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ORIGINAL STUDY

Outcomes of primary surgical repair of zone 2 dDigital nerve injury

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The objective of our study was to assess the functional and sensory outcomes of the primary repair of 138 digital nerve injuries in 48 consecutive patients between January 2012 and November 2014, and to determine whether there were any relationships between demographics, clinical characteristics, or functional test results and post-operative sensory recovery outcomes. Mean follow-up was 14 (range, 10 to 20) months. Sensory evaluation was performed using the static two-point discrimination test, and post-operative sensoryrecovery results were classified according to the Seddon Classification: 69 (50%) injuries were S3+, 3 (2%) were S3, 15 (11%) were S2, 18 (13%) were S1, and 33 (24%) were S0. Sensory recovery was associated with time between surgery and testing and with objective functional recovery. More than half of digits sustaining nerve injuries had good intermediate-term recovery of sensation after early primary surgical repair. Surgeon experience and early primary repair may have a favorable impact on results.

Keywords: digital nerve ; functional result ; hand function test ; rehabilitation ; sensory recovery.

INTRODUCTION

The process of industrializationhas increasedthe prevalence of hand injuries, and these injuries can lead toserious disabilities and socioeconomic burden *(15)*. Digitalnervesare injured more oftenthan any otherupper extremity nerves, and these injuries are often associated with other hand injuries, complicating evaluation, management, and prognosis *(21,24,26)*.Digital nerve injuries occur most often in zone 2 of the hand, which extends from the middle of the middle phalanx to the distal palmar crease *(3)*.

For many years, the most common surgical approach for the repair of a digital nerve injury has been primary repair, and this continues to be preferred when the injury has not resulted in loss of nerve substance *(5)*. Since the majority of cases do

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not involve substantial nerve loss, other alternatives such as nerve autografts and allografts, termino-lateral neurorrhaphy, and tubulizationare often not necessary.

During the period between January 2012 and November 2014, we encountered at our medical center a large number of patients with zone 2 digital nerve injuries who were treated uniformly by a single surgeon. The objective of our study was to retrospectively investigate the demographics and clinical characteristics of these patients with digital nerve injuries, assess the functional and sensory outcomes of the primary repair of these injuries, and determine whether there were any significant relationships between post-operative sensory recovery outcomes and demographics, clinical characteristics, or functional test results.

PATIENTS AND METHODS

We retrospectively analyzed 138 zone 2 complete digital nerve injuries in 48 consecutivepatients who presented to and received surgery at Konya Necmettin Erbakan University Meram Medical Faculty Hospital between January 2012 and November 2014. We excluded patients older than 60 years and younger than 16 years, as well as those with diabetes mellitus.We also excluded patients who required any kind of surgical grafts (i.e., nerve, vein, or synthetic nerve conduit), so that only those undergoing primary nerve repairs were included. The study was approved by theInstitutional Review Board, and it was conducted in accordance with the principles of the Declaration of Helsinki.

We captured patient demographic and clinical characteristicdata from retrospective chart reviews, andthese items included age, sex, occupation, dominant hand, mechanism of injury, location of injury, affected fingers,associatedinjuries, time between injury and surgery, time between surgery and testing, and post-operative follow-up.

We obtained written informed consent for surgery from each adult patient and from the parent of each child between 16 and 18 years old. All patients had surgery the same day as their injury and received cefazolin 1 gram IV pre-operatively. A single surgeon (EA) performed allsurgeriesusing a tourniquet and with patients under general or axillary block anesthesia.We used appropriate incisions to enlarge and explore the injured structures inthe injury zone. We repaired digital nerve lacerationsprimarily with 8-0 propilenesuture using anepineural repair techniqueunder 4.5 loop magnification.If there was an associated digital artery laceration, we repaired itusing10-0 propilene suture under an operating microscope.Patients were instructed to take 2 tablets diclofenac sodiuim extended-release 75 mg daily and an oral antibiotic of the surgeon’s preference for one week after surgery.

Members of the hand surgery team performed post-operative evaluations.Follow-up visits were typically at one, three, and six months after surgery and included physical examinations. Sensory and functional testing was planned to occurabout 12 months after surgery, because this is when we expected there to be enough recovery to make testing worthwhile, but the actual scheduling of the testing varied among our patients.Post-operative management and rehabilitation programsvaried for each patient, becausesome of the injuriesinvolved isolated nervelacerations, while other injuries involved associated arterial injuries, phalangeal fractures, and/ortendon lacerations. Post-operatively, patients with isolatednerve lacerations and those with nerve lacerations and associated arterial injuries had a short-arm splint to the fingertips for one week, then passive exercises were allowed for one week, and after that active motion was started. Patients were allowed to resume normal activities of daily life after a total of three weeks.

