REVIEW
Hand function after nerve repair

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Abstract
Treatment of injuries to major nerve trunks in the hand and upper extremity remains a major and challenging reconstructive problem. Such injuries may cause long-lasting disabilities in terms of lost fine sensory and motor functions. Nowadays there is no surgical repair technique that can ensure recovery of tactile discrimination in the hand of an adult patient following nerve repair while very young individuals usually regain a complete recovery of functional sensibility. Post-traumatic nerve regeneration is a complex biological process where the outcome depends on multiple biological and environmental factors such as survival of nerve cells, axonal regeneration rate, extent of axonal misdirection, type of injury, type of nerve, level of the lesion, age of the patient and compliance to training. A major problem is the cortical functional reorganization of hand representation which occurs as a result of axonal misdirection. Although protective sensibility usually occurs following nerve repair, tactile discriminative functions seldom recover – a direct result of cortical remapping. Sensory re-education programmes are routinely applied to facilitate understanding of the new sensory patterns provided by the hand. New trends in hand rehabilitation focus on modulation of central nervous processes rather than peripheral factors. Principles are being evolved to maintain the cortical hand representation by using the brain capacity for visuo-tactile and audio-tactile interaction for the initial phase following nerve injury and repair (phase 1). After the start of the re-inner-vation of the hand (phase 2), selective de-afferentation, such as cutaneous anaesthesia of the forearm of the injured hand, allows expansion of the nerve-injured cortical hand representation, thereby enhancing the effects of sensory relearning. Recent data support the view that training protocols specifically addressing the relearning process substantially increase the possibilities for improved functional outcome after nerve repair.

Keywords brain plasticity, cortical reorganization, hand function, nerve regeneration, nerve repair.
injuries on the patient as well as on society: the total cost for a median nerve injury in Sweden is more than 51 000 € (Rosberg et al. 2005).

Despite an enormous amount of new data and evolving new scientific concepts, nerve injuries are still one of the most challenging and difficult surgical reconstructive problems. Today there is no surgical technique which can ensure recovery of tactile discrimination in the hand of an adult after he suffers from a median nerve lesion. Thus, considering the impact of nerve injuries on quality of life as well as working capacity and economy there are good reasons to re-evaluate and revise some of the current principles of nerve repair.

### The sensational hand

The human hand is not only a working tool but also a delicate instrument of great importance for our daily activities and well-being. It is a body part that links us to the outer world by the sense of touch and one that makes our expression to the world heard via body language or via the art of painting or music. The hand has an enormous capacity to perceive, to execute and to express – simultaneously, in the act of touch (Gibson 1962).

Besides the capacity for delicate motor functions, the hand represents a sense organ with extremely well-developed sensory functions. Besides protective sensitivity, the term ‘tactile gnosis’ is often used to illustrate the specific aspects of functional sensibility representing the interplay between peripheral function of the nerve and the interpretation of sensory impressions in the somatosensory cortex of the brain (Moberg 1958). The discriminative touch, one aspect of tactile gnosis, is dependent on cutaneous mechanoreceptors in the hand sensitive to pressure, vibration and stretching. The physiology of function and distribution of the mechanoreceptors in the subepidermal, dermal and subcutaneous layers of the volar glabrous skin of the hand have been well defined and described in numerous investigations (Johansson & Vallbo 1979, 1983, Vallbo & Hagbarth 1968, Vallbo & Johansson 1984, Stark et al. 1998). This is a function that enables perception and localization of touch, discrimination of touch and recognition of qualities and identification of objects without using vision. In this view, the hand can be described as a sense organ, strongly linked to the brain (Lundborg 2003, 2004, Wynn-Parry 1986). The well-developed feedback system between the hand and the brain, with continuous proprioception and tactile input that are coordinated with memory systems in the brain, is a prerequisite for regulation of grip force and grip speed (Johansson 2002). The feedback from a functioning sense of touch is also essential (Ramachandran & Hirstein 1998). A nerve injury leaving the hand with an impaired sensation will have a high impact on the patient’s capacity to use the hand, and there are not only medical disabilities but also a considerable social disability.

