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# A Preliminary Study of the Effect of Electrode Placement in Order to Define a Suitable Location for Two Electrodes and Obtain Sufficiently Reliable ECG Signals When Monitoring with Wireless System

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*Abstract*— **Most countries face high and increasing rates of cardiovascular disease. Each year, heart disease kills more Americans than cancer. Therefore, there has been a promising market for portable ECG equipment and it is increasing. To use portable ECG measuring devices, it is essential to define a suitable location for the measuring as we need to reduced electrode size and distance. This research proposes to study how the inter-electrode distance affects the signal and how the electrode pair should be placed on the chest in order to obtain a sufficiently reliable ECG signal to detect heart arrhythmias in any environment, such as home or work. Therefore, we developed a compact, portable patch type ambulatory ECG monitoring system, Heart Tracker, using a microprocessor for preliminary study of signal analysis. To optimize the electrode arrangement in wireless environment, we compared HT and standard 12 lead with changing electrode position.**

## I. INTRODUCTION

Cardiac disease has emerged as the leading cause of death worldwide in modern times, particularly in developed countries. The World Health Organization (WHO) reported that 16.7 million deaths in 2003 (29.2% of total global deaths) were caused by some form of cardiovascular disease. Though the rate of cardiac disease is highest in developed countries, developing countries are seeing an increase in the occurrence of cardiac disease, as well as a corresponding rise in the number of heart-related deaths [1]. The WHO estimates that by 2010, cardiac disease will surpass AIDS as the leading cause of death in developing countries [2].

The electrocardiogram (ECG) is a diagnostic tool that measures and records the electrical activity of the heart in detail. Being able to interpret these details allows diagnosis of a wide range of heart problems. One of the most widely used tools in cardiac diagnosis is the 12-lead ECG. Although the 12-lead ECG is the most popular ECG acquisition method, an advanced method called the Body Surface Potential Map (BSPM) has been deemed more accurate for diagnosing cardiac pathologies [3]. In figure 1, the location of BSPM electrodes is represented. Black squares denote the location of standard 12-lead system chest electrodes V1-V6. Physicians are well-aware that many heart problems are more likely to occur during normal routine activities, such as walking, eating, sleeping, etc. Therefore, they often recommend a portable ECG monitoring device that can provide continuous monitoring, since it is more likely to represent a more realistic portrait of heart abnormalities. Therefore, in this study, we have developed a simple wireless ECG monitoring system, Heart Tracker (HT). This system is lightweight and simple to operate for non-professionals, so it might be helpful in virtually any environment. Moreover, it is designed for portable applications using Bluetooth communication, which makes it as effective method to monitor the ECG.

However, when designing small measurement systems, it is essential to define a suitable location for the two measuring electrodes, as the signal may change or diminish when decreasing the inter-electrode distance. The obtained signal strength varies between different electrode positions. Moreover, individual variations also may cause deviation in the results. Nevertheless, there has not been widely studied about the effect of electrode placement when monitoring ECG signal in wireless environments.

Therefore, this study focused on the effect of electrode arrangement on the ECG signal strength by means of comparing the ECG signals using the HT with 12 lead ECG

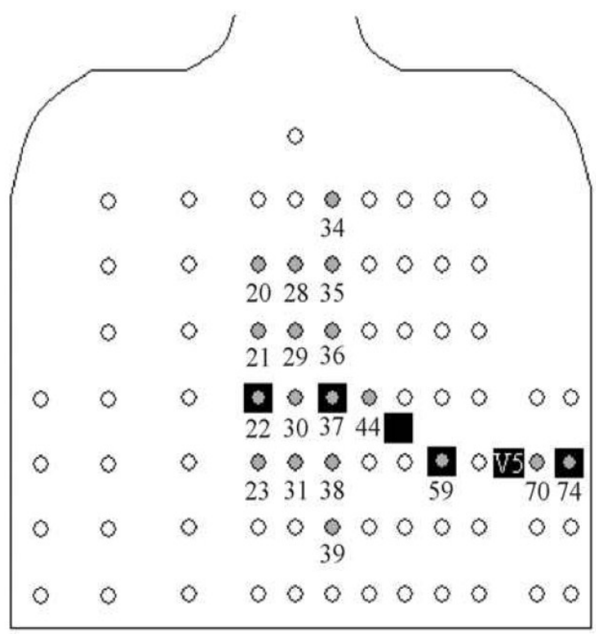


Figure 1. Front view of Body Surface Potential Map (BSPM) [4].

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signal. The main purpose of this study was to evaluate how the bipolar electrode pair should be located on the chest in order to obtain a sufficiently reliable and strong ECG signal for analysis and arrhythmia detection.

