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Design of TENS Electrodes Using Different Production Techniques

Original Scientific Article

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Abstract

Transcutaneous electrical nerve stimulation (TENS) treatment has been widely used in physical therapy to relieve different types of pain. The TENS therapy is a non-invasive method applied with general types of electrodes, i.e. carbon and self-adhesive hydrogel electrodes. These electrodes are reusable, which might cause hygiene problems. In this study, two different types of textile TENS electrodes were designed and produced with the sewing and embroidering technique using conductive yarn. Afterwards, the resistance values of produced electrodes were measured and compared to conventional carbon and self-adhesive hydrogel electrodes. Furthermore, the designed electrodes were connected to a commercially available TENS device and current transmission from the electrodes was tested on subjects.

Keywords: textile electrodes, conductive yarn, TENS electrodes, electrode design

1 Introduction

Transcutaneous electrical nerve stimulation (TENS) treatment has been widely used in physical therapy to relieve different types of pain, e.g. labour pain, low back pain, clinical pain, neuropathic pain, post-operative pain, pain in knee osteoarthritis, pain in musculoskeletal disorders [1–7]. The TENS treatment is extensively preferred since it is safe, more inexpensive and has no side effects when compared with the drug therapy [8].

The effect of the TENS treatment in pain relief is provided by two basic neurophysiological mechanisms which aim to close the spinal door. These mechanisms are gate-control theory and opioid system, the most commonly used one being the gate-control theory (Figure 1). This theory is related to the large A-beta, and small C- and A-delta peripheral fibres. The gate-control theory is thought to be responsible for the activities of inhibitor interneurons located in substantia gelatinosa of the spinal cord dorsal horn.

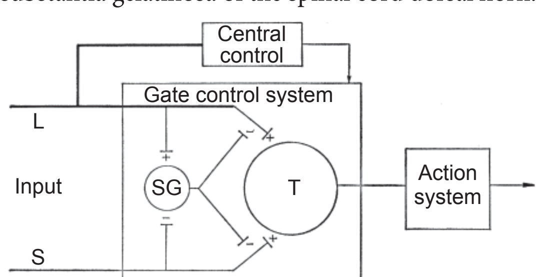

Figure 1: Schematic diagram of gate control theory of pain mechanisms [10]; L – the large-diameter fibres; S – small-diameter fibres; SG – substantia gelatinosa; T – transmission cells; + excitation, – inhibition

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After the activation of inhibitor interneurons, the gate closes and the data related to pain sensation cannot reach the level of consciousness [9].

The TENS therapy is a non-invasive method applied with two different types of electrodes, i.e. general electrodes and special electrodes [9]. General electrodes are made from different materials and are the most commonly used type. These electrodes are reusable and are therefore called a non-sterile type of electrodes. In the market, metal plates covered with a fabric, carbon electrodes and self-adhesive hydrogel electrodes are known as general electrodes [11]. Special electrodes are developed for use after the surgery. They represent a disposable and sterile type of electrodes [9].

Despite these electrode types still being used in some cases, the preferred electrode for the TENS treatment is the self-adhesive hydrogel electrode [9]. This electrode has a gel membrane on one side, so it does not need a conductive gel application prior to its use. Furthermore, it can be used more than once [11]. These features can first be seen as advantages of self-adhesive hydrogel electrodes but can also cause hygiene problems.

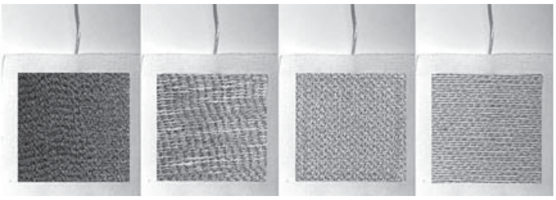
In this study, two different types of TENS electrodes were designed with different production methods (sewing and embroidery), using conductive yarn. Their resistance values were compared to commercially available carbon electrodes and self-adhesive hydrogel electrodes. Moreover, the designed electrodes were connected to a commercially available TENS device and the current transmission from the electrodes was tested on subjects.

2 Experimental

Two different textile electrodes were produced with two different production techniques (sewing and embroidery) and compared with standard TENS electrodes with regard to their resistance values. A 100% polyester woven fabric weighing 245 g/m^2 was used as the electrode base fabric. 369 denier silver coated yarn was used for the production of electrodes. The resistance value of this yarn is about 110 Ω/m. The textile electrodes were made of the same raw materials.