### Regeneration and repair – physiological aspects

Restoration of motor and sensory functions in the hand after nerve repair is a complex process based on multilevel cellular, chemical and functional changes – from the fingertips to brain cortex (Lundborg 2004). Axonal outgrowth and orientation is dependent on complex molecular mechanisms in the microenvironment with various types of mechanisms for axonal attraction or repulsion, stimulating or inhibiting the advancement of axons.

Following transection of a nerve, the reactions at the cell-body level lead to a shift in metabolism from a mode of maintenance to a mode of growth expressed in structural and functional changes of the nerve cell bodies (Lieberman 1971, Grafstein 1975, Aldskogius & Arvidsson 1978, Dahlin et al. 1987). During axonal transection, a large number of neurones die because of apoptosis. There may be a cellular loss of 20–50% of neurones in the dorsal root ganglia (Aldskogius & Arvidsson 1978, Ygge 1989, Liss et al. 1996) and motor cells may also die, although to a lesser extent (Li et al. 1994, Novikov et al. 1995). Several factors may have an influence on the post-traumatic neuronal loss in the dorsal root ganglia such as age, time laps from injury to repair and proximity of injury. Immediate repair of a nerve may reduce post-traumatic cell death (Ma et al. 2003).

A major problem is that axonal misdirection, regardless of the repair technique, always occurs at the repair site so that sensory axons grow into motor Schwann cells and vice versa (Ramon y Cajal 1928, DeFelipe & Jones 1991, Lundborg 2004, Witzel et al. 2005). In the distal segment, there is Wallerian degeneration and Schwann cells start to proliferate and produce a number of various growth factors such as nerve growth factor (NGF) (Heumann 1987, Thoenen et al. 1988), ciliary neurotrophic factor (CNTF), brain-derived neurotrophic factors (BDNF) and NT-3, NT-4/5 and NT-5–6 (Funakoshi et al. 1993, Lundborg 2004). Invading macrophages release interleukin-1 which triggers increased NGF transcription and NGF receptor density in the Schwann cells (Taniuchi et al. 1986, Heumann et al. 1991). (For details of the physiology of regeneration and the importance of growth factors see, for instance, Fu & Gordon 1997, Terzis et al. 1997, Frostick & Kemp 1998, Yin et al. 1998, McAllister et al. 1999, Terenghi 1999, Lundborg 2000a, 2004, Dahlin 2004 and Dahlin & Brandt 2004).

A crucial factor is the extent of ‘specificity’ in axonal growth. The existence of ‘preferential motor...
regeneration’ under strict laboratory conditions has been stressed by Brashart (1988, 1990), Brashart & Seiler (1987) and Brashart (1993), implying that motor fibres preferentially innervate distal motor Schwann cell tubes in contrast to distal sensory Schwann cells. The basis for this has been suggested to be the presence of specific ‘recognition molecules’ in motor Schwann cell tubes as opposed to sensory Schwann cell tubes (Kunemund et al. 1988). However, according to Maki and associates (Maki et al., 1996), there is specificity in sensory regeneration but not in motor regeneration. According to Maki, the outgrowth of Schwann cells in the distal nerve segment has an important role in this context. Although the issue of specificity in axonal regeneration is a crucial issue, opinions vary regarding the expression of specificity in experimental regeneration models. It is not known if, or to what extent, specificity mechanisms are active in clinical situations.

**Regeneration after nerve repair – clinical aspects**

Repair of nerves was long regarded primarily as a technical problem and various techniques have been described to make the adaptation of nerve ends as accurate as possible. Following a nerve transaction, the surgeon can approximate and suture the two nerve ends by putting sutures in the outer nerve sheath (epineurium) or in deeper perineural layers to adapt bundles of fascicles separately (Lundborg 2004). It may even by possible to suture separate fascicles individually. However, the surgeon can never address individual Schwann cell tubes or axons. Thus, regardless of how accurate the repair technique is, axonal misdirection is unavoidable and constitutes the basis for cortical functional reorganizations when incorrect peripheral targets are reinnervated by regenerating axons (Witzel et al. 2005).

