Fabrication and Evaluation of Graphene in Three-Lead System

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Abstract: Because of its superlative properties, graphene is used in different applications today. The electrical properties of this carbon allotrope have led the study to apply it on medical electrodes which record the activity of the heart. Furthermore, different quantities of graphene such as its quality, size, and shape were assumed to yield an effect on the data acquisition. Through the process of exfoliation, graphene was extracted in polyethylene vinyl-acetate (EVA) which acts as the substrate. The samples were analyzed through a set of tests which verify the presence of the carbon material, followed by its adhesion to medical electrodes using a transducer gel. Following the three-lead ECG system, the electrodes were then compared by the following factors: Vrms difference for signal amplification, signal-to-noise ratio (SNR) for sensitivity, and peak time interval for signal verification. Vrms difference results for commercial graphene electrodes show that amplification has occurred on the P wave, while the T and R waves have been dependent on the position of the conductors. Increased sensitivity was exhibited for all the ECG waves as indicated by the commercial graphene's SNR values at 21.837 dB for P waves, 21.824 dB for R waves, and 20.902 dB for T waves. Considering their SNR values, the size and shape of graphene has barely affected the performance of the data acquisition. Despite these promising results, the fabrication of this to the electrodes still needs enhancement.

Key Words: ECG; Graphene; Vrms Difference; SNR; Peak Time Interval

1. INTRODUCTION

1.1. Electrodes Throughout the Years

Previous checking of heart condition uses the Holter Monitor System where five (5) electrodes were directly patched to one's body and connected to a tape recorder through wires. (Hyejung, Yazicioglu, Merken, & Van Hoof, 2010) Modification of the electrode was done throughout the years, and one instance of this is the manufacturing of a non-woven and non-adhesive electrode by the researchers, where they named it as *Textrodes*. (Calalan & Go, 2011)

1.2. Potentials of Graphene

Graphene is a carbon allotrope that contains promising opportunities, in which it has already been under different researches. It is found out that this material exemplifies in different properties such as mechanical, chemical and electrical. (Bunch, 2008) This research just shows that the allotrope is so much more to discover, and it is being looked forward to conduct many studies that would relate to medicine as part of the researcher's field.

1.3. *Objectives and Scope*

A comparative study would be made to determine the effect of graphene in the data acquisition of the electrodes. These parameters which are the composition, size and shape are the elements that would meet up the requirements of a preeminent electrode.

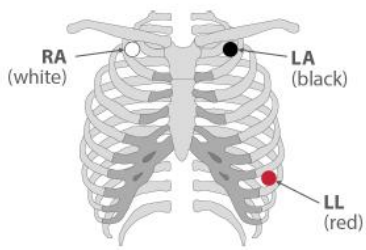

Fig. 1. The Three-Lead System is composed of electrodes which are only attached on the chest.

The more electrodes would be attached to the body, the more accurate the reading of the ECG would be. This is for the conventional lead system where it uses 12 electrodes to be attached not only in the chest cavity, but also in the extremities. However, this research will not be able to form this kind of lead system due to lack of resources. Instead, the study utilizes the three-lead system shown in

2. METHODOLOGY

2.1. *Fabrication of Graphene on Electrodes*

Through the process of exfoliation, graphene was assumed to be displayed. However, it was expected that this would not be as pure as the one made from Chemical Vapor Deposition (CVD). Exfoliation has been the most considerable procedure in this study due to its simple and cost-effective way of acquiring graphene. Using a laminating film which is composed of ethylene-vinyl acetate (EVA), the contents of an activated carbon were spread throughout the film. This was followed by lamination for further distribution of the carbon particles. The two sides of the film that were adhered in the mentioned process was forcibly opened, leading to the samples which were to be cut in different sizes (3, 4 & 5 cm) and shapes (Triangular, Square & Circular).

Compositional electrodes on the other hand consist of graphene from a commercial product and the exfoliation procedure. The process on applying the commercial graphene did not need the laminating procedures mentioned; instead, it was directly placed to the substrate. Each sample was continuously spread using a tissue, until there were no more graphite or unwanted particles that would stick on the paper. The samples were attached to the medical electrodes by putting holes enough for the size of the cap as shown in Fig. 2. The attachment was secured by applying same amount of transducer gel to all the electrodes.

