



Results of a differentiated approach to open decompression of the median nerve in carpal tunnel syndrome

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Abstract

Introduction Open decompression of the median nerve is a common surgery performed for carpal tunnel syndrome (CTS). Transection of the transverse carpal ligament (TCL) results in impaired hand biomechanics and decreased grip strength when specific anatomy necessitate transection of the thenar muscles along with the ligament.

The **objective** was to compare short-term and long-term surgical results of CTS patients treated with open decompression without thenar muscle reconstruction, with thenar muscle reattachment and with reconstruction of the thenar muscles.

Material and methods A total of 80 patients with idiopathic CTS treated with 92 surgical procedures were included in the study. They were divided into three groups. The first group included 38 patients (39 surgeries) treated with open decompression without reconstruction of the TCL. Forty surgical procedures were produced for 31 patients of the second group including dissection and reattachment of the thenar muscles located at the site of the median nerve dissection. Median nerve decompression followed by TCL reconstruction were performed for 11 patients of the third group treated with 13 surgical procedures.

Results All patients demonstrated positive dynamics with more significant recovery of the hand function achieved after open decompression of the median nerve and reattachment of the thenar muscles and reconstruction of the spinal nerve with the outcome improved at three months and stabilized at six months of the surgery.

Discussion A differentiated approach to treatment ensured the amplitude of the M-response of the brevis muscle abducting the pollicis increased by 15.9 % in the first group, by 34.3 % in the second group, and by 30.5 % in the third group; the impulse velocity along the motor fibers of the median nerve increased by 6.6 %, 13.2 %, and 10.9 %, respectively, at six months. Less improvement in electrophysiological parameters in patients of the first group could be associated with a more advanced surgical technique employed for the patients of the second and third groups.

Conclusion A comparative analysis of the short-term and long-term surgical outcomes of CTS patients revealed clinically significant improvement with both options. However, the hand function recovery was more accomplished in the second and third groups with use of the two methods we developed.

Keywords: carpal tunnel syndrome, transverse carpal ligament, surgical treatment.

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INTRODUCTION

Carpal tunnel syndrome (CTS) is a mononeuropathy of the median nerve caused by its compression by surrounding tissues. The prevalence of CTS is 150–276 individuals per 100,000 population. The condition is progressive, resistant to conservative therapy, prone to recurrence, and necessitates surgical treatment, which is effective in 70–90 % of clinical observations [1].

Idiopathic CTS is one of the clinical forms, without obvious causes (acute trauma, post-traumatic deformities of the hand and the wrist, endocrine, metabolic or chronic systemic diseases, intraneural tumors). The disease can be associated with repeated loads on the hand when bending at the wrist, keeping it in one position for a long time, and playing vibrating instruments. Installers, packers, assemblers, artists, jewelers, office workers, and pianists have a high risk of developing the disease [1].

Open decompression of the median nerve is a common surgery for CTS to facilitate rapid relief of debilitating pain and increased sensitivity in the fingers, achieving lasting clinical improvement. However, transection of the transverse carpal ligament (TCL) can result in impaired biomechanics of the hand and decreased grip strength and pillar pain [2, 3, 4, 5, 6].

Several methods have been proposed by hand surgeons to restore the dissected carpal tunnel [7, 4]. The authors took into account the fact that the carpal tunnel is the anterior border of the carpal tunnel and the attachment of the thenar and hypothenar muscles [3].

It is known that approximately half of the area of the anterior surface of the ligament is occupied by the muscles of the eminence of the thumb (m. flexor pollicis brevis, abductor pollicis brevis) on the radial side [8]. These muscles are attached on the ulnar side in 55 % of clinical observations, in the projection of the site of the supposed ligament dissection [9]. The muscles are either transected or peeled off to the radial side in such situations to allow dissection of the TCL in the ulnar part of the carpal tunnel, avoiding injury to the median nerve and its motor branch during the repair [10].

The procedure can be associated with loss of the thenar muscle attachment after detachment or transection and cause their hypo- or atrophy affecting the restoration of the hand function [11].

To prevent such complications, we developed a method for refixing the muscles of the eminence of the thumb after open decompression of the carpal tunnel [12].

The **objective** was to compare short-term and long-term surgical results of CTS patients treated with open decompression without thenar muscle reconstruction, with thenar muscle reattachment and with reconstruction of the thenar muscles.

MATERIAL AND METHODS

The study included 80 patients with idiopathic CTS treated with open decompression of the median nerve between January 1, 2024, and June 1, 2025. There were 67 female and 13 male patients with a mean age of 58 years (range, 36–86 years). Bilateral surgeries were performed in 12 patients at an interval of at least three months. Surgery on one side was considered one clinical observation. A total of 92 surgical interventions were performed. Right-sided surgery was performed in 61 (66 %) cases and 31 (34 %) patients had left-sided procedures.

The study was a non-randomized, prospective, single-center, longitudinal, parallel-group controlled clinical trial. Inclusion criteria included CTS diagnosed preoperatively and confirmed intraoperatively. Exclusion criteria included the presence of concomitant systemic, metabolic, and endocrine diseases, posttraumatic conditions of the hand and the forearm, cubital tunnel syndrome, and recurrent CTS. No patients were excluded from the study.

The primary endpoint of the study was to evaluate the effectiveness of surgical treatment of CTS patients by open decompression of the median nerve and re-attachment of the muscles at the eminence of the thumb and open decompression of the median nerve with reconstruction of the TCL as well as to develop recommendations for differentiated surgical treatment depending on the anatomy of the wrist and pathological changes.

