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Original Article

Effect of ultrasonic wave therapy on nerve conduction parameters in patients with carpal tunnel syndrome

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Abstract
Background. The carpal tunnel syndrome (CTS) is one of the most frequent peripheral neuropathies of the upper extremities, caused by increasing pressure in the carpal tunnel or a decrease in its volume, which leads to compression and disturbances in blood supply to the median nerve. Some authors consider the CTS an occupational disease. This condition significantly affects quality of life, limiting manual dexterity and the ability to perform daily activities. Thus, social needs dictate finding effective treatment methods for CTS. **Objective.** The principal aim of this study was to assess the effects of ultrasound wave on the severity of CTS symptoms. **Material and methods.** The study enrolled 20 patients (90% of whom were women) with carpal tunnel syndrome and a control group of 20 healthy volunteers aged 20-40 years. The patients were qualified for physical therapy on the basis of a medical diagnosis and results of electrophysiological testing which included an assessment of nerve conduction in the median nerve. The mean age in the study group was 58.2 ± 10.2 years, and 85% of the patients were physical workers. 55% of the patients had mononeuropathy in their right limb, 45% - in the left one. In the study group, 95% of the patients were right-handed. The patients underwent 10 ultrasound therapy procedures with the following parameters: ultrasonic wave frequency – 3MHz, power 0.8 – 1.2W/cm^2, duration of treatment – 3 minutes. The procedures were performed using the dynamic technique. **Results and conclusions.** Ultrasound wave therapy shortens the terminal latency as well as increases the amplitude of the sensory potential in patients with CTS. On the other hand, in the control group, there is an increase in the terminal latency in the motor fibers, an increase in amplitude and a reduction in the conduction velocity in the motor and sensory fibers of the median nerve.
Keywords: CTS, physiotherapy, ultrasound wave.

Introduction

Carpal tunnel syndrome (CTS) is one of the most common peripheral mononeuropathies of the upper limb. It is caused by increased pressure or decreased volume of the carpal tunnel, which leads to compression and disturbed blood supply to the median nerve (Zwolińska et al., 2007; Ciechanowska et al., 2017b). One of the first symptoms of carpal tunnel syndrome is painful paraesthesia, followed by weakness and atrophy of the muscles innervated by the median nerve. The syndrome has a significant impact on the quality of life; affected patients tend to have difficulty performing even the simplest everyday activities. This is why it is extremely important to identify effective methods of treating this syndrome and thus improve the quality of life of these patients (Litak et al., 2016, Litak et al., 2017).

CTS is a disorder of diverse aetiology. According to some authors, it is mainly caused by a mechanical factor accompanied by ischaemia and secondary damage to nerve fibres. Other researchers make a distinction between local and systemic causes of CTS. There are also cases of idiopathic origin, associated with inflammation in the sheaths of the tendons in the carpal tunnel. A factor that contributes to the development of idiopathic CTS is narrowing of the carpal tunnel resulting from overexertion of the carpal joint due to the nature of a person's occupation. Local compression that is present in this neuropathy can result from repeated movements, continuous twisting motions or many years of work. These types of work include, without limitation: typing on a computer or a typewriter, playing the piano, assembling electronics, working a cash register, as well as hairdressing, knitting, gardening, sewing, and working as a mechanic. Such repetitive movements with associated bending of the wrist and fingers can also be seen when playing some musical instruments and propping oneself on one's hands with dorsiflected wrists when riding a bicycle or walking with crutches. Researchers believe another contributing factor might be vibrations transferred into the hands when using equipment such as drills, pneumatic hammers, grinders or saws (Ciechanowska et al., 2017a; Tsimerakiset al., 2020). Authors have also observed that some congenital syndromes can predispose to the development of CTS, i.e. a congenitally narrow carpal tunnel canal, muscular disorders, persistent median artery and hereditary neuropathy with a hypersensitivity to pressure. Other conditions that can contribute to the development of the

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syndrome include injuries such as forearm bone fractures, especially Colles fractures, as well as sprains and dislocations of the carpal joint (Bagatur, et al., 2002; Nakasato, 2002).