At first, the fabric was cut into 6 × 6 cm pieces and 5 × 5 cm areas of these fabric pieces were sewn/embroidered with conductive yarn. For the sewing, a JUKI DDL-5550N-3 sewing machine was used and the stitch density on the sewing machine was set to 3 stitches/cm. Conductive yarn was preferred as both the needle and bobbin thread to achieve better conductivity. For the production of embroidered electrodes, a Tajima TFGN series embroidery machine was used. The 15-cm long transmission cables were embedded in both sewn and embroidered electrodes to connect the measurement and TENS device.

In the production phase of textile electrodes, two different patterns were designed and produced with sewing/embroidering techniques (Figure 2). These patterns were overlapping patterns (type 1) and not overlapping patterns (type 2). In the overlapping patterns (type 1), the stitch lines intersected each other at many points on the electrode surface and generated very short conductor lines. In the patterns without overlapping, the pattern formation formed a long continuous conductor line on the electrode surface. In the pattern type 2, the main stitch lines were parallel to each other, thus generating a series connection.



A1 A2 B1 B2

Figure 2: Electrode samples, i.e. (A1) sewn electrode – overlapping pattern, (A2) sewn electrode – not overlapping pattern, (B1) embroidered electrode – overlapping pattern, (B2) embroidered electrode – not overlapping pattern

Different types of patterns with different levels of stitch densities were investigated in a previous study, where it was established that high stitch density is more appropriate due to the homogeneity of resistance values [12]. Here, high stitch density means there are no spaces between the stitch lines. Based on these findings, the electrodes in this study were produced only with high stitch density.

Six electrode pairs with the sewing technique and six electrode pairs with the embroidering technique were produced and used for the measurements. The conventional electrodes for a comparison with the newly designed textile electrodes were chosen as six self-adhesive hydrogel electrodes (5 × 5 cm in dimension) and six carbon electrodes (5 × 4.5 cm in dimension).

The resistance values of electrodes were measured with a Thurlby 1503 Digital Multimeter at 20 points. Furthermore, the current transmission from the electrodes was tested subjectively. For this test, the sample electrodes were connected to a TENS device and placed with Velcros on the subjects' forearm.

3 Results

The measured resistance values were evaluated with IBM SPSS Statistics 22 software and are presented in Table 1. Here, type 1 means the patterns with overlapping and type 2 the patterns without the overlapping for textile electrodes.

As seen in Table 1, the average resistance to electrical current is very low for textile electrodes. The average resistance of textile electrodes was about 0.6 ohms. When conventional electrodes were examined, it was seen that this value increased to 445 ohms at carbon electrodes and 153 ohms at self-adhesive hydrogel electrodes.

Another important issue to be considered is the resistance distribution on the electrode surface. Inhomogeneous resistance distribution causes a different amount of current flow to the skin, which is not desired. Regions with lower resistance on the electrode surface will transmit higher current to the skin. If the current flow to the skin increases in particular regions, it causes pain and skin burns.

In Figure 3, the resistance distribution on textile electrode surfaces can be seen. The sewn and embroidered electrodes gave similar results in terms of resistance values. However, the pattern type determined the resistance distribution. It can clearly be seen that the electrodes with the overlapping pattern (type 1) had a homogeneous resistance distribution.

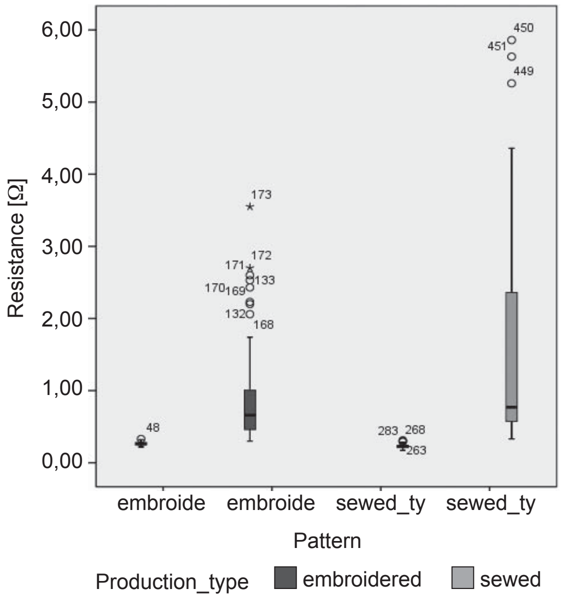


Figure 3: Resistance distributions of designed textile electrodes

Due to the high resistance values of conventional electrodes, the resistance distribution of these electrodes was examined separately to provide clear results (Figure 4). Figure 4 shows that the self-adhesive hydrogel electrodes have similar resistance values on their surfaces, whereas the carbon electrodes have a wide range of resistance values due to the inhomogeneity.

The same as for the resistance measurements from electrodes, subjective tests were conducted on four subjects to evaluate current transmission. Subjective test results show that all subjects received electrical stimulation from all textile electrode samples.

