Micro-pulse Stimulation

Marie Nedvedova, Milan Chmelar, Ivo Provaznik and Zdenek Reznicek

Abstract This paper deals with a new electrotherapeutic method for use in physiatric treatment. The micro-pulse stimulation is based on the combination of three electrotherapeutic methods: burst therapy, high-voltage pulsed current therapy, and microelectrostimulation. Micro-pulse stimulation is special for its unusual configuration of pulse parameters; high-voltage electric pulses are safely used as a result of a cumulative effect of the subthreshold monophasic pulses with a very short duration. This combination of parameters should connect the advantages of used methods. This includes an analgesic effect without any obvious adaptation of the stimulated tissue and making the tissue penetration easier. As the micro-pulse stimulation was designed especially for the treatment of swelling and pain in animal therapy, the device is small, portable, battery-operated and easy to use.

Keywords Burst therapy · High-voltage pulsed current therapy · Micro-pulse stimulation · Subthreshold stimulation

1 Introduction

The role of electrotherapy and electrostimulation is quite extraordinary in comparison to other methods of physical therapy. Their usage is limited not only for rehabilitation as a standard application but it has a great significance for the

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diagnostics, treatment and for research. Instead of the classical electrostimulation methods with single pulses of the specified frequency, shape, duration and period, there were found new alternatives that seem to be more effective in some applications. We can mention various types of modulation (amplitude, frequency) or burst therapy [1–3]. Micro-pulse stimulation was designed as a type of electrotherapy which could combine the advantages of the three chosen methods, especially microelectro stimulation, high-voltage pulsed current and burst therapy.

MicroElectroStimulation (MES) is also known as MicrocurrentElectroTherapy (MET) or MicroElectroNeuroStimulation (MENS). The prefix "micro" is common for all modalities because of using extremely low values of electric current about the millionth of ampere. Similar microampere values can be measured both at humans and some animals because their bodies form the natural electromagnetic field [4]. That is why it can be also called Biostimulation. The current values for the MES are subthreshold and thousand times lower than for the Transcutaneous Electrical NeuroStimulation (TENS). There are described positive therapeutic effects of MES on all sorts of pain, it moderates inflammation and edema, evolves the moving potential, muscular strength and relaxation [5]. Furthermore, MES supports significantly the wound healing [6–8], treatment of patients with the diabetes mellitus, hypertension and chronic wounds [9], obesity reduction [10], reduction of inflammatory induced by ultraviolet irradiation [11]. But not all the studies are so optimistic [12]. Study [13] revealed that MES could enhance apoptosis, the adverse effect to the tissue healing. Despite it, MES is highly promising for very problematic tendon regeneration at horses.

High-Voltage Pulsed Current (HVPC) uses the pulsed current with relatively low intensity, short duration (usually 10–30 μs), but voltage much higher than it is usual in electrotherapy (up to 500 V) [1]. The device for HVPC must work in the regime of the constant voltage. The level of the stimulation intensity is usually threshold up to motor suprathreshold. The pulse frequency can be constant or modulated and it directly influences the myorelaxation and analgesic effect. HVPC causes vasodilatation supporting the edema reduction [14], tissue regeneration and wound healing, especially decubitis ulcers [15], venous crural ulceration [16] and diabetic foot ulcers [17].

The Burst Therapy is based on the theory of the subthreshold pulses summation [18]. The pulses of the burst come separately and gradually summate so that each of them brings the membrane closer to its threshold. The membrane threshold is reached when the pulse summation culminates in the sufficient depolarization leading to the formation of an action potential (AP). The total number of APs agrees with the number of bursts [19]. The summation effect requires that each pulse in the burst follows so fast that there is not enough time for the membrane relaxation after the subthreshold polarization. The depolarization caused by the summation of the subthreshold pulses is expected at the higher kilohertz frequencies [20]. According to available sources, the burst therapy has good results in the prevention of venous thrombosis at the orthopaedic patients and postoperative cases [21] and in treatment of the various types of arrhythmia, such as ventricular and atrial tachycardia [22]. Further, it has a noticeable analgesic effect and the great advantage lies in no obvious adaptation of the tissues that is a common problem in all classic electrotherapeutic methods [1].

