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The role of sensory re-education of the brain in functional restoration of the hand after median nerve re-attachment

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ABSTRACT

PURPOSE: The aim of this study is to prove the role of sensory re-education of patients after the restoration of complete, distal damage to the median nerve, through comparative tests between a group of retrained patients and a group of patients who did not participate into a similar re-education program.

PATIENTS - METHOD: In this study, a comparative evaluation of 63 patients (51 men and 12 women with a mean age of 38 years (20 -51)) with complete, distal median nerve transection and surgical restoration was performed among a group of patients who had sensory re-education and a group without re-education. Evaluation was done through re-education tests that began after successful reattachment and nerve regeneration. The clinical evaluation took place after 18 months, 3 years and 6 years.

RESULTS: From the statistical analysis, the conclusions obtained were that the individuals in the re-educationgroup displayed superiority in the sensoryrehabilitation and functional ability of the hand in a shorter time compared to the non-re-education group, in all the tests, especially in the test concerning the ability of recognition and location of the stimuli in the hand.

CONCLUSIONS: The damage to the median nerve leaves a significant sensory and functional disorder in the hand. Surgical restoration alone is not sufficient for the functional rehabilitation of the hand, which requires sensoryre-education in order to produce better results in a shorter time.

KEY WORDS: Median nerve, re-education, microsurgical technique

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Introduction

Besides the eyes, hands are man's most useful tool for identifying and communicating with the surroundings. These are the first tools of communication with the environment immediately after birth. A person senses the touch and vibrations and perceives the texture, shape and dimensions of the objects he or she touches using the hands, as a collective - sensitive sensory organ. Finally, through hands a person can feel the temperature of the body and the objects. The optical-motorcoordination, which is the synchronized movementof the hand and optical stimuli, leads to the execution of a multiple precision movements making the hand the ultimate tool of creativity and expression of man.

The median nerve plays an important role in the functionality of the hand as a sensory tool. It is the nerve that has the most involvement in the sensory path. The hand is the area of the body with the highest number of receptors per unit area than any other part of the body. Thus,itis the limb with the largest representation in the sensory area of the brain. There, each part of the limb is assigned to a specific part of the gyrus. (**fig.1a,b**)

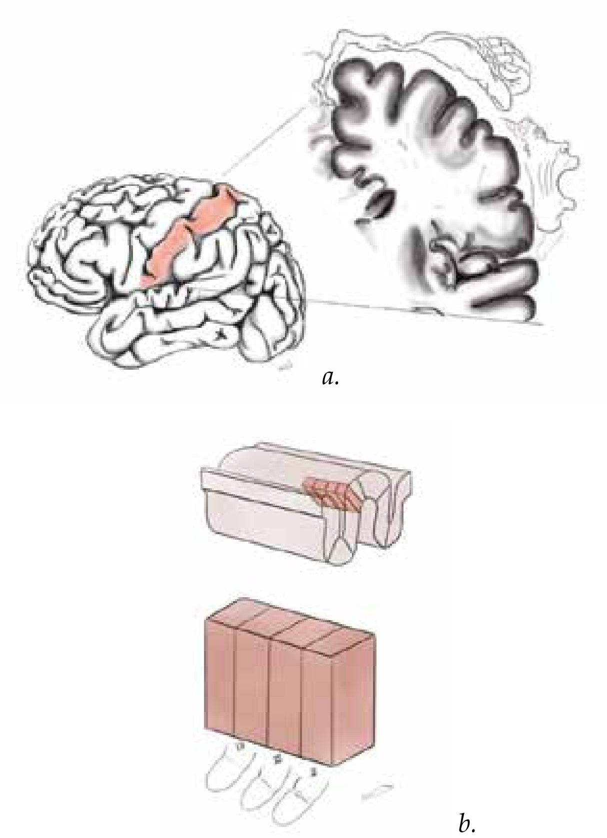

Figure 1. *a. Somatotopic representation of the brain. b. Representation of the final phalanx of the fingers in the sensory area of the brain.*

