

Multidisciplinary treatment and functional outcome evaluation of combined injuries of nerves, vessels, and flexor tendons: spaghetti wrist

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Abstract. – OBJECTIVE: In this study, we aimed to evaluate the effectiveness of the modified Kessler technique in managing spaghetti wrist lacerations by multidisciplinary treatment.

PATIENTS AND METHODS: Patients who were operated and followed up with the diagnosis of spaghetti wrist tears in our clinic between January 2012 and December 2020 were included in the study. In the postoperative follow-ups, the parameters evaluating the functionality of the patients were examined.

RESULTS: Patients were 105 male (86.7%) and 16 women (13.2%), with a mean age of 36.83 ± 16.38 years. At the final follow-up, functional outcomes were assessed. The most common injury mechanism was glass-related injuries (35.5%). The mean starting surgery time of the patients was 4.64 ± 2.98 hours. The most frequently involved structures were the palmaris longus with a rate of 51% and the flexor digitorum superficialis with a rate of 45%. There were significant differences regarding intrinsic function and grip strength between male and female patients ($p = 0.04$, $p = 0.21$, respectively). There were significant differences regarding sensation and grip strength between smoker and nonsmoker patients ($p = 0.03$, $p = 0.01$, respectively). The number of the damaged structures was negatively correlated with postsurgical functional outcomes of four tests, including tendon function, opposition, intrinsic function, and grip strength. The physical therapy period was correlated to hand function tests ($r = 0.756$, $p < 0.05$). Nerve damage was negatively correlated with sensation ($p = 0.011$, $r = -0.932$).

CONCLUSIONS: The modified Kessler technique is reliable with functional outcomes for spaghetti wrist injuries involving tendons, nerves, and arteries. Meticulous and early surgical treatment within the first 8 hours of spaghetti wrist injury and early initiation and long-term physical therapy are vital in patients' functional outcomes.

Key Words:

Spaghetti wrist, Modified Kessler, Multidisciplinary treatment, Functional outcome.

Introduction

Injuries of the volar wrist side are called spaghetti wrist, suicide wrist, or full house syndrome¹. Spaghetti wrist injuries are severe and extensive wrist injuries in which at least three of the 16 structures between the distal wrist crease and the flexor musculotendinous junction are completely cut². Spaghetti wrist injury involves multiple tissue structures on the volar wrist side, including the flexor tendons, median, ulnar, radial nerves, and arteries³. The volar wrist region's injuries, which have complex anatomy with delicate structures, are primarily treated in hand surgery centers. The most successful results of these injuries are achieved with adequate physical therapy after rapid and meticulous surgical treatment. Hypoxic conditions resulting from delayed surgical intervention, multiple tendon and neurovascular structure sutures at the same level, prolonged immobilization time, and inflammatory processes occurring during the rehabilitation period affect morbidity⁴.

Researchers have developed many suture techniques to improve mechanical properties and tissue strength. Four-thread core suture techniques are used the modified Kessler method, which is easy to apply with enough force to allow active mobilization^{5,6}.

The treatment approach modalities in volar wrist injuries are limited by weak evidence



Figure 1. Intraoperative image of one of the patients.

based on management and outcomes. Our study aimed to evaluate the patient demographics, injury mechanism, spaghetti wrist definitions, the functional results of the modified Kessler technique, and physical therapy in spaghetti wrist injuries.

Patients and Methods

The study was approved by the Ethics Committee of University of Necmettin Erbakan, Faculty of Medicine (Approval no: 2021/3552). The study included 121 patients (105 males and 16 females) who had surgery due to spaghetti wrist injuries and followed for a mean period of 15.61 ± 3.85 months (range, 8-24) in the Orthopaedic/Hand-Upper Extremity Surgery and Microsurgery Department. The volar side injury of the wrist was evaluated as having injuries in at least 3 of the 16 existing structures (at least one of these three structures must include an artery or

nerve) (Figure 1). All patients were operated on with the modified Kessler method within the first 8 hours of injury. Nerve ruptures were repaired with epineural repair (with 8/0 sutures), and 8/0 sutures were used for arterial anastomoses. The skin incisions were primarily repaired with 4/0 prolene to avoid hematoma compression. Postoperatively, the patients were hospitalized for 1 to 3 days. The outpatient follow-up was performed at 1 week, 3 weeks, and every 3 months. All the patients were included in the Physical Therapy and Rehabilitation program after nearly 3 weeks of a thermoplastic splint.