Secondary endpoints of the study included the analysis of clinical parameters (power grip of the hand, daily activities, severity of symptoms and functional impairments), ENMG parameters (amplitude of the M-response of the abductor pollicis brevis muscle, distal latency of the motor fibers of the median nerve, impulse conduction velocity in the motor fibers of the median nerve, impulse conduction velocity in the sensory fibers of the median nerve).

The clinical observations were divided into three groups depending on the method of surgical intervention used (Table 1). The first group included 38 patients (39 operations) who had no TCL repair after decompression of the median nerve. The second group consisted of 31 patients (40 operations) who had the muscles at the eminence of the thumb (m. flexor pollicis brevis and m. abductor pollicis brevis) overlapping the line of the intended dissection of the TCL. The muscle attachment site was carefully separated with the underlying superficial part of the ligament. Re-attachment was produced after decompression of the carpal tunnel without reconstruction of the TCL. The operation was performed using the method we developed [11]. The third group included 11 patients (13 operations) who underwent reconstruction of the TCL after decompression of the median nerve, using another method we had developed earlier [13].

The clinical groups (Table 2) were comparable in age, timing of surgery from the onset of the disease, the severity of CTS as classified by Beck [14].

Table 1

Characteristics of the study groups

Study groups	Type of surgical procedure	Number of patients (n = 80)		Number of surgeries (n = 92)	
		abs.	%	abs.	%
No. 1	Open decompression of the median nerve	38	47.50	39	42.5
No. 2	Open decompression of the median nerve and re-attachment of the thenar muscles	31	38.75	40	43.5
No. 3	Open decompression of the median nerve and reconstruction of the TCL	11	13.75	13	14.0

Table 2

Characteristics of patients in the study groups

Description		Клинические группы						$p^{1-2},$ $p^{1-3},$ p^{2-3}
		No. 1 ($n = 39$)		No. 2 ($n = 40$)		No. 3 ($n = 13$)		
		абс.	%	абс.	%	абс.	%	
Age	< 50 years	9	23.7	11	27.5	4	30.7	> 0.05
	51–60 years	16	41.1	17	42.5	6	46.1	> 0.05
	> 60 years	14	35.2	12	30.0	3	23.2	> 0.05
Timing of surgery from the onset of the disease	< 6 years	27	69.2	28	70.0	9	69.2	> 0.05
	6 < 12 years	8	20.5	7	17.5	2	15.4	> 0.05
	≥ 12 years	4	10.3	5	12.5	2	15.4	> 0.05
Severity of CTS	mild	10	25.6	12	30.0	4	30.8	> 0.05
	moderate	13	33.3	13	32.5	4	30.8	> 0.05
	severe	16	41.1	15	37.5	5	38.4	> 0.05

Diagnosis of the TCL relied on pain in the hand, mainly at night and in the morning, numbness at the site innervated by the median nerve, duration of the disease and failed conservative treatment, the presence of positive clinical symptoms of Phalen, Tinel, the flick maneuver, the scratch collapse test, ENMG and ultrasound findings. Indications for surgery included CTS diagnosed by a hand surgeon, by ENMG and ultrasound, lack of clinical improvement after a three-month conservative treatment, and negative dynamics in ENMG findings.

The choice of surgical treatment was based on preoperative ENMG and ultrasound findings, intraoperative visualization of pathological changes at the surgical site. The final decision on the surgical technique was made intraoperatively.

Isolated median nerve decompression without posterior ligament reconstruction was performed for patients with severe flexor tenosynovitis detected intraoperatively, preventing full restoration of the TCL (group one). The thenar muscles were separated along with the superficial portion of the underlying ligament and re-attached en bloc after transection if the muscles were identified at the site of the intended TCL transection during ultrasound examination of the carpal tunnel or intraoperatively (group two). Open carpal tunnel decompression and true posterior ligament reconstruction were produced for individuals whose jobs were associated with repetitive and forceful activities that would 'overload' the tendons and muscles (group three).

The effectiveness of surgical treatment was evaluated using eight criteria including four clinical (handgrip strength, daily activities, severity of clinical symptoms, and functional deficiency) and four relied on electroneuromyography (M-response amplitude of the abductor pollicis brevis muscle, distal latency of the median nerve motor fibers, and impulse conduction velocity along the median nerve motor and sensory fibers). The parameters were explored dynamically: preoperatively, at three months of surgery, and at six months post-op. The magnitude of the hand grip strength was measured using a DK-50 hand spring dynamometer (ZAO Nizhny Tagil Medical and Instrumental Plant, Russia). The test was performed on each hand twice with a one-minute interval, with the mean calculated.

The severity of patients' daily activities was determined using the DASH questionnaire [15, 16, 18].

The BCTQ questionnaire was used to evaluate treatment outcomes [17, 18, 19].

The functional status of the peripheral motor and sensory fibers of the median nerve was examined in both hands using standard programs of the Lightbox electromyograph (Neurosoft, Russia), two cables for connecting disposable electrodes with a touch-proof alligator connector (black and red), a ground electrode, and a disposable skin electrode 22×34 mm. The examination was performed according to standard methods [20].

An ultrasound examination was performed on both upper extremities using a Samsung Medison HS 40 system and a linear transducer with a frequency of 3–16 MHz. The scan identified the median nerve, its size, structure, nerve compression sites at the wrist and upper forearm, the location of the thenar muscles in the carpal tunnel, and the condition of the surrounding tissues, muscles, and tendons.

Statistical analysis of the data was performed using SPSS 25 (IBM SPSS Statistics, USA, license no. 5725-A54). The conformity of the quantitative trait values to the normal distribution law was tested using the Shapiro – Wilk and Kolmogorov – Smirnov tests, with the Liliefors correction. Descriptive statistics were presented as the mean and standard deviation ($M \pm SD$). Groups were compared using the Kruskal – Wallis rank analysis of variance, Mann – Whitney tests, the Wilcoxon paired test, and Pearson's χ^2 (for nominal variables).

