Journal of Hand Therapy 32 (2019) 305–312

Contents lists available at ScienceDirect

Journal of Hand Therapy

journal homepage: www.jhandtherapy.org

JHT Read for Credit Article #616.

Scientific/Clinical Article

Similar 2-point discrimination and stereognosia but better locognosia at long term with an independent home-based sensory reeducation program vs no reeducation after low-median nerve transection and repair

Dimitrios K. Antonopoulos MD [a], Andreas F. Mavrogenis MD [b,*], Panayiotis D. Megaloikonomos MD [b], Evanthia Mitsiokapa MD [b], George Georgoudis PT [c], Christos Th. Vottis MD [b], George K. Antonopoulos MS [a], Panayiotis J. Papagelopoulos MD, DSc [b], Spyridon Pneumatikos MD [a], Sarantis G. Spyridonos MD [d]

[a] Third Department of Orthopaedics, National and Kapodistrian University of Athens, School of Medicine, Athens, Greece
[b] First Department of Orthopaedics, National and Kapodistrian University of Athens, School of Medicine, Athens, Greece
[c] Department of Physical Therapy, Technological Educational Institute (T.E.I.) of Athens, Athens, Greece
[d] Department of Hand and Upper Extremity Surgery and Microsurgery, KAT General Hospital, Athens, Greece

ARTICLE INFO

Article history:
Received 1 August 2017
Received in revised form
9 October 2017
Accepted 9 October 2017
Available online 4 November 2017

Keywords:
Sensory reeducation
Median nerve
Wrist
Microsurgical repair
Locognosia
Stereognosia
Two-point discrimination

ABSTRACT

Study Design: Prospective controlled study.
Introduction: Previous studies evaluated the effectiveness of sensory reeducation (SR) after peripheral nerve injury and repair. However, evidence for long-term clinical usefulness of SR is inconclusive.
Purpose of the Study: The purpose of this study is to compare the sensory results of patients with low-median nerve complete transection and microsurgical repair, with and without SR at long term.
Methods: We prospectively studied 52 consecutive patients (mean age, 36 years; range, 20-47 years) with low-median nerve complete transection and microsurgical repair. When reinnervation was considered complete with perception of vibration with a 256-cycles per second tuning fork (mean, 3.5 months after nerve injury and repair), the patients were sequentially allocated (into 2 groups [group SR, 26 patients, SR; group R, 26 patients, reassured on recovery without SR). SR was conducted in a standardized fashion, in 2 stages, as an independent home-based program: the first stage was initiated when reinnervation was considered complete, and included instruction in home exercises to identify familiar objects and papers of different roughness, and localization of light touch (eyes open and closed); the second stage was initiated when the patients experienced normal static and moving 2-point discrimination (2PD) at the index fingertip of injured hand, and included instruction in home exercises for stereognosia, supplementary exercises for localization of light touch, and identification of small objects (eyes open and closed). Exercises were prescribed for 5-10 minutes, 4 times per day. At 1.5, 3, and 6 years after nerve injury and repair, we evaluated the static and moving 2PD, stereognosia with the Moberg's pick-up test, and locognosia with the modified Marsh test. Comparison between groups and time points was done with the nonparametric analysis of variance (Kruskal-Wallis analysis of variance).
Results: Static and moving 2PD and stereognosia were not significantly different between groups at any study period. Locognosia was significantly better at 1.5 and 3 years in group SR; locognosia was excellent in 17 patients of group SR vs 5 patients of group R at 1.5-year follow-up and in 14 patients of group SR vs 5 patients of group R at 3-year follow-up. Locognosia was not different between the study groups at 6-year follow-up.

Conflict of interest: All named authors hereby declare that they have no conflicts of interest to disclose.

* Corresponding author. First Department of Orthopaedics, National and Kapodistrian University of Athens, School of Medicine, Athens, Greece. Tel./fax: +30 210 6542800.

E-mail address: afm@otenet.gr (A.F. Mavrogenis).

https://doi.org/10.1016/j.jht.2017.10.008

Conclusion: A 2-stage home program of SR improved locognosia at 1.5 and 3 years after low-median nerve complete transection and repair without significant differences in other modalities or the 6-year follow-up of a small subsample.

Introduction

Peripheral nerve injuries in the upper extremity often result in long-lasting disability of the hand due to loss of fine sensory and motor function, psychological stress, and distressing long-term effects on occupational performance.[1,2] Without training, even after optimal restoration of motor function, sensibility of the hand can be significantly affected.[3-5] The hand loses its ability to identify textures and shapes (tactile gnosis or stereognosia) and to localize touch (locognosia); therefore, restoration of sensibility of the hand in patients with peripheral nerve injuries is important and should not be neglected.[6,7] However, even after appropriate physical therapy– and occupational therapy–related methods and techniques, restoration of sensibility of the hand may last several years or it may remain incomplete.[2,8,9]

After peripheral nerve injury, the distal disconnection between the somatosensory cortex and skin receptors leads to the absence of sensory input to the corresponding cortical area. Initially, this condition generates a dynamic interplay between the cortical networks resulting in the expansion and invasion of the adjacent cortical territories.[10-12] The nerve-injured patient is faced with an unrecognizable or at least unfamiliar volley of sensory input.[13] In the second phase, when the regenerated nerve axons reach the peripheral targets, another abnormal afferent inflow occurs to the somatosensory cortex due to incomplete or mismatched reinnervation.[14,15] At this point, the reorganized cortex is expected to adapt to this new condition and create new connections with the peripheral receptors.[14,16] Children generally present a better outcome, probably due to the superior plasticity of their brain.[17] In contrast, in adults, the functional outcome after nerve peripheral injury repair is often disappointing.[3,18] Despite technically optimal microsurgical repair after nerve injury, regeneration of sensory fibers is imprecise. Without training, the patients remain confused and unable to interpret these new patterns of sensory input leading to false locognosia and impaired or absent stereognosia.[6,7,19] Stereognosia and locognosia rely on the integrity of peripheral end organs as well as the somatosensory representation of the surface of the body in the brain.

