EVALUATION OF GRAPHENE ELECTRODE IN CAPTURING THE CHANGES OF MUSCLE ACTIVITY DURING FLEXION AND EXTENSION

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

This study was performed to determine and evaluate the performance of the graphene-based electromyogram sensor as an alternative to silver/silver chloride (Ag/AgCl) electrode for data acquisition. The main advantage of using graphene electrode is that it is more comfortable for sensitive skin, reusable and convenient. An experiment to capture the changes of biceps brachii and triceps brachii during flexion and extension was conducted to test the performance of graphene electrode over Ag/AgCl electrode. The test measurement was carried out using a portable surface electromyography (sEMG). MATLAB software was used to process the acquired signals and analysed its signal-to-noise ratio (SNR) of both electrodes. In addition, SPSS software was used to determine the significant different of both electrodes and to measure the agreement level of both acquired data by using Bland Altman (BA) analysis plot. At 1kg load, graphene electrode's SNR = 27.081 dB from biceps brachii, SNR = 23.709 dB from triceps brachii. Meanwhile, Ag/AgCl electrode get SNR = 24.932 dB from biceps brachii, SNR = 24.348 dB from triceps brachii. Besides that, it shows agreement of 100 % between both electrode's performance when using BA analysis. This shows that both electrodes are statistically comparable in terms of SNR, and the graphene electrode are able to perceive 100 % of Ag/AgCl electrode to the standard reading of EMG. The solution presented in this study could be a key factor for continuous innovation to increase user comfort and save earth from electrode waste.

ABSTRAK

Kertas kerja ini dilakukan untuk mengkaji prestasi penderia elektromiogram berasaskan graphene sebagai alternatif setanding kepada elektrod Ag/AgCl menggunakan sistem pemerolehan data. Kelebihan utama elektrod graphene adalah selesa, boleh diguna semula dan mudah. Untuk menguji prestasi elektrod ini, eksperimen menangkap perubahan otot biceps brachii dan otot triceps brachii semasa aktiviti fleksi dan lanjutan dijalankan. Ujian ini dijalankan dengan menggunakan SPSS dan MATLAB untuk mengkaji nisbah isyarat-ke-bunyi (SNR) dan plot Bland Altman bagi kedua-dua elektrod. Kaedah terperinci untuk pengukuran ujian sEMG dan pemprosesan isyarat juga akan dibincangkan. Pada beban 1kg, elektrod graphene mendapat SNR=27.08 dB daripada bicep brachii, SNR=23.709 dB daripada tricep brachii. Sementara itu, elektrod Ag/AgCl mendapat SNR=24.932 dB daripada bisep brachii, SNR=24.348 dB daripada tricep brachii. Selain itu, ia menunjukkan persetujuan 100 % antara prestasi kedua-dua elektrod apabila menggunakan analisis Bland Altman. Ini menunjukkan bahawa kedua-dua elektrod adalah setanding secara statistik dari segi SNR, dan elektrod graphene dapat 100 % persamaan dengan elektrod Ag/AgCl dalam bacaan standard EMG.

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LIST OF ABBREVIATIONS

sEMG	-	Surface electromyography
SNR	-	Signal-noise ratio
Ag/AgCl	-	Silver/silver chloride
PDMS	-	Polydimethylsiloxane
EMG	-	Electromyography
TD	-	Time-domain
FD	-	Frequency domain
IIR	-	Infinite Impulse Response
SD	-	Standard deviation
BA Plot	-	Bland Altman Plot
LOA	-	Limits of agreement
rGO	-	reduced Graphene Oxide
ECG	-	Electrocardiogram
DIFF	-	Mean difference
UCL	-	Upper confident limit
LCL	-	Lower confident limit
DC	-	Direct current
fL	-	Low cutoff frequency
fH	-	High cutoff frequency
fN	-	Notch frequency
fS	-	Sampling frequency