Boxplots showing the median, quartiles, minimum, and maximum were used to visualize the data. The critical value of the significance level was taken as 0.05 in all cases except for between-the-group comparisons in the analysis of variance, where the Bonferroni correction was applied with a critical value of $p = 0.017$.

Surgical technique

Identical surgical conditions, the surgical approach and stages of the operation in patients of the first group corresponded to the principles we reported earlier [19].

Skin incision and aponeurosis similar to that in the first group was produced in patients of the second group. The TCL was dissected along the ulnar aspect. Moving proximally to the point of intersection with the thenar muscles (Fig. 1a), an incision bending around the apex of muscle attachment was used to dissect the superficial leaf of the ligament along with the muscles. They were retracted outward. Then, the TCL and the deep fascia of the forearm were completely dissected (Fig. 1b). The median nerve was repaired. The dissected muscles and a portion of the ligament were re-attached (sutured back in place or outward up to 3 mm) using a U-shaped suture with two locking loops on each side (Fig. 1c). After this, the palmar aponeurosis was sutured with three to four separate stitches to allow for the thenar muscles to be shifted inwards, reducing the tension at the point of their fixation. Donati sutures were applied to the skin.

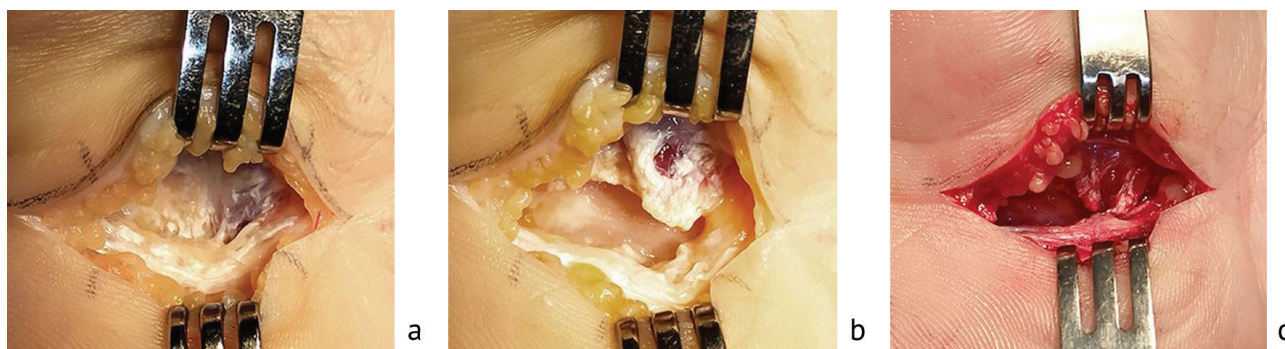


Fig. 1 The thenar muscles located in the projection of the TCL intersection line (a); the transected and abducted thenar muscles (b); appearance of the surgical wound after re-attachment of the thenar muscles (c)

Skin incision and aponeurosis in patients of the third group were similar to those produced in the first and second groups. The TCL was transected, creating two trapezoidal flaps: a radial (proximal) flap and an ulnar (distal) flap. The ligament flaps were re-aligned at their minor bases and joined together after exploration, mobilization, and epineurotomy of the median nerve. The palmar fascia and skin were stitched with separate sutures.

Postoperative management of the patients was performed according to the principles described earlier [19].

The study received a favourable opinion from the Bioethics Committee of Samara State Medical University (Protocol No. 312 dated November 25, 2025). The study was performed in accordance with ethical principles for medical research involving human subjects stated in the 1975 Declaration of Helsinki developed by the World Medical Association as revised in 2008. Information about the patients' personal data was not included.

RESULTS

Between-the-group comparison revealed positive dynamics of clinical and functional parameters in patients of the three groups, which was most evident at six months of surgery.

However, there were differences between the groups. The hand grip strength decreased by 35.0 % ($p^{0-3} < 0.001$) at three months, and increased after six months, but did not reach the initial level in patients of the first group (Table 3). The DASH activity of daily living improved by 31.9 % ($p^{0-3} = 0.002$) after three months, but change significantly by 61.1 % ($p^{0-6} < 0.001$) after six months. A similar trend was observed in assessment of the severity of clinical symptoms and functional impairments. The BCTQs index and the BCTQf index improved by 52.8 % ($p^{0-6} < 0.001$) and by 37.7 % ($p^{0-6} < 0.001$), correspondingly, at six months. The ENMG parameters indicated shortening of the distal motor latency by 35.6 % ($p^{0-6} < 0.001$) and the increase in sensory velocity by 72.2 % ($p^{0-6} < 0.001$) after six months, which objectively suggested clinical effectiveness of the median nerve decompression.

