffness, and/or pain after their injury, especially during the initial stage of injury. Critical anatomic structures, which include tendons, nerves, and the vasculature located beneath the skin, make the nature of hand injuries complicated and clinical evaluations difficult. Therefore, functional outcomes after hand injury are measured with diverse tools, such as total active motion (TAM),[4–8] grip strength,[4,5,7–9] Disability of Arm, Shoulder and Hand,[4,5,8,9] Weinstein monofilament test,[9] global measures by a surgeon,[10–12] Purdue pegboard test,[4] pain,[4] and return to work.[5,13] Among functional measurements, TAM has been used as a good general metric for joint and tendon function.[4–7]

The factors associated with functional outcome after hand injuries are not well understood. To our knowledge, a large number of damaged structures,[10] hand injury severity score,[13] level of injury,[6] avulsion injury,[6] and nerve injury[10] are factors associated with functional outcome. Most of the previously described factors are related to the characteristics of the initial injury.[6,10,13] Therefore, those are unmodifiable and correlated with each other. Given the impact of hand injuries, however, it is important to elucidate the factors that are independently associated with limited finger motion, which represents a functional decrement.

The aim of the present study was to identify the factors that are independently associated with hand function after injury. We studied the association between hand function measured by TAM and clinical assessment factors as well as the initial injury characteristics.

2. Methods

2.1. Study design and subjects

A single center, retrospective study was conducted to assess the association between various factors, such as demographic and injury-related factors and the results of clinical assessment, and posttraumatic hand function at the first visit to an outpatient rehabilitation clinic. The medical records of operatively treated complex hand injury patients (n = 140), who were referred for an outpatient rehabilitation program, were reviewed from January

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2014 to February 2017. The exclusion criteria were patients under 16 years of age with concomitant trauma, such as brain or spinal cord injury, previous trauma history, or disabilities in the affected hand or refusal to participate in evaluations, including electrodiagnostic (EDX) studies. Patients who had received surgery in another hospital were also excluded because of insufficient medical records regarding the initial injury severity and operative findings. Fifty subjects with complete medical records were recruited for this study. Our hospital is specialized in the treatment of trauma patients because it plays a major role both as a regional emergency and trauma center in northern region of Gyeonggi-do Province. The loading of patients with hand injuries is larger in our hospital than in other university hospitals in Korea, and we have more than 5 hand surgeons. Due to the many industrial factories in northern region of Gyeonggi-do Province, farms and military bases around our hospital, we experience complex hand injuries related to traumata in these places. The protocol of this study was approved by the institutional review board of the Catholic University of Korea Uijeongbu St. Mary's Hospital (IRB no. UC17RESI0082).

2.2. Measurement of TAM in hand

We assessed TAM as a primary outcome of post-traumatic hand function at the first visit to the outpatient rehabilitation clinic; this function was measured before starting the rehabilitation program by an experienced physical therapist. TAM was defined as the sum of active flexion measurements of all digit joints (metacarpophalangeal [MCP], proximal interphalangeal, and distal interphalangeal) and thumb joints (MCP, interphalangeal) minus the sum of all extension deficits of the digits and thumb.[4,5] Each joint of the digits and thumb in the affected hand was measured individually using a finger goniometer while the wrist was in a neutral position with the forearm pronated. All measurements were conducted according to the guidelines of the American Medical Association.[14]

2.3. EDX studies

During the patient's first visit to the outpatient rehabilitation clinic, the indications for EDX studies in the affected hand were as follows: motor weakness and/or muscle atrophy; paresthesia or hypoesthesia; neuropathic pain or allodynia; nerve injury recognized during surgery; and limited movement in the noninjured fingers. EDX studies were performed with electromyography and an evoked potential system (Synergy, Oxford Instruments, Cambridge, UK) by 2 qualified physiatrists. Nerve conduction studies were recorded using surface electrodes, and needle electromyography was performed with monopolar needle electrodes. Motor and sensory conduction studies were performed in the unaffected hand as well as the affected hand to avoid individual variation of reference values according to anthropometric factors. The needle electromyography examination was performed following standard techniques.[15–17] A pathological response was defined as a decrease or absence in sensory nerve action potential and compound muscle action potential amplitude with denervation potentials and a decrease in motor unit recruitment.[18,19] A side-to-side amplitude difference exceeding 50% between the affected and unaffected hands was also considered as a pathologic decrease.[20]