For patients with digital nerve lacerations and associated phalangeal fractures, the hand was immobilized post-operativelywith a short-arm splint to the fingertips until fracture union was confirmed radiographically. After that, the patient initiated passive and active range of motion exercises. The patient was allowed to resume normal activities ofdaily lifeas tolerated after a short period of range of motionexercises.For patients with digital nerve lacerations and associated flexortendon injuries, the hand was immobilized post-operatively with a short-arm splint to the fingertips for one week, after which the Kleinert orthosis was typically used for six weeks *(16)*. Mild resistive exercises were allowed from the six to the eighth week, full resistive exercises were encouraged after the eighth week, and resumption of normal activities of daily living were allowed after the twelfthweek.

Evaluation of Functional Recovery

We carried out functional evaluation of the hand usingthe Sollerman Hand Function Test (SHFT) *(18)*. This objective testassessesthe functional competence and quality of seven basic hand grip actions involved in daily activities, and it consists of 20 stages. Each stage is scored from 0 to 4, and the scores from all 20 stagesare added to obtain thetotal score. The total score can range from 0 and 80, and 80 is considered normal for the dominant hand, while between 78 and 80 is considered normal for the non-dominant hand.

Another method that we used to evaluate functional recovery wasthe Quick-Disabilties of Arm, Shoulder, and Hand (Q-DASH) questionnaire *(14)*. Thisis a patient-reported tool which evaluates the physical function and symptoms of patients with upper extremity problems.The questionnairehas 11 sections, and at least 10 of the 11 sectionsneed tobe answered for a Q-DASH score to be calculated. Each section hasfive items, the scores for each section are added to obtain the total score, and the results can range from 0 (no disability) to 100 (most severe disability).

Evaluation of SensoryRecovery

We used the static two-point discrimination (STPD) test to evaluate post-operative sensory recovery. The patient was asked to close the eyes and report whether one or two points was felt. Ten stimulations were performed, and discrimination of two separate points in seven or more of these was considered affirmative. If the patient was unable to discriminate two points that were 5mm apart, the gap was widened and the same procedure was performed, up to a gap of 15 mm *(8)*. The smallest distance between two points that still resulted in the perception of two distinct stimuli was recorded as the patient's two-point discrimination threshold.We categorized the STPD test results according to the American Society for Surgery of the Hand (ASSH) recommendations as follows: Normal if less than 6 mm, fair if 6 to 10 mm, poor if 11 to 15 mm, and non-protective if only one point is perceived *(8)* (Table I).

Table I. — Distribution of American Society for Surgery of the Hand [8] static two-point discrimination testing (STPD) results for post-operative sensory recovery after primary surgical repair of 138 digital nerve injuries in 48 patients at Konya NE University Meram Medical Faculty Hospital, Turkey, January 2012 to November 2014

	STPD threshold	Injuries, N (%)
Normal	<6mm	48 (34.8)
Fair	6-10 mm	6(4.3)
Poor	11-15 mm	84 (60.9)
Non-protective	One point	0 (0)

Table II. — Distribution of Seddon Classification (19,20) of post-operative sensory recovery results after primary surgical repair of 138 digital nerve injuries in 48 patients at Konya NE University Meram Medical Faculty Hospital, Turkey, January 2012 to November 2014

Stage	Clinical Description	Injuries, N (%)
S0	No protective or vibrotactile sensation	33 (23.9)
S1	Return of protective sensation for pain and heat, no vibrotactile sensation	18 (13.0)
S2	"Poor sensitivity", return of superficial sensation for pain and touch, beginning of vibrotactile sensation; possible dysesthesia (S2+)	15 (10.9)
S3	"Fair sensitivity", superficial sensation for pain and touch, beginning of mobile and static two-point discrimination (TPD) (between 15 and 30 mm)	3 (2.2)
S3+	"Correct sensitivity", equivalent to S3 but with good localization of mobile and static TPD (between 7 and 15 mm)	69 (50.0)
S4	"Normal sensitivity", full recovery, mobile and static TPD between 2 and 6mm	0 (0)

We also classified sensory recovery using the Seddon Classification *(19,20)* (Table II). For the purposes of statistical analysis, we categorized patients with Seddon stage 3 and higher as having good sensory recovery, because these stages are considered to involve fair (or better) sensitivity and protective sensation; conversely, those with Seddon stage 2 or lower were considered to have poor sensory recovery.