Table 3

Changes in clinical and functional parameters in the first group (intra-group comparison)

Description	Normal	Follow-up period			% changes		<i>p</i>	
		pre-op	at 3 months	at 6 months	at 3 months	at 6 months	p^{0-3} M-W*	p^{0-6} M-W*
Strength, daN	–	20,32 ± 4,37	13,20 ± 4,52	19,72 ± 3,98	–35,0 %	–2,9 %	< 0,001	0,511
DASH**, score	< 25	38,01 ± 9,99	25,86 ± 17,26	14,80 ± 7,38	–31,9 %	–61,1 %	0,002	< 0,001
BCTQs***, score	1.0	3,32 ± 0,66	2,02 ± 0,73	1,57 ± 0,45	–39,1 %	–52,8 %	< 0,001	< 0,001
BCTQf****, score	1.0	3,10 ± 0,63	2,37 ± 0,92	1,93 ± 0,48	–23,5 %	–37,7 %	0,013	< 0,001
Amplitude, mV	> 6.0	4,92 ± 2,89	4,55 ± 2,91	5,71 ± 2,53	–7,5 %	15,9 %	0,597	0,423
Latency, ms	< 4.2	6,62 ± 2,21	4,55 ± 0,65	4,26 ± 0,83	–31,2 %	–35,6 %	0,001	< 0,001
Motor speed, m/s	> 50	45,57 ± 17,64	48,03 ± 15,49	48,61 ± 16,36	5,4 %	6,6 %	0,351	0,200
Touch speed, m/s	57–71	21,18 ± 15,40	33,22 ± 16,01	36,47 ± 12,09	56,8 %	72,2 %	0,006	< 0,001

Note: * comparison using the Mann – Whitney test; ** questionnaire for assessing functional impairment of the upper limb; *** scale of severity of clinical symptoms; **** scale of severity of functional deficit.

The dynamics in the parameters of patients of the second group (Table 4) was slightly different from those seen in the first group. There was no significant decrease in hand grip strength at three months of the surgery. There was 9.6 % decrease from the initial level ($p^{0-3} = 0.035$). After six months, the grip strength increased by 15.2 % compared to the preoperative value ($p^{0-6} = 0.025$). The results of the clinical tests systematically improved at the follow-up periods, demonstrating a significant increase at six months: daily activities of the limb according to the DASH questionnaire improved by 70.5 % ($p^{0-6} < 0.01$); BCTQs, by 56.3 % ($p^{0-6} < 0.01$) and BCTQf, by 47 % ($p^{0-6} < 0.001$). A similar trend was observed in ENMG parameters. The amplitude of the M-response of the abductor pollicis brevis increased by 34.3 % ($p^{0-6} = 0.008$), distal motor latency improved by 31.7 % ($p^{0-6} < 0.001$), and sensory velocity by 72.4 % ($p^{0-6} < 0.001$).

Table 4

Changes in clinical and functional parameters in the second group (intra-group comparison)

Description	Normal	Follow-up period			% changes		<i>p</i>	
		pre-op	at 3 months	at 6 months	at 3 months	at 6 months	p^{0-3} M-W*	p^{0-6} M-W*
Strength, daN	–	20.53 ± 6.58	18.56 ± 4.49	23.65 ± 7.47	–9.6 %	15/2 %	0.035	0.025
DASH**, score	< 25	34.54 ± 15.48	15.15 ± 9.40	10.17 ± 8.09	–56.2 %	–70.5 %	< 0.001	< 0.001
BCTQs***, score	1.0	3.14 ± 0.81	1.59 ± 0.40	1.37 ± 0.38	–49.2 %	–56.3 %	< 0.001	< 0.001
BCTQf****, score	1.0	2.80 ± 0.83	1.83 ± 0.55	1.49 ± 0.48	–34.7 %	–47.0 %	< 0.001	< 0.001
Amplitude, mV	> 6.0	5.51 ± 2.95	6.29 ± 1.79	7.39 ± 2.63	14.3 %	34.3 %	0.277	0.008
Latency, ms	< 4.2	6.12 ± 1.84	4.09 ± 0.56	4.18 ± 0.57	–33.1 %	–31.7 %	< 0.001	< 0.001
Motor speed, m/s	> 50	47.46 ± 12.55	51.56 ± 9.16	53.74 ± 5.35	8.6 %	13.2 %	0.026	0.005
Touch speed, m/s	57–71	24.54 ± 14.56	42.21 ± 7.15	42.30 ± 7.49	72.0 %	72.4 %	< 0.001	< 0.001

Note: * comparison using the Mann – Whitney test; ** questionnaire for assessing functional impairment of the upper limb; *** scale of severity of clinical symptoms; **** scale of severity of functional deficit.

Patients in the third group (Table 5) demonstrated less loss of the hand grip strength than patients in the first and second groups three months after the operation, by 2 % ($p^{0-3} = 0.935$), and increase by 24 % seen after six months ($p^{0-6} = 0.05$). There was a significant increase in functional activity of the limb measured with the DASH after six months and it was 76.9 % ($p^{0-6} < 0.001$). Patients in the third group showed the greatest improvement after six months according to the BCTQs questionnaire, with the increase of 61.8 % ($p^{0-6} < 0.001$) in dynamics, and 51.2 % ($p^{0-6} < 0.001$) according to the BCTQf questionnaire.

Table 5

Changes in clinical and functional parameters in the third group (intragroup comparison)

Description	Normal	Follow-up period			% changes		<i>p</i>	
		pre-op	at 3 months	at 6 months	at 3 months	at 6 months	p^{0-3} M-W*	p^{0-6} M-W*
Strength, daN	–	22.08 ± 6.05	21.63 ± 5.47	27.38 ± 5.61	–2.0 %	24.0 %	0.935	0.05
DASH**, score	< 25	34.93 ± 19.48	18.67 ± 3.46	8.07 ± 5.83	–46.6 %	–76.9 %	0.065	< 0.001
BCTQs***, score	1.0	2.86 ± 0.81	1.51 ± 0.19	1.09 ± 0.13	–47.1 %	–61.8 %	0.004	< 0.001
BCTQf****, score	1.0	2.38 ± 0.70	1.73 ± 0.37	1.16 ± 0.27	–27.3 %	–51.2 %	0.049	< 0.001
Amplitude, mV	> 6.0	6.83 ± 2.67	6.94 ± 1.79	8.91 ± 2.28	1.6 %	30.5 %	0.693	0.088
Latency, ms	< 4.2	5.61 ± 1.15	3.86 ± 0.38	4.10 ± 0.32	–31.2 %	–26.9 %	0.004	0.003
Motor speed, m/s	> 50	54.46 ± 4.95	56.15 ± 4.00	60.39 ± 6.09	3.1 %	10.9 %	0.456	0.039
Touch speed, m/s	57–71	29.64 ± 11.35	44.82 ± 3.03	47.04 ± 2.81	51.2 %	58.7 %	0.003	< 0.001

Note: * comparison using the Mann – Whitney test; ** questionnaire for assessing functional impairment of the upper limb; *** scale of severity of clinical symptoms; **** scale of severity of functional deficit.