Table 1: Measured resistance values of electrodes

Electrodes	N	Minimum resistance [Ω]	Maximum resistance [Ω]	Mean resistance [Ω]	Std. deviation [Ω]	Variance [%]
embroidered_type1	120	0.22	0.33	0.2679	0.02315	0.001
embroidered_type2	120	0.30	3.55	0.8529	0.57753	0.334
sewn_type1	120	0.17	0.31	0.2265	0.02758	0.001
sewn_type2	120	0.33	5.86	1.3983	1.22005	1.489
carbon	120	150.00	860.00	445.2500	157.34650	24757.920
self-adhesive	120	90.00	210.00	153.5833	27.49472	755.959

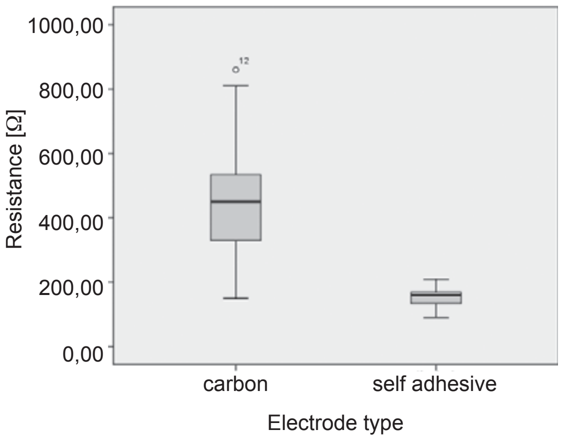


Figure 4: Resistance distributions of conventional electrodes

4 Discussion

In this study, textile electrodes were designed and produced using two different production techniques. When newly designed textile electrodes were investigated in accordance with the production technique, it is seen that both the sewn and embroidered electrodes have similar electrical behaviour and conduct electrical current from the electrode to the skin. However, their appearance differs. In the embroidering technique, the production is machine-intensive; thus, there is less possibility of pattern failures coming from the production. In contrast, the sewing production process is more related to the operator's talent; hence, the production may not always be in the same standard, meaning that there is a high possibility for pattern differences. In consequence, the embroidering technique is recommended.

The resistance measurement results pointed out that the proposed textile electrodes provide smaller resistance values than the conventional electrodes. Since there is no need to use a conductive gel, conditions that are more hygienic can be obtained. Furthermore, the designed and produced electrodes are reusable. In this case, it is required that the electrodes be washable.

The results show that the resistance distribution of conventional electrodes is much higher than the textile electrodes. When using carbon electrodes, a conductive gel needed to be used for current conduction. In the case of self-adhesive hydrogel electrodes, this gel membrane is already on the electrode surface. In addition to the current transmission function, these conductive gels also help obtain a smooth surface on the skin and prevent inhomogeneous current distributions. However, standard deviation values of resistance show that the homogeneity of resistance values on the electrode surface is better at textile electrodes. These results and the tests on subjects with textile electrodes show that there is no need for gel usage to transmit the current. It is concluded that due to low resistance values and homogeneous resistance distribution on the electrode surface, current can be transmitted without using a conductive gel. In this way, hygiene problems associated with the use of gel could be removed.

Another important issue to be considered is the pattern type. The average resistance values for the sewn and embroidered electrodes are almost the same but their standard deviations differ. For different pattern types, different connection types and conductor lines in different lengths occur. The distribution difference of resistance values on electrodes can be explained by these differences.

5 Conclusion

In this study, textile electrodes were designed and produced using two different production techniques and the developed electrodes were compared to conventional TENS electrodes. The results show that standard deviation values for textile electrodes are smaller. This means that the resistance distribution is more homogeneous on the electrode. Moreover, textile electrodes have fairly lower resistance values than the carbon and self-adhesive electrodes. Lower resistance means that there is no need for a conductive gel, which was also confirmed by the results of performed subjective tests. The produced electrodes can conduct the electrical current from the electrode surface to the skin without using any coupling medium, not causing any pain or discomfort. This also leads to conditions that are more hygienic. Additionally, textile electrodes are washable. In this sense, textile electrodes seem more favourable.

During the comparison of textile electrodes, it was noticed that the pattern type causes differences. The overlapping patterns (type 1) generate a more homogeneous resistance distribution. These results are similar for both production techniques. However, the embroidered electrodes have a smoother surface appearance.

Based on the study results, the embroidered electrodes with the pattern type 1 can be proposed for TENS electrodes. In further studies, it is planned to integrate the developed electrodes into a garment component for pain relief. In addition, the washing tests of textile electrodes are going to be performed, and the performance of electrodes is going to be obtained and evaluated.

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