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Proceeding Paper

Wearable Preventive Pressure Ulcer System Using Embroidered Textile Electrodes †

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Abstract: Approximately 80 percent of patients with limited mobility experience pressure ulcers (PU). Electrical stimulation (ES) is an effective therapeutic approach for PU prevention and treatment. This study reports the design of a custom-made adaptive garment as a wearable preventive pressure ulcer system by using embroidered textile electrodes to induce electrical stimulation for the gluteal muscles. Eight electrodes were embroidered using a satin stitch on a 100% cotton knitted fabric, only the bobbin was loaded with conductive threads, and cotton/polyester thread was used for the top stitch. An ES-induced protocol of 1:4 s on–off was applied for 3 min, with 17 min rest periods.

Keywords: pressure ulcers; electrical stimulation; textile electrode; embroidery; conductive thread; adaptive apparel; patient garment

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1. Introduction

Pressure ulcers (PU) are a frequent complication encountered by doctors and patients and are a burden in terms of pain and treatment. They are localized tissue damage areas arising from excess pressure, shear, or friction [1]. They are common in patients with limited activity and mobility, such as paralyzed patients, surgical patients, and spinal cord injury (SCI) patients. Prevention has focused on support surfaces of cushions and mattresses to redistribute the interface pressure, but these passive methods do not address intrinsic risk factors such as tissue ischemia and decreased circulation [2].

On the other hand, electrical stimulation is an effective therapeutic prevention approach that decreases the interface pressure and activates the muscles to potentially reduce PU development [3]. The mechanism underlying the reduction is based on (i) changing blood flow that increases tissue oxygenation, which helps muscles to survive [4]; (ii) a decrease in tissue pressure caused by gluteal muscle contractions with the redistribution of pressure from ischial tuberosities (ITs) to the direction of the knees [5]; (iii) improved local circulation of muscle and skin and improved paralyzed muscle strength and mass [6]; (iv) muscle hypertrophy [7].

Patient clothing can contribute to objectification with a focus on disease and symptoms, and by doing so also contributes to the optimal treatment of ill health [8]. Therefore, textile-based electrodes can be ideal in medical high-tech applications; they are comfortable in a non-intrusive way and create a natural harmony with the patient's body. Textile electrodes, also known as textrodes, can be integrated into a garment using conventional textile production techniques by weaving, knitting, embroidery, etc. [9]. They are commonly used for biosignal monitoring as well as electrostimulation. However, embroidery offers advantageous characteristics of dimensional stability, rapid prototyping, better skin–electrode contact, good reproducibility, and flexibility with electrode designs [10].

2. Materials and Methods

2.1. Wearable Preventive Pressure Ulcer System Design

The electrical stimulation garment was designed to be adaptive and meet immobile patients' specific demands; it was designed with a seamless center crotch construction, to avoid bulky seams and to allow the electrode connection traces to run smoothly and freely without any interruption, as shown in Figure 1. The conductive thread, from Kitronik's (Kitronik's Electro-Fashion®, Nottingham, United Kingdom), was used for embroidering the electrodes using a conventional embroidery machine (JUKI LZ-271). A preliminary sample was made with one layer of 100% cotton knitted stretch fabric; the top stitch and bobbin were both loaded with conductive thread. A satin stitch was embroidered to a (4.5 × 4.5) filling electrode (12 stitches per cm/1 cm wide) and the connection trace was also created with a stain stitch (10 stitches per cm/4 mm wide), as shown in Figure 2. Unfortunately, running the machine was not easy with this specific thread; it was cut and jammed several times. As a result, the final electrodes were embroidered by simply filling the bobbin with the conductive thread.

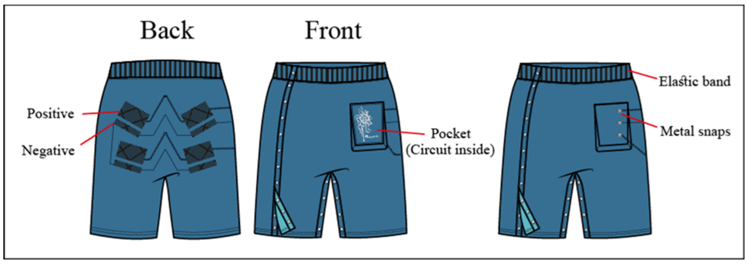


Figure 1. Illustration of the proposed electrical stimulation shorts.