## II. System configurations and Methods

### A. System configurations

HT consists of amplifiers, a microprocessor, and a Bluetooth module as shown in Figure 2. We chose the MSP430F5437A (TI, USA) as a microprocessor because of its multiple tasking ability, low price, and low power consumption. ECG signals have principal amplitude of about 1 mV and a signal frequency range of 0.02Hz to 150Hz. To meet this strict amplifier requirement, we constructed a cascade circuit, which consisted of instrumentation differential amplifier, a gain stage, 150Hz low pass filter, and 0.02 Hz high pass filter. We used a Bluetooth chip, HBM2X1M (HANA Micron, KOREA) for wireless communication. The system is composed of 2 distributed H/W modules with 2 disposable Ag/AgCl electrodes attached to each module, respectively. The two distributed modules are connected with each other using the cable including five wires connected to micro B type USB connector. Distributed modules are small enough to be used as a portable device. In figure 2, the size of (a) main module and (b) the Bluetooth module is 33 x 40(mm) and 33(mm) diameter, respectively. The length of the cable is approximately 12(cm).

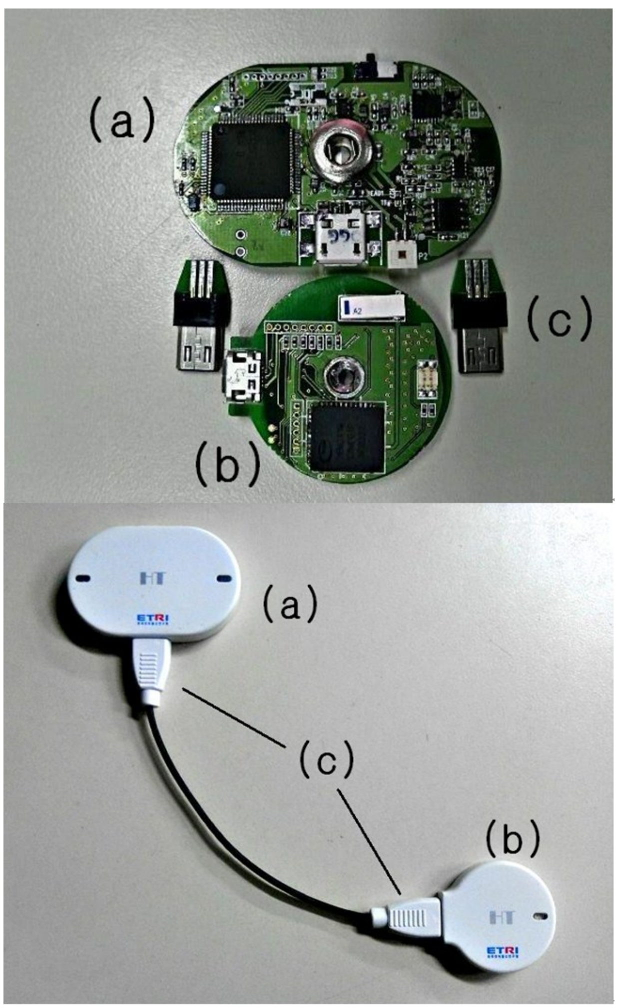


Figure 2. Photo of hardware.
(a) The main module including power management circuits, analog ECG circuits, Microprocessor.
(b) Bluetooth module including Bluetooth chip and circuit, Antenna.
(c) Micro USB B-type connectors connected to developed PCB board.

The main module includes power management circuits, and the power source is Li-Polymer rechargeable battery, and also it is supplied to the Bluetooth module through the cable. The main module also includes analog ECG circuit and MCU, which undertakes signal acquisition and processing. The ECG signal is measured in this module through sampling and A/D (Analog to Digital) converting by MCU.

The Bluetooth module functions wireless communication. This module includes Bluetooth chip communicating with variable terminals such as PC, PDA, or smart phone. In this study, we used a PC with Bluetooth dongle to communicate with Bluetooth module. The PC includes the software which could represent the measured ECG signal data which is transmitted from the module.

### B. Methods

In this study, to optimize the electrode arrangement in wireless ECG monitoring, we compared two different method of ECG monitoring. One method was wireless ECG monitoring using developed portable system, HT, with changing electrode positions in BSPM. The other method was standard 12-lead ECG. In 12 leads ECG, six of the leads are considered as limb leads since they are placed on the arms and legs of the person. The other six leads are considered as precordial leads since they are placed on the person's torso (precordium) [5]. However, in this study, we compared only limb lead in 12-lead ECG with the signals gained by our developed portable system, because HT is a single channel device which has two electrodes. Also, the lead aVR usually has dominantly downright QRS complex, so we excluded it as it was not proper to compare in this test. To conduct the tests, we chose several pairs of electrode arrangement for monitoring using HT. Based on Merja Puurtinen's study, they found that the best locations for QRS-complex and P-wave detection are around the chest electrodes of the standard precordial leads V1, V2, V3, and V4 and above the chest electrodes of leads V1 and V2, respectively [6]. Therefore, seven pairs of electrode displacement for wireless ECG monitoring were chosen as shown in figure 3. The seven electrode pairs were 20-37, 22-59, 28-44, 35-37, 59-22, 59-37, 74-22, 74-37, respectively. The tests were performed on three healthy adults in age 20 to 30 with no prior history of heart disease. When monitoring using HT, the disposable Ag/AgCl electrode (3M) was connected to metal button in each module and attached to the patients' chest. The main module was located at RA (right arm) position, and the Bluetooth module was located at LL (left arm) position. 12-lead standard ECG signal was also measured from each subject. The obtained ECG data were analyzed by using a patient monitoring device, Complexity (Laxtha, Korea).