It is known that the representation of each part of the hand in the somatosensory cortex, in the posterior central gyrus, can vary depending on personal experiences and is related to brain plasticity. For example the representation of the index finger is greater in blind people due to the need for reading by the Braill method, or, the representation of the left hand is greater in the musicians, as it is the hand of skill concerning the musical instruments. (**fig.2**)

The median nerve allows people to "see" with their eyes closed. The amount of receptors in the hand, the abundance of nerve fibers and the size of the sensory field it occupies, the high perception of touch, and stereognosia combined with its large response to the brain, make scientists consider it as human's "third eye".

Neurological damage to the median nerve by disrupting its fibers and the sensory pathway to the brain leads to loss of perception of position and recognition of stimuli, a loss that indirectly affects the motor function of the hand, since the response is related to the receiving and processing of the stimuli. An important part in this is also the loss of kinesthesia, which is important for the functionality of the hand. Thus, people cannot perform tasks without seeing what they touch and how their hand performs them. It is similar to wearing a metal glove and the hand is unable to feel.

Non-neurological repair initially leads the area of the corresponding cortical representation to disorganization. Then, through the plasticity of the brain and the necessary use of the hand, adaptive reorganization occurs over time, with the establishment of new structural and functional nerve pathways in the cortex, with new synapses and a change in nerve networks. [1, 2, 4, 5, 16, 23, 24, 52] It is therefore obvious that immediate nerve repair with nerve suture is required.

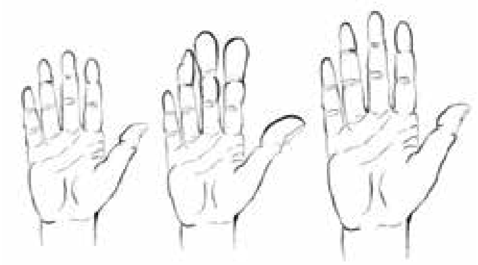

Figure 2. *Differences of hand's representation in the brain, in a blind person (middle) due to increased use of the fingertips that get their stimulation from the median nerve and in a musician (right), due to required increased virtuosity in comparison with the usual representation in a regular person (left).*

Figure 3. *Disturbance of somatosensory area of the hand after median nerve's transection.*

Successful nerve regeneration will lead to the restoration of the sensory pathway and there-information of the corresponding cortical area. However, after nerve restoration, the brain will have to re-learn to "read" the incoming information by hand such as learning a foreign language. [5, 25, 52]

In nerve reattachment the results are evaluated in the long term with multiple criteria, many of which are subjective, and with various parameters which perhaps are unknown in their entirety. Factors such as the time elapsed from transection to nerve reattachment, the incorrect orientation of nerve regeneration in target organs, the number of fibers regenerated, the age, any co-existing diseases, smoking, alcohol, etc. play an essential role in the process of nerve regeneration. [35, 53]

For this purpose, the idea of re-education[17,21,25,38,55] from the early stages of nerve rehabilitation has been proposed, which will provide more complete functional rehabilitation of the hand in a shorter time. Without re-education the brain has difficulty in re-defining the area that represents the reattached median nerve, unable to interpret the input data from the sensory receptors of the hand. As a result, nerve rehabilitation and nerve regeneration do not lead to full functioninghand rehabilitation, even after successful nerve reattachment and nerve regeneration. [18,28]. (**fig.3**)

Several studies [6,9,17,21,25,38,55] have investigated the benefits of sensoryre-education, using a control group and tests related to hand functionality such as the hand stimulus recognition and locating test, [16, 23, 24, 44, 46] the Moberg Pickup test, [41,45] and the static and moving two-point discriminationtest. [20, 22, 31, 37, 42, 43, 46, 49]