2.4. Independent covariables

Covariates included demographic, injury-related, time interval, and clinical assessment factors, such as pain killers, laboratory, and EDX results. Demographic and injury-related factors such as age, sex, weight, height, occupation, smoking status, mechanism of injury, and foreign body in the wound were obtained by reviewing medical records. Injured structures were stratified as integument, tendon, vessel, skeletal injury, and nerve injury (which were all recognized during surgery or at the first physical examination) by reviewing medical records.[4,5,13] Three types of time intervals were calculated: the time interval from accident time to emergency room visit time (minutes), from accident time to operation start time (ATO, minutes), and from admission to discharge (hospital stay length, days). Laboratory data in the emergency room were also included for evaluation of inflammation or infection. Elevated white blood cell count, percent segmented neutrophils (% segs), and C-reactive protein (CRP) were defined as >10,000 cells/mL, >75.0%, and >3 mg/L, respectively, according to the reference values of our hospital.

2.5. Statistical analysis

Univariate linear regression analyses were employed to determine the association between TAM at the first visit to the outpatient rehabilitation clinic and independent variables. The relationships between TAM and all covariates were analyzed using the Spearman ρ correlation. Residual plot analysis was used to check the assumptions of normality and homogeneity of variance in each analysis. Multivariate linear regression analysis was performed with a forward selection method using significant covariates in the univariate analyses. To prevent potential omission bias, P values ≤ .2 in the univariate analyses were entered in the multiple linear regression analyses. The premises of multicollinearity were not violated in any of the analyses. We compared nerve injury recognized during surgery and diagnosed with EDX studies, using Pearson chi-squared test. The significance level for all hypothesis testing was set at $P < .05$. SPSS version 24.0 (IBM/SPSS Inc, Armonk, NY) was used for statistical calculations.

3. Results

The baseline characteristics of 50 subjects are shown in Table 1. The mean age of subjects was 47.7 years and most of the subjects were male (78.0%). Among the 50 subjects, 22 (44.0%) were involved in manual work such as manufacturing laborers, house builders, factory operators, and mechanics. The occupation of 19 (38.0%) was office worker, 7 (14.0%) housewife, 1 (2.0%) student, and 1 (2.0%) soldier. The most common mechanism of injury was machinery injury (60.0%). The other mechanisms of injury were falls (14.0%), cut by a knife or a glass (12.0%), struck by heavy objects (8.0%), and traffic accidents (6.0%). The most commonly involved structures were integument (74.0%) and skeleton (74.0%). Tendon injuries occurred in 33 subjects (66.0%), nerve injuries in 25 subjects (50.0%) which were recognized during surgery, and vessel injuries in 15 subjects (30.0%), which were treated with arteriorrhaphy in 12 patients. Because the injuries to bone and muscle structures in the hand are complex, the location of each injured structure is schematically presented in Fig. 1. The mean duration between the date of injury and TAM measurements was 54.7 ± 34.0 days. The mean TAM in the affected hand was 884.0 ± 316.4° (74.9% of TAM in the unaffected hand).

The results of the univariate linear regression analyses between TAM and each covariate are presented in Table 1. Among covariates, machinery injury, integument injury, nerve injury, skeletal injury, EDX pathological response, ATO, and hospital

Table 1

The baseline characteristics of 50 patients and univariate linear regression analyses for total active motion in affected hand.

