HIGHLIGHTS

Physiotherapeutic techniques used in the management of patients with peripheral nerve injuries

Peripheral nerve injuries affect a wide range of functional, manual and social function, and frequently lead to constant disabilities. After complete transection of nerve, axonal degeneration process gives rise to a variety of symptoms including hyperesthesia, reduced or altered sensation, pain and atrophy (Lee and Wolfe, 2000). With an array of choices for surgical and treating peripheral nerve injuries, there is also, a lot of new, coherent strategies on rehabilitation and physiotherapy protocols - which should be indispensable after injury. Physiotherapy, with a view to compensate dysfunctions relieves in sensory symptoms and creates grater neuroplasticital potential, forms essential part of the treatment for people after peripheral nerve injuries (Inoue et al., 2003).

In the present paper we present the physiotherapeutic methods, protocols, and strategy currently used for initiation and support of peripheral nerve regeneration after injuries.

Kinetic therapy in peripheral nerve injuries: Impact of kinetic therapy on peripheral nerve repair after its damage is mostly determined by the time required for regeneration of nerve fibers as well as for muscle reinnervation. Stress put on a paralyzed muscle through stretching or strengthening delays, and may even prevent full nerve recovery, and such treatment should not be started until the late stage of nerve regeneration, when progressive strength return can be seen. After injury of the nerve, physiotherapeutic methods are dedicated to eliminate paresis and to restore normal function of muscles as well as to improve circulation and following energetic supply to the tissues. **Table 1** presents an overview of the current methods most commonly used in physiotherapy after peripheral nerve injury.

Electrostimulation: Electric stimulation plays an important role in the treatment of various neuromuscular dysfunctions. With a wide range of applications and the possibility of combining this method with others, it is considered as one of the most effective. There are many types and ways of electrostimulation which differ one from another with the technical embodiment. The most common method is transcutaneous electrical nerve stimulation (TENS), which consists of transcutaneous stimulation pulses of electric current with a frequency of 90–130 Hz.

Chen et al. (2001) showed that percutaneous electric stimulation of 2 Hz frequency enhanced the mean values of the axon density, blood vessel number, blood vessel area and percentage of blood vessel area in total nerve area in injured rat sciatic nerve. As studies show, stimulation current of low frequency (20 Hz) for 1 hour a day for 2 weeks after the injury shortens the period of axonal outgrowth of three nerve bundles through the implanted graft (Al-Majed et al., 2000; Gordon et al., 2003. It also showed that electrical stimulation has a positive influence on regeneration processes by stabilizing the cholinergic receptors at the neuromuscular junction.

Electroacupuncture is a simple method of indirect application of an electrical stimulation to injured nerve. Pomeranz and Campbell (1993) revealed that the regeneration of injured nerve was enhanced by continuous electrical stimulation at the site of the injury *via* chronically implanted electrodes. However, Inoue et al. (2003) showed that it is unclear whether electroacupuncture enhanced the axonal regeneration processes. Most frequently used patterns of electrical stimulation of peripheral nerve trauma are presented in **Table 2**.

Magnetotherapy: For the treatment of damaged peripheral nerve, a pulsed low frequency magnetic field can also be applied. Magnetic field therapy has well-known effects on enhancing enzymatic activity, oxy-reductive processes and better blood circulation what results in better oxygenation and conduction characteristics of regenerating peripheral nerves. These mechanisms base on the influence of magnetic field on liquid-crystal structure of many membranes and cell organelles resulting in ion-channels transmission changes. Alteration in intra- or extracellular ion distribution leads to changes in electric potentials in organella membranes as well as in cellular membranes of living biological systems. Magnetic stimulation enhances the regeneration of nerve fibers, as the nerve conductivity increases as well as the amplitude of the action potential (Negredo et al., 2004; Mert et al., 2006). The pulsed electromagnetic field (PEMF) has a high clinical value, as applied immediately after peripheral nerve injury - shortens the duration of functional defects (Mert et al., 2006). Unlike electrical stimulation, magnetic stimulation carries no risk of infection due to electrodes pinned around the wound, and it is completely painless, even in patients with well-preserved sensation. Therapeutic effects of PEMF and CEMF in the case of peripheral nerve damage are comparable and may be used complementarily (Bannaga et al., 2006).