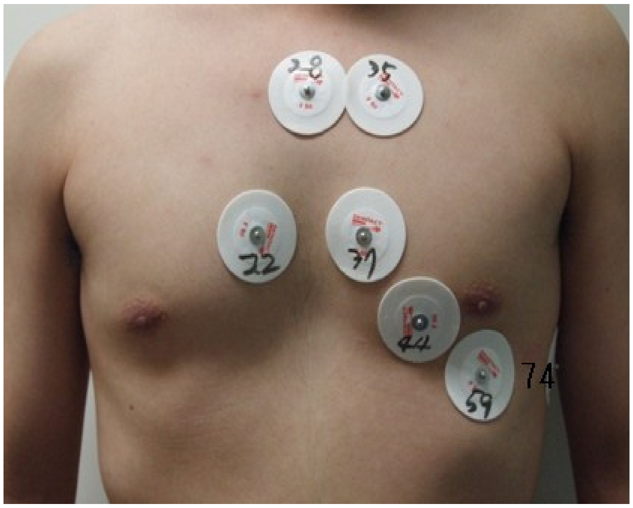



Figure 3. Best locations for detection of QRS-complex and P-wave based on the previous research.

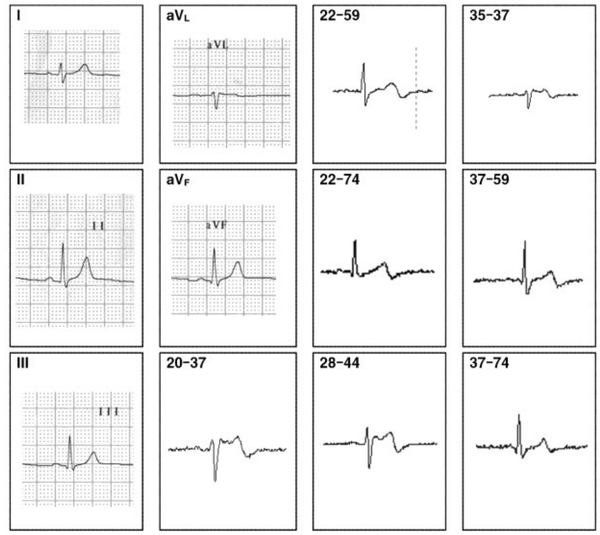
## III. Results and Discussion

The results of tests are shown in figure 4. The limb lead signals were compared as standard 12-lead ECG which were represented as I, II, III, aVL, aVF.

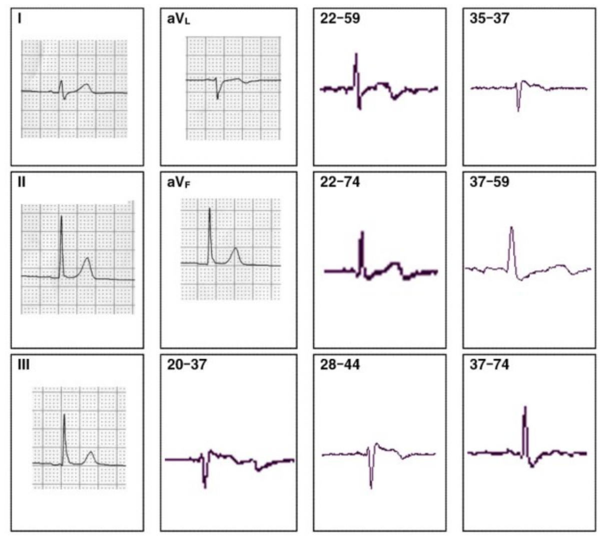
Subject (a) results show an increasing depth in the S-wave at 22-59, 37-59 compared to lead II. The pair of 37-59 also shows a negative deflection at the end of the T wave. Usually P- wave is one of the smallest diagnosed parameters of the ECG wave. The pairs 22-74, 28-44, P-waves are seen, although they are not quite clear to be observed. The ST segment should not be elevated or depressed but the pairs of 20-37, 28-44, 35-37 show ST segment distortion, so they are not considered as proper position for reliable ECG monitoring.