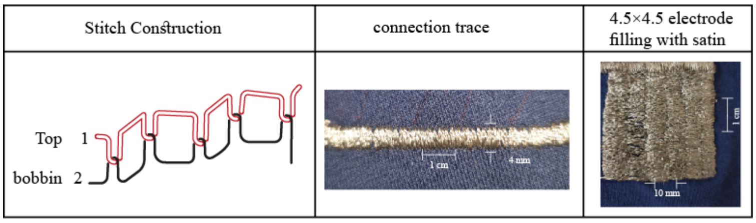


Figure 2. Close-up of stitched samples using a conventional embroidery machine.

The study conducted a custom-made circuit with an electrostimulation protocol of 1:4 s on–off that lasted for 3 min, with a 17 min rest period, as reported by Smit et al. [5] and shown in Figure 3; the gluteal muscle was activated for 1 s, and resting for 4 s resulted in better pressure relief and comfort without marked muscle fatigue. Parameters for the prevention of pressure ulcers that the circuit induced were set according to previous studies: frequency >20–50 Hz, amplitude 20–50 mA, and pulse width 64 to 600 µs [3].

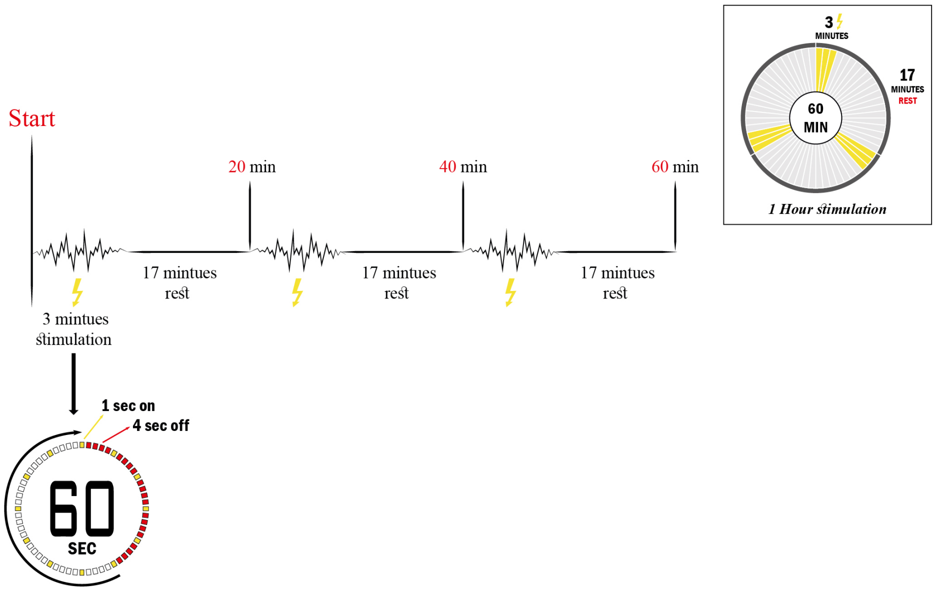


Figure 3. The 1 h stimulation protocol of 1:4 s on–off for 3 min, and 17 min rest [5].

2.2. Electrical Resistance of the Electrodes

Experiments were applied for the manufactured electrodes to evaluate their electrical performance. An AVO multimeter was used to measure the surface resistance of each electrode before and after washing, followed by the Martindale abrasion test. The change in resistance was compared with the number of washing cycles (up to 15 times with home laundry washing, interval of 5 times between each measurement, resulting in a total of 3 measurements), and the surface resistance was measured between cycles. The Martindale machine was used for up to 3000 rubs against raw wool, testing abrasion for the electrode test. Two prototypes were provided, one for each test.