Restoration of sensibility of the hand is not only affected by the microsurgical technique and optimal nerve stump coaptation to enhance maximum nerve axon regrowth but also by the postoperative physical therapy, rehabilitation, and training protocol. However, for optimal results, the rehabilitation protocol needs to include a reeducation process called sensory reeducation (SR), so that the somatosensory cortex will understand the new afferent sensory input of the hand.[19] SR is based on the assumption that the regenerating peripheral nerve begins to demonstrate less recovery than patient's potential. The reason for this underachievement is the patient's inability to interpret the altered impulses. This alteration in perception of precise touch occurs along the entire sensory pathway. At the periphery, there is degeneration of receptors, reduction in nerve fibers, erroneous reinnervation, establishment of erroneous receptive fields, cross innervations, reduced conduction velocity, and changes in sizes of receptive fields.[20]

SR may be applied in an early or late method, aiming to enhance recovery after the corresponding cortical incidence. Early SR may be applied to prevent cortical reorganization; it begins immediately after nerve repair, before regenerated axons reach the end receptors.[21] Using alternate inputs via other senses, early SR may prevent the expansion of the adjacent cortical territories to the silent cortical area.[19] Sensory relearning in early SR combines different cognitive learning techniques in order to stimulate and prepare neurons in the primary somatosensory cortex and motor network for when the injured nerve has regenerated, to improve stereognosia. However, early sensory relearning includes abstract components, which can be a cognitive challenge; imagining the sense of a specific texture, when at the same time there is no sensibility in the hand, requires a certain amount of capacity of abstract thinking.[22,23] In contrast, late SR begins when reinnervation has been documented and aims to reeducate the somatosensory cortex on the perception of precise touch.[13,14,24] Late SR is based on the fact that some perception of touch or sensation should be regained; therefore, it should begin when the patient can perceive touch in the injured area. This indicates that the injured nerve has regenerated and has reinnervated receptors in the skin.[22,23]

SR protocols and assessments reported in the related literature vary in regard to their effectiveness in restoring sensorimotor function in patients with a number of conditions that affect function of the hand and wrist.[25-27] There is a potential value of SR for individuals with specific upper extremity conditions; however, there is a paucity of current literature to support any one intervention for sensorimotor function of the hand.[28] Previous studies evaluated the effectiveness of SR after peripheral nerve injury and repair,[6,14,29] digital reimplantation,[30-32] free flap transfer,[14,33] and toe-to-hand reimplantation,[30,34,35] advocating that SR is strongly related to the final sensory outcome and hand function.[6,29-36] However, further studies are necessary to improve the treatment of sensorimotor deficits and understand sensorimotor interventions,[26,37,38] and there is limited evidence to support the application of early or late SR to improve hand's sensibility after median and ulnar nerve injuries and repair.[37,38] Moreover, the existing evidence for long-term clinical usefulness and effectiveness of SR for hand's sensibility is still inconclusive.[37] Therefore, we performed this prospective study to compare the sensory results of patients with low-median nerve complete transection and microsurgical repair, with and without SR. The study key question was how effective is SR for sensory function of the hand after microsurgical repair of the median nerve at long term.

Materials and methods

We prospectively studied 52 consecutive patients (42 men and 10 women; mean age, 36 years; age range, 20-47 years) admitted and treated at the authors' institutions with a median nerve complete transection and microsurgical repair at the wrist level (Fig. 1A-C). Patients with severe upper limb trauma, injury to additional neural structures, prior significant wrist trauma, and chronic metabolic or degenerative diseases related to the peripheral or central nervous system were not included. The mean follow-up was 3 years (range, 1.5-6 years); 34 patients were lost at the 6-year follow-up. All patients gave written informed consent for their data to be included in this study. This study was approved by the institutional review board/ethics committee of the authors' institutions.