An important part of CTS rehabilitation is using physical medicine procedures. The efficacy of the methods used depends on many factors that must be considered when planning and managing physical therapy (Kwolek, Zwolińska, 2009; Ciechanowska, 2015). Treatment outcomes in patients with CTS are often unsatisfactory, which means that there is still an unmet need for effective rehabilitationmodalities. The importance of physical therapy in the treatment of carpal tunnel syndrome is undebatable both as a maintenance and a post-operative intervention. The main purpose of rehabilitation treatment is primarily to alleviate pain and improve the functionality of the hand, since it translates directly to the patient's everyday existence. Physical therapy also facilitates the regeneration of the nerve – both its motor and sensory fibres – and improves the passive movement range of the affected limb, preventing muscle and joint contractures. The most commonly used physical therapy methods are: ultrasonic wave therapy, electrotherapy, low-level laser therapy and magnetic field treatment. Besides physical therapy procedures, also recommended are nerve and tendon gliding exercises, manual therapy and whirlpool massage (Kocjan 2016, Genova et al., 2020).

Physiotherapeutic procedures used in the treatment of CTS include mainly: laser therapy, ultrasound, iontophoresis, TENS, pulsed lowfrequency magnetic field, vortex bath of the upper limb, neuromobilization, PIR, passive stretching of the forearm flexors by the therapist with the patient’s relaxed muscles, deepening of passive flexion in the wrist, stretching and massage (Wilk 2015, Wolny et al. 2016, Wolny et al. 2017).

In the literature, we can also find studies describing unconventional methods of treatment, incl. acupuncture or the use of traditional cupping (Blumer 2017, Bujara 2020) which improve the sensory and motor function of the median nerve. However, there are still too few studies in the literature that would provide conclusive evidence that alternative treatment brings very good and lasting results. On the other hand, the latest reports of the American Academy of Orthopedic Surgeons suggest low effectiveness and efficiency of non-operative methods of treating patients with CKD (Elsami 2019, Dakowicz et al. 2018). However, there are many scientific reports indicating the beneficial effects of physiotherapeutic treatments, which improve the functional activity of the limb, its strength and reduce pain in patients. One of the most frequently used therapies in the field of physical medicine is sonotherapy.

Ultrasonic wave is a treatment modality whereby heat generated in the tissues causes a number of secondary effects, including analgesic, anti-inflammatory and hyperaemic one. Ultrasound therapy is a form of thermal therapy aimed at transferring thermal energy through the skin or generating it inside the body. One of the major effects of ultrasonic waves on the body is also the mechanical action of ultrasound therapy. The wave penetrates the tissues and by causing molecules to vibrate, it provides an effect referred to as micro-massage. This phenomenon is used, among other things, to soften tissues in order to relieve spasm, increase mobility which is limited by the adhering tissues, as well as break down calcium deposits and promote scarring (Oztas et al., 1998).

Objectives

The objective of this research was to evaluate the impact of ultrasonic wave on nerve conduction parameters of the median nerve in patients with carpal tunnel syndrome.

Material and methods

Participants. The study enrolled 20 patients (90% of whom were women) with carpal tunnel syndrome and a control group of 20 healthy volunteers aged 20-40 years.

Measurement procedure. Electroneurography was performed with the Neurosoft apparatus using the Neuro - MEP program in constant temperature conditions. Final latency, M wave amplitude and nerve conduction velocity in motor fibers as well as conduction velocity and amplitude of the sensory potential of the median nerve were assessed in the study. The patients were qualified for physical therapy on the basis of a medical diagnosis and results of electrophysiological testing which included an assessment of nerve conduction in the median nerve. The mean age in the study group was 58.2 ± 10.2 years, and 85% of the patients were physical workers. 55% of the patients had mononeuropathy in their right limb, 45% - in the left one. In the study group, 95% of the patients were right-handed. The patients underwent 10 ultrasound therapy procedures with the following parameters: ultrasonic wave frequency – 3MHz, power 0.8 – 1.2W/cm^2, duration of treatment – 3 minutes. The procedures were performed using the dynamic technique.