The classical technique is to suture only the external epineurium (Diao & Vannuen 2000, Trumble & McCallister 2000, Lundborg 2004, Rowshan et al. 2004). Although epineural repair gives a nice appearance of the suture site there may be misalignment of the interior fascicles. An improved orientation of fascicles is achieved by the group fascicular repair technique where individual bundles of fascicles are repaired separately (Diao & Vannuen 2000, Lundborg 2004, Rowshan et al. 2004). With this technique, fascicular groups are carefully freed by dissection under high magnification, the epineurial tissues resected over a short distance from the cut nerve ends and the fascicular bundles are sutured individually. This technique gives an improved accuracy in fascicular orientation, but there is no evidence that this technique, in general, results in improved functional outcome when compared with the epineurial technique (Lundborg 2004).

Tubes of various types have been used for primary and secondary repair of nerves (Lundborg et al. 2004). Silicone tubes were used for primary repair of human median and ulnar nerves at the wrist level by Lundborg et al. (2004), and various types of tubes, resorbable and non-resorbable, have since been used in experimental animals and clinical praxis (Archibald et al. 1991, 1995, Schlosshauer et al., 2006). During tube repair, a short space, about 5 mm in length, may deliberately be left between the nerve ends inside the tube. A gap is rapidly filled with fibrin and is thereafter invaded by microvessels, fibroblast, Schwann cells and axons (Lundborg 2004).

**Assessment of hand function after nerve repair**

Assessment of hand function following nerve repair is not an easy task as several tests, addressing different aspects of hand function should be conducted. For appreciation of the overall function of the hand, different measures are needed to quantify the outcome in a set of modalities, such as sensibility, motor function, pain and discomfort (Rosén 1996, Rosén & Lundborg 2003, Szabo 2001, Jerosch-Herold 2005, MacDermid 2005). Historically, the most commonly used scale for assessment of sensory and motor functions of the hand is the MRC scales (Medical Research Council & Committee 1954). The sensory scale is however based on subjective findings, and thus it has psychometric drawbacks. Several attempts have been made to quantify the outcome over the years. The most recent is the ‘Model Instrument for Outcome After Nerve Repair’ which is a model for routine documentation and quantification of the functional outcome after nerve repair at the wrist or distal forearm level including sensory and motor function as well as problems from pain and discomfort in a summarized scoring system (Rosén & Lundborg 2000). Specific sensibility tests can hierarchically be divided into detection tests, discrimination tests and identification tests (Fess 1990). Detection of a single stimulus is required, such as the light pressure from a filament. Most commonly Semmes-Weinstein monofilaments (SWM) or von Frey’s hair (von Frey 1922) are used. Nylon filaments of different thickness are used and the test is performed in a standardized way where the subject indicates when touch by the filament can be felt. Thereby the smallest per touch/pressure can be defined (Bell-Krotoski 2002).

Various tests for tactile discrimination have been described. A commonly used test for discriminative capacity is the two-point discrimination (2PD) test, which is commonly used to assess functional hand sensibility by surgeons and therapists. The classic static-two-point discrimination test was developed by Weber...
and popularized by Moberg (1958, 1962). In this test, one or two points are randomly applied to the tested skin area and the subjects are asked whether they are able to perceive them. It is important that 2PD results are always accompanied by a detailed description as to how the test was performed because the amount of pressure towards the skin can influence the result considerably (Lundborg & Rosén 2004, Jerosch-Herold 2005). The recently described shape/texture-identification (STI) test is a standardized test based on active touch with identification of shapes and textures of increasing difficulty (Rosén & Lundborg 1998). The model instrument (Model Instrument for Outcome After Nerve Repair) mentioned earlier, based on subjective as well as objective measures, focusing on the totality, takes into account sensory, motor and pain/discomfort aspects. This model correlates well with the patient’s opinion of the impact of the nerve injury on activities of daily living (ADL) (Rosén & Lundborg 2000).

**Factors influencing the outcome**

The outcome from nerve repair is much dependent on prevailing conditions as well as the technique that is used. However, the outcome from peripheral nerve surgery varies considerably among patients, even when conditions as well as surgical techniques are virtually identical. Various factors are known to influence the outcome from nerve repair.