Fig. 2. The graphene samples labeled and attached in the medical electrodes.

2.2. *Evaluation of Graphene on Electrodes*

To verify the presence of Graphene from exfoliation, each sample was analyzed by Raman Spectroscopy provided by the National Institute of Physics (NIP).

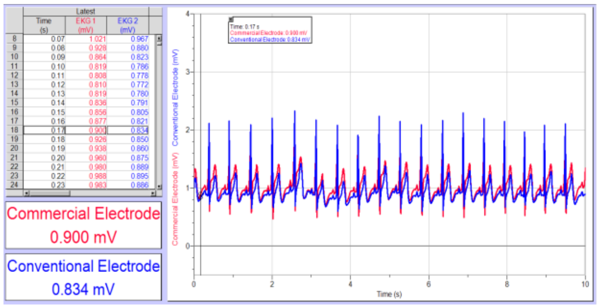

Fig. 3. ECG peaks recorded from the LoggerPro software.

Using the LoggerPro software which allows to view the signal (Vrms) and its corresponding time, each peak recorded from the electrodes was analyzed, namely the P, R, and T waves. (Refer to Fig. 3) To minimize the error from this experiment, the electrodes were in turn exchanged for the data aqcuisition. On the first trial, those sets of electrodes were altogether placed on the body for the simulation. However, the peaks and intervals of the waves under a certain parameter were not matched. Another factor that contributes to the error is the less accuracy of the signal produced due to the distance of the electrodes to the specific areas that produce the electrical simulation. With this, two electrodes were instead probed, taking turns for the unplaced electrode. Together with the conventional electrodes that use Ag-AgCl as their conductor, graphene-based electrodes were compared in terms of different factors:

2.2.1. Vrms Difference of the Electrodes

In order to determine if the signal coming from graphene electrodes has amplified, the Vrms of these were subtracted by the values of the conventional electrodes. Now that I obtained commercial graphene, the process was done by subtracting the Vrms of the electrodes from the experimental conductors. Positive differences are in favor of the amplification from the higher quality of graphene, the larger size of electrode, and greater sides of the shape.

2.2.2. SNR of the Electrodes

The Signal-To-Noise ratio (SNR) is a factor that indicates the sensitivity of the electrodes. (Poole, 2017) Positive results favor the better signal coming from the desired electrode, while negative data can be due to noise coming from different factors, such as the simultaneous data acquisition from another electrode. SNR in decibel (dB) was computed using the formula:

$$\text{SNR (dB)}=|V_{DE}/V_{NE}| \qquad \text{(Eq.1)}$$

where:
V_{DE} = Vrms of desired electrode
V_{NE} = Vrms of neighboring electrode

The upper portion of the fraction always aims on the better quality, larger size, and greater side number of the sample.

2.2.3. Peak Interval of the Electrodes

It is significant to determine the simultaneity of the electrodes since they altogether gathered the signal coming from the heart. By getting the difference of the time a specific peak was gathered, the peak time intervals of P, R, and T waves were obtained for the two kinds of electrodes.

3. RESULTS AND DISCUSSION

3.1. Vrms Difference of the ECG Waves

Table 1. The Vrms difference of the ECG waves for the P, R, and T waves coming from the electrodes based on composition.

	P Wave	R Wave	T Wave
Conventional on Left, Commercial on Right	0.085	0.557	-0.103
Commercial on Left, Conventional on Right	0.050	-0.501	0.153
Experimental on Left, Conventional on Right	-0.029	0.390	-0.152
Conventional on Left, Experimental on Right	-0.050	-0.478	0.081
Experimental on Left, Commercial on Right	0.139	0.713	-0.041

Conventional on Left, Experimental on Right	0.115	-0.380	0.197

Despite the changing of the placement of the commercial electrodes with respect to the conventional and experimental ones, results have shown consistent positive differences for P-wave which indicate that the signal was amplified for the commercial graphene electrodes. (Refer to Table 1) The 2 negative results under the same wave indicate the signal was more amplified by the conventional electrode than the experimental conductor. The results of R-wave and T-wave are highly affected by the positioning of the electrodes. Exchanging the positions of graphene (both commercial and experimental) and conventional electrodes have led the amplification to alter either on R-wave or T-wave.