The functional outcomes were evaluated with intrinsic and tendon function, opposition, sensation (by two-point discrimination), and grip strength, according to the Noaman's report⁷. The different categories were graded as excellent, good, fair, and poor. The individual tendon function was considered excellent in patients with an 85% to full range of motion or finger flexion of 1 cm or less from the distal palmar fold. Patients



Figure 2. Postoperative functional images of one of the patients.

with 70-84% normal range of motion or 2 cm from the distal palmar fold were evaluated as good, 50-69% as moderate to normal, while patients with fixed contraction or adhesion were evaluated as poor tendon function. An excellent opposition was defined when the tip of the thumb could move freely over the three phalanges of the other four fingers. If the tip of the thumb touches only the tip of the other four fingers, it is considered good; if not, it is considered moderate opposition (Figure 2). The intrinsic function was evaluated as excellent when the patient performed both finger abduction and adduction with the froment sign. The patients were evaluated as good when they could perform both finger abduction and adduction with the froment sign, moderate when doing any of them, and weak when they could not make any movement. The two-point discrimination less than 10 mm was considered excellent, between 10 and 20 mm it was considered good, greater than 20 mm it was considered moderate, and poor if tropic changes or skin ulcerations were present.

Grip strength measurement was performed with the calibrated Jamar dynamometer while the patient was sitting, shoulder in adduction, elbow flexed to 90 degrees, and forearm and wrist in a neutral position⁸.

Clinical functional aspects were evaluated with Q-DASH score, Sollerman test, and Allen test. The rapid arm-shoulder-hand disability questionnaire (Q-DASH) is a self-answered questionnaire containing 11 titles extracted from the DASH survey, with validity and reliability that measures physical function and symptoms in patients with upper extremity problems. At least 10 of 11 items must be answered to calculate the Q-DASH score. Each heading contains 5 answer options; the score of the scale is calculated from the heading scores (0= no disability, 100= most severe disability)⁹. The test includes movements such as: unlocking a door, using a zipper, collecting coins, using a screwdriver, buttoning the shirt, loosening the screws jars, writing, folding paper, turning the doorknob, and pouring

Table I. Injury pattern in the patient with spaghetti wrist.

	Structures injured	Number of cases (n)	% (of total cases n)
Flexor tendons	2 nd FDP	34	28
	3 rd FDP	37	30,5
	4 th FDP	37	30,5
	5 th FDP	40	33
	1 st FDS	8	0,6
	2 nd FDS	33	41
	3 rd FDS	52	42,9
	4 th FDS	34	45
	5 th FDS	37	45
		PL	42
	FPL	29	36
	FCR	33	40
	FCU	38	47
	Total incision	14	17
Nerves	Median nevre	56	68
	Ulnar nevre	56	68
	Radial nerve	1	8
Arteries	Radial	37	45
	Ulnar	59	72

FDP: flexor digitalis profundus; FDS: flexor digitalis superficialis; PL: palmaris longus; FPL: flexor pollicis longus; FCR: flexor carpi radialis; FCU: flexor carpi ulnaris.

water¹⁰. In the Sollerman test, scoring is done by giving points from 0 to 80 for each test, a higher score indicates a better hand function¹¹. The Allen test is a standard primary care test used to assess arterial blood flow to the hand.

Statistical Analysis

SPSS (Statistical Package for Social Sciences, Chicago, IL, USA) Windows v.11.5 program was used for the statistical analysis. Descriptive statistics were expressed as mean ± Standart deviation. Independent Samples *t*-test was used to define the parametric data, while the One-sample Kolmogorov-Smirnov test examined non-parametric data. A two-tailed test was used to detect correlation. The significance *p*-level was approved for <0.05.