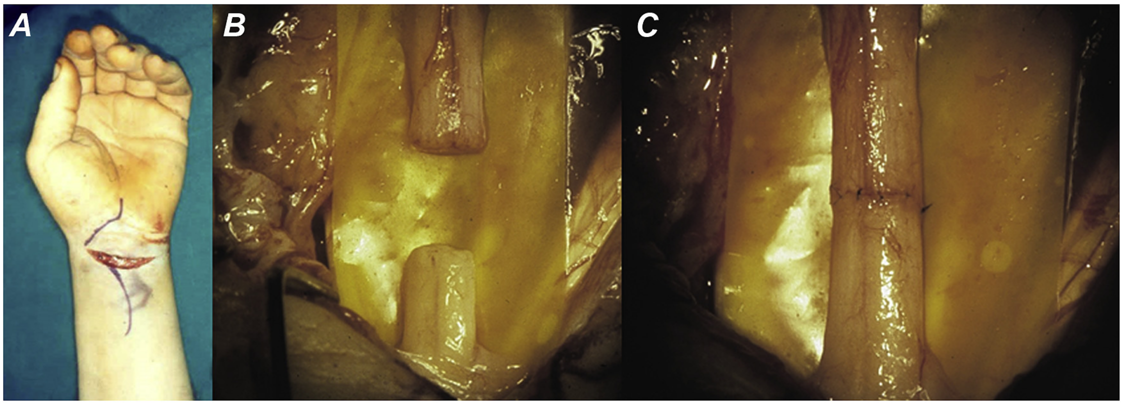

Fig. 1. (**A**) A 30-year-old man with a laceration at the volar aspect of his left wrist by a glass. Intraoperative photographs show (**B**) complete transection of the median nerve and (**C**) microsurgical epineural repair (magnification, 4 ×).

With the patients under regional anesthesia and a binocular loupes 4 × magnification, all patients were treated with primary end-to-end microsurgical epineural repair. Adjacent tendon lacerations observed intraoperatively in 9 patients were also repaired in the same setting. The mean interval between injury and surgical repair was 10 hours (range, 2-26 hours). Postoperatively, in all patients, immobilization of the wrist was done with a dorsal orthotic device in neutral position of the wrist with the digits included for 4 weeks, aiming to rest the hand for nerve repair and wound healing; the wrist was placed in 10-20 degrees of extension, the metacarpophalangeal joints were positioned in 70-80 degrees of flexion, and the interphalangeal joints were straight. After orthotic removal, physical therapy was recommended for another 4 weeks, aiming to regain mobility of the wrist.

At a mean time of 3.5 months (range, 3-4 months) after nerve injury and repair, perception of vibration was recovered at the fingertips of the 3.5 radial fingers in all patients, as confirmed with a 256-cycles per second tuning fork; at that time, reinnervation was considered complete (Fig. 2A). Then, the patients were sequentially allocated into 2 groups, one-by-one, according to their order of presentation. Group SR included 26 patients that were instructed the SR protocol, and group R included 26 patients that were provided reassurance on recovery with time, with ordinary activities of daily living of the hand; for the purpose of this study, these patients were not instructed any SR training or further rehabilitation protocol. The SR protocol used was a late SR protocol as previously described by Dellon et al.[6,7] In the present series and our practice, we are in favor of late SR to allow for nerve repair and wound healing before any physical therapy intervention is initiated. The SR protocol was instructed to group SR patients in 2 teaching sessions of 20 minutes each at the clinic, by the author S.G.S., who is a fellowship-trained hand, upper extremity, and microsurgery physician with more than 20 years of experience in upper extremity surgery, microsurgery, and sensory reeducation training protocols. The SR protocol was conducted as an independent home-based program, in a standardized fashion in 2 stages (Table 1). At the first stage, the patients were instructed exercises to enhance their ability to identify familiar objects and papers of different roughness (Fig. 2B), with their eyes open and then closed[7] and to identify light touch (locognosia)[39] at their injured hand (Fig. 2C). The second stage was initiated when the patients experienced normal static and moving 2-point discrimination (2PD) at the index fingertip of the injured hand (Fig. 3A);[6] this was evident at a mean of 3.5 months (range, 3-4 months) after the initiation of the first stage. At the second stage, the patients were instructed exercises for tactile gnosis (stereognosia)[40] (Fig. 3B), in addition to supplementary locognosia exercises (Fig. 3C), and identification of small objects between similar objects such as pins, keys, clips, cubes, or small balls hidden in a box with beans (Fig. 3D). The patients were instructed to follow the SR protocol at their homes with the help of physical therapists or their relatives and were advised to perform these exercises concentrated, in a quiet room, for 5-10 minutes, 4 times per day. Additionally, they were instructed to carry in their pockets or purses, small objects and to continuously practice during the day trying to identify them. Patients' progress and compliance to the SR protocol was assessed approximately every 2 weeks for the first 3 months, every 6 months for the next 1.5 years, and annually thereafter, at a 20-minute outpatient visit by the same examiner (S.G.S.). At the beginning,

Fig. 2. (**A**) Evaluation of perception of vibration at the fingertip of the index finger with the 256 cycles per second tuning fork. (**B**) Training the ability to identify papers of different roughness (inset). (**C**) Training localization of light touch (locognosia).

Table 1
Stages, timing, and tests used for SR in the group SR of patients included in this series

SR stages	Training	Timing	Tests
First stage	Identification of familiar objects and papers of different roughness and localization of light touch (eyes open and closed)	After nerve repair, wrist immobilization, and physical therapy, when reinnervation was considered complete (perception of vibration at the fingertips of the 3-1/2 radial fingers of their injured hand with a 256-cps tuning fork)	None
Second stage	Pick up and put in a box objects of different size, shape, material, and texture using the thumb, index, and long finger, localization of light touch, identification of small objects between similar objects such as pins, keys, clips, cubes, or small balls hidden in a box with beans (eyes open and closed)	After the first stage, when normal static and moving 2PD was documented at the fingertip of the index of their injured hand	Caliper (2PD), Moberg's pick-up test (stereognosia), modified Marsh's test (locognosia)

Cps = cycles per second; 2PD = 2-point discrimination; SR = sensory reeducation.

all patients reported exciting and compliant with the SR protocol; at the 1.5-year follow-up, 15 patients (28.8%) complained that the SR protocol was taking much time and 5 patients (9.6%) complained that the SR protocol was boring.