ENMG parameters showed a tendency to normalize: after six months, the shortening of distal motor latency was 26.9 % ($p^{0-6} = 0.004$), and the in motor and sensory speeds increased by 10.9 % ($p^{0-6} = 0.039$) and 58.7 % ($p^{0-6} < 0.001$), respectively. The increase in the ENMG parameters in patients of the third group was smaller than in patients of the first and second groups, which was likely associated with their higher/better preoperative values.

Comparison of clinical and functional parameters between groups showed that hand grip strength decreased three months after surgery in patients of the three groups (Fig. 2a), and decreased to a greater extent in the first group (by 35 %), significantly differing from the second and third groups ($p^{1-2}, 1-3 < 0.001$). There were no differences in the measurements of the second and third groups. The average value of the hand grip strength increased in all patients at six months. The hand grip strength significantly exceeded the initial data in the second and third groups (by 15.2 % and 24 %, respectively), and remained 2.9 % lower in the first group as compared to preoperative, significantly differing from the second ($p^{1-2} = 0.006$) and third ($p^{1-3} < 0.001$) groups.

More uniform improvement was seen in activities of daily living of the upper limb, assessed by the DASH questionnaire, as compared to the handgrip strength (Fig. 2b). The upper limb function increased by 61.1 % in the first group, by 70.5 % in the second, and by 76.9 % in the third at six months. The differences between the first and second groups and between the first and third groups were statistically significant ($p^{1-2} = 0.014$ and $p^{1-3} = 0.005$).

The severity of clinical symptoms measured with the BCTQs questionnaire decreased, generally in a consistent manner (Fig. 2c). The severity of symptoms decreased by 52.8 % in the patients of the first group, by 56.3 % in the second, and by 61.8 % in the third group after six months. There were no significant differences between the first and second groups, and the differences between the first and third were statistically significant ($p^{1-3} < 0.001$).

There was positive dynamics in impaired function measured with the BCTQf questionnaire (Fig. 2d). The function improved by 37.7 % in the first group, by 47.0 % in the second, and by 51.2 % in the third group after six months. The differences between the first and second groups, between the first and third groups, were statistically significant ($p^{1-2, 1-3} \leq 0.001$).

Along with the clinical data, There were several significant changes in the ENMG parameters, suggesting a uniform improvement in the functional status of the hand. The amplitude of the M-response of the short abductor pollicis muscle increased in the groups (Fig. 2d). It improved by 15.9 % in the first group, by 34.3 % in the second, and by 30.5 % in the third group after six months. The differences between the first and third groups were statistically significant ($p^{1-3} = 0.008$).

The distal motor latency of the median nerve showed positive dynamics at all stages of the study and in all groups (Fig. 2e). This was evident after three months with improvement by almost one third in all groups: by 31.2 % in the first, by 33.1 % in the second, and by 31.2 % in the third group. This unidirectional dynamics dissociated after six months. While distal motor latency continued to progressively decrease in the first group, reaching 35.6 % of the baseline, the dynamics were less pronounced in the second and third groups. There was 31.7 % improvement in the second group and 26.9 % improvement in the third group as compared with the baseline level. In addition, motor latency in the second and third groups returned to normal values (< 4.2 ms).