Results

The median age of the patients was 33 (min: 12; max: 84), and 14.9% (n=18) of the patients were smokers. The spaghetti injury was on the right wrist in 56.2% of the patients and on the left wrist in 43.8%. The mean time between the injury and surgery was 4.64±2.98 hours. Follow-up time was 14.22±3 .37, *p*>0.05 mounths. The spaghetti wrist injury mechanism was as follows; glass-related injuries in 35.5%, spiral injuries in

19%, knife-related injuries in 15.7%, piercing cutter in 10.7%, power machines in 9.1%, gunshot wound in 6.6%, traffic accident 2.5%, and dog bite injuries in 0.9%. The most frequently affected structures were the tendons of palmaris longus in 51% and flexor digitorum superficialis in 45%. Median nerve injury and ulnar nerve injury were seen in 68% of the patients, while ulnar arterial injury was present in 72%, and radial artery injury in 45% (Table I). The tendon and intrinsic function, opposition, sensation, and grip strength were graded as excellent, good, fair, and poor (Table II). The tendon and intrinsic function, opposition, sensation, and grip strength concerning gender and smoking were graded as excellent, good, fair, and poor (Table III and Table IV, respectively). There were significant differences regarding intrinsic function and grip strength between male and female patients (*p* = 0.04, *p* = 0.21, respectively). No significant difference was found regarding the follow-up time (mean±SD; 15.57±3.84, 13.75±3.25, respectively). Sensation and grip strength were significantly different between smoker and nonsmokers patients (respectively, *p* = 0.03, *p* = 0.01). The physical therapy period time correlated with hand function tests (*r* = 0.75, *p* < 0.05). In Pearson correlation analysis, tendon function and grip strength decreased with increasing age (*p* = 0.02, *r* = -0.81). Nerve damage was negatively

Table II. Results of overall functional outcome evaluation based on different categories (n=121).

	Tendon function (%)	Opposition (%)	Intrinsic function (%)	Sensation (%)	Grip Strength (%)
Excellent	37.2	32.2	31.4	19	19
Good	45.5	43	38	52.9	51.2
Fair	14.9	21.5	26.4	24	28.1
Poor	2.5	3.3	4.1	4.1	1.7
Total	100	100	100	100	100

correlated with sensation ($p = 0.011$, $r = -0.932$). The number of the damaged structures were negatively correlated with functional outcomes of four tests including tendon function, opposition, intrinsic function, and grip strength after surgery ($p = 0.04$, $r = -0.34$; $p = 0.04$, $r = -0.11$; $p = 0.03$, $r = -0.76$; $p = 0.03$, $r = -0.53$, respectively).

The mean of the postoperative Q-DASH score was 34.21 ± 14.73 (min: 10; max: 89). The mean of the postoperative Sollerman function test score was 53.54 ± 10.05 (min: 29; max: 74). Allen's test was negative in 4.1% (n=5) of the patients. Only 2 (1.7%) of the patients required additional surgery. Complications were seen in 5.8% (n=7) of the patients. Partial necrosis developed in 2 patients, adhesion in 5 patients, and clawing hand deformities in 3 patients. A small percentage (4.2%) of the patients with poor or moderate functional recovery underwent secondary procedures such as tenolysis, neurolysis, and vessel wrapping.

Discussion

This study evaluated patient demographics, spaghetti wrist definitions, injury mechanism, and postoperative surgical outcomes. Spaghetti wrist injuries define extensive lacerations of the volar wrist side. Sixteen different structures, including tendons, nerves, and arteries between the distal wrist crease and the flexor musculotendinous junction can be injured¹².

The tendon injuries are very common among all wrist injuries, while nerve and arterial injuries less commonly occur. Ulnar side injuries are more common than radial side injuries. In our study, the most frequently injured structures were palmaris longus (51%), flexor digitalis superficialis 4 and 5 (45%) among flexor tendons, and median and ulnar nerve (both; 68%).

Paschos et al¹³ reported that flexor digitorum superficialis (88.5%), Palmaris longus (83.6%), and median nerve (75.4%) were the most commonly injured structured among 61 patients. The difference may be due to the number of injured structures. In another cross-sectional study, including 153 patients with spaghetti injuries reported the most common structures as flexor digitorum superficialis 3,4 (98.04%), ulnar nerve injuries (86.27%), and median injuries (73.86%). The study focused on extensive injuries, including more than seven structures. In our study, the high percentage of palmaris longus injury can be explained by the superficial position of the palmaris longus.