For the purpose of this study, all patients of both groups were scheduled for reevaluation at 1.5, 3, and 6 years after their nerve injury and repair. At the 1.5-year follow-up, all patients ($n = 52$ patients) were reevaluated; at the 3-year follow-up, 12 patients were lost to follow-up ($n = 40$ patients); and at the 6-year follow-up, 34 patients were lost to follow-up ($n = 18$ patients). The patients lost to follow-up did not present to scheduled follow-up visits and were not able to recall until the end period of this study. At each follow-up examination, we evaluated the static[41] and moving.[42] 2PD, stereognosia using the Moberg's pick-up test,[40] and locognosia using the modified Marsh's test.[39] These tests were chosen taking into account practical issues, such as cost, conduction time, availability, and clinical practice.[43] At the first (1.5-year) and second (3-year) follow-up examination, the assessors (S.G.S., A.F.M., and D.K.A.) were not blinded to the patients being examined. At the last follow-up examination (6 years), the assessors (E.M., G.G., and P.D.M.) were blinded to the patients being examined.

Static and moving 2PD were measured with a caliper with blunt tips.[41,42] A light touch of the caliper was applied on the skin of the 3.5 radial fingers in a static or moving fashion, parallel to the digital nerves and perpendicular to the fingers' axis. The shortest distance between the caliper tips at which the patient could identify a 2-point touch was recorded. The final score for each of the 2 2PD tests was calculated as the mean value of the distances recorded to all 3.5 fingers. A lower value indicated a better performance.

Moberg's pick-up test[40] was performed by picking up objects of different size, shape, material, and texture using the thumb finger, index finger, and long finger and putting them into a box, first with the eyes open and then with the eyes closed; the time to complete the task was measured and the mean time with the eyes open and closed was recorded. A lower time indicated a better performance.

Modified Marsh's test[39] was performed by dividing the fingertip of each finger of the 3.5 radial digits (thumb, index, middle, and radial side of the ring finger) into 4 quadrants (a total of 14 quadrants). A stimulus was applied in each quadrant in random with the patient with the eyes closed, and the patient was asked to point to a hand diagram, the quadrant where he/she felt the stimulus. Correct identification of the quadrant measured 1 point, and correct

Fig. 3. (**A**) Evaluation of 2PD with a caliper with blunt tips. (**B**) Training and evaluation of tactile gnosis (stereognosia) with the Moberg's pick-up test; the patient was asked to pick and put in a box objects of different size, shape, material, and texture, using the thumb, index, and long finger, with the eyes open and then closed, and completion time was recorded. Training begun with large objects such as pliers, scissors, pens, pencils, and screwdrivers and progressed to smaller objects such as keys of different size, coins, and screws. (**C**) Training and evaluation of light touch (stereognosia) with the modified Marsh test; a stimulus was applied randomly in different zones of the hand with the patient with eyes closed, and the patient was asked to point to a hand diagram the zone/s where he/she felt the stimulus. (**D**) Identification of small objects between similar objects such as pins, keys, clips, cubes, or small balls in a box with beans. 2PD = 2-point discrimination.

identification of the finger measured 1 point more (maximum, 28 points). A higher value indicated a better performance.

The scores of the tests were analyzed at 1.5, 3, and 6 years of follow-up for the available patients at each follow-up examination. Comparison between groups and time points was done with the nonparametric analysis of variance (Kruskal-Wallis analysis of variance) using SPSS version 18.0 (IBM Corp., Armonk, NY).

Results

Static and moving 2PD and Moberg's pick-up test were not statistically significantly different between the study groups at any follow-up period. In contrast, locognosia was statistically significantly better at 1.5 ($P = .005$) and 3 years ($P = .034$) in the group SR, without, however, any statistically significant difference between the study groups at 6 years ($P = .269$; Table 2).

Discussion

After peripheral nerve transection, denervation occurs and the projection of other sensory inputs expands into the deafferented area. Optimal microsurgical nerve repair is critical, aiming not only to enhance maximum nerve axons regrowth but also to successfully guide them to the corresponding cutaneous targets.[13,19,44] After distal reinnervation, another unfamiliar afferent input occurs to somatosensory cortex, due to incomplete or mismatched reinnervation, and a functional remodeling of the hand projection areas to the corresponding cortical territory occurs.[14,16] Wynn-Parry and Salter were the first to describe an SR protocol to enhance sensory outcome.[45] Since then, variable SR protocols have been reported with respect to timing of SR (early or late) according to the cortical deafferentiation or reafferentiation processes.[6,7,19-38,46-49] Traditionally, late SR protocols have been used, based on the fact that some perception of touch or sensation should be regained.[35,47-53] Dellon et al studied the physiological basis of late SR and described a number of simple tests that may be used to the relearning process, as well as to the evaluation of the functional outcome of the hand, with each one assessing different sensory submodalities.[6,7] In the present study, we prospectively evaluated a cohort of patients with low-median nerve complete transection, microsurgical repair, and late SR and compared at long term with a similar group of patients without SR. We applied the second-stage late SR that recommends initiation of SR after reinnervation has occurred, as confirmed with the 256-cycles per second tuning fork. The second-stage SR was initiated when 2PD was normal at the index fingertip of the injured hand. Then, we evaluated SR using the same tests that were used for SR training (static and moving 2PD tests, Moberg's pick-up test and modified Marsh's test).[39-42,54] Our results showed similar 2PD and stereognosia but better locognosia at 1.5 and 3 years after nerve injury and repair for the patients who had SR compared to those who did not. Thereafter, locognosia was also similar between the 2 groups.