Table 2. The Vrms difference of the ECG waves for the P, R, and T waves coming from the electrodes based on size.

	P Wave	R Wave	T Wave
4cm on Left, 3cm on Right	-0.132	-0.697	0.046
3cm on Left, 4cm on Right	0.395	0.524	-0.238
5cm on Left, 4cm on Right	0.012	-0.631	0.209
4cm on Left, 5cm on Right	0.052	0.812	-0.072
5cm on Left, 3cm on Right	-0.095	-0.627	0.096
3cm on Left, 5cm on Right	-0.079	0.611	-0.158

From Table 2, 5 cm results have shown positive differences in the P-waves when compared to 4 cm. However, when these conductors were placed together with the 3cm, the smaller size amplified more signal. Alternating results were obtained from the P-wave signal between 3 cm and 4 cm. In terms of the R-wave and T-wave, the occurrence that happened on the data based from composition was also exhibited in this area. The signal amplification favors either on the two different electrodes, depending on how these were placed. This leads to the assumption that the results of the electrodes of different sizes was greatly affected by their placement. The amplification of each R-wave and T-wave has a favored position on the subject's body for these to occur.

Table 3. The Vrms difference of the ECG waves for the P, R, and T waves coming from the electrodes based on shape.

	P Wave	R Wave	T Wave
Rectangle on Left, Triangle on Right	-0.135	-0.573	0.178
Triangle on Left, Reactangle on Right	-0.112	0.364	-0.268
Circle on Left, Rectangle on Right	0.018	0.74	-0.256
Rectangle on Left, Circle on Right	-0.059	-0.430	0.126
Circle on Left, Triangle on Right	0.111	0.592	-0.165
Triangle on Left, Circle on Right	0.071	-0.345	0.220

Triangular electrodes show both positive Vrms differences on different sides along with the circular electrodes. (Refer to Table 3) The rest of the differences under the same wave indicate that circular electrodes are more dominant for signal amplification. Same with the statement mentioned from the previous paragraphs, the differences on R-wave and T-wave also favor in a specific position which results to their alternating data.

3.2. SNR of the ECG Waves

Table 4. The SNR of the ECG waves for the P, R, and T waves coming from the electrodes based on their composition.

	Commercial	Conventional	Experimental
P Wave	21.837	19.778	18.387
R Wave	21.824	20.818	19.585
T Wave	20.902	20.154	19.243

The data gathered was based on the SNR collected for each type of electrodes at different positions. From Table 4 above, the commercial graphene electrodes have exhibited the highest in all the ECG waves. This consistency can lead to the observation that the application of pure graphene has therefore increased the sensitivity of the electrodes in obtaining the signals coming from the heart. Aside from the mentioned electrodes, both conventional and experimental electrodes exhibit consistency on the SNR. Since the experimental electrodes are still characterized to have impurities, this might lead to less sensitivity than the conventional electrodes which use Ag-AgCl for the conductance.

Table 5. The SNR of the ECG waves for the P, R, and T waves coming from the electrodes based on their size.

	3 cm	4 cm	5 cm
P Wave	20.228	20.939	19.521
R Wave	21.062	20.029	22.068
T Wave	21.048	18.978	20.339

Unlike Table 4, the electrodes with different sizes found on Table 5 are inconsistent on their SNR values. Each wave favors on each of the electrodes present. For instance, 4 cm electrodes are most sensitive at P-wave, while lowest on the remaining waves. T-wave favors on 3 cm electrodes, while the largest electrodes are most sensitive on R-wave. A factor that can contribute to the results is the composition of each electrodes, since the process of doing this is through exfoliation which as mentioned in the previous chapters are more prone to impurities. With this, the findings infer that the size of graphene electrodes has barely affected the electrodes in doing the recording of the electrical signals from the heart.

Table 6. The SNR of the ECG waves for the P, R, and T waves coming from the electrodes based on their shape.