We used to repair the modified Kessler technique with intratendinous longitudinal and transverse structures crossing the separated end of the tendon and the far end of the lengthwise structure. The results after surgical intervention regarding tendon function were found as excellent and good in 82.7%, consistent with the literature. However, the heterogeneity in the etiology and age range of the patient group is a disadvantage.

Table III. Results of overall functional outcome evaluation based on different categories in for male/female (n: 105/16).

	Tendon function (%)		Opposition (%)		*Intrinsic function (%)		Sensation (%)		*Grip Strength (%)	
	M	F	M	F	M	F	M	F	M	F
Excellent	39.3	21.4	33.3	21.4	34.6	7.1	20.6	0	21.5	21.4
Good	44.3	50.0	43.0	42.9	35.5*	50.0	53.3	57.1	50.5*	78.6
Fair	13.1	28.6	19.6	35.7	27.1	35.7	22.4	42.9	26.2	0
Poor	2.8	0	3.7	0	2.8	7.1	3.7	0	1.9	0

M: Male, F: Female.

*Male vs. female, significant ($p < 0.05$).

Table IV. Results of overall functional outcome evaluation based on different categories in smoker patients (n=18).

	Tendon function (%)	Opposition (%)	Intrinsic function (%)	*Sensation (%)	*Grip Strength (%)
Excellent	22.2	33.3	38.9	27.8	27.8
Good	55.5	38.9	22.2	27.8	27.7
Fair	22.2	16.7	33.3	38.9	38.9
Poor	0	11.1	5.6	5.6	5.6

*significant ($p < 0.05$).

Similar to our postsurgical outcome results after the modified Kessler technique, Yazdanshenas et al¹² reported that the tendon functions were ‘excellent’ and ‘good’ in 91.7% of the spaghetti wrist. In another study¹⁴, 61 patients with spaghetti wrist injuries were examined, and tendon function results were found as excellent and good in 91.8%. Satisfactory simultaneous and tension-free reconstruction can be achieved in all damaged layers when the modified Kessler technique is applied in a timely manner together with microsurgical techniques by a qualified hand surgeon in wrist injuries. We perform surgery within the first 8 hours after injury in our clinic. Boynuyogun et al¹⁵ reported that examined twenty patients who were operated on within the first 24 due to combined tendon, artery, and nerve injuries of the volar wrist side retrospectively. Noaman’s study examining the results of spaghetti wrist postsurgical outcomes reported that excellent and good postsurgical function rate was 32.32%. In our study, nearly 84.3% of patients had excellent/good level in all five tests for the functional postsurgical assessment regarding tendon function, opposition, intrinsic function, sensation, and grip strength. Although the same Kessler technique was used in both mentioned literature studies, the results highlight the importance of rapid surgical intervention. Bircan et al¹⁶ examined functional outcomes in patients with only flexor tendon lacerations with the Kessler technique and reported that functional results were excellent in 92.8% of the digits. In addition, the number of the damaged structures was negatively correlated with all four tests examining postsurgical functional outcomes regarding tendon and intrinsic function, opposition, and grip strength. Functional test results of a single tendon injury will be better without nerve and vascular damage. Nerve injuries often occur with penetrating tears or glass cuts in the forearm and are accompanied by tendon and vascular injuries¹⁷. In our patients, median and ulnar nerves injuries were present in 68% (separately, for both). Nerve damage

was negatively correlated with sensation. Many studies have stated that nerve injury rather than tendon injury is responsible for the postsurgical sequelae. Spaghetti wrist injuries may involve median or ulnar nerve injuries, or a combination of both, especially on the volar side of the forearm. Combined nerve injuries are significant causes of morbidity, mainly sensory and motor sequelae¹⁸.