LIST OF SYMBOLS

SNR_{Diff}	-	Difference of both electrodes
SNR_{μ}	-	Mean of both electrodes

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Electromyography (EMG) is a tool used to measure the electrical activity of skeletal muscles. It has a wide range of uses, such as in the human machine interaction, clinical and biomedical applications. Clinical applications of EMG as an evaluation tool, include the kinesiology, assessment of low back pain, neuromuscular diseases and disorders of motor control (Reaz *et al.*, 2006). Besides that, EMG also very useful for the therapy of prosthetic patients (Mulas *et al.*, 2005; Al-Jumaily and Olivares, 2009). Meanwhile, human machine interface applications refers to any device that controlled by human such as drones and robots (Kiguchi and Hayashi, 2012; Jeong *et al.*, 2013; Rangwani and Park, 2019).

To track the EMG signals, biopotential electrodes are used, which can be divided into invasive (using wire/needle electrode) and non-invasive (sensor and electrode are placed on the body surface). For the invasive electrodes, the intracellular and extracellular fluids act as an electrolytic medium to enhance the signal acquisition. Normally, this implementation needs guidance of a trained professional, because the requiring of electrodes to insert into the skin. Meanwhile, for the non-invasive electrodes, electrolytic gel might or might not be applied. Those that can be used without the electrolytic gel, were classified as dry contact electrodes (Alizadeh-Meghrazi *et al.*, 2021). Basically, the non-invasive method, measured by surface EMG signals (sEMG), is preferred due to minimal discomfort and risk of infection (Chowdhury *et al.*, 2013; Nazmi *et al.*, 2016). Figure 1.1 shows the implementation of surface EMG (invasive method) and needle EMG (non-invasive method).

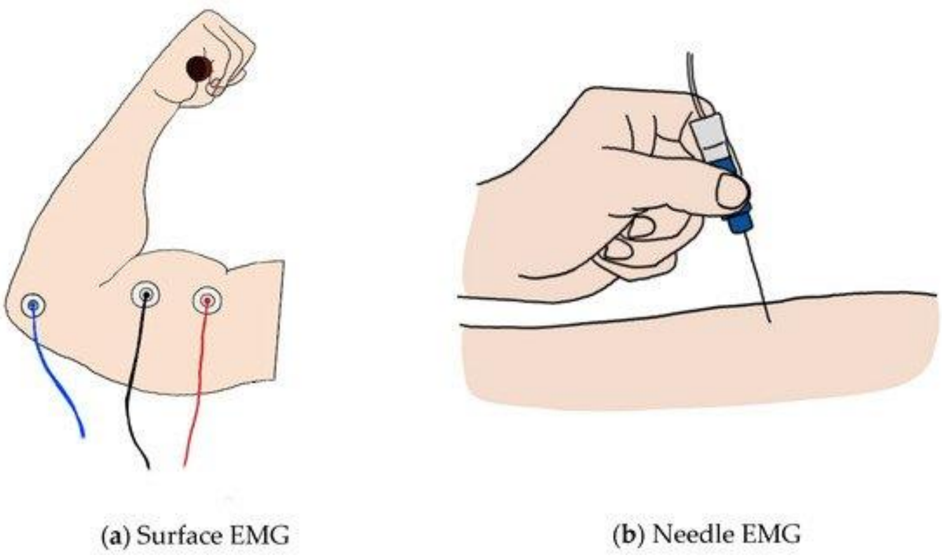

Figure 1.1 (a) Surface EMG (sEMG) (b) Needle EMG (Nam, 2021)

Commercially available biopotential electrodes for sEMG are the wet electrode (gel) using silver/silver chloride (Ag/AgCl). These electrodes needed an electrolyte gel to improve the electrical conductivity by hydrating the skin layer and causing additional impedance (Alizadeh-Meghrazi *et al.*, 2021). Besides that, the gel will dry up during long-term acquisitions, letting the recorded signal to be distorted and degrade the performance of the electrodes (Rodrigues *et al.*, 2020). Because of these issues, researchers have been working hard to find alternatives for the standard Ag/AgCl electrode. While due to the limits of traditional gelled electrodes, dry electrodes have been widely explored to overcome the fundamental constraint of Ag/AgCl electrodes.