	Triangular	Square	Circular
P-Wave	22.277	18.431	19.556
R-Wave	21.581	20.854	19.240
T-Wave	20.752	19.406	20.501

Between these three types of electrodes, the consistency is only shown by the triangular electrodes which also got the highest SNR values. Under the Raman Spectroscopy, these electrodes correlate the most with pure graphene from CVD. With this regard, this reason can be the explanation of the data mentioned in Table 6, since the rest of the SNR values coming from the square and circular electrodes do not correlate with each other. Circular electrodes are least sensitive on R-waves, while the rectangular ones on both P-waves and T-waves.

3.3. Peak Time Interval of the ECG Waves

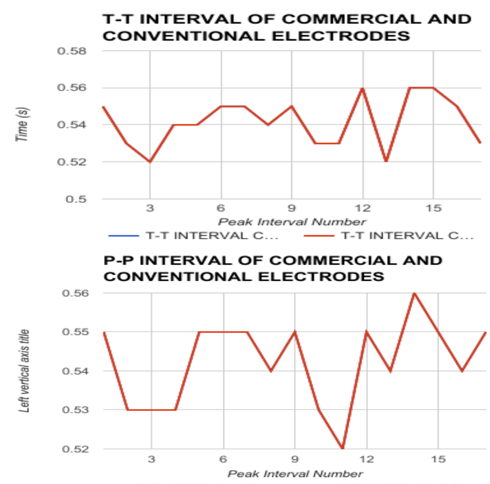

Fig. 4. The time intervals of the conventional and commercial graphene electrodes between their P and T waves.

By getting the time interval between the two kinds of electrodes, this would determine if both are acquiring the right heart signal. (Calalan & Go, 2011) Found on Fig. 4 is the time interval between the P and T peaks of commercial and conventional electrodes. The time for commercial electrodes are barely seen on the illustration, since its data coincides with the conventional conductors'. This indicates that at the data acquisition, both electrodes are obtaining the right heart signal simultaneously. This occurrence also happened throughout the two kinds of electrodes placed on the patient's body.

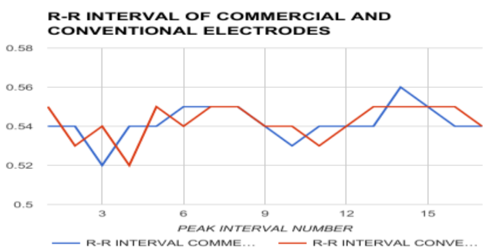

Fig. 5. The time intervals of the conventional and commercial graphene electrodes between their P and R waves.

The difference of time intervals occurred on the R-waves as shown in Fig. 5. The error between the data can be a result of the subject's respiration. The expansion of his chest has led the distance of the signal to also increase, therefore causing a variance from the neighboring electrodes. 10-20 millisecond difference was found between the values of the electrodes with regards to the R-waves. This has led to have an overall percent difference of about 0.11%. The mentioned range is also exhibited on the R-waves coming from the other electrodes.

4. CONCLUSIONS

Based from the peak time intervals, the electrodes were acquiring the same heart signal for all ECG waves, considering the minimal differences at R waves due to subject's respiratory cycle. The amplification of commercial graphene electrodes was exhibited on P-waves despite the exchanging placement of the conductors. The data acquisition is highly dependent on the positioning of the electrodes which serves as a major factor of the error. Nevertheless, the application of graphene to the electrodes has shown the greatest sensitivity with their considerable SNR values.

The size and shape of graphene has barely affected the signal amplification and sensitivity of the electrodes in obtaining the electrical activity of the heart. Triangular electrodes have exhibited the greatest SNR values, indicating that it the most sensitive electrodes for all the ECG waves. The results can still be dependent on the composition of each sample, since it is assumed there are still certain impurities aside from graphene.

Graphene was prepared here through the process of exfoliation in a laminating film, thus the only way for application is by attaching the product to the electrode. Furthermore, the commercial graphene I obtained is minimal. With this, more feasible ways should be done to incorporate the graphene in the electrodes. Exfoliation is one of the possible ways to make graphene, however the chances of obtaining a pure extract is trifling.

5. ACKNOWLEDGMENTS

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