Statistical Methods

Descriptive analysis was applied to numeric variables, and results were presented as means and ranges for demographics and follow-up or as means and standard deviations for outcome measures. Descriptive analysis was also applied to categorical variables, and results were presented as frequencies.Some of the independent variables were treated ascontinuous (age,time between surgery and testing, SHFT score, and Q-DASH score) and some were converted to binomials (mechanism of injury as sharp vs. crush, associated injury as no vs. yes). Correlation analysis was performed to analyze the relationshipsbetween Seddon Classification sensory recovery andthe other variables, and results were presented using Spearman's rho (r) value. We considered an r value >.3 to be significant. Statistical significance was defined at the 5% ($P \leq .05$) level.

Statistical analysis was performed using the Number Cruncher Statistical System Statistical Program for Windows (NCSS, Kaysville, Utah, USA, 2007) and the Performance Analysis of Systems and Software (PASS) (NCSS, Kaysville, Utah, USA, 2008).

RESULTS

Of the 48 patients, 42 (87.5%) were maleand 6 (12.5%) were female (Table III). The mean age of patients was 33.6 (range, 16 to 60) years. The mean follow-up for patients was 14 (range, 10 to 20) months. The mean time between surgery and sensory-functional testing was 10 (range, 8 to 20) months. There was no objective data available on the evolution of sensory recovery during the time after surgery and before testing. Among patients in the study, 18 (37.5%) were laborers, 6 (12.5%) were housewives, 6 (12.5%) were students, and 3 (6.3%) each were z furniture dealers,restauranteurs, janitors, technicians, farmers, and retired.

The dominant hand was the right hand in 45 (93.8%) patients and the left hand in 3 (6.3%) patients (Table III). Injuries were to the non-dominant hand in 30 (62.5%) patients and the dominant hand in18 (37.5%) patients. The location of injury was at home in 30(62.5%) patients and at work in 18 (37.5%) patients. The mechanism of injury included knife cuts in 12 (25%), chainsaw cuts in 9 (18.8%), industrial accidents involving

Table III. — Demographic and clinical characteristics of 48 patients with 138 digital nerve injuries at Konya NE University Meram Medical Faculty Hospital, Turkey January 2012 to November 2014

Category	Characteristic	Patients, N (%)
Sex	Male Female	42(87.5) 6(12.5)
Occupation	Laborer Housewive Student Retired Furniture dealer Restauranteur Janitor Technician Farmer	18(37.5) 6(12.5) 6(12.5) 3(6.3) 3(6.3) 3(6.3) 3(6.3) 3(6.3) 3(6.3)
Mechanism of Injury	Knife cut Chainsaw cut Industrial (crush) accident Spiral blade cut Stuck under marble (crush) Kitchen mixer Iron edge cut Glass cut	12(25.0) 9(18.8) 6(12.5) 6(12.5) 6(12.5) 3(6.3) 3(6.3) 3(6.3)
Associated Hand Injury	None Phalanx fracture and digital artery injury Phalanx fracture, digital artery injury, flexor tendon injury Digital artery and flexor tendon injury Flexor tendon injury	18(37.5) 12(25.0) 9(18.8) 6(12.5) 3(6.3)

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Fig.1. — .Left second (index) finger digital nerve injury before (A and B) and after (C) primary surgical repair

crush injuries in 6 (12.5%), spiral blade cuts in 6 (12.5%), stuck under marble with crush injuries in 6 (12.5%), kitchen mixers in 3 (6.3%), iron edge cuts in 3 (6.3%), and glass cuts in 3 (6.3%) (Table III). All patients had completelacerations of the involved digital nerves. Of the 138 digital nerve injuries, 48 (34.8%) involvedthe second finger (Figure1), 39 (28.2%) involved the third finger, 21 (15.2%) involved the thumb (Figure 2), 21 (15.2%) involved the fourth finger, and 9 (6.5%) involved the fifth finger. While 18 (37.5%) patients had no other associated handinjuries, 12 (25%) patients had associated phalangeal fracture and digital artery injuries, 9 (18.8%) had associated phalangealfracture with both digital artery and flexor tendon injuries, 6 (12.5%) had associated digital artery and flexor tendon injuries, and 3 (6.2%) had associated flexor tendon injuries.

