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A comparison of conductive textile-based and silver/silver chloride gel electrodes in exercise electrocardiogram recordings

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Abstract

Background: The goal of this study was to compare disposable silver/silver chloride and reusable conductive textile-based electrodes in electrocardiogram (ECG) signal monitoring during physical activity.

Materials and Methods: The reusable electrodes were produced using thin silver-plated nylon 117/17 2-ply conductive thread (Statex Productions & Vertriebs GmbH, Bremen, Germany) sewed with a sewing machine on a chest belt. The disposable and reusable electrodes were compared in vivo according to ECG signal baseline drift, broadband electrode noise properties, and influence of electrode area to ECG signal morphology and frequency content. Twelve volunteers were included in this study.

Results: Electroconductive textile-based ECG electrodes produce significantly more noise in a very low frequency band (0-0.67 Hz) and not significantly less of broadband noise (0-250 Hz) than disposable silver/silver chloride electrodes. Decreasing area of textile electrodes decreases fidelity of registered ECG signals at low frequencies.

Conclusion: Textile electrodes having adequate area can be used in more applications than only R-R interval monitoring.

Keywords: ECG electrode; Exercise monitoring; Baseline wander; Broadband noise

Introduction

New materials and enabling technologies, electroconductive textiles, miniaturized electronics, new microelectromechanical devices, and signal processing methods, are looking for biomedical applications. One such application is smart, textile-based, wearable, biomedical systems for ambulatory monitoring of electrocardiogram (ECG) signals in personalized medicine, wellness, and sports.[1] This application boosted much of scientific interest in the previous and the last decade, but still, not many practical products were developed until now. Many problems were left to be solved,[2] and one of them is unobtrusive, long-term, wearable, and accurate monitoring of ECG signals in various everyday life conditions. Although many factors are important for quality improvement in ECG signal recording and interpretation,[3] biopotential-capturing electrodes are the key problem in everyday-life, long-term monitoring applications.

Today, disposable silver/silver chloride (Ag/AgCl)–gelled electrodes are most commonly used for biopotential and ECG signal measurements. The standard Ag/AgCl electrodes have limited storage time (<1 year) and are not reusable; it means that if applied to the body, they are suitable for 1 time use only. They can only be used for a few days because they suffer from drying. The drying leads to increase of electrode impedance, which generates noise and other artifacts in the measured signal. Furthermore, the gel can cause skin irritations and support bacterial growth. Skin preparation by abrasion of outermost cells from the surface of the skin is used to decrease motion artifact in stress testing at clinics. This measure is not suitable for long-term monitoring because the cells of stratum corneum (outermost layer of the skin) regenerate from deeper skin layers during 24 hours, and the abrasion effect disappears; also, skin abrasion is unpleasant and, if used together with gels, significantly increases the risk of skin irritation. Finally, there is also the personal inconvenience of not being able to shower or bathe while using the electrodes. Because of these limitations, researchers have tried to discover alternatives to

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Ag/AgCl electrodes that would still meet the requirements of the long-term monitoring of ECG signals.[4,5]

Several investigations have published work regarding the measurement of ECG signals using electroconductive textile-based electrodes. Xu et al[1] gives a comprehensive overview of this subject. The Association for the Advancement of Medical Instrumentation (AAMI) has proposed and American National Standard Institute (ANSI) has approved a standard "Disposable ECG Electrodes - ANSI/AAMI EC12:2000/(R)2005", which contains performance requirements and test methods for pregelled, disposable ECG electrodes; however, no standard for dry electrodes such as electroconductive textile electrode testing exists. Different studies investigated various properties of electroconductive textile electrodes in application for biopotential measurements: skin-electrode impedance,[6,8] skin-electrode impedance changes in time,[5,7,8] subjective (visual) comparison of recorded ECG signals with electrodes under investigation and reference electrodes,[6,8-10] biocompatibility and skin response,[6] correlation analysis,[7] signal-to-noise ratio,[7] detectability of ECG waves,[4] power spectral density,[9,10] and electrode electrical properties evaluation.[5]

Many challenges are associated with in vivo comparison of biopotential electrodes. ECG signal morphology strongly depends on electrode placement location. Thus, even a short distance between electrodes under comparison generates differences in recorded biopotentials. These differences can be mistakenly attributed to differences between electrode types. The body motion caused by noises in ECG signals depends on the physical activity type; thus, to compare the electrodes with several subjects, the physical activity type must be standardized. Intersubject variability in body forms and skin properties add to the problem.