2 Device Working Principles

The goal was to construct the device combining the principles of high-voltage pulsed current, microelectrostimulation and burst therapy. Using voltage up to 1000 V makes the tissue penetration easier, but the high voltage must be compensated by the setting of other parameters to maximally keep the safety [23]:

(a) An appropriate choice of the pulse duration and working frequency prevents inadequate load.
(b) The electric circuit is closed between the concentric electrodes that precisely define the application area and prevent the current flow through other area.
(c) The battery power itself disables the secondary circuit formation (e.g. through the heart); this is a prevention of the electric current injury.

Microstimulator generates high-voltage pulses (about hundreds volts) with a very short duration (microseconds). Considering the easier construction and therapeutic advantages, an accumulation of subthreshold pulses was used for formation of the final pulse with required characteristics. Several pulses are arranged in the burst coming with the working frequency many times lower than the repeating frequency of each pulse. The advantage of high carrier pulse frequency is an easier penetration into the body, again. In this case, the envelope of the whole burst can be understood as one therapeutic pulse in classic electrotherapy. This agrees also with the fact that the threshold voltage drops with the cumulative number of the pulses in one series (with the burst width) [19]. The burst can be formed by both biphasic and monophasic pulses. The experiments using the bursts in Functional ElectroStimulation advert to the better efficacy of the monophasic rectangular pulses for the lower threshold of the AP initiation [24]. In our case, we have used just the monophasic pulses.

3 Design of the Microstimulator

The design of the Microstimulator is protected by the patent no. 304960 published in the Bulletin No. 5/2015 by the Industrial Property Office of Czech Republic. An exact electrotechnical scheme of the device exceeds the range of this article; however, Fig. 1 shows a principal scheme of the Microstimulator.

The circuit consists of three 555 precision timers (marked A, B, C), two NAND gates (D, E), switch (F) and pulse transformer (G). Generator C generates the pulses with high frequency (about 100 kHz) that are arranged into the bursts with the

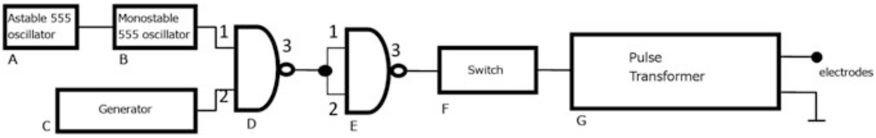

Fig. 1 Principal scheme of microstimulator

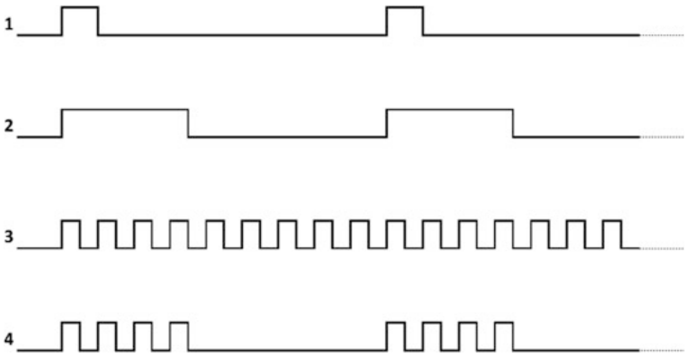

Fig. 2 Time diagram of the output signals from the astable 555 oscillator (*1*), monostable 555 oscillator (*2*), generator (*3*), and switch (*4*)

stimulation parameters (frequency and burst width) adjusted by the astable and monostable 555 oscillators. NAND gate D separates the burst of pulses according to the required parameters of stimulation. NAND gate E inverts the output of gate D. Switch F manages transfer of the pulses to the primary winding of pulse transformer G.