Patients and method

In the present study, a comparative evaluation was performed on 63 patients (51 men and 12 women; mean age 38 years (20 - 51)) with complete,distal transection of the median nerve and surgical restoration with or without sensoryre-education. All patients had low median nerve damage unilaterally and the wounds were neither neglected nor contaminated. **(Figure 4, 5)** Rehabilitation was performed soon after injury in all patients with microsurgery techniques. The study did not include children, as it has been observed that brain dynamics during childhood lead to excellent sensory, functional rehabilitation.[13] Patients with bilateral impairment were also not included, since the healthy hand was used in order to compare sensitivity with the damaged hand as well as cases of major complicated damages (spaghetti wrist).

In all patients included in the study, the surgical technique was found to be excellent and ideal for nerve rehabilitation. After surgical restoration of the limb, a plaster cast was placed on the wrist in few degrees of flexion for immobilization, which lasted

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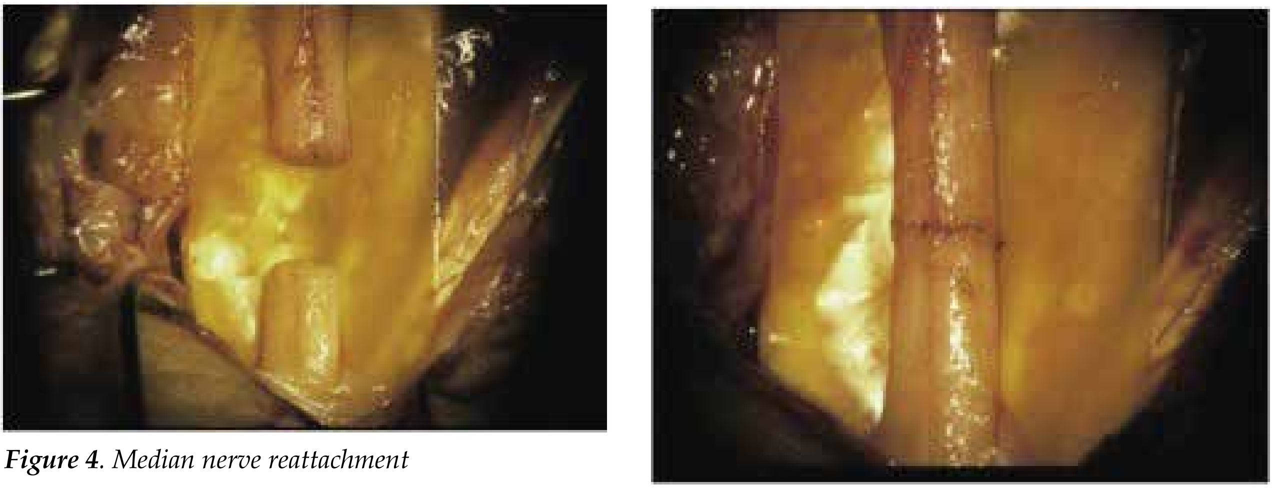

***Figure 4**. Median nerve reattachment*

***Figure 5.** Restoration of collateral damages*

for 4 weeks. Patients with sutures of flexor tendons were following a mobilization protocol.

Patients were then entering to an additional 4 weeksprogram of physiotherapy for the restoration of mobility of the stiff joints. In all patients the mobility of the joints and the functionality of the tendons were considered complete and satisfactory.

Postoperatively and after removal of the plaster cast, regeneration of the median nerve was evaluated with the Tinelpoint.Completionofnerveregenerationwasestimatedusinga 256 cpstuningfork (cyclespersecond)atthe 31⁄2fingertips, approximately 3.5 months (3-4M) inallpatientsincludedinthestudyafterepineuralsuture. **(Figure 6)** The use of the tuning fork as a criterion is based on the fact that once the nerve regeneration has reached the fingertips receptors the vibration will be perceived, even though roughly, diffusely perceptible through the stimulation of the respective receptors. A perceivable sense from the tuning fork means incomplete nerve regeneration. [47]

According to the monitoring protocol, patients were divided into two groups at this time. In group A 32 patients were selected who would undergo a sensory re-education program while in group B, 31 patients selected would not follow a re-education program. Patients were randomly divided. However, care was taken in order to have isometric division of men and women and also even distribution of age. At the same time, in group A, patients who were preferred were those being more cooperative and motivated by the outcome.