Weber's static 2PD evaluates the slowly adapting fiber-receptor system and provides information about the functional value of hand sensibility.[40-42] Moving 2PD evaluates the innervation density of the quickly adapting fiber-receptor system that mediates the perception of touch stimuli moving across the hand[42] and provides information about the results of nerve repair sooner than static 2PD because it recovers distally sooner.[6,7,45,55] Some authors suggested both static and moving 2PD to represent accurate monitoring of functional progress during SR.[6,7,42,45,55] Jerosch-Herold in a study using late SR reported similar findings in terms of 2PD 1.5 years after nerve injury and repair, suggesting that this evaluation test should not be used as a critical measure to quantify sensory outcome.[43] Another study concluded that it is wrong to consider the level of 2PD recovery to predict stereognosia and locognosia recovery, and that high values of 2PD may not necessarily mean poor functional outcome.[52] Other studies also supported these

Table 2
Static and moving 2PD and stereognosia were not statistically significantly different between the group SR and group R at follow-up

Variables	1.5 y ($n = 52$)		3 y ($n = 40$)		6 y ($n = 18$)	
	Group SR	Group R	Group SR	Group R	Group SR	Group R
Static 2PD[a]						
>16 mm	3	7	2	4	0	1
12-15 mm	9	11	6	9	3	3
7-11 mm	14	8	12	7	5	5
2-6 mm	0	0	0	0	1	0
Statistical analysis	$P = .195$		$P = .239$		$P = .536$	
Moving 2PD[a]						
>8 mm	0	2	0	2	0	0
6-8 mm	3	7	2	4	1	1
4-6 mm	11	9	7	8	2	3
<4 mm	12	8	11	6	6	5
Statistical analysis	$P = .196$		$P = .170$		$P = .724$	
Stereognosia (Moberg's pick-up test)[a,b]						
>30 s	4	6	2	3	0	0
20-30 s	8	12	5	11	1	1
10-20 s	14	8	11	5	2	3
<10 s	0	0	2	1	6	5
Statistical analysis	$P = .197$		$P = .147$		$P = .712$	
Locognosia (modified Marsh test)[b,c]						
0-7 points	0	1	0	0	0	0
8-14 points	2	6	1	2	0	0
15-21 points	7	14	5	13	1	3
22-28 points	17	5	14	5	8	6
Statistical analysis	$P = .005$		$P = .034$		$P = .269$	

2PD = 2-point discrimination; SR = sensory reeducation.
Locognosia was statistically significantly better in the group SR at the 1.5- and the 3-year follow-ups but not at the 6-year follow-up.
[a] A lower value indicates a better performance.
[b] Mean values with eyes closed and open.
[c] A higher value indicates a better performance.

reports.[56,57] According to Dellon,[6,7] 2PD is necessary for the second stage of late SR to begin, and probably, the first stage of SR little affects long-term sensibility recovery of the hand. In addition, in the present study, because 2PD was not statistically different between the study and control groups at follow-up, it would be wrong to consider that 2PD can be used as an outcome measure between the patients who had SR and those who did not.[43,58,59]

Moberg's pick-up test requires initially the ability to perform static grip and not object recognition. If the hand has normal sensibility, it can "see even with the eyes closed."[60-63] Locognosia test examines the ability to localize touch relying on the integrity of peripheral sensory targets and the corresponding representation to somatosensory cortex.[39,54] A previous study reported good sensitivity of Moberg's pick-up test and object recognition; however, it concluded that this test presented limited clinical relevance.[43] Other authors reported a statistical trend to significance when evaluating Moberg's pick-up test between SR patients and controls at 1.5 years after nerve injury and repair.[52] Based on the results of these studies, stereognosia may not improve with SR as patients gradually regain dexterity with activities of everyday living. In the present study, Moberg's pick-up test was not statistically significantly different between the study and control groups in the studied time periods. In contrast, locognosia was statistically significantly better after late SR at 1.5 and 3 years; however, statistical significance was not observed at 6 years after injury and repair; this may also be explained by the attrition of subjects. Therefore, the SR protocol used in this series significantly improved locognosia in a sooner time, as compared with patients who were left to reeducate on their own.[51] Thereafter, recovery of locognosia continues slower, improving sensibility of the hand for many years after nerve repair, however, in a not significantly different manner.[63-65] This may be attributed to the maturation of the reestablishment of new fiber-receptor systems, and the cortical reeducation that attends the daily use of the injured hand.[32,45,66,67]