Statistical analysis. Statistical analysis was performed with software Statistica 10.0. To test normality of distribution of the analysed variables, the Shapiro-Wilk test was used. Student’s T-test and ANOVA analysis were used for variables that met the criteria for parametric tests, while the remaining data were analysed with the use of Friedman's test and a suitable post-hoc test. Similarly, the Mann-Whitney U test was used for comparisons of variability of two independent parameters versus the group that did not meet the criteria for parametric tests.

Results

Nerve conduction values in motor and sensory fibres of the median nerve in the study group and the control group before and after ultrasonic wave therapy are summarised in **Table 1** and **Table 2.**

Table 1. Nerve conductivity parameters of CTS patients and the controls, determined prior to and after ultrasound

Parameter	UD					
	STUDY n=20		GROUP	CONTROLS n=20		
	prior to UD (01)	after UD (02)	p	prior ro UD (01)	after UD (02)	p
R_Lat (ms)	5,2±1,4	4,7±1,2	**P<0,01**	3,4±0,3	3,6±0,3	**P<0,01**
R_A (mV)	6,1±3,0	6,9±3,0	0,1353	10,2±2,4	11,8±2,5	**P<0,01**
R_V (m/s)	57,4±6,8	58,8±7,2	0,5502	59,5±5,1	58,5±4,8	0,2684
C_A (µV)	1,4±1,2	2,5±1,6	**0,0157**	11,3±3,1	12,6±3,9	**0,0186**
C_V (m/s)	39,3±7,6	43,9±8,3	**P<0,01**	60,7±4,0	60,3±4,9	0,3225

R_Lat – latency in motor fibers
R_A – amplitude in motor fibers
R_V – conduction velocity in motor fibers
C_A – sensory potential amplitude
C_V – conduction velocity in sensory fibers

Table 2. Post-treatment changes in the nerve conductivity parameters of CTS patients and the controls.

Parameter	UD		
	STUDY GROUP n=20	CONTROLS n=20	p
ΔR_Lat (ms)	- 0,5±0,8	0,1±0,2	**P<0,01**
ΔR_A (mV)	0,8±1,9	1,6±2,4	0,2541
ΔR_V (m/s)	1,3±7,6	- 1,1±3,9	0,2138
ΔC_A (µV)	1,0±1,8	1,2±2,1	0,7761
ΔC_V (m/s)	4,5±4,9	- 0,4±3,0	**P<0,01**

After ultrasonic wave treatment in the study group, latency in motor fibres of the median nerve was reduced (R_Lat p<0.01, **Fig. 1**), while the amplitude (C_A p=0.0157) and conduction velocity increased in both the motor and sensory fibres (C_V p<0.01, **Fig. 2**). In the control group, there was a visible prolongation of terminal latency in motor fibres (R_Lat p<0.01), an increase in amplitude (C_A p=0.0186), and a decrease in conduction velocity of the motor and sensory fibres of the median nerve.

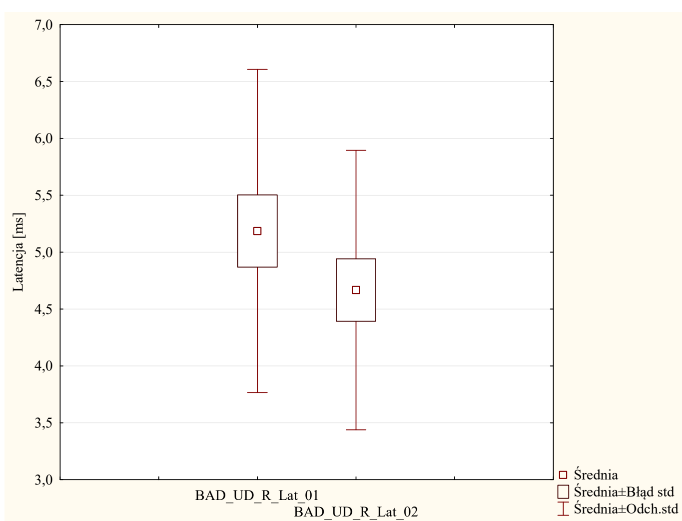

Fig. 1. Terminal latency in the motor fibers of CTS patients, determined prior to and after ultrasound