We found that the postsurgical functional outcomes are better in younger patients with spaghetti wrist injuries. Hand injuries are usually seen in young and productive people and result in an economic loss of the workforce. In this study, mean age of patients was 36. In addition to the economic impact, it also brings serious social and functional losses¹⁹. In our study, the most common etiology of spaghetti wrist injury was work accidents (38.8%) (spiral injuries, piercing cutter, power machines). Despite occupational safety measures, the number of hand injuries still occurs at a high level. It is important to evaluate the etiology, treatment, rehabilitation process, functional recovery, and loss of injuries in large case series. When applied to tendons with appropriate and sufficient force, rehabilitation exercises in physiotherapy induce healing without gap formation²⁰. A previous study by Yazdanshenas et al¹² reported that 28% of spaghetti wrist injuries were work-related. Even if the causes of spaghetti wrist injuries vary depending on the geographical region, industrialization area, and cultural structure, work-related accidents take place in the upper ranks. We concluded that tendon function and grip strength decreased with increasing age. The success rate of the tendon function test showing finger flexion or distal palmar crease decreases with increasing age, which may be due to the more superficial incisions due to suicide or faster healing in young people. It is a certain knowledge that decreased testosterone is related to loss of muscle tone and reduced muscle mass²¹. In the literature, resistance training is shown to improve muscle mass^{22,23}. The level of testosterone may positively affect the treatment period in male

patients. Although, in our study postoperative Sollerman's scores were similar between men and women. According to our knowledge, there is no study examining the testosterone effect on spaghetti injuries in literature.

The postoperative Q-DASH score in this study was 34.21 ± 14.73 (min: 10; max: 89). Based on these scores, this surgical procedure was unlikely to impair activities of daily living due to functional impairment of the wrist and fingers. In Kabak et al²⁴ reported that the higher Q-DASH scores that have poor clinical evaluation were determined, it was seen that the patient sample had sharp lacerations including 10 or more volar anatomical structures. The damaged structures such as nerves and vessels, early treatment, surgical method, patient compliance, dynamic splinting during the postoperative period, adequate lymphatic drainage, and physiotherapy affect clinical results. As a result of extended follow-up in the Q-DASH score, it was seen that the results improved after physiotherapy. Our study initiated the physiotherapy program three weeks after the thermoplastic splint application depending on clinical progress. Generally, at 6 to 10 weeks, the physiotherapy program was practiced²⁵. The exercises at the beginning may affect the Q-DASH score. In addition, the acceptance of the Sollerman test as a standard test in reconstructive hand surgery is of great importance in the evaluation of surgical success and postoperative treatments, as it gives results in a short time and can be easily repeated²⁶. The mean Sollerman function test score was 53.54 ± 10.05 in our study. We used the Sollerman test because it reflects the quality of grip and pinch patterns for daily life activities. There is not enough information about the Sollerman test in spaghetti wrist injuries. In our study, the Allen test was used to evaluate vascular function. The Allen test was negative in 5 out of 121 patients. Yildirim et al²⁷ reported that adequate hand function was reached in 20 out of 35 patients who underwent wrist flexor tendon injury repair according to Allen's test.

Conclusions

The studies subjecting the spaghetti wrist laceration in our country region are limited. However, our results provide guiding information about both patient demographical knowledge and postsurgical outcomes. In general, transverse wounds cause spaghetti wrist injuries. In order to maximize healing and minimize complications, hand surgeons with adequate experience should

provide a complete reconstruction of all injured structures on the axial plane in a timely surgical procedure. The most significant factor on functional recovery is early surgical treatment and, accordingly, early initiation and a long period of physical therapy in addition to the involved structures, the presence of nerve damage, gender, and smoking.

Conflict of Interest

The authors declare that they have no conflict of interests.

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Informed Consent

The authors declare that the patients included in the study signed informed consent forms to use their medical information in the studies.

Ethical Statement

The study was approved by the Ethics Committee of University of Necmettin Erbakan, Faculty of Medicine (Approval no: 2021/3552).

Authors' Contributions

Concept: N. Atilgan, N. Duman, M. Demiryurek; Design: N. Atilgan, T.S. Colak, I.H. Korucu; Supervision: N. Duman, M. Demiryurek, T.S. Colak, I.H. Korucu; Funding: N. Atilgan; Materials: N. Atilgan, N. Duman, M. Demiryurek, T.S. Colak, I.H. Korucu; Data: N. Atilgan, N. Duman, M. Demiryurek, T.S. Colak, I.H. Korucu; Analysis: N. Atilgan, N. Duman; Literature search: N. Atilgan, N. Duman, I.H. Korucu; Writing: N. Atilgan, N. Duman; Critical revision: M. Demiryurek, T.S. Colak, I.H. Korucu.

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