This study adds to a limited body of knowledge on SR. However, we acknowledge multiple limitations that may have introduced selection or assignment biases that would have affected our results, the nature of our conclusions and the size of the effects. First, our study was not randomized as we alternated assignment of the patients, and we did not control for potentially confounding patient-related variables such as profession, gender, and age of the patients at baseline. Instead, we aimed to include all patients with this type of injury to increase the sample size of our study. Further, the follow-up examinations were not performed by the same examiners, patients' adherence was not formally evaluated; the program was completed independently with minimal training and supervision and may not have had a sufficient dosage. Although we were interested in long-term outcomes, we did not study standardized time points throughout that interval, and different examiners evaluated the patients at follow-ups. This means that many important clinical time points were not examined and we may have missed important clinical differences. Furthermore, 65.4% of the sample was lost at the 6-year follow-up due to the attrition of subjects. Loss to follow-up is very important because it can severely compromise a study's validity; patients may be lost to follow-up because they became asymptomatic and felt no need to return to see their treating physician, or they may be lost because they had a particularly bad outcome or they experienced a complication. In either case, bias can affect the validity of the inferences drawn from the study.[68] Finally, combining the mean values of the 2PD distances recorded to all 3.5 fingers may not be an accepted method of calculation. However, in a previous study,[52] we did not find significant differences of static and moving 2PD with respect to SR when these variables were examined independently. Therefore, in the present study, at longer term, we decided to use the mean values of 2PD to make our analysis less complicated. We believe that further research with a formal randomization method and without assignment bias is necessary to evaluate novel SR training tools and evaluation tests for SR in patients with peripheral nerve injuries and impaired functional hand abilities, to identify patients who could benefit the most from this intervention and to differentiate patients according to basic cognitive and motor functions.

In conclusion, to obtain the best sensibility of the hand after median nerve complete transection and microsurgical repair, SR is recommended. Despite the multiple limitations in our study, a brief instruction of an independent home-based SR protocol at a mean of 3.5 months after median nerve injury and repair did show improvement in locognosia at 1.5- and 3-year follow-up compared to patients who were provided reassurance on recovery. The lack of consistency in improvement across different sensory tests and the limited power in our study to examine long-term effects indicate the need for larger and more complete randomized studies.

References

1. Rosberg HE, Carlsson KS, Dahlin LB. Prospective study of patients with injuries to the hand and forearm: Costs, function, and general health. *Scand J Plast Reconstr Surg Hand Surg*. 2005;39(6):360–369.
2. Jaquet JB, Luijsterburg AJ, Kalmijn S, Kuypers PD, Hofman A, Hovius SE. Median, ulnar, and combined median-ulnar nerve injuries: Functional outcome and return to productivity. *J Trauma*. 2001;51(4):687–692.
3. Lundborg G, Rosén B. Sensory relearning after nerve repair. *Lancet*. 2001;358(9284):809–810.
4. Wall JT, Kaas JH, Sur M, Nelson RJ, Felleman DJ, Merzenich MM. Functional reorganization in somatosensory cortical areas 3b and 1 of adult monkeys after median nerve repair: Possible relationships to sensory recovery in humans. *J Neurosci*. 1986;6:218–233.
5. Clark SA, Allard T, Jenkins WM, Merzenich MM. Receptive fields in the body-surface map in adult cortex defined by temporally correlated inputs. *Nature*. 1988;332:444–445.
6. Dellon AL, Jabaley ME. Reeducation of sensation in the hand following nerve suture. *Clin Orthop Relat Res*. 1982;(163):75–79.
7. Dellon AL. *Evaluation of sensibility and re-education of sensation in the hand*. Baltimore: Williams & Wilkins; 1981.
8. Chen R, Cohen LG, Hallett M. Nervous system reorganization following injury. *Neuroscience*. 2002;111(4):761–773.
9. Amini D. Occupational therapy interventions for work-related injuries and conditions of the forearm, wrist, and hand: A systematic review. *Am J Occup Ther*. 2011;65(1):29–36.
10. Wall JT, Xu J, Wang X. Human brain plasticity: An emerging view of the multiple substrates and mechanisms that cause cortical changes and related sensory dysfunctions after injuries of sensory inputs from the body. *Brain Res Brain Res Rev*. 2002;39(2-3):181–215.
11. Taylor KS, Anastakis DJ, Davis KD. Cutting your nerve changes your brain. *Brain*. 2009;132(Pt 11):3122–3133.
12. Lundborg G. Richard P. Bunge memorial lecture. Nerve injury and repair—a challenge to the plastic brain. *J Peripher Nerv Syst*. 2003;8(4):209–226.
13. Lundborg G. Peripheral nerve injuries: pathophysiology and strategies for treatment. *J Hand Ther*. 1993;6(3):179–188.
14. Merzenich MM, Jenkins WM. Reorganization of cortical representations of the hand following alterations of skin inputs induced by nerve injury, skin island transfers, and experience. *J Hand Ther*. 1993;6(2):89–104.
15. Qi HX, Stepniewska I, Kaas JH. Reorganization of primary motor cortex in adult macaque monkeys with long-standing amputations. *J Neurophysiol*. 2000;84(4):2133–2147.
16. Lundborg G. *Nerve injury and repair*. Edinburgh, New York: Churchill Livingstone; 1988.
17. Tajima T, Imai H. Results of median nerve repair in children. *Microsurgery*. 1989;10:145–146.
18. Lundborg G, Rosén B, Dahlin L, Holmberg J, Rosen I. Tubular repair of the median or ulnar nerve in the human forearm: A 5-year follow-up. *J Hand Surg Br*. 2004;29(2):100–107.
19. Rosén B, Lundborg G. Sensory re-education after nerve repair: aspects of timing. *Handchir Mikrochir Plast Chir*. 2004;36(1):8–12.
20. Singh P. Sensory Recovery in Median Nerve Repair Following Sensory Reduction. *J Hand Ther*. 2010;23(4):e9.
21. Cheng AS, Hung L, Wong JM, Lau H, Chan J. A prospective study of early tactile stimulation after digital nerve repair. *Clin Orthop Relat Res*. 2001;384:169–175.
22. Lundborg G, Rosén B. Hand function after nerve repair. *Acta Physiol (Oxf)*. 2007;189:207–217.
23. Vikström P, Carlsson I, Rosén B, Björkman A. Patients' views on early sensory relearning following nerve repair—a Q-methodology study. *J Hand Ther*. 2018;31(4):443–450.