**Age**

Although the outcome of nerve repair is disappointing in adults (Jerosch-Herold 1993, 2000, Allan 2000, Kallio & Vastamäki 1993, Rosén et al. 2000), it is well known that children usually achieve superior functional results (Lundborg & Rosén 2001). Despite of generally shorter regeneration distance in children and better regeneration capacity in general, the better adaptability of the brain in children has usually been proposed as an explanation. There seems to be a critical age period for recovery of functional hand sensibility, with the best results seen in those less than 10 years, followed by a rapid decline, levelling out after late adolescence (Lundborg & Rosén 2001). Interestingly, there is a striking analogy between this pattern and the pattern illustrating the scores of immigrants on a grammar test, plotted against age at which they start to learn a new language (Lundborg & Rosén 2001, Lundborg 2004). Thus, the critical period for regaining discriminative tactile capacity after nerve repair is analogous to a corresponding critical period for acquisition of a second language, indicating a strong learning component in acquisition of functional sensibility as well.

**Cognitive brain capacities**

Specific cognitive capacities of the brain such as verbal learning capacity and visuo-spatial logic capacity can help to explain variations in the recovery of functional sensibility in adult after nerve repair (Rosén et al. 1994). Verbal learning capacity and visuo-spatial cognitive capacity have been shown to play a significant role for recovery of functional sensibility in median and ulnar nerve repair in adults.

**Timing of repair**

It is generally agreed that freshly transected nerves should be repaired acutely with no or minimal delay (Birch & Raji 1991, Diao & Vannuyen 2000, Trumble & McCallister 2000, Lundborg 2004). Early repair will substantially reduce the postoperative nerve cell death (Ma et al. 2003) and at this time natural landmarks such as epineurial blood vessels can still be used to ensure a correct matching of the nerve ends. With increasing preoperative delay the results become progressively worse as a result of fibrosis of the distal nerve segment, atrophy of Schwann cells and progressive loss of neurones.

**Type of nerve**

The type of nerve that is injured considerably influences the outcome. If a pure motor nerve is injured the risk of mismatch between motor axons and sensory axons is eliminated thus optimizing the accuracy in re-innervation. For pure sensory nerves, such as a digital nerve, the situation is analogous.

**Level of injury**

After nerve transection there is an initial delay followed by sprouting and axonal outgrowth. A nerve outgrowth rate of at most 1–2 mm/day in humans has been suggested (Buchthal & Kühle 1979). In digital nerve injuries there is only a short distance separating the regenerating axons from their distal targets while injuries at the upper arm level create different situations with longer time before reinnervation of the hand occurs. Median nerve lesions at the wrist level may require 3–4 months before the first signs of re-innervation in the hand occur.

**Type of injury**

A crush lesion always results in better functional outcome when compared with total severance of a nerve trunk (Lundborg 2004). The initial delay is shorter and the growth of axons proceeds at a faster
rate after a crush injury when compared with a nerve transection. The Schwann cell basal lamina are still in continuity and can thus guide the axons back to their original peripheral targets. The correct peripheral re-innervation of the crush injuries are reflected in a perfect restoration of the original cortical representational areas corresponding to the re-innervated body part (Merzenich & Jenkins 1993).

### The role of the brain in functional recovery following nerve repair

Clinical experience shows that the outcome of nerve repair in adults is often disappointing and far from satisfactory, especially with respect to recovery of tactile discrimination (Jerosch-Herold 1993, 2000, Allan 2000, Wynn-Parry 1986, Moberg 1991, Kallio & Vastamäki 1993, Rosén 2000, Lundborg et al. 2004). Introduction of microsurgery and refined surgical repair techniques have not led to dramatically improved results (Lundborg 2000b, 2003, Lundborg 2004). Thus, there are good reasons to look for explanatory factors in the central nervous system in addition to the cellular and biochemical events which are associated with degeneration and regeneration in the peripheral nervous system. A nerve injury in the upper extremity is followed by profound functional reorganizational changes in the somatosensory cortex, mainly because of misdirection of regenerating axons. A major component in rehabilitation after nerve injury should therefore be to focus on the relearning process which is required to learn the ‘new language spoken by the hand’.