Sensory re-education of Group A patients was performed in two stages according to Dellon [18,28,55]. The first stage began when there was a

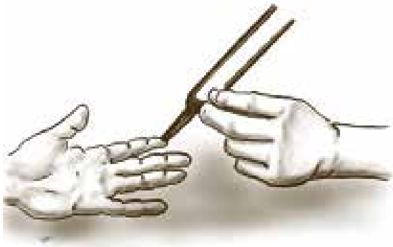

***Figure 6**. Use of tuning fork for the evaluation of the regeneration.*

***Figure 7.** Recognition of objects through feeling, with the eyes closed.*

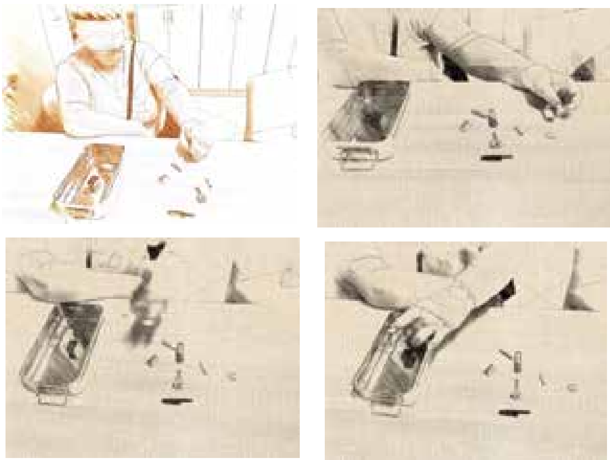

***Figure 8**.Moberg's pick-up test.*

renewal of innervation at the fingertips that get their stimulation by the median nerve. At this stage, patients were asked to recognize the shape, texture, material of different objects from their environment, both with their eyes open or closed [27] at various times. **(Figure 7)** This exercise leads to the stimulation of thebrainin order to identify stimuli received by different sensory receptors of the hand and the development of stereognosia. This stage also includes the stimulus recognition and locating test, using stimuli such as those coming from cotton, pressure from a spike or a blunt object, sting or application of warm-cold on the hand, modified byMarsh [44,46] for the separation and recognition of the senses. At this stage the tests seek to continually irritate the sensory area of the hand corresponding to the brain so that it is gradually reorganized, by re-sensing the area. [17,50]

The second, late stage took place when static and kinetic discrete sensation was perceived in the 3 1/2 Dellon18 fingers from the radius side, about 3.5 months after the start of the early phase. (3-4M). This phase includes: a) the Moberg's Pick-up test, (stereognosia) [41,45] b) two-point discrimination test [31,42,43,49] and recognition ability exercises and c)detectionofseveralstimuli on the hand (locognosia) [44,46].·There were also exercises to identify objects through palpation, similar to each other, such as coins, keys and fruits. In addition, at this phase, group A patients were advised to carry various small items in their pockets (keys, screws, dice, fruits, coins) that they were asked to feel and recognize through their pockets without seeing them.