24. Rosén B, Balkeniu C, Lundborg G. Sensory Re-education Today and Tomorrow: A Review of Evolving Concepts. *Br J Hand Ther*. 2003;8(2):48–56.
25. King PM. Sensory function assessment. A pilot comparison study of touch pressure threshold with texture and tactile discrimination. *J Hand Ther*. 1997;10(1):24–28.
26. Valdes K, Naughton N, Algar L. Sensorimotor interventions and assessments for the hand and wrist: A scoping review. *J Hand Ther*. 2014;27(4):272–286.
27. Kalron A, Greenberg-Abrahami M, Gelav S, Achiron A. Effects of a new sensory re-education training tool on hand sensibility and manual dexterity in people with multiple sclerosis. *NeuroRehabilitation*. 2013;32(4):943–948.
28. Walsh MT. Interventions in the disturbances in the motor and sensory environment. *J Hand Ther*. 2012;25(2):202–219.
29. Polatkan S, Orhun E, Polatkan O, Nuzumlali E, Bayri O. Evaluation of the improvement of sensibility after primary median nerve repair at the wrist. *Microsurgery*. 1998;18(3):192–196.
30. Dellon AL. Sensory recovery in replanted digits and transplanted toes: a review. *J Reconstr Microsurg*. 1986;2(2):123–129.
31. Shieh SJ, Chiu HY, Lee JW, Hsu HY. Evaluation of the effectiveness of sensory reeducation following digital replantation and revascularization. *Microsurgery*. 1995;16(8):578–582.
32. Shieh SJ, Chiu HY, Hsu HY. Long-term effects of sensory reeducation following digital replantation and revascularization. *Microsurgery*. 1998;18(5):334–336.
33. Brown CJ, Mackinnon SE, Dellon AL, Bain JR. The sensory potential of free flap donor sites. *Ann Plast Surg*. 1989;23(2):135–140.
34. Vitkus K, Vitkus M, Krivulin A. Long-term measurement of innervation density in second toe-to-thumb transfers receiving immediate postoperative sensory reeducation. *Microsurgery*. 1989;10(3):245–247.
35. Wei FC, Ma HS. Delayed sensory reeducation after toe-to-hand transfer. *Microsurgery*. 1995;16(8):583–585.
36. Nakada M, Uchida H. Case study of a five-stage sensory reeducation program. *J Hand Ther*. 1997;10(3):232–239.
37. Miller LK, Chester R, Jerosch-Herold C. Effects of sensory reeducation programs on functional hand sensibility after median and ulnar repair: A systematic review. *J Hand Ther*. 2012;25(3):297–306. quiz 307.
38. Oud T, Beelen A, Eijffinger E, Nollet F. Sensory re-education after nerve injury of the upper limb: A systematic review. *Clin Rehabil*. 2007;21(6):483–494.
39. Marsh D. The validation of measures of outcome following suture of divided peripheral nerves supplying the hand. *J Hand Surg Br*. 1990;15(1):25–34.
40. Moberg E. Objective methods for determining the functional value of sensibility in the hand. *J Bone Joint Surg Br*. 1958;40-B(3):454–476.
41. Weber E. Uber den tastsinn. *Arch Anat Physiol Wiss Med*. 1835;52:152.
42. Dellon AL. The moving two-point discrimination test: Clinical evaluation of the quickly adapting fiber/receptor system. *J Hand Surg Am*. 1978;3(5):474–481.
43. Jerosch-Herold C. A study of the relative responsiveness of five sensibility tests for assessment of recovery after median nerve injury and repair. *J Hand Surg Br*. 2003;28(3):255–260.
44. Penfield W, Boldrey E . Somatic Motor and Sensory Representation in the Cerebral Cortex of Man as Studied by Electrical Stimulation. *Brain*. 1937;1x:389.
45. Wynn Parry CB, Salter M. Sensory re-education after median nerve lesions. *Hand*. 1976;8(3):250–257.
46. Rosén B, Lundborg G. Enhanced sensory recovery after median nerve repair using cortical audio-tactile interaction. A randomised multicentre study. *J Hand Surg Eur Vol*. 2007;32(1):31–37.
47. Paula MH, Barbosa RI, Marcolino AM, Elui VM, Rosen B, Fonseca MC. Early sensory re-education of the hand after peripheral nerve repair based on mirror therapy: A randomized controlled trial. *Brazil J Phys Ther*. 2016;20(1):58–65.
48. Rosén B, Bjorkman A, Lundborg G. Improved sensory relearning after nerve repair induced by selective temporary anaesthesia - a new concept in hand rehabilitation. *J Hand Surg Br*. 2006;31(2):126–132.
49. Hassan-Zadeh R, Lajevardi L, Esfahani AR, Kamali M. Improvement of hand sensibility after selective temporary anaesthesia in combination with sensory re-education. *NeuroRehabilitation*. 2009;24(4):383–386.
50. Imai H, Tajima T, Natsuma Y. Interpretation of cutaneous pressure threshold (Semmes-Weinstein monofilament measurement) following median nerve repair and sensory reeducation in the adult. *Microsurgery*. 1989;10(2):142–144.
51. Imai H, Tajima T, Natsumi Y. Successful reeducation of functional sensibility after median nerve repair at the wrist. *J Hand Surg Am*. 1991;16(1):60–65.
52. Mavrogenis AF, Spyridonos SG, Antonopoulos D, Soucacos PN, Papagelopoulos PJ. Effect of sensory re-education after low median nerve complete transection and repair. *J Hand Surg Am*. 2009;34(7):1210–1215.
53. Parry CB. Sensory rehabilitation of the hand. *Aust N Z J Surg*. 1980;50(3):224–227.
54. Trotter W, Davies H. Experimental studies in the innervation of the skin. *J Physiol*. 1909;38(2-3):134–246.
55. Nolan MF. Two-point discrimination assessment in the upper limb in young adult men and women. *Phys Ther*. 1982;62(7):965–969.
56. Rosén B, Jerosch-Herold C. Comparing the Responsiveness over Time of Two Tactile Gnosis Tests: Two-Point Discrimination and the STI-Test. *Br J Hand Ther*. 2000;5(4):114–119.
57. Jerosch-Herold C. Should sensory function after median nerve injury and repair be quantified using two-point discrimination as the critical measure? *Scand J Plast Reconstr Surg Hand Surg*. 2000;34(4):339–343.
58. Keunen R, Sloof A. Sensibility testing after nerve grafting. *Clin Neurol Neurosurg*. 1983;85:93–99.
59. Rosén B. Recovery of sensory and motor function after nerve repair: A rationale for evaluation. *J Hand Ther*. 1996;9:315–327.
60. Moberg E. Criticism and study of methods for examining sensibility in the hand. *Neurology*. 1962;12:8–19.
61. Moberg E. Reconstructive hand surgery in tetraplegia, stroke, and cerebral palsy: some basic concepts in physiology and neurology. *J Hand Surg Am*. 1976;1(1):29–34.
62. Moberg E. Two-point discrimination test. A valuable part of hand surgical rehabilitation, e.g. in tetraplegia. *Scand J Rehabil Med*. 1990;22(3):127–134.
63. Moberg E. Aspects of sensation in reconstructive surgery of the upper extremity. *J Bone Joint Surg Am*. 1964;46:817–825.
64. Nicholson OR, Seddon HJ. Nerve repair in civil practice. *Br Med J*. 1957;2(5053):1065–1071.
65. Hakstian RW. Funicular orientation by direct stimulation: An aid to peripheral nerve repair. *J Bone Joint Surg Am*. 1968;50(6):1178–1186.
66. Honner R, Fragiadakis E, Lamb D. An investigation of the factors affecting the results of digital nerve division. *Hand*. 1970;2(1):21–30.
67. Kaas JH, Merzenich MM, Killackey HP. The reorganization of somatosensory cortex following peripheral nerve damage in adult and developing mammals. *Annu Rev Neurosci*. 1983;6(1):325–356.
68. Dettori JR. Loss to follow-up. *Evid Based Spine Care J*. 2011;2(1):7–10.