The time relation of the important output signals is demonstrated in Fig. 2. Signal no. 3 represents function of the generator C. Signal no. 1 demonstrates the output of the astable 555 oscillator A that activates the monostable 555 oscillator B to generation of the pulse with the required width, see signal no. 2. This way, the equivalent number of pulses is defined and transferred from the generator, see signal no. 4.

A final realization of the Microstimulator and measured signal output are shown in Fig. 3. Microstimulator was designed in such a way the device is suitable for human and also for animal electrotherapy, particularly for horses that were chosen as the target objects for the following micro-pulse stimulation effect testing [25].

The device is small, portable, battery-operated and easy to use. The horse is a typical skittish and restless animal with an unpredictable behaviour which could be the reason of some dangerous situations not only for themselves but also for their close surroundings. Therefore, a compliance with some requirements and conditions was in an effort to keep considering the safety and preventive precaution when an unpredictable situation occurs. Microstimulator is classified as a medical electrical device and strict requirements for the design and function must be kept

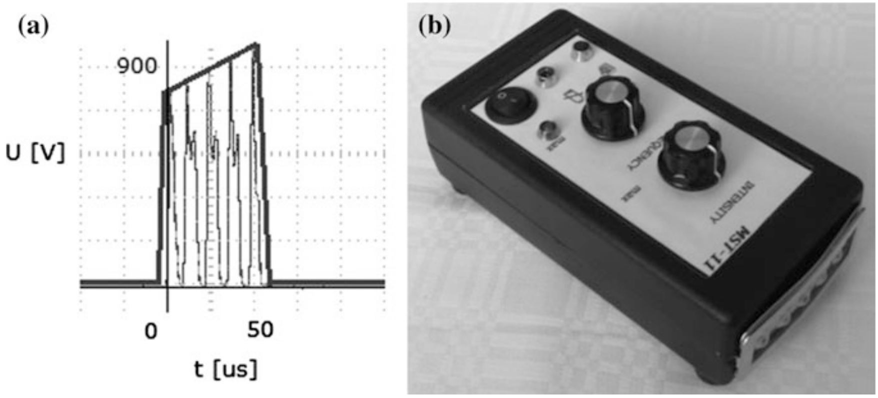

Fig. 3 The Microstimulator (**b**) and the shape of pulses on Microstimulator's output (**a**) [23]. The recording was made during the real measurement using oscilloscope. The therapeutic pulse is marked clearly as an envelope of the burst

according to the relevant standards. The device was tested by the accredited testing laboratory and got CE mark certification.

Two preliminary studies of the micro-pulse stimulation effects were carried out. First experiment explored the physiological effect of the micro-pulse stimulation in an objective way [25]. Two miniature thermodynamic sensors were applied on the skin of two limbs when one of them was stimulated and the other one was just considered as a reference. This type of sensor is able to detect even minor thermal changes. Based on the results, an increased thermal activity was detected in the stimulated limb compared to the reference. This should be caused by an increased blood perfusion and warming-up of the stimulated area. Parallel to this experiment, a pilot experiment investigating the therapeutic effect on the edema reduction of the horses' limbs was carried out with the promising result [26]. The edema treatment relates to the blood circulation support closely, therefore the results of both studies complement each other.

4 Conclusion

This paper presents a design of the Microstimulator; a new electrotherapeutic device for a micro-pulse stimulation. Its therapeutic effect is based on the connecting of the selected electrotherapeutic methods to take the therapeutic advantages of all of them; using high-voltage pulses coming with high frequency makes tissue penetration easier and causes no adaptation of stimulated tissue. The device is designed especially for animal electrotherapy, therefore there must be kept both the strict safety instructions and preventive precautions to manage also unpredictable reaction of animal. The therapeutic effects of the micro-pulse stimulation were successfully tested on horses.

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