### What happens in the brain after nerve injury and repair?

A nerve injury in the hand or arm represents a sudden de-afferentation with immediate and longstanding influence on the cortical hand representation as well as the representation of adjacent cortical territories (Kaas et al. 1983, Merzenich et al. 1983, Wall et al. 1986, 2002, Chen et al. 2002). After a median nerve transection there is a silent ‘black hole’ in the somatosensory brain cortex corresponding to the median nerve projectional areas. Rapidly, adjacent cortical areas expand and occupy the former median nerve territory (Merzenich et al. 1983, Silva et al. 1996). These changes which happen within minutes are probably based on unmasking of normally occurring but inhibited synaptic connections. They will last over the initial post-injury period before regenerating axons have reached the hand. During this period, phase 1, the hand is without sensation and there is no sensory input from median innervated areas.

Although our microsurgical nerve repair techniques have been refined to an optimal level, there is still a great extent of misorientation of regenerating axons at the repair site. Thus, the skin areas of the hand will, to a large extent, not be re-innervated by their original axons. Instead, they may be re-innervated by axons originally innervating other parts of the hand. The result is significant reorganizational changes in the cortical territory where the median nerve is normally represented. The originally well-organized hand representation is changed to a mosaic-like pattern (Wall et al. 1986, Florence et al. 1994, Kaas & Florence 1997, Jain et al. 1998) and the median nerve does not recapture all of original territory. The former well-defined individual cortical representation of separate fingers disappears and changes into distorted discontinuous islands. Surfaces of the skin with normally well-defined cortical representations such as the thumb, a segment of a finger, or a palmar pad, now become represented across multiple cortical patch-like areas, sometimes overlapping (Wall et al. 1986, Lundborg 2004). This knowledge is based primarily on primate experiments, but analogous findings have been made also in humans on the basis of functional magnetic resonance imaging (fMRI) techniques (Hansson & Brismar 2003). This period, representing the beginning of re-innervation of the hand, is termed phase 2. After a median nerve injury at the wrist level phase 2 usually begins 3–4 months after nerve repair.

### Sensory re-education and sensory relearning – current concepts

Following nerve injury and repair, a relearning process is required for recovery of functional sensibility. As a result of misdirection of axons and the consequent remapping of the cortical hand representation, ‘the hand speaks a new language to the brain’ (Dellon et al. 1974, Wynn-Parry & Salter 1976, Dellon 1981, Lundborg 2004). This new language has to be interpreted by the brain, a process which can be achieved by sensory relearning through sensory educational programmes. It is not known how such programmes influence the functional cortical organization (Florence et al. 2001). The functional improvement seen after training may be based either on normalization of the distorted hand map or it can be due to adaptations in higher brain centres with a capacity to decipher the distorted hand map.

Learning is a key word in the rehabilitation process after all injuries. New sensory and motor codes are presented to the brain that has to cope with this for purposeful sensory–motor interaction and functional use. The extensive cortical reorganizational changes
which occur after nerve repair requires a relearning process in order to adapt to the new and distorted afferent sensory input when familiar objects are touched – the mind does not understand the new ‘sensory code’ associated with specific textures and shapes. To facilitate and enhance this process, specific programmes for sensory re-education are routinely used in adult patients for regaining tactile gnosis, starting once touch can be perceived (Dellon 1981, 1997, Callahan 1995, Dellon et al. 1974, Wynn-Parry & Salter 1976, Rosén et al. 2003). According to these strategies, the brain is reprogrammed on the basis of a relearning process (Lundborg 2004). First, the perception of different touch modalities and the capacity to localise touch is trained, followed by touching and exploration of items, presenting shapes and textures of varying and increasing difficulty with the eyes open and closed. In this way, an alternate sense (vision) assists the training and improves the deficient sense (sensation).

However, the sensory re-education programmes that are used today were designed in the 1970s and 1980s and have not been changed much since then. They do not have a solid scientific base and are not updated in view of evolving concepts of learning mechanisms, cortical remodelling and brain plasticity. They do not take into account the time factor in view of the rapid cortical reorganizational changes which follow a changed sensory input (Rosén et al. 2003, Rosén & Lundborg 2004).