Spatial magnetic field generator is one of most recent achievements among the magnetostimulators. Prototype generates magnetic field through 3 pairs perpendicularly arranged magnetic coils. This allows for the interference of fields and results in obtaining the rotational magnetic field focused in small area. This new method may be more effective than other widely used techniques of magnetostimulation and magnetotherapy, as shown in animal experiments where strong spatial alternating magnetic field exerted positive effect on peripheral nerve regeneration. This improvement was found in all experimental groups, with best outcome observed in group exposed to the strongest magnetic field. Also dorsal root ganglion survival rate and nerve regeneration intensity were significantly higher in the group treated with the strongest field (Suszyński et al., 2014). Magnetic fields used in treatment of peripheral nerve injury are shown in **Table 3**.

Bio-laser stimulation: For the treatment of peripheral nerve injury, low energy biostimulation lasers are used, applied in the way of pulsatile (905 nm), continuous (808 nm), or pulsing-constant rays. Laser therapy increases the formation of ATP, and the energy of the ATP hydrolysis can be used by nerve cell to restore normal transmembrane potential, which facilitates the generation of electrical impulses and thereby restoring nerve conduction (bioelectric effect). Application of laser beams improves microcirculation and hence nutrition and regeneration of nerve cells – bio-stimulation effect – and increases the release of endorphins and the concentration of neurotransmitters in the synapses – analgetic effect.

Laser radiation can also be used to rejoin the nerve stumps (Lanre method – laser-assisted nerve repair). Studies evaluating the use of this method show comparable or even more effective reconstruction then surgical treatment. Less scar formation is observed in the site of anastomosis, which creates favorable conditions for the regeneration of nerve fibers (Huang and Huang, 2006). There are also promising results of the coupled use of

Table 1 The most commonly used methods of kinetic therapy in peripheral nerve damage

Method name	Technique	Result
Jacobsen (Jacobsen and Edinger, 1982)	Points of strong pressure applied around the coils and nerve plexus	–Elimination of venous stasis
Brunkow (Brunkow et al., 2004)	Comprehensive synergy ascending and descending by the proper choice and orientation of exercise different groups of muscles	–Activation (voltage) of a particular, denervated muscle group –Reducing the risk of contractures and muscle atrophy
Brunnström (Brunnström and Mauritz, 1993)	Composure, focus and use of muscle synergies	–Neuromuscular reeducation: control of voluntary movements –Elimination of paralysis
NDT Bobath (Brunnström and Mauritz, 1993)	Manipulation of key points, Supporting techniques: traction, placing, tapping	–Alignment of muscle tone, –Restoration of proprioceptive sensation –Development of normal movement patterns
Johnstone (Johnstone, 1982)	Use of pneumatic cuff to the appropriate muscle groups	–Alignment of muscle tone, –Restoration of proprioceptive sensation, –Development of normal movement patterns
Rood (Brunnström and Mauritz, 1993)	Exteroceptive stimulation (using feedback: receptor-analyzer-effector)	–Neuromuscular reeducation through successive patterns of movement (mobility, stability, mobility imposed on stability) –Facilitation of motor response
Proprioceptive neuromuscular facilitation (Lustig et al., 1992)	The performance of motor patterns in the diagonal planes Supporting techniques: rotation, elongation, rhythmic stabilization	–Activation of the nervous system receptors and movement, –Obtaining the highest possible functional level –The use of the phenomenon of plasticity of the nervous system
Vojta (Brunnström and Mauritz, 1993)	Increased, time-space part of the central nervous system stimulation reception area with a reflex exercises (for use in children)	–Reflex activation of innate motor patterns

Table 2 The most commonly used patterns of electrical stimulation of peripheral nerves after injury