Figure 1.2 shows the skin-electrode interface, which is modelled by an electrical circuit model that consists of resistive and capacitive components (Button, 2015). From the figure, we can observe that, compared to the Ag/AgCl wet electrode, the dry electrode has lower skin-electrode contact impedance by eliminate the electrolyte gel.

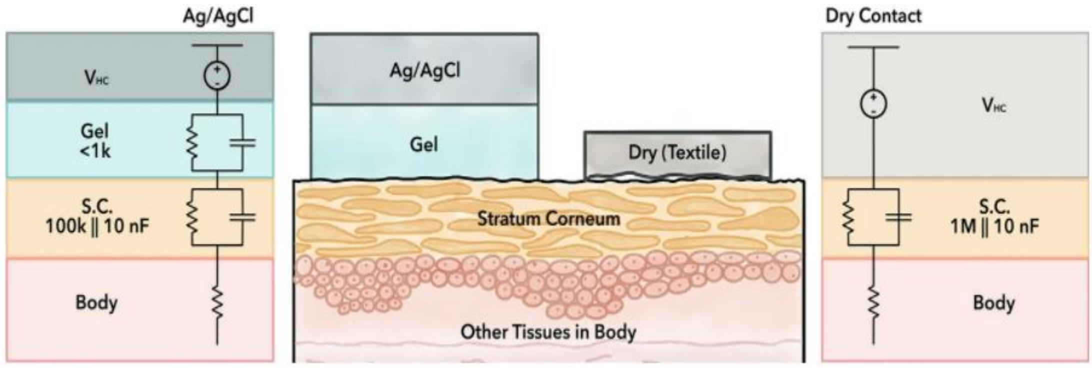

Figure 1.2 Skin-electrode interface of Ag/AgCl gel electrode vs dry textile electrode (Button, 2015)

Furthermore, dry electrodes based on flexible materials are introduced for a better wearing comfortable besides reducing motion artifacts when analysing the long-term sEMG (Rodrigues *et al.*, 2020). Commonly used conductive materials to fabricate dry and flexible electrodes include carbon allotropes (e.g. carbon nanotubes and graphene (Hu *et al.*, 2010)), parylene (Peng *et al.*, 2016), polydimethylsiloxane (PDMS) (Chen *et al.*, 2018), and textile (e.g. woven cotton, nylon, and polyester) (Saleh *et al.*, 2020). They can also be fabricated on textiles using different techniques such as printing techniques (e.g. ink-jet) (Newman *et al.*, 1992; Safaryan *et al.*, 2017) and screen printing (Chlaihawi *et al.*, 2018; Lamas-Ardisana *et al.*, 2018), dip coating (Tang and Yan, 2017; Ankhili *et al.*, 2018; Zhao *et al.*, 2018), and physical vapor deposition (Lacerda Silva *et al.*, 2013; Pawlak *et al.*, 2017). However, the advantages of graphene have been extensively studied due to its consistent electrical performance, strong chemical stability and innate flexibility (Xu *et al.*, 2011). The potential of these materials to replace the current Ag/AgCl electrode can be reflected by several studies with a relevant frequency range of 1-500 Hz, getting up to 97 % of correlation values between these two electrodes (Ozturk and Yapici, 2019).

This study is to compare the performance of a reduced Graphene Oxide (rGO)-coated cotton dry electrodes which is still under development, with commercially available wet Ag/AgCl electrodes. This dry electrode using soaking technique and diminish with ascorbic acid to coat the graphene oxide (GO) with the cotton fabric. Then, the electrode was combined with a fabricated cotton fabric, one cotton fabric with thin layer of wax and four coating of blank cotton as shown in Figure 1.3 (Saleh *et al.*, 2020). The details are mentioned in previous study (Saleh S.M et al., 2018).