New strategies in sensory re-education and sensory relearning

According to routine sensory re-education protocols, the sensory training starts at first in phase 2, that is during the start of the re-innervation of the hand and when the cortical reorganizational changes resulting from the nerve injury are well manifested. The cortical hand representation has since long disappeared and is occupied by expanding adjacent cortical areas. In our current and evolving protocols for sensory re-education we focus on the timing of initiation of the training programme with emphasis on new training concepts not only in phase 2 but also in phase 1, i.e. early after nerve injury and repair, long before hand re-innervation has started. The strategy is to activate the cortical area representing the damaged nerve, thereby diminishing cortical reorganization aiming at a maintenance of the cortical representation of the denervated body part.

Phase 1: maintaining the cortical hand map

Background

Nerve transection results in a rapid disappearance of the corresponding cortical representation. For instance, a combined median and ulnar nerve injury is followed by disappearance of the cortical hand representation followed by a rapid expansion of the adjacent cortical territories. In our treatment regimen in phase 1, we focus on maintaining the cortical hand representation by using the brain’s capacity for visuo-tactile and audio-tactile interaction. Activation of motor neurones – ‘mirror neurones’ in premotor cortex by the mere observation of hand motor actions is a well-known phenomenon which is believed to play a fundamental role in both action and understanding and imitation (Rizzolatti et al. 2001, Rizzolatti & Craighero 2004). Activation of somatosensory cortex by the visual observation of touch has been demonstrated with reference to the lower extremity (Keysers et al. 2004) and does occur also with the observation of a hand being touched (Avikainen et al. 2002, Grezes et al. 2003, Hansson et al. 2005). Premotor cortex may also be activated by reading or listening to action or words (Hauk et al. 2004). It is well known that the brain has a multimodal capacity implying that specific neurones and associated cortical areas respond to stimuli provided by touch as well as vision and hearing (Bavelier & Neville 2002). In analogy, an interesting principle is the activation of somatosensory cortex by listening to the friction sound of a hand being touched or a hand touching various textures (Lundborg & Rosén 2003, Lundborg et al. 2005).

Training concepts (phase 1)

Visuo-tactile interaction and mirror training. The patient’s observation of his hand being touched by the therapist is an important component of early sensory training which might activate the cortical hand area due to visuo-tactile interaction. The effect can be further enhanced by using mirror training. We use a mirror placed transversally in front of the patient with the nerve-injured hand hidden behind the mirror, the healthy hand being reflected in the position of the injured hand (Ramachandran et al. 1995, Ramachandran & Hirstein 1998). Touching the healthy hand gives an illusion of touching the nerve-injured hand. In these training sessions, the patient often gets a perception of the tactile stimuli in the nerve-injured non-sensate hand by the combined mirror illusion and the true touch of the healthy hand.

Audio-tactile interaction and the use of sensor glove. We use a sensor glove system with microphones mounted dorsally at fingertip levels in a glove connected to earphones – via a miniature stereo processor. With this system ‘the patients can listen to what the hand feels’. Thus, auditory stimuli substitute for absent tactile stimuli – specific and typical friction sounds are associated with touching of various textures.
In a clinical randomized prospective study run at five hand centres in Sweden patients with median nerve injuries were randomized either to a group using the sensor glove from the first postoperative day or to a group not using the glove but subjected to routine sensory re-educational programmes. Preliminary results, obtained from 1 year of follow-up show that tactile discrimination, as assessed in the STI test and hand dexterity, assessed by the Sollerman test showed a significantly better recovery in the group using the sensor glove (Lundborg & Rosén 2003, Rosén & Lundborg 2003).

Phase 2: enhancing the effects of sensory re-education

Background

The brain’s capacity for rapid redistribution of cortical resources as a component of brain plasticity has been well described in the literature in rehabilitation of stroke patients. For instance, it has been shown that selective anaesthesia of ventral roots of C5–C8 (motor innervation of shoulder and elbow) results in enhanced motor function of the hand (innervation C8–C11; Muellbacher et al. 2002). The mechanism is that de-afferentation of specific cortical area (shoulder and elbow representations) allows expansion of adjacent cortical representational areas (the hand). In analogy, cutaneous de-afferentation of the forearm would hypothetically result in expansion of the adjacent cortical hand representation.