Characteristics	Baseline values	Univariate analyses β	Univariate analyses *P*
Demographic factors			
Age, y	47.7 (±13.5)	−3.52	.296
Male sex	39 (78.0%)	−60.72	.579
Body mass index, kg/m^2	23.0 (±2.8)	−20.17	.230
Manual worker	22 (44.0%)	−150.84	.099
Smoker	19 (38.0%)	33.84	.718
Injury-related factors			
Right-side injury	26 (52.0%)	79.01	.383
Machinery injury	30 (60.0%)	−327.08	<.001*
Integument injury	37 (74.0%)	−269.02	.007*
Tendon injury	33 (66.0%)	−132.09	.164
Nerve injury†	25 (50.0%)	−212.00	.016*
Skeletal injury	37 (74.0%)	−222.25	.028*
Vessel injury	15 (30.0%)	−186.41	.057
Foreign body at wound	2 (4.0%)	−358.33	.118
Clinical assessment factors			
Nerve injury diagnosed with EDX	20 (40.0%)	−291.67	.001*
Pain medication after discharge	41 (82.0%)	−14.09	.905
ATE, min	141.3 (±299.7)	0.00	.663
ATO, min	546.6 (±342.8)	0.01	.014*
Hospital stay length, d	13.9 (±11.6)	−15.94	<.001*
Elevated WBC count	14 (28.0%)	−55.26	.588
Elevated % segs	9 (18.0%)	−89.71	.449
Elevated CRP	6 (12.0%)	−239.04	.083

Values are presented as number (percentage (%) or mean (±standard deviation)).
β = unstandardized coefficient, ATE = the time interval from accident time to emergency room visit time, ATO = the time interval from accident time to operation start time, CRP = C-reactive protein, EDX = electrodiagnostic, WBC = white blood cell, % segs = percent segmented neutrophils.
* $P < .05$.
† Recognized during surgery or first physical examination.

stay length were significantly associated with TAM in the affected hand. Machinery injury, integument injury, nerve injury, skeletal injury, and EDX pathological response were negatively correlated with TAM ($P < .001$, $P = .007$, $P = .016$, $P = .028$, and $P = .001$, respectively). With 1-minute increments of ATO, TAM increased by 0.01°. However, as hospital stay length increased by 1 day, TAM decreased by 15.94°. Manual worker, tendon injury, vessel injury, foreign body in the wound, and elevated CRP were not significantly associated with TAM, but were included in the multiple regression analyses to prevent omission bias. The multiple linear regression model was adopted to identify factors independently associated with TAM and is presented in Table 2. The factors that independently decreased TAM in the affected hand were nerve injury diagnosed with EDX studies, hospital stay length, elevated CRP, and skeletal injury.

During the analysis, we observed inconsistency between nerve injuries recognized during surgery and diagnosed with EDX studies. Nerve injuries were identified in 25 (50.0%) of 50 subjects and were treated with neurorrhaphy during surgery. By contrast, nerve injuries were diagnosed in 20 (40.0%) of 50 subjects with EDX studies performed in the rehabilitation clinic. Among the 25 patients with the nerve injury recognized during surgery, only 15 subjects (60.0%) showed pathological response in EDX studies; 10 (40.0%) patients did not have any abnormal findings in the EDX study. Moreover, among the 15 subjects with EDX pathological response, 10 subjects (66.7%) showed remote or extensive nerve lesions, which were not recognized or predicted, as well as the same lesions that were directly damaged and also recognized during surgery. Of 25 subjects without nerve injury recognized during surgery, 5 (20%) subjects showed nerve injuries diagnosed with EDX studies. This inconsistency between nerve injury recognized during surgery and diagnosed by EDX studies was statistically significant ($P = .004$). The 30 patients with any type of nerve injury are summarized in Table 3.

4. Discussion

The current study demonstrated that nerve injuries diagnosed by an EDX study, skeletal injury, elevated CRP, and hospital stay length are independently associated with TAM after complex hand injuries. In addition, the ATO interval, nerve injuries recognized during surgery, machinery, and integument injury are also significantly associated with TAM. Interestingly, there is an inconsistency between nerve injury recognized during surgery and diagnosed by EDX studies. A comprehensive EDX study can reveal occult and/or recovered nerve injuries.