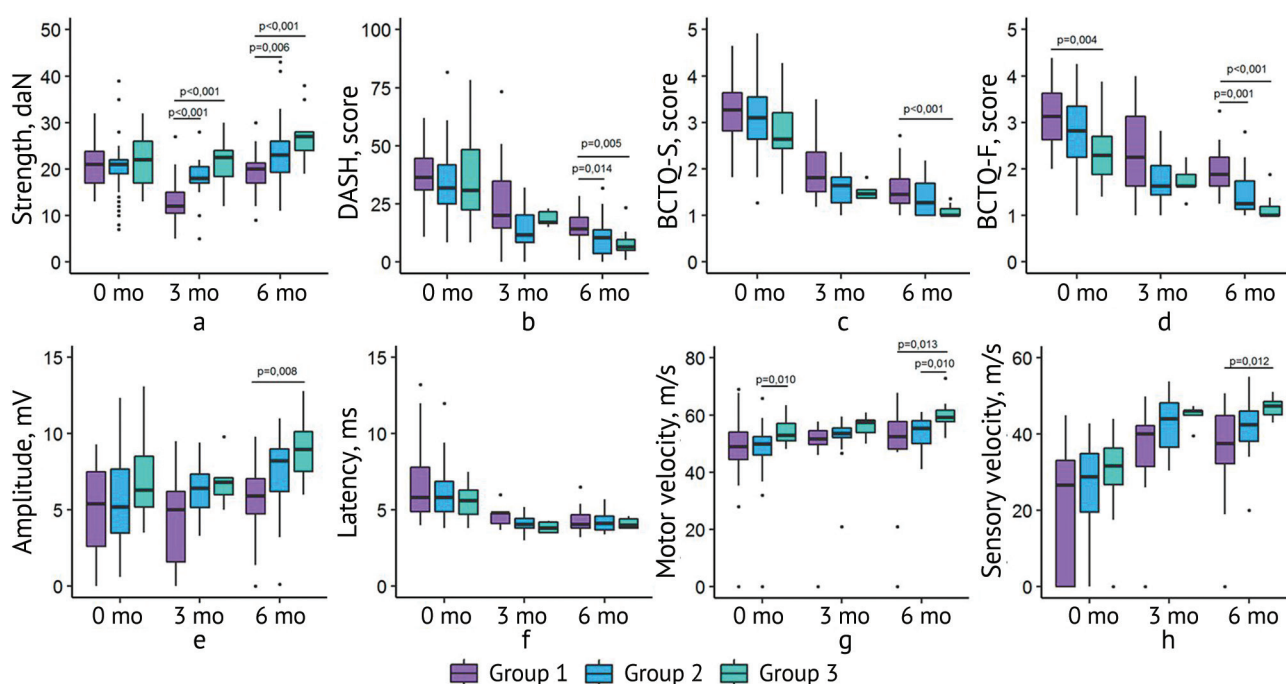


Fig. 2 Dynamics in the parameters: (a) hand grip strength measured (intergroup comparison), daN; (b) daily activities measured with the DASH questionnaire (intergroup comparison), score; (c) results of the BCTQs questionnaire (intergroup comparison), score; (d) results of the BCTQf questionnaire (intergroup comparison), score; (e) the amplitude of the M-response of the short abductor pollicis muscle (intergroup comparison), mV; (f) the distal motor latency of the median nerve (intergroup comparison), ms; (g) the impulse conduction velocity along the motor fibers of the median nerve (intergroup comparison), m/s; (h) the impulse conduction velocity along the sensory fibers of the median nerve (intergroup comparison), m/s

The impulse conduction velocity in the motor fibers of the median nerve gradually increased in the patients (Fig. 2g). The velocity increased by 6.6 % in the first group, by 13.2 % in the second group, and by 10.9 % in the third group at six months of surgery. The differences between the first and second groups, between the first and third groups were statistically significant with a reliability value of $p^{1-2} = 0.013$ and $p^{1-3} = 0.01$.

The impulse conduction velocity in the sensory fibers of the median nerve, similar to the previous ENMG indicators, also improved (Fig. 2h). A particular “jump” occurred in almost all patients three months after the operation: the impulse conduction velocity increased by 56.8 % in the first group, by 72.0 % in the second group and by 51.2 % in the third group. The increase in the velocity was not so evident at six months. The difference in the velocity increase between groups was insignificant at different time points, indicating the clinical effectiveness of the three surgical techniques.

Complications Two patients in the first group were diagnosed with pillar pain 1.5 months after surgery, which resolved spontaneously. Two patients in the second and two patients in the third groups developed short-term pain in the postoperative scar one month later, which might be caused by incomplete removal of skin sutures in the outpatient setting.

Therefore, patients in the three groups experienced clinically significant improvement after surgery. However, based on the magnitude of changes in dynamometry, questionnaire, and ENMG results, it can be concluded that patients in the second and third groups experienced a more rapid and complete recovery of hand function, which was seen after three months and became most pronounced and persistent at six-month follow-up.

We present a **clinical case** of a patient from the second group who underwent open carpal tunnel decompression with thenar muscle re-attachment using the technique we developed.

The 47-year-old patient, a lawyer, presented with complaints of sensory disturbances and pain in the first, second, and third fingers of her right hand, which worsened in the morning and after yoga classes. The pain had been gradually increasing over three years. Moderate hand pain and numbness were predominantly nocturnal, waking the patient four to five times. The swelling of the hand developed in the morning, and finger movement became difficult. Her professional, everyday, and athletic activities had significantly decreased. In recent months, she had been treated conservatively with minor improvement.

Initial examination showed no changes in the appearance of the right hand, no thenar muscle hypotrophy, full range of motion in the fingers. She had pain in the projection of the carpal tunnel radiating to the I–II–III fingers. Tinel's and Phalen's tests were positive. Fist grip strength was 22 daN. The activity of daily living measured with the DASH scored 32.5. The results of the BCTQs and BCTQf questionnaires scored 2.55 and 2.88, respectively. ENMG revealed changes characteristic of CTS: the amplitude of the M-response of the short abductor pollicis muscle was 7.2 mV; distal latency of the motor fibers of the median nerve measured 4.6 ms; impulse conduction velocity along the motor fibers of the median nerve was 51.3 m/s; The impulse conduction velocity along the sensory fibers of the median nerve measured 34 m/s. Ultrasound demonstrated increased cross-sectional area (CSA) of the median nerve in the carpal tunnel measuring 16 mm² with a norm of < 11 mm² [20].

Surgery performed on the right hand in September 2024 revealed the thenar muscles occupying more than half of the anterior surface of the TCL. Open decompression of the median nerve with re-attachment of the muscles at the eminence of the thumb was performed using the method we developed. Neuropathic pain relieved on the second day. The patient scrupulously followed all recommendations. The postoperative period was uneventful.

The wound healed by primary intention. The patient had no complaints, could return to her job, to yoga, she had no numbness or tingling in the hand, no pain at rest or with load, she could experience full range of active motion in the fingers at six months (Fig. 3a). Fist grip strength was 26 daN (Fig. 3b). The functional status of the limb and daily activities measured with the DASH scored 0.83. The BCTQ scale showed positive dynamics with BCTQs scoring 1.0, and BCTQf being 1.0. She was satisfied with the treatment results.