Stimulus recognition testing had a standard execution procedure. Itwasdone four times per day, lasted 10'-15'each time and was performed in a quiet environment keeping the patient's attention. After that, the examination and assessment of patients' progress was being performed weekly. Patients were initially monitored by physicians or physiotherapists and later by their family. Finally, the results were evaluated at 18 months (63 patients), 3 years (40 patients) or 6 years (18 patients) and included the evaluation of patient's test results of both groups.

a) The assessment of the efficiency of the use of the hand, when there is no visual-motor participation and the effectiveness of the re-education at this level was done with the Moberg's Pick-up test, which was performed with the patient sitting in an office in a quiet environment. Inside the office twelve different objects were placed in terms of size, shape,

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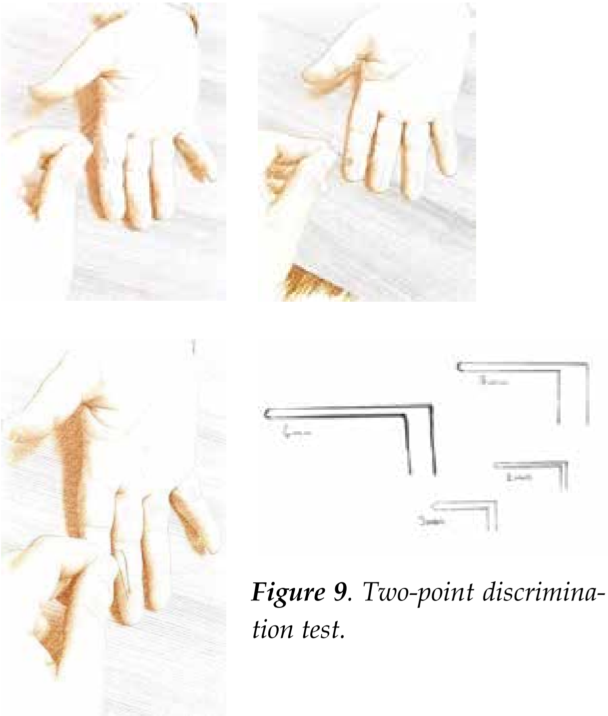

Figure 9. *Two-point discrimination test.*

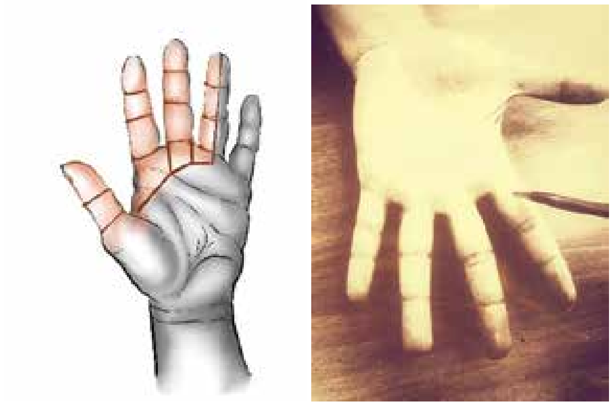

Figure 10.*Hand stimulus recognition and locating ability test*

texture and construction material. The patient was asked, first with his eyes open, to place the objects one by one in a container next to him. Then, the exercise was repeated with the eyes closed. **(Figure 8)** The average of the time required to complete the placement of all items in the container in both cases was considered as the performance of the test. The grading was based on the performance in four categories: “Excellent”, “Good”, “Moderate”, and “Poor”.

(b) According to the two-point discrimination test, the examiner exerts pressure, initially static, along the fingers innervated by the median nerve, on the palm, with pairs of spikes placed 8mm-1mm apart. The purpose is to identify the shortest spike distance that can be seen by the patient as two rather than one touch. **(Figure 9)** The average score on the control fingers (31⁄2 fingers in the radius side) was being noted as the score of performance with grading scale: “Excellent”, “Good”, “Moderate”, “Poor”. Then, he applies each pair of spikes moving along the longitudinal axis of the finger from proximal to distal.