3. Results and Discussion

3.1. Wearable Preventive Pressure Ulcer System Design

Regarding the embroidery process, the conductive thread showed superior performance when used on the bottom bobbin only of both the embroidery and sewing machine. Therefore, eight electrodes (4 identical positives 4 × 8 cm, 4 identical negatives 2 × 8 cm) were embroidered using a satin stitch, only the bobbin was loaded with conductive threads, and cotton/polyester thread was used for the top stitch. On the opposite side of the fabric, electrical traces were sewn with a lock stitch using the sewing machine; these traces were connected to metal snaps to be connected to the circuit, as shown in Figure 4.

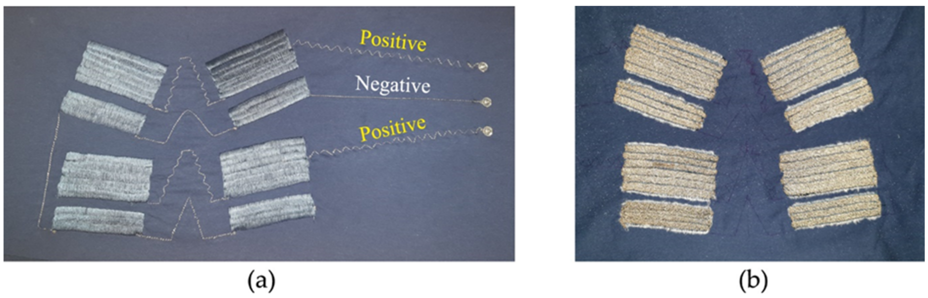
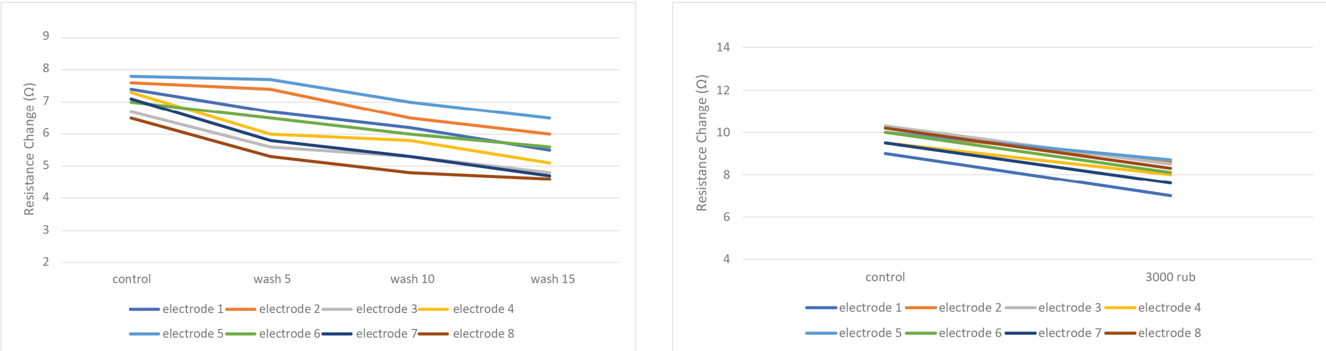


Figure 4. (**a**) The face of the fabric with cotton/poly; (**b**) the back of the fabric with the conductive thread.

3.2. Electrical Resistance of the Electrodes

The resistance of the embroidered textile electrodes was measured for each electrode and it was slightly changed after each washing cycle, as shown in Figure 5a. Similarly, the variation in resistance was almost stable before and after abrasion, as indicated in Figure 5b, with no observed visible damage in appearance. This indicated that the electrodes had the demanded flexibility and bendability for the purpose of electricity performance.



(**a**) (**b**)

Figure 5. (**a**) Resistance value with washing cycle; (**b**) resistance change after abrasion.

4. Conclusions

Wearable technologies could offer promising tools as an alternative to physical therapy. This study designed a custom-made adaptive garment as a wearable preventive pressure ulcer system by using embroidered textile electrodes to induce electrical stimulation for the gluteal muscles. We developed a cable-free system that is comfortable, lightweight, flexible, easy to use for both caregiver staff and self-dressing patients, cost-effective for mass production and less time-consuming, and fit for purpose with ensured contact of the electrodes placed on the skin. Moreover, it eliminates the problems of conventional Ag/AgCl electrodes, which cause skin irritation and feelings of discomfort, cannot be washed, and are not hygienic.

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Conflicts of Interest: The authors declare no conflict of interest.

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