The results of the current study suggest that a high-energy mechanism of injury will be an important factor associated with decreased hand movement after hand injuries. Damage to the skeleton which is a mechanically strong structure and elevated levels of CRP may imply high-energy trauma and subsequent inflammation. A force with a high-energy often leads to a crushing injury and significantly increases pressure, damaging multiple tissue types, including bones, blood vessels, nerves, and soft tissues.[21] These injuries produce tremendous inflammation and swelling, potentially followed by compartment syndrome or other vascular damage, infection, neurological injury, and tissue necrosis.[22] The length of hospital stay seems to be related to the limited movement of the hand because it also reflects the severity and complications of the trauma. Therefore, prevention of high-energy trauma such as machinery injury would be the first step to reduce hand impairment.

Our results found that the nerve injury diagnosed by an EDX study was an independent predictor of decreased hand motion. This finding suggests a critical impact of nerve dysfunction on functional outcome in patients with hand trauma. Of all patients admitted to Level I trauma centers, it is estimated that approximately 2% to 3% have peripheral nerve injuries.[23] However, the impacts of peripheral nerve injury on functional outcome have not been studied in depth, except for a few reports of major nerve rupture requiring emergent nerve repair.[9,10] A multicenter prospective study in the Netherlands revealed that damaged nerve, the location of the injury, and type of nerve injury after repair of the peripheral nerve were found to be predictors of different aspects of functional recovery in upper extremity.[9] To the best of our knowledge, this is the first study that evaluated the impacts of nerve injuries on functional outcome after hand injuries.

Our study indicated that functional nerve impairment rather than visible anatomical disruption of the nerve trunk may be a more important factor associated with postoperative hand motion. Our study assessed the nerve injuries, which included not only visible anatomical disruption (Sunderland IV–V) but also continuity (Sunderland II–III) of the nerve, which could not be recognized because of barely visible skin disruptions even through surgical exploration and physical examination.[22–24] Statistical analysis demonstrated that nerve damage diagnosed by an EDX study, which included Sunderland classification II–III as well as IV–V nerve damage, was selected as one of the covariates