Fig. 3 The range of active movements (extension, flexion) in the fingers at six months after surgery (a); dynamometry measured at six months of surgery was 26 daN in the right hand and 22 daN in the left hand (b)

ENMG revealed improvement in the amplitude of the M-response of the brevis abductor pollicis muscle measuring 8.6 mV; in the distal latency of the motor fibers of the median nerve measuring 3.2 ms; the impulse conduction velocity along the motor fibers of the median nerve measuring 51.5 m/s; in the impulse conduction velocity along the sensory fibers of the median nerve measuring 49 m/s (Fig. 4).

Ultrasound results: the CPS of the median nerve in the carpal tunnel was 8 mm² (Fig. 5).

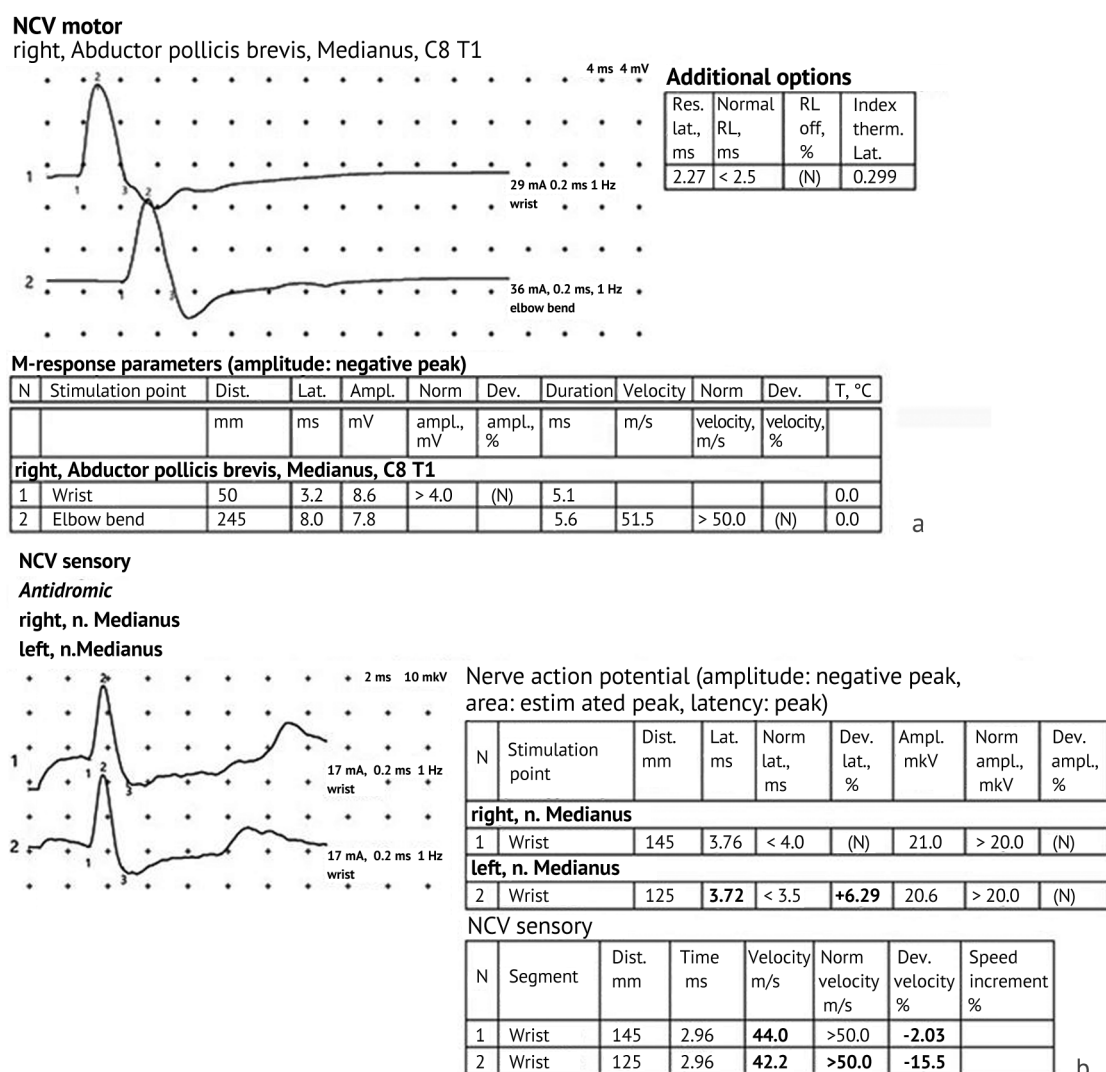


Fig. 4 ENMG parameters six months after surgery: (a) M-response of the median nerve of the right hand; (b) impulse conduction velocity along the sensory fibers of the median nerve



Fig. 5 Ultrasound of the right carpal tunnel six months after surgery

Therefore, the clinical observation illustrated the positive outcome of timely, adequate surgical intervention for idiopathic CTS that resulted in preserved thenar muscles, which occupied more than half of the anterior surface of the CTS, through careful separation from the ligament followed by re-attachment.

DISCUSSION

The effectiveness of surgical decompression of the median nerve in CTS patients has been confirmed by several clinical studies. Gilweg et al. reported a significant reduction in pain and other neuropathic disorders one month after surgery, and a significant improvement in the hand function after six months [21].

Adverse events and complications after open decompression of the median nerve are reported in the literature. The main disadvantages of the surgical modality for CTS patients identified by Belyakov et al. included a high probability for the nerve trunk to be involved in the scar, compression of the median nerve by the edges of the transected ligament, and the chronic trauma in manual workers [22]. Gartsman et al. found that surgery related width of the carpal arch increased by more than 20 % correlates with a handgrip strength decreased by 25.8 % [23]. Luchetti and Amadio reported a decrease in handgrip strength in 16–25 % of clinical observations due to the CTS transected during open decompression of the median nerve [24].