Injury type	Method	Stimulation parameters	Time of treatment start	Duration of treatment	Effects of therapy
Unilateral peroneal nerve crush injury (Aydin et al., 2006)	Power frequency electric field	Frequency 50 Hz, 10 kV/m	At the moment of lesion	21 days postoperatively	– ↓ Nerve cross-sectional area – ↓ Total regenerating axon area – ↑ Myelin debris area – ↓ Rates of Wallerian degeneration – ↓ Recovery of TSR
Long standing quadriceps denervation (Kern et al., 2005)	Intensive electrical stimulation	Phase I: 200 mA, 120 ms, 2 Hz Phase II: 40 ms, 20 Hz (2 s ON, 2 s OFF)	18 months after injury	26 months, 15 min/d, 5 d/week	– ↑ Muscle cross-sectional area – ↑ Regeneration of myofibers
Unilateral transection of the sciatic nerve (Negredo et al., 2004)	Polyimide regenerative electrodes (RE)	±1.0 V	At the moment of lesion	2 months	–RE is not an obstacle for the re-growth of sensory fibers –RE partially hinders fiber regeneration from motoneurons

Table 3 The use of magnetic fields in the treatment of peripheral nerve injuries

Magnetic field	Field strength (mT)	Frequency (Hz)	Duration of exposure (hour)	Frequency of exposure during the day	Duration of the study (days)	Results
PEMF	1	20	1	1	10	↓ Atrophy of muscle fibers (Yoichi et al., 2006)
PEMF	0.3	2	4	1	6	↑ 22% of the axial regeneration of nerve fibers (Sisken et al., 1993)
PEMF	0.6	2	4	1	4	↑ Nerve fiber length (Kanje et al., 1991)
	3	2	0.25	1	2	
PEMF	0.2	50	4	1	6	No effect on the regeneration of nerve fibers (Rusovan and Kanje, 1992)
CEMF	0.2	–	4	1	6	↑ Nerve fiber length (Rusovan and Kanje, 1992)
PEMF	0.4	50	4	1	3	↑ Nerve fiber length (Rusovan and Kanje, 1992)
CEMF	0.4	–	4	1	6	↑ The greatest length of nerve fibers - 21% (Rusovan and Kanje, 1992)
PEMF	0.1	250, 500, 1,000	–	–	3, 4, or 6	↑ Significant length of nerve fibers (the greatest = 24% at 1,000 Hz) (Rusovan et al., 1992)
	0.1	> 2,000 and < 50	–	–	3, 4, or 6	No effect on the regeneration of nerve fibers (Rusovan et al., 1992)

PEMF: Pulsed electromagnetic field; CEMF: continuous electromagnetic field.

fiber membranes or Gore-Tex™ with laser beams. This aids in assembling the ends of the nerve, and affects the speed and efficiency of the regeneration process. Application of laser irradiation (Ga-As laser) in the site of the anastomosis inhibits the degeneration process, accelerate remyelination, and nerve function recovery (Bae et al., 2004; Miloro et al., 2002).

One of the major complications of peripheral nerve damage is the formation of a neuroma at the end of the proximal stump. Biostimulation with CO_2 or Neodymium-Yag lasers reduces the risk of its formation, or at least alleviates severe pain caused by the formation of a neuroma (Kuzbari et al., 1996).

Therapeutic use of ultrasounds (US) gave some promising results in animal experiment (Raso et al., 2005). However, before this technique might be implemented in human therapy, it is indispensable to precisely elucidate the influence of the US on nervous tissue, as well as to determine the most effective and safest therapeutic protocol that could be used in clinical practice.

In general, there is a lack of randomized, good quality data representing results of clinical application of particular therapeutic methods using standardized dozymetry. Current research encompassing treatment and intervention in nerve injuries is limited, consisting mostly of descriptive and exploratory studies. Especially nonsurgical or post-surgical physical therapy is poorly understood by many physical therapists and even physicians, many clinicians fail to recognize that such nerves often need considerable time to regenerate.

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