Our patients had no post-operative complications or infections. No patients were lost to follow-up. Functional outcomes were assessed using the SHFT and Q-DASH scores. When post-operative testing was done, the mean SHFT score was 73.6±5.9, while the mean Q-DASH score was 39.0 ±18.8.

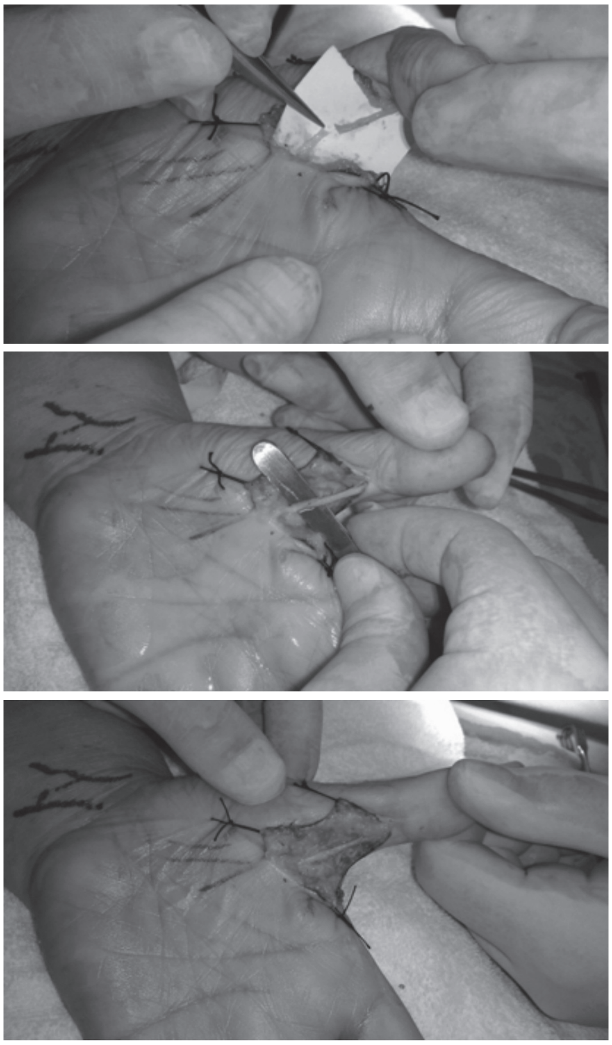

Fig. 2. — Left thumb digital nerve injury before (A) and after (B and C) primary surgical repair.

Sensory outcomes were evaluated using the STPD test and results were classified according to theSeddon Classification. Of the 138 digital nerve injuries, when post-operative testing was performed 48 (34.8%) had a normal STPD result (less than 6 mm), 84 (60.9%) had a fair result (6 to 10 mm), 6 (4.3%) had a poor result (11-15 mm), and none had non-protective sensation (Table I).Applying the Seddon Classification post-operatively to the 138 digital nerve injuries, none were stage S4, 69 (50.0%) were stage S3+, 3 (2.2%) were stage S3, 15 (10.9%) were stage S2, 18 (13.0%) were stage S1 and 33 (23.9%) were stage S0 (Table II). When the binomial definition was applied to the Seddon Classification outcomes, 72 (52.2%) of the nerve injuries had good sensory recovery (stage S3 or higher) and 66 (47.8%) had poor sensory recovery (stage S2 or lower).

Table IV. — Relationships between Seddon Classification (19,20) post-operative sensory recovery and demographic-clinical characteristics and functional outcomes, after primary surgical repair of 138 digital nerve injuries in 48 patients at Konya NE University Meram Medical Faculty Hospital, Turkey, January 2012 to November 2014

Characteristics and Outcomes	Spearman's rho (r) value	P-value
Age	.255	.097
Time between surgery and testing	.373	.020
Mechanism of Injury (Sharp vs. Crush)	.128	.410
Associated HandInjury (No vs. Yes)	.031	.832
Sollerman Hand Function Test (SHFT) Score	.452	.001
Quick-Disabilities of Arm, Shoulder, Hand (Q-DASH) Questionnaire	.057	.692

We determined the relationships between sensory recovery, as measured by the Seddon Classification outcome, and age, time between surgery and testing, mechanism of injury, associated injury, SHFT score, and Q-DASH score (Table IV) We found no correlation between sensory recovery and age (r=.26, P=.10), mechanism of injury (r=.13, P=.41), presence of associated injuries (r=.03, P=.83), or Q-DASH score (r=.06, P=.69). Conversely, we found a significant positive correlation between sensory recovery and time between surgery and testing (r=.37, P=.02) as well as between sensory recovery and SHFT score (r=.45, P=.001).