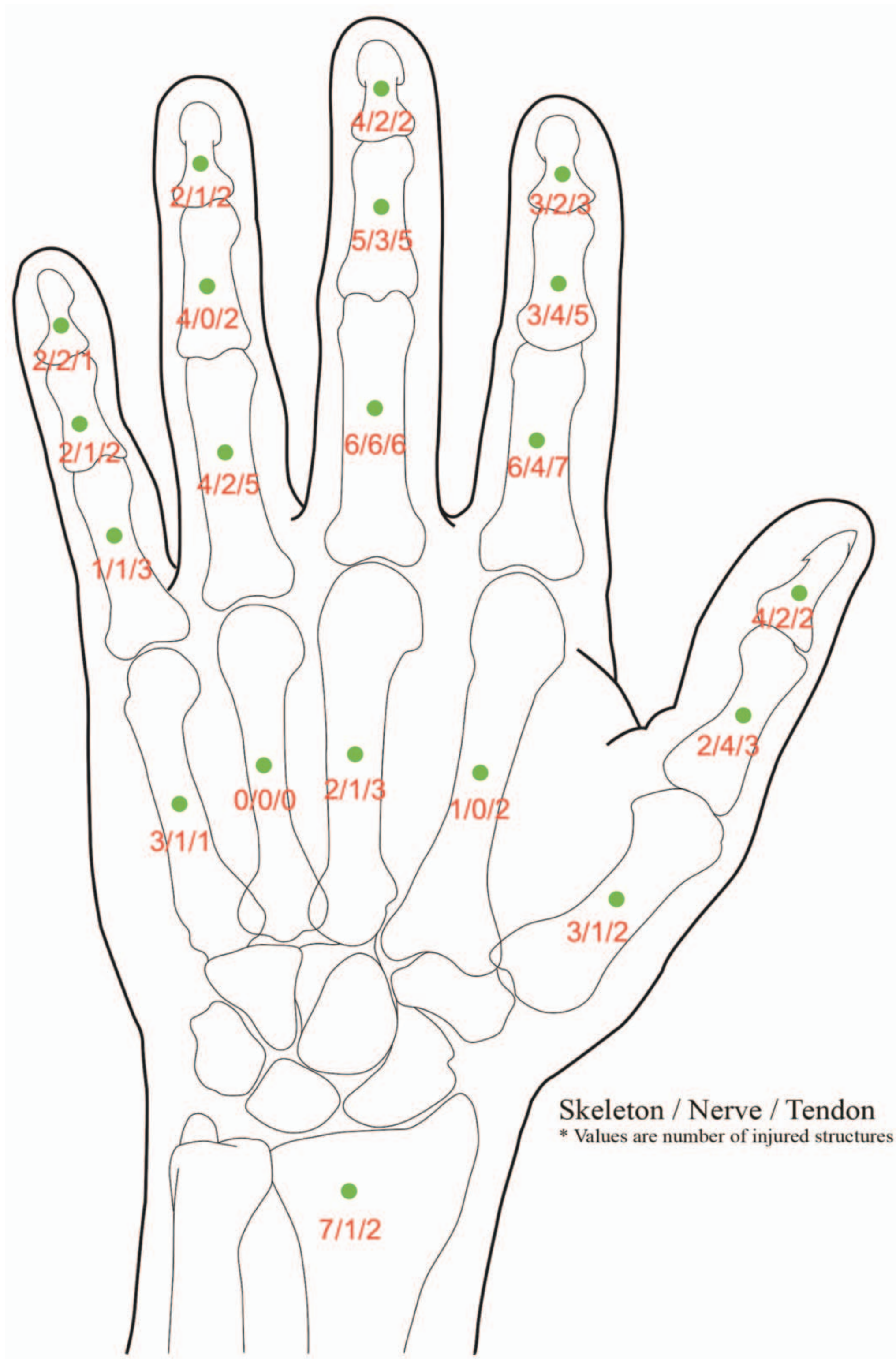

Figure 1. The location of each injured structure in 50 patients.

in the final multiple regression model. On the other hand, previous studies have emphasized the importance of rehabilitation in patients with hand injuries,[4,6,7,10] and the main goal of the rehabilitation is to increase hand motion and strength.[25,26] If post-traumatic hand function is closely related to nerve dysfunction, the rehabilitation protocol in patients with hand trauma may proceed in a direction that promotes axonal regeneration of the nerve, such as electrical stimulation and therapeutic activities that mimic the activities of daily living as well as a simple range of motion exercise.[8,27]

Table 2

Multiple linear regression analysis for total active motion in affected hand.

	β	SE	*P*	VIF
Intercept	1253.88	76.17		
Nerve injury diagnosed with EDX	−228.88	74.50	.004	1.21
Hospital stay length	−8.74	3.33	.013	1.33
Elevated CRP	−259.35	100.68	.015	1.02
Skeletal injury	−203.97	83.05	.019	1.18

Adjusted $R^2 = 0.55$, $F = 12.40$, $P < .001$.

β = unstandardized coefficient, CRP = C-reactive protein, EDX = electrodiagnostic, SE = standard error, VIF = variance inflation factor.

An unexpected finding of our study is that 10 of 25 patients (40%) with nerve injury recognized during surgery and surgically treated did not show any EDX evidence indicating nerve damage. This emphasizes the importance of thorough evaluation and prompt nerve repair surgery to prevent sequelae. The recovery of hand function after an injury can be achieved with timely and appropriate surgical management. Furthermore, evaluating the extent and distribution of nerve injuries by EDX study may helpful for making a diagnostic or therapeutic plan, especially when patients exhibit unexplained limitation of finger movement after surgery and postoperative immobilization. In addition, we often encounter patients with unexplained limited range of motion in noninjured fingers, although the cause could be postoperative immobilization, disuse atrophy, swelling, or pain. A recent study found that patients with zone 1 replantation showed grip strength deficits for 4 months despite the lack of joint or tendon injury.[7] The authors presumed that this unexplained strength deficit is either due to a confounding variable such as pain or a clinical consequence of splinting the whole hand. Our results suggest that one of the causes of this unexplained limited motion or strength deficit can be an occult nerve injury that was not detected during surgery.