The test is based on the fact that the human hand can normally identify two distinct points that are at least 1mm apart, with greater sensitivity at the tips of the fingers that are innervated by the median nerve. Irritation of the skin of the fingers with spikes less than 1mm apart is not recognized as two points. After brain disorganization, discrimination decreases.

c) The hand stimulus recognition and locating ability test was done using the modified Marsh’s test, where the fingers that are innervated by the median nerve (thumb, index, middle, radius rim of ring finger) are divided into a total of 14 zones (4 zones for the three fingers and two for the thumb). The examiner randomly touches the zones in the hand of the patient who is asked to identify the touch and mark the corresponding zone in the hand profile with the eyes closed. **(Figure 10)** One point was awarded for each correct detection of a zone and another point was assigned for each exact locating of the position (Excellent: 28 points).

It is obvious that after the transection of the nerve the stimuli in the hand cannot be fully matched due to the disorganization of the cortical area. The re-education aims to reorganize the respective central area through a continuous stream of hand stimuli. [23,25,26,27,54] Performance-based grading was done in four categories: “Excellent”, “Good”, “Moderate”, “Poor”.

Evaluations were made each time by the same examiner using the above techniques. Statistical analysis was performed using simple analysis of variance (ANOVA) for baseline data and x^2 test for data recorded in the 4 categories: Poor / Moderate / Good

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TABLE 1 *The grading was based on the performance in four categories for each test*

	Marsh	S2PD	M2PD	MOBERG PICK UP TEST
Poor	0-7	>16mm	>8mm	>30′′
Moderate	8-14	12-15mm	6-8mm	20-30′′
Good	15-21	7-11mm	4-6mm	10-20′′
Excellent	22-28	2-6mm	<4mm	<10′′

TABLE 2 *Statistical analysis performed using simple analysis of variance (ANOVA)*

S2PD (a)	18M-A	18M-B	36M-A	36M-B	72M-A	72M-B
>16mm	5	9	2	4	0	1
12-15mm	11	13	6	9	3	3
7-11mm	16	9	12	7	5	5
2-6mm	0	0	0	0	1	0
Statistical analysis	ANOVA P=0,164 X^2 P=0,197		ANOVA P=0,239 X^2 P=0,275		ANOVA P=0,536 X^2 P=0,572	
M2PD (a)	**18M-A**	**18M-B**	**36M-A**	**36M-B**	**72M-A**	**72M-B**
>8mm	0	3	0	2	0	0
6-8mm	5	8	2	4	1	1
4-6mm	14	11	7	8	2	3
<4mm	13	9	11	6	6	5
Statistical analysis	ANOVA P=0,203 X^2 P=0,190		ANOVA P=0,170 X^2 P=0,240		ANOVA P=0,724 X^2 P=0,865	
Modified Marsh test(b,c)	**18M-A**	**18M-B**	36M-A	36M-B	72M-A	72M-B
0-7	0	1	0	0	0	0
8-14	3	7	1	2	0	0
15-21	9	16	5	13	1	3
22-28	20	7	14	5	8	6
Statistical analysis	ANOVA P=0,009 X^2 P=0,013		ANOVA P=0,034 X^2 P=0,017		ANOVA P=0,269 X^2 P=0,257	

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Moberg's pick up test (a,b)	18M-A	18M-B	36M-A	36M-B	72M-A	72M-B
>30sec	5	7	2	3	0	0
20-30sec	11	15	5	11	1	1
10-20sec	16	9	11	5	2	3
<10sec	0	0	2	1	6	5
Statistical analysis	ANOVA P=0,162 X^2 P=0,235		ANOVA P=0.147 X^2 P=0,169		ANOVA P=0.712 X^2 P=0,865	