As a result of subject (b), the pairs of 35-37, 20-37, 28-34 provide relatively smaller R peak than others. Also, they show depth of the S wave in QRS complex compared to standard lead II. In these bipolar electrode pairs, the P-wave may be lower than the noise level. This means that these bipolar electrode pairs are not suitable for diagnostic purposes. Usually, TP segment should always be at baseline and is used as a reference to see if the ST segment is elevated or depressed [7], but this segment depression is seen at 22-59. All electrode pairs with the exception of 22-74 and 37-74, T-wave may disappear under the noise. The pair of 22-74 provides relatively normal waves in all rhythm, although it has a little negative deflection at the end of the T wave.

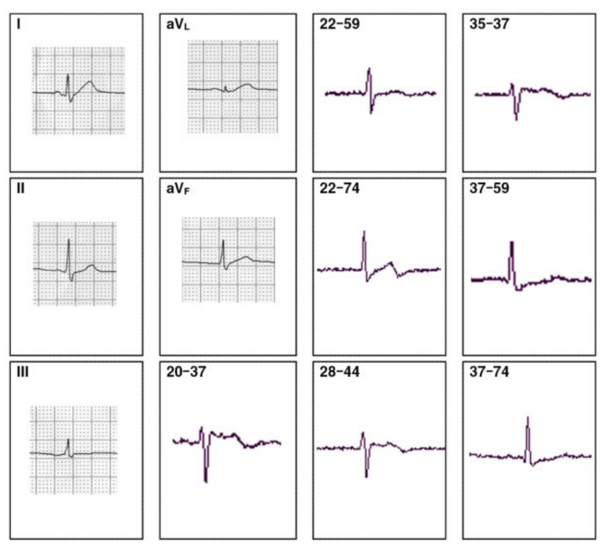
Subject (c) results show excessive downward deflection of S wave at the pair of 22-59. Morphologically, the signal pattern at 22-74 pair is similar to normal rhythm in terms of shapes of negative deflection at the end of QRS complex compared to standard lead. However, it also has a little negative deflection at the end of the T wave, which is different from the normal standard lead. The pairs of 37-59, 37-74 show quite similar shape of QRS compared to the normal rhythm, but T wave is not clear to observe. ST segment distortion is seen at the pairs of 35-37, 20-37.




Subject (a)




Subject (b)




Subject (c)

Figure 4. The obtained ECG signals with regard to electrode positions from each subject (a), (b), (c).

Synthetically, as represented in three patients' results, if one electrode is placed at 59, an increasing depth in S-wave is observed and T wave is diminished. Therefore, the proper electrode location for LL is considered as position 74 that is close to heart border. To choose the proper position for RA electrode, we looked over the position 22 and 37. The pair of 37-74 scarcely shows T wave, so ST segment is not to be seen. It also shows excessive downward deflection of S wave. Among the bipolar electrode pairs, pair 22-74 provides a clear QRS complex than others. This is probably because the distance between two electrodes at 22-74 is quite long and the pair is also positioned in the direction of heart electrical axis. Thus, this result suggests that the electrode pair should be placed at the pair 22-74 that could be considered as proper position so as to perform a reliable monitoring using a wireless system.

## IV. Conclusion

Portable ECG monitoring device for continuous monitoring has lots of advantages over the standard 12-lead with the benefits. Wireless ECG system enables patients to monitor their heart activity continuously during normal routine activities. Also it allows physicians and health care providers to monitor and assess their patients' heart health for a variety of medical reasons. However, it is essential to define a suitable location for the measuring electrodes when monitoring with wireless device. To optimize the electrode arrangement in wireless environment, we have developed the portable ECG monitoring system (HT), and we compared HT and standard 12 lead with changing electrode position.

Tests results indicate that reliable ECG signal could be obtained from a bipolar measurement on the chest using wireless device provided that the electrodes are properly positioned. Also, the result suggests that the electrode pair should be located in the direction of heart's electrical axis, in order to obtain the strongest QRS amplitude. In these tests, we regarded that electrode pair should be placed at the pair 22-74 that could be considered as proper position.

However, there are several variables to consider that pose limitations to these study. For diagnostic purposes, bipolar measurement between electrodes is not probably sufficient because P wave was not clear enough among the electrode pairs. The clinical significance of these limitations also must be considered when deciding about the appropriateness for continuous ECG monitoring. While there are differences between ECG data collected using the portable ECG monitoring device and standard 12-lead, the clinical significance of these changes is questionable. Another limitation is that tests were performed with only three subjects. Therefore, for the future studies, we will perform sufficient additional tests with subjects including patients to evaluate and optimize electrode arrangement for wireless ECG monitoring. Moreover, statistical analysis should be performed to optimize the results.

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