Table 3

Patients with nerve injury recognized during surgery or diagnosed with EDX studies.

Cases	Nerve injury recognized during surgery	Nerve injury diagnosed with EDX studies
1	DN1	DN1*
2	DN1, DN2, DN3, DN4	DN2, DN3*
3	DN1, DN5	DN1, DN4, DN5, median, ulnar, radial (hand)†
4	DN1, DN3, DN5	Median, ulnar, radial (hand)†
5	DN2	DN2*
6	DN2, DN3	Median (hand)†
7	DN2	Median (hand)†
8	DN2, DN3	DN2, DN3*
9	DN3	DN3, DN4†
10	DN2, DN3	Median (forearm)†
11	DN3	Radial (forearm)†
12	DN2, DN3, DN4	DN3, ulnar, DCU (hand)†
13	Ulnar, DN5	Ulnar, DN5 (hand)*
14	Radial	Median, radial (hand)†
15	Ulnar	Median, ulnar (forearm)†
16	DN1, DN4	
17	DN2, DN3	
18	DN2	
19	DN2	
20	DN2	
21	DN3	
22	DN3	
23	DN3	
24	DN5	
25	DN5	
26		Radial (hand)
27		Median (hand)
28		Median, ulnar, radial (forearm)
29		Median, ulnar, radial (forearm)
30		DN3, ulnar, DCU (hand)

DCU = dorsal cutaneous ulnar, DN = digital nerve, EDX = electrodiagnostic.

* Nerve lesion in region affected by trauma.

† Remote or extensive nerve lesion beyond trauma (hand, forearm): the level of nerve injury diagnosed by EDX study.

Several studies have adopted hand active range of motion as the most appropriate measurement of tendon function after hand injury from the perspective of the surgeons.[5,6,10] Ross et al reported that TAM was affected by the level and type of injury.[6] Another descriptive study showed that TAM was 67% of normative of the healthy digits after 10 months of complex, multistructural hand injuries (duration of rehabilitation range: 1–4 months).[5] These studies concluded that the outcome was satisfactory, but the factors associated with worse outcomes were not analyzed. In our results, TAM measured 1 to 3 months after the injury before starting a rehabilitation program was independently associated with nerve and skeletal injury rather than tendon injury. From a biomechanical perspective, the motion is generated by a muscle-tendon complex innervated by peripheral nerves. Therefore, muscle, tendon, and nerve are impossible to evaluate separately because a motion deficit can result from an abnormality of any of these structures. Although structural damage to muscle, tendon, and nerve can be reconstructed by surgery, motion limitation is more likely due to abnormal neuromuscular transmission than merely the decrease of tendon function.

There are some limitations to be considered in the current study. First, this is a retrospective study. Second, this study has a limitation stemming from the single-center design with a small sample size that restricts the generalizability. In addition, neuropraxic injuries could not be included because EDX studies in the outpatient clinic were performed at least 4 weeks after injury.[24,28] Therefore, axonotmesis and neurotmesis in each different stage of denervation or reinnervation were only considered as a pathological response. Therefore, there may have been a selection bias toward patients with worse outcomes or those who wished to follow up more closely. Despite its limitations, the current study provides valuable information in patients with hand injuries that has not been presented previously. This study provides a rationale for a future prospective longitudinal study focusing on the improvement of TAM and EDX nerve injury.

5. Conclusion

Among multiple injury-related and initial clinical assessment factors, nerve injuries diagnosed by an EDX study, skeletal injury, elevated CRP, and hospital stay length are independently associated with TAM in the affected hand after adjusting for covariates. A comprehensive EDX study may be able to identify occult and/or recovered nerve injuries, which would be helpful to rehabilitative physicians and therapists. Based on the current study, future research on hand injuries should consider the injured structures, especially nerves, and mechanism of injury.

Author contributions

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