Training concepts (phase 2)

Cutaneous de-afferentation of the forearm. In our treatment regimen we perform anaesthesia of the forearm proximally to the nerve-injured hand with the purpose of allowing expansion of the cortical hand representation. Cutaneous anaesthesia of the volar part of the forearm is induced by EMLA-creme twice a week for 2 weeks. This is combined with intense classical sensory training. In a double-blind, randomized clinical study of patients treated for median or ulnar nerve injuries, the EMLA group showed a significantly improved tactile discrimination when compared with the control group (Rosén et al. 2005), subjected to sensory training only, when assessed at 2 and 4 weeks after the last EMLA treatment.

Functional outcome after nerve repair

Following nerve repair at the distal forearm level of major nerve trunks, the fingers may be without sensibility for up to 6 months before re-innervation at the finger level occurs. Using the diagnose specific outcome instrument Model Instrument for Outcome after Nerve Repair (Rosén & Lundborg 2001), a reference interval for the outcome with the estimated 95% predicted values for the outcome shows ongoing improvements up to 5 years after the nerve repair.

In spite of the use of microsurgical techniques for nerve repair, median, ulnar or combined injuries lead to long-lasting disabilities in terms of fine sensory and motor functions, and in addition pain and discomfort from hyperaesthesia and cold intolerance that can be very problematic with large impact on ADL (Rosén 1996, Jaquet et al. 2001, Carlsson et al. 2003). The individuals’ ability to experience and interact with the surrounding world is thereby disturbed.

Five years following surgery, a mean functional symptom score of 19 (0 = no disability, 100 = max disability) on the Disability of the Arm, Shoulder and Hand (DASH) questionnaire has been reported (Jaquet 2004). In a recent Dutch study, 59% of patients with median or ulnar nerve repairs returned to work within 1 year with an average time off work of 31 weeks (Jaquet 2004). Substantial costs for the society are also generated in terms of sick leave. A mean cost of 51 000 € for a median nerve repair has been calculated (Rosberg et al. 2005).

In addition to the large number of peripheral and central factors, active and conscious use of the hand in activities of daily life, combined with high motivation by the patient, is since long reported to be a factor of great importance for useful return of functional sensibility (Callahan 1995). Bruyns et al. (2003) found that high education, high compliance to hand therapy and an isolated injury predict quicker return to work in patients with median and/or ulnar nerve injuries. A recent meta-analysis showed that age, site, injured nerve and delay significantly influence the prognosis after nerve repair (Ruijs et al. 2005).

The surgeon’s ambition is to use repair techniques, which brings a maximal number of nerve fibres into peripheral cutaneous territories. There are however at least three strong indications that central nervous factors associated with cortical re-modelling represent a major reason for the inferior functional outcome following nerve repair: (1) children up to the age of 10–12 years usually present excellent recovery of functional sensibility in contrast to adult patients. This critical ‘age-window’ for perfect sensory recovery presented by children corresponds well to what is known from other types of learning processes, for instance the ability for acquisition of a second language (Lundborg & Rosén 2001); (2) cognitive functions are important explanatory factors in adults for variations in recovery of tactile discrimination (Rosén et al. 1994, Jaquet 2004); (3) The peripheral repair technique in median nerve lesions has not been found to influence the functional outcome in a
clinical randomized study at a 5-year follow-up (Lundborg et al. 2004). Silicone tubular repair, leaving a short distance between the nerve cuts, was compared with the outcome from routine microsurgical repair in a clinical randomized prospective study, comprising 30 patients with median or ulnar nerve injuries in the distal forearm. Postoperatively, the patients were assessed regularly over a 5-year period with neurophysiological and clinical assessments. After 5 years there was no significant difference in outcome between the two techniques except that cold intolerance was significantly less severe with the tubular technique. The most significant improvement of perception of touch occurred during the first postoperative year, while improvement of motor function could be observed much later (Rosén et al. 2000). In the total group, however, functional sensibility was reported to improve through the 5 years after repair, although there was no further impairment in nerve conduction velocity or amplitude after the first 2 years (Lundborg et al. 2004). This supports the fact that the central nervous factors associated with the cortical remodelling after a nerve repair are important, and that efforts to improve the results from nerve repair in the future must address the brain as well as the peripheral nerve.

References