The purpose of the present study was to compare in vivo disposable Ag/AgCl and reusable conductive textile-based electrodes for ECG monitoring during rest and exercises. Our approach is to compare ECG signals that were registered at the same place of the body but asynchronously and to compare noises generated by both electrode types. Physical activity type was standardized by using an elliptical trainer with rotation measurements. In addition, aspects of decreasing textile electrode area were investigated.

Materials and methods

Electrodes under comparison

In this study, electroconductive textile electrodes are compared to conventional Ag/AgCl electrodes with respect to their ability to perform in measurement of ECG signals. Two types of electrodes were compared: disposable oval-shaped Ag/AgCl (Fiab SpA, Vicchio Firenze, Italy) electrodes and thin silver-plated nylon 117/17 2-ply conductive thread (Statex, Productions & Vertriebs GmbH, Bremen, Germany)–based electrodes sewed with a sewing machine on a chest belt (Fig. 1A). The conductive thread–based electrodes were selected because initial trials with conductive fabric electrodes (eg, commercial Polar WearLink+ chest belt, Polar Electro Oy, Kempele, Finland) showed worse quality of acquired ECG signals. That was also observed by Pola and Vanhala.[4] Our experience shows that conductive thread–based electrodes are more resistant to motion-caused artifacts than conductive fabric electrodes because the conductive threads of the former electrodes imprint into the skin and are less prone to slipping during motion.

The chest belt has an elastic insertion that keeps the belt in stable position during the exercise. The length of the belt was adjusted with hook and loop strap to adhere the body of each experiment participant. The skin was not specially prepared for the measurements; however, textile electrodes were slightly moistened with a thin spray of water to reduce the transition time needed for electrodes to establish contact with the skin. The electrodes were placed on the thorax 25 cm apart from each other (Fig. 1B) and were allowed to adapt for 5 minutes before the start of the experiment.

Subjects and data collection protocol

Eight healthy male and 4 healthy female volunteers participated in the study, with an age range from 21 to 40 years and a body mass index (BMI) of 17.8 to 30.1 kg/m^2. Data of the subjects are summarized in Table 1. A letter in brackets indicates whether the participant is a male (M) or a female (F).

The morphology of ECG cycles depends on the location of measurements (Fig. 1B); thus, it is not fair to compare the recorded ECG signals directly. To overcome this problem, 2

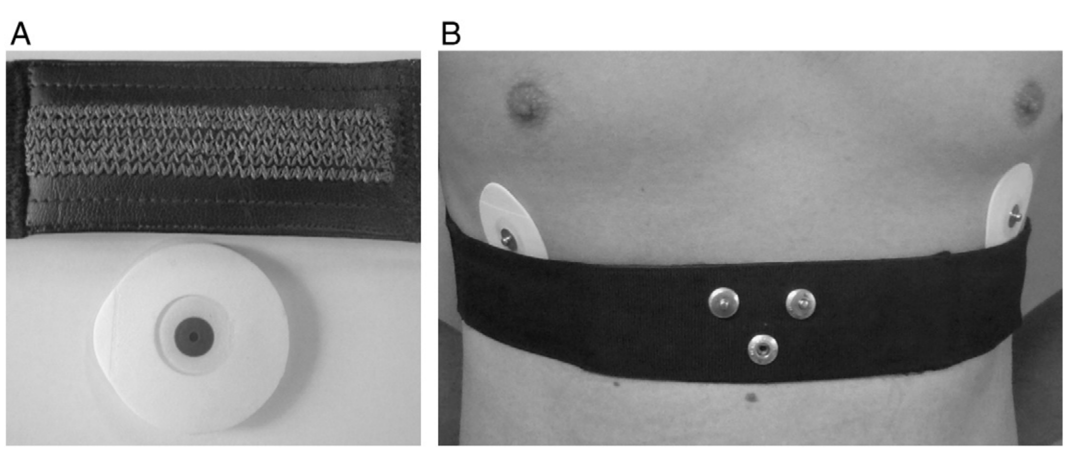

Fig. 1. A, Two types of electrodes: textile electrode (top) and Ag/AgCl electrode (bottom). B, Electrode attachment to the body for synchronous ECG recording.