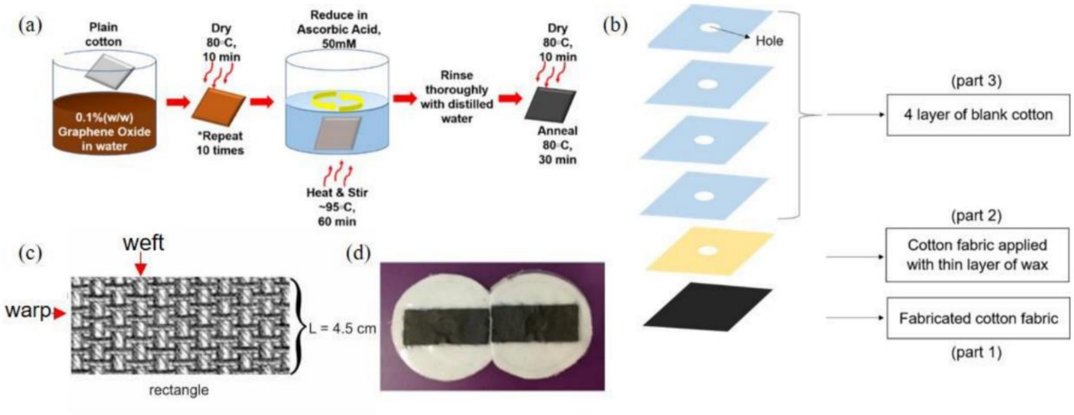

Figure 1.3 Fabrication of electrode (Saleh *et al.*, 2020)

1.2 Problem Statement

The performance of commercially available Ag/AgCl wet electrodes will degrade due to the gel's drying up during long-term acquisitions (Tronstad *et al.*, 2010; Ying *et al.*, 2020). Besides that, the gel also provides additional impedance to the skin-electrode interface (Button, 2015) and might have skin irritation over time (Ask *et al.*, 1979). Therefore, evolution of textile-based dry electrode could lead to a promising result which is comparable than existing commercial electrode.

For the development of rGO coated cotton dry electrode, the longevity and thermal test, measurement of skin-electrode impedance and SNR were done and compared with Ag/AgCl electrode from previous study (Saleh *et al.*, 2020). However, there were not sufficient data for the SNR measurement. Only one female subject was tested for the ECG measurement at the position of left chest mimic Einthoven Triangle lead III (Saleh *et al.*, 2020). It is hard to show if both electrodes are comparable in term of SNR. Moreover, the previous work used graphene electrode for ECG measurement without considering EMG effect to the study of acquired ECG.

1.3 Research Objectives

The objectives of this thesis are described below:

(a) To evaluate the performance of graphene electrodes and Ag/AgCl electrodes.

(b) To analyse performance of both electrodes using SNR and Bland Altman plot.

1.4 Scope of study

This thesis focuses on evaluate the performance of available graphene dry electrode to the commercially available wet Ag/AgCl electrode. An experiment to study the activity of biceps brachii and triceps brachii during flexion and concentration was conducted. Then, filtering was applied to the raw data and SNR of both electrodes were analyzed and reviewed using Bland Altman analysis.

1.5 Significance of Study

The thesis presents a significant contribute to the development of rGO coated cotton dry electrode. The performance of the dry electrode was analyzed and compared to the gold standard Ag/AgCl wet electrode. Since the data involves multiple participants, the fulfilment of the dry electrode was examined in details before marketing.

1.6 Outline of Thesis

This thesis is divided into five chapters; the first chapter is the introduction to the thesis. This chapter describes the study's background, problem statements, research objective and scope of study. These sub-topics will give the reader a basic overview about the thesis. In Chapter 2, some literature review of theoretical background is presented. General characteristic of the sEMG signals, and overview of the upper limbs experiment were introduced. Besides that, SNR of dry electrodes from previous studies and statistical analysis that used in the experiment were also presented. Furthermore, Chapter 3 represents the approach of the experiment and gives a guideline framework with methods, or techniques used in the thesis' implementation. This study continues with Chapter 4, which explains the details of the experiment and discuss about the results. Finally, Chapter 5 provides summaries of the conclusions in accordance with the objectives of the research, as well as some recommendations for further work of the thesis.

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