JHT Read for Credit
Quiz: # 616

Record your answers on the Return Answer Form found on the tear-out coupon at the back of this issue or to complete online and use a credit card, go to *JHTReadforCredit.com*. There is only one best answer for each question.

\# 1. All subjects were
  a. patients with low median nerve transection treated by microsurgical repair
  b. tested for static and M2PD
  c. tested with the Moberg Pick Up Test and the modified Marsh Test
  d. all of the above

\# 2. The sensory re-education program was
  a. precisely as Dellon originally described
  b. too difficult for 25% of the original subject population who were subsequently removed from the study data
  c. initiated on average at 3.5 months post repair
  d. initiated on average at 3 weeks post repair

\# 3. It can be said that
  a. stereognosia as well as 2PD and M2PD were not significantly different between groups at any evaluation point throughout the study
  b. 2PD and M2PD out performed locognosia at all evaluation points throughout the study
  c. sensory re-education is more effective in re-establishing 2PD than in re-establishing locognosia
  d. that a strenuous home program of sensory re-education is profoundly effective

\# 4. The 2nd stage in the SR group was
  a. initiated at one year post repair
  b. initiated once 2PD & M2PD were considered normal at the index fingertip
  c. initiated when the patient expressed a desire to move forward in their training
  d. was stopped at 18 months post repair

\# 5. At the 6 year follow up evaluation for locognosia there was no significance difference between groups
  a. false
  b. true

When submitting to the HTCC for re-certification, please batch your JHT RFC certificates in groups of 3 or more to get full credit.