Lluch, Castro-Menéndez et al., Seitz et al. reported the feasibility of TCL reconstruction to facilitate a more rapid and complete restoration of the hand function by increasing grip strength and reducing the risk of pain at the site of the postoperative scar and pillar pain [4, 7, 25]. Netscher et al. reported the maximum strength of the coarse and fine grips reaching the baseline at three months of TCL reconstruction which was significantly higher than similar measurements in no-TCL-reconstruction patients [26]. Kotelnikov et al. also reported the effectiveness of TCL reconstruction with increased grip strength of the hand, improved BCTQs and BCTQf scores, ENMG data in patients aged 18–60 years with a moderately severe condition [27].

Mujadzic et al. reported a fourfold decrease in the incidence and duration of pillar pain in patients treated with a minimally invasive surgical approach (7.2 %) as compared to a standard incision (32.1 %) [5]. Seitz et al. reported a twofold decrease in the incidence of pillar pain and increased hand grip strength in patients after TCL reconstruction (19 %), compared to no-TCL-reconstruction patients (8.6 %) [25]. Kumar et al. reported a statistically significant decrease in the incidence of pillar pain 3–6 months after minimally invasive transection of the TCL ($p = 0.41$). The outcomes at a longer follow-up period did not reach statistically significant values [28].

Bernstein et al. suggested the restored integrity of the palmar aponeurosis being essential for preventing pillar pain. Suturing after open decompression would minimize the risk of re-occurrence [29]. In our series, the palmar aponeurosis was sutured in patients in all three groups. The procedure reduced the time it took to regain hand grip strength, prevented flexor tendon subluxation, and median nerve scarring. The approach could minimize the incidence of pillar pain which was seen in only two clinical cases of the first group with no cases observed in the second and third groups.

Hollevoet et al. reported the site of attachment of the thenar muscles to the TCL being located at the ulnar side of the median nerve in some clinical observations or significantly displaced inward in a cadaver study. The palmar surface of the TCL was 85 % covered by the thenar muscles in some cases, [9]. Alsafar et al. suggested that 50 % of the radial surface of the ligament was occupied by the muscles at the eminence of the thumb (thenar) or lying on the path of the dissection line [8]. In our series, we established that the site of attachment of the thenar muscles to the TCL was located on the ulnar portion in 40 (43.5 %) clinical observations seen in the second group of open decompression of the median nerve and re-attachment.

Jegal et al. reported that the entire surface of the carpal tunnel could be covered by the thenar muscles in clinical practice. In such cases, a carpal tunnel release requires dissection of the muscle bellies of these muscles, increasing the risk of injury to the motor branch of the median nerve, which may have a transligamentous structure. The authors recommended dissecting the thenar muscles radially to allow for the transection of the carpal tunnel along the ulnar portion of the carpal tunnel, simultaneously inspecting the median nerve and its muscular branch to avoid a iatrogenic injury [10]. Green and Morgan reported cases of the thenar muscles located on the ulnar portion of the carpal tunnel, which is an indirect sign of an abnormal origin of the motor branch of the median nerve in 90 % of cases, and can be easily damaged with muscles transection [30].

Chern et al. reported that the TCL transection could result in the thenar muscles losing the attachment site, in atrophy, and the decreased hand function. There was 25 % shortening of the superficial head of m. flexor pollicis brevis (relative to the resting length), 20 % of the ulnar part of m. abductor pollicis brevis (opposition and adduction), 20 % of m. opponens pollicis and 10 % of m. opponens digiti minimi [11]. Fuss and Wagner suggested that it was one of the reasons for the column pain in the postoperative period [2].

Neither clinical nor ENMG signs of injury to the motor branch of the median nerve were associated with decompression of the median nerve and re-attachment of the thenar muscles at a short term or a long term. No one developed pillar pain. Restoration of the thenar muscle attachment site contributed to an handgrip strength increased by 15.2 % at six months of the operation, a 70.5 % improvement in the DASH scores, BCTQ-s improved by 56.3 %, BCTQ-f by 47 %, an amplitude of the M-response of the brevis abductor pollicis muscle increased by 34.3 %, the distal latency of the motor fibers of the median nerve decreased by 31.7 %, motor speed increased by 13.2 % and sensory speed by 72.4 % compared to preoperative measurements. These data suggested a positive effect on the final results of the thenar muscle re-attachment that we used in cases where they occupied more than half of the anterior surface of the TCL.

A differentiated approach to surgical treatment for our CTS patients ensured high-quality outcomes in the three groups. However, the less positive and statistically insignificant differences in intermediate and final results in patients of the first group compared to those in the second and third groups may be caused by more sophisticated surgical techniques employed in the second and third groups. Alternatively, this may be due to the more common severity of CTS in the first group (41.1 % versus 37.5 % in the second and 38.4 % in the third groups), although no statistically significant differences were found (Table 2).

CONCLUSION

Open median nerve decompression for CTS, performed in the three groups of patients, resulted in significant clinical and functional improvement six months after surgery in all clinical observations.

The majority of patients who underwent thenar muscle re-attachment (Group 2) and TCL reconstruction (Group 3) following median nerve decompression using the methods offered showed recovery of clinical, functional, and EMNG parameters within three months and improved significantly within six months compared to patients who had no TCL reconstruction (Group 1).

The anatomy of the wrist, severity of pathological changes at the site, the age and professional characteristics of the patients are essential for the differentiated approach to open median nerve decompression for CTS.

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