DISCUSSION

Hands and fingers are the most commonly injured organsseen in the emergency room *(15,22)*.

In fact, one study examining the epidemiological pattern of all peripheral nerve injuries found that digital nerves were the most common peripheral nerves injured *(4)*.Young people and malesare most often affected by hand injuries. The male to female ratio for hand injuries was 5 to 1 in one study, and it has been estimated that hand injuries are most frequent in the third decade of life *(9)*. Furthermore, a large study concerning 108 patients with digital nerve injuries reported that 83% of these occurred in males and 17% occurred in females *(3)*.The same study reported that themean age of those suffering digital nerve injuries was 35 years old. All of these results are consistent with the findings in our study of digital nerve injuries, in which the mean age of patients was 36 years old and the male to female ratio was 7 to 1.

At least one study reported that the dominant hand is the one that most often sustains serious injuries *(9)*. However, several other studies found that non-dominant hand injuries wereactually more common *(15,17,22)*. In our study, almost two-thirds of the digital nerve injuries occurred in the non-dominant hand. These findings make sense, because most mechanical and electronic devicesare held with the dominant hand, typically leaving the non-dominant hand more prone to injury from the devices *(22)*. As in other studies, we also found that the index finger was the most commonly injured digit, as it was involved in almost 35% of the injuries *(17,22)*.

Digital nerve injuries are rarely isolated injuries *(3)*. In a largestudy of 172 digital nerve injuries, only 24.6% were isolated injuries, while 33.5% had associated flexor tendon injuries, 9% had associated flexor tendon injurieswithphalangeal fractures, 7.2% had associated digital arteryinjuries, and 4.2% had associated phalangeal fractures *(25)*. Our findings were similar, with 37.5% of ourpatients sustainingisolated digital nerve injuries, while 62.5% had additional associated handinjuries. It is not surprising that the type and severity of trauma necessary to cause digital nerve injuries would also increase the risk for associated fractures as well as tendon and artery injuries.

Informationabout outcomes after primary repair of digital nerve injuries is available in the literature, although there has been considerable variation in what has been reported. Studies have varied in length of follow-up and have used a wide variety of outcome measures to assess the results, including time away from work, presence or absence of pain, positive or negative Tinel's sign, two-point discrimination (TPD) and other sensory testing, and patient satisfaction.

Andjelkovic et al evaluated sensoryrecovery in 108 patients with digital nerve injuries, and only 9 patients had full recovery after primary surgical repair *(3)*. Their patients reported that they were away from work for six months orlonger, and in some their disability was permanent. In another study involving 110 patients with digital nerve injuries, Chaise et al found that after surgery 86% of the patients had no pain, 75% had a negativeTinel's sign, 68% hada TPD of 7 mm or less, and only 18% had a TPD of 9 mm or more one year after surgery*(7)*. In the study of Goldie et al, 30 patients had surgery for isolated zone 2 digital nerve lacerations *(12)*.At a mean follow-up of 25 months, 43% were suffering from persistent hyperesthesia, 37% had normal TPD, none had normal finger sensation, and only 27% were satisfied with the outcome.

We sought to use two types of functional testing as outcome measures—a patient-reported questionnaire (Q-DASH) and a more objectiveassessment ofthe functional competence and quality of seven basic hand grip actions (SHFT). We found that the post-operativemean Q-DASH score in our patients was 39.0 ± 18.8 while the mean SHFT score was 73.6 ± 5.9.When used before and after surgery forupper-extremity musculoskeletal disorders, the Q-DASH can detect and differentiate small and large changes of disability over time, and a 10-point difference in mean Q-DASH score is considered to be the minimal important change *(13)*. As an alternative, the SHFT has been shown to have high reliability in other settings *(6)*. However, for both tests, there is sparse normative data available with which to compare our results, particularydata related to digital nerve injuries. In addition, both are ideally suited for comparisons of function before and after intervention, but given the retrospective nature of our study and the extent of injury of our patients, pre-operative testing was not feasible.