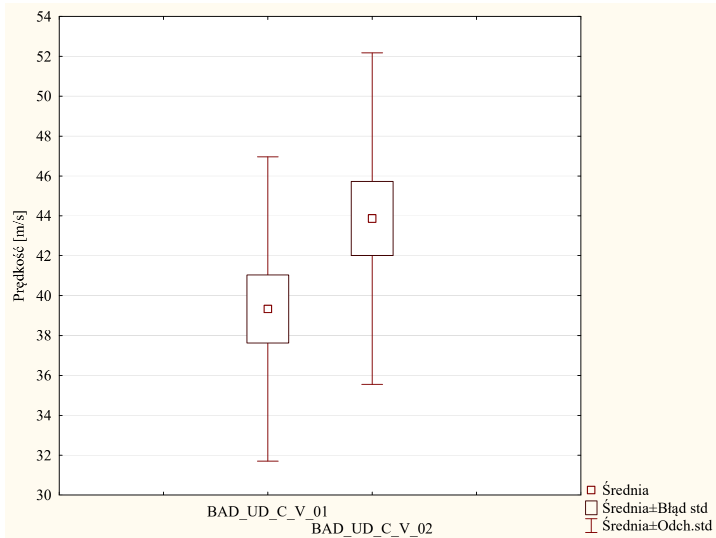

Fig. 2. Conduction velocity in the sensory fibers of CTS patients, determined prior to and after ultrasound

Unlike the control group, patients with CTS had shorter terminal latency (ΔR_Lat $p<0.01$) after completing all the treatment sessions. Also observed was an increase in conduction velocity in sensory fibres of the median nerve (ΔC_V $p<0.01$). However, there were no significant differences in amplitude in motor and sensory fibres, nor in conduction velocity in motor fibres either in the study group or the control group.

Discussion

Ultrasonic waves provide therapeutic effects characteristic of heat, such as increased elasticity of collagen fibres, hyperaemia of the tissues, changes in nerve conduction, and analgesia (Hsin-Pai et al., 2013). Studies of the effects of ultrasound therapy on the peripheral nervous system have been conducted both in animal models and in humans – including healthy volunteers and patients with nervous system dysfunctions such as a diagnosis of carpal tunnel syndrome.

Since this kind of therapy belongs to treatment courses that generate heat in tissues, conduction velocity of peripheral nerves is expected to increase. Researchers at Collegium Medicum UMK in Bydgoszcz (Ciechanowska-Mendyk et al., 2011) have tested the effects of ultrasonic waves on nerve conduction in the median nerve of healthy people. The studies revealed that ultrasound therapy with a continuous wave with a power of 1 W/cm^2 and a frequency of 3MHz had a significant impact on terminal latency and the amplitude of the motor potential. A statistically significant increase of terminal latency and amplitude was observed, while conduction velocity decreased. A similar effect was reported in a study on the sensory potential. When using an impulse wave with a power of 1 W/cm^2, frequency of 3MHz and a 50% duty cycle, studies have failed to establish a statistically significant impact of the ultrasonic wave on the parameters of response amplitude from both motor and sensory fibres of the median nerve. On the other hand, a tendency has been observed towards a longer terminal latency and slower conduction velocity in motor and sensory fibres of the median nerve. Hence, the authors conclude that the efficacy of ultrasound therapy might not follow from the thermal effect, but the mechanical function of the ultrasound wave. Similar results have been observed in this study. In the control group, where ultrasound therapy was administered to healthy volunteers, there was a slight prolongation of terminal latency by 0.1 ms ($p<0.01$), as well as a decrease in conduction velocity in both motor (-1.1 m/s) and sensory fibres (-0,4 m/s, $p<0.01$) of the median nerve. It can therefore be concluded that the efficacy of ultrasound therapy and its impact on a healthy nerve is debatable, to say the least. This opinion is shared by Draper (Draper, 2007), who wrote about biophysical principles of ultrasound, in particular about its thermal effects. A different point of view is expressed by Johns (Johns L.D. et al. 2003), who attributed the therapeutic effect of ultrasound to thermal doses beginning from 0.3 W/cm^2. Hong (Hong,1991) studied the impact of different doses of ultrasonic waves on nerve conduction in patients with polyneuropathy. Doses of 0.5, 1.0 and 1.5 W/cm^2 were used on the front of the leg, along the peroneal nerve. Nerve conduction testing was done before, during and after ultrasonic wave therapy. The therapy caused a significant decrease in CAMP amplitude (for doses 1.0 and 1.5 W/cm^2, $p<0.05$) and an increase in terminal latency (for doses 1.0 and 1.5 W/cm^2, $p<0.05$). All nerve conduction parameters were shown to go back to pre-procedure values even 5 minutes afterwards. The significant impact of the ultrasonic wave on terminal latency has also been established by Perrin (Perrin, 1985) in a study aimed at determining the biophysical effects of continuous wave and pulsed wave ultrasound with a frequency of 1 and 3 MHz on nerve conduction in the median nerve. The study involved the participation of 15 healthy subjects. Nerve conduction parameters were measured before and after ultrasound treatment.