TABLE 3 *Statistical analysis performed using x^2 test*

S2PD (a)	18M-A	18M-B	36M-A	36M-B	72M-A	72M-B
Poor – Moderate	16	22	8	13	3	4
Good - Excellent	16	9	12	7	6	5
Statistical analysis	X^2 P=0.089		X^2 P=0.113		X^2 P=0.628	
M2PD (a)	**18M-A**	**18M-B**	**36M-A**	**36M-B**	**72M-A**	**72M-B**
Poor – Moderate	5	11	2	6	1	1
Good - Excellent	27	20	18	14	8	8
Statistical analysis	X^2 P=0.070		X^2 P=0.114		X^2 P=1	
Modified Marsh test(b,c)	**18M-A**	**18M-B**	**36M-A**	**36M-B**	**72M-A**	**72M-B**
Poor – Moderate	3	8	1	2	0	0
Good - Excellent	29	23	19	18	9	9
Statistical analysis	X^2 P=0.086		X^2 P=0.548		X^2 P=1	
Moberg's pick up test (a,b)	**18M-A**	**18M-B**	**36M-A**	**36M-B**	**72M-A**	**72M-B**
Poor – Moderate	16	22	7	14	1	1
Good - Excellent	16	9	13	6	8	8
Statistical analysis	X^2 P=0.089		X^2 P=0.027		X^2 P=1	

Results A=group with sensory re-education / B=group B with no sensory re-education
S2PD=static 2point discrimination / M2PD=moving 2point discrimination
Results at 18, 36,72 months of the study
a= A lower value indicates a better performance
b= Mean values with eyes closed and open
c= A higher value indicates a better performance

/ Excellent. The x^2 test was also used to compare the sum of the results readjusted for two categories of excellent - good versus moderate - poor. (**table.1**)

Results

The statistical analysis ANOVA & x^2, which was performed upon the collection of results regarding the ability to recognize and detect hand stimuli (Locognosia),suggested a statistically significant difference in patients of group A who received sensory re-education compared to patients of group B in the control period of 18 and 36 months.

ConcerningMoberg's Pick-up test using x^2 per group of Good-Excellent results versus Poor - Moderate results, statistical trend was shown for group A patients (who underwent sensory re-education) for 18 months and statistically significant difference in favor of group A for 36 months.

Also, for the M2PD using the x^2 test when grouping Good-Excellent results versus Poor-Moderate, statistical trend was shown in favor of group A for 18 months.

Finally, for the S2PD using the x^2 test when grouping the Good-Excellent results versus Poor-Moderate, a statistical trend was shown for group A for 18 months. (**Table. 2,3**)

Often, the execution of the surgeon's task ends with nerve suturing whereassensoryre-education is neglected. At the same time, more attention is paid to the protective sensation and the motor function of the limb, which, however, is incident to sensation because the hand that does not feel does not move normally. [9,17,29]

Sensation disorder can occur after damage in the sensory pathway at any level and not just after a peripheral nerve transection. The idea of sensoryre-education finds application in all cases where the loss of sensation will lead by the same mechanisms to disorganization of the area and functional redesign in order to compensate for the loss, such as damage to the sensory area of the CNS, [1,15,40, 48,49] transfer of flaps with vessels and nerves, [12, 36, 51] andlimb reattachments [6, 9, 30, 39].

The idea of sensoryre-education in cases of patients with sensory nerve transection is suggested by studies coming from the 1970s by various researchers. [18, 19, 31-38] In all the above studies, regardless the individual techniques applied, the contribution of the method to sensory restoration and functionality was recognized, reducing the minimum limit, that is the threshold of recognizing the stimuli of pressure, touch, perception, position, as well as the restoration of stereognosia. [3, 6, 7, 8, 10, 11, 14, 17]

The above, as well as other techniques, help patients with sensory dysfunction after neurological damage and restoration, to reinterpret the incoming feelings, redefining through the plasticity of the brain the perception of each stimulus separately. Practically, the patient learns again in more detail and in a short time.

Sensoryre-education as a method does not promote nerve regeneration, but promotes the perception and redefinition of incoming information from stimuli of peripheral hand receptors. The goal is the most complete sensory restoration possible.

Thus, after damage and surgical restoration of the median nerve, the method is suggested as necessary for the restoration with the best possible final outcome. [9,10,18,30,31-39] A

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