We also endeavored to use sensory recovery testing results as outcome measures. Post-operatively, 35% of the digital nerve injuries in our study had a normal STPD result (less than 6 mm), 61% had a fair result (6 to 10 mm), 4%had a poor result (11-15 mm), and none had non-protective sensation. Using the Seddon classification for post-operative sensory recovery, 50% of the injurieswere Seddon stage S3+, 2% were stage S3, 11% were stage S2, 13% were stage S1, and 24% were stage S0. When we modified the Seddon data into a binomial result, more than half of the digital nerve injuries hadnormal sensory recovery. In addition, we found that sensory recovery was positively correlated with time between surgery and testing as well as with the SHFT score, and we noted that it was not correlated with age, mechanism of injury, associated injuries, or Q-DASH score.

As opposed to the lack of normative data available for functional testing, we found a number of studies reporting specifically on digital nerve injuries and providing sensory recovery results as well as information about the relationships of sensory recovery with a variety of different independent variables. Al-Ghazal et al evaluated 71 patients who had primary digital nerve repair and achieved very good sensory results in 17% of the patients, good results in 51%, fair results in 23%, and poor results in 9% of the patients(1). Conversely, in two different studies regarding primary repair ofdigital nerve injuries, 13% to 14% of patients had normal post-operative TPD, 34% to 37% had 6-10 mm TPD, 23% to 24% had 11-15 mm TPD, and 26% to 28% had only protective sensation *(2,10)*.These authors identified a close correlation between age and recovery of sensation after repair, and they concluded that complete recovery of sensation could be only expected in children. In comparison, in our study a higher proportion of patients had good sensory recovery, despite the fact that we excluded most children.

In the study of Wang et al, 90 adults with complete digital nerve injury were re-evaluated more than a year after surgery using fixed and static TPD, and those patients older than 40 years and with chainsaw injuries had significanty worse results than those who were younger or had simple lacerations *(24)*. Similarly, Weinzweig et al reportedthat age, certain mechanisms of injuries, and specific associated injuries were related to sensory recovery based on TPD in 172 nerves after microsurgical epineural repair *(25)*. In their study, patients older than 40 years, those with pulverizing injuries, those with associated fractures or fractures with tendon injuries, and those requiring re-plantationshad worse sensory recovery. Also, Al-Ghazal et alreported close relationships between sensoryrecovery and young age, non-smoking, and clean-cut (as opposed to pulverized) nerves *(1)*.

Conversely, in our studywe found no correlation between sensory recovery and age; however, we were unable to fullyevaluate this relationship because we excluded all patients younger than 16 years old from our study. Also, we found no correlation between sensory recovery and the mechanism of injury or the presence of associated injuries. We wonder if this was because we have had considerable experience with these injuries and we did immediate surgical repair in all of our cases. It has been suggested by others that immediate primary epineural repair and the level of surgeon experience are important factors in achieving good results in these cases *(11)*.

We found that sensory recovery did correlate with objective functional testing results (SHFT score) and the time between surgery and testing. Although sensory recovery did not correlate with functional recovery when defined byasubjective patient questionnaire (Q-DASH), it is noteworthy and makes sense that as sensation improved so did functional recovery when defined by objective measures of hand grip power and function. Furthermore, it is not surprising that sensory recovery correlated with the length of time between surgery and testing, as nerve regeneration takes time, typically progressing by 2 to 3 mm daily after a clean cut and even more slowly after a crush injury *(23)*. Indeed, in light of this, we believe that our intermediate-term (14 month mean follow-up) results are satisfactory, and that it is possible that sensory function in our patients may continue to improve in the future.

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Our study had some limitations. First, it hada retrospective design and this along with the impracticality of pre-operative sensory and functional testing limited our ability to assess pre- and post-operative changes in these outcome measures. Second, we excluded younger patients, and as a result we were unable to fully evaluatethe impact of age onsensoryrecovery after primary digital nerve repair. Third, our outcome measures for post-operative function lacked normative data in the setting of digital nerve injury, making it difficult to assess the meaning of the functional testing results. Finally, despite the fact that our intermediate-term results were satisfactory, our mean follow-up was relatively short, possibly resulting in an underestimation of long-term sensory recovery in our patients.

CONCLUSIONS

Digital nerve injuries are common, usually occur in zone 2 of the hand, and are most often treated with primary surgical repair. More than half of the digits sustaining nerve injuries in our study had good recovery of sensation after early primary surgical repair during a mean follow-up of 14 months. Sensory recovery may improve with a longer period of time between surgery and testing and along with improvements in hand function. Surgeon experience and early primary repair may have a favorable impact on results. However, additional large-scale all-age prospective trials that include pre- and post-operative sensory and functional testingwith normative data are required to confirm our findings.

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