Cosentino (Cosentino et al., 1983) also studied the effect of different ultrasound wave doses on the median nerve. Sensory and motor nerve conduction was assessed after ultrasound therapy treatment courses using doses of 0.5 W/cm^2, 1 W/cm^2, and 1.5 W/cm^2. The authors discovered no statistically significant differences in nerve conduction parameters between the three groups. Oztas (Oztaset al., 1998) evaluated the efficacy of ultrasonic wave in patients with carpal tunnel syndrome. The patients were divided into three groups and received treatment with the doses of 1.5, 0.8 and 0.1 W/cm^2, respectively. The ultrasound was applied to the carpal tunnel area for 5 minutes; the treatments was performed every day except weekends for two weeks. Electroneurographic tests were carried out before and after the course of treatment. The analysis of the results obtained revealed a drop in conduction velocity of the motor nerve in two groups, but the differences were not statistically significant. In our study in CTS patients undergoing ultrasonic wave therapy, electroneurographic measurements showed that terminal latency was shortened by 0.5 ms ($p<0,01$), while the amplitude increased and so did conduction velocity in motor (1.3 m/s) and sensory (4.5 m/s, $p<0.01$) fibres of the median nerve.

It is, however, necessary to continue this research in order to establish how long this effect can last and possibly when patient-reported symptoms return or intensify in patients with CTS (Ciechanowska, 2013).

It should be emphasised that discontinuation of treatment in the case of people with CTS inevitably leads to irreversible damage of the median nerve and causes significant limb disfunctions. As a result, the patient may be permanently disabled and thus be unable to perform his professional duties (Kiwerska-Jagodzińska et al., 2001, Kmieciak et al., 2007). Research conducted in Poland and abroad regarding the impact of different physical impulses on the peripheral nervous system, including on carpal tunnel syndrome and other nerve compression syndromes, are still subject to much debate and require further observation and analysis.

Conclusions

The effectiveness of sonotherapy can be demonstrated by the mechanical effect of the ultrasound wave, which causes the increased pressure in the carpal tunnel to relax and the compressed median nerve to be released. The research proved that the reduction of pressure in the wrist canal caused by the mechanical action of the ultrasound wave has a decisive influence on the reduction of the final latency and the increase in the amplitude of the sensory potential in patients with CTS. The applied physiotherapeutic treatment showed an increase in the conduction velocity in the study group, which leads to a reduction in pain and an improvement in superficial sensation in the wrist area. The described changes in nerve conduction parameters also improve the functional state of the limb in patients with CTS.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study. All subjects of the institutional survey gave consent for anonymized data to be used for publication purposes.

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