Usefulness of a Developed Four-Channel EGG System with Running Spectrum Analysis

Deok Won Kim¹, Chang Yong Ryu², and Sang In Lee³

--- Abstract ---

Electrogastrography (EGG) is a method of measuring action potentials on the abdomen. It is noninvasive, inexpensive and easy to measure. However, the EGG signal has a very low frequency (0.05 Hz) and an extremely low amplitude (10-100 µV). Consequently, its measured waveform is difficult to analyze and it is not yet completely understood. In this study, a four-channel EGG measurement system was built to measure the action potential of the stomach. This system was compared with the commercially available one-channel Digitrapper EGG. The 3 cpm percentages were compared between the best channel of the four-channel system and channel 1, whose electrode position was similar to the commercially available one-channel system for normal subjects. The average 3 cpm percentage of the best channel and channel 1 for preprandial measurement was 89.5% and 83.2%, respectively, and this was statistically significant (p<0.001). Also the average 3 cpm percentage of the best channel and channel 1 for postprandial measurement was 90.4% and 76.5%, respectively, and this was statistically significant (p=0.003). From these results, it can be concluded that a multi-channel EGG system is required for better EGG measurement.

Key Words: Electrogastrography, four-channel EGG, pre- and postprandial, electrode placement, running spectrum

INTRODUCTION

It is known that peristaltic movement of the human stomach accompanies action potential.¹ While the action potential has a periodic rhythm for digestion in a normal stomach, it has a non-periodic pattern in an abnormal one.²⁻⁴ Therefore, the action potential could be useful in evaluating the motility of the stomach.

Three methods have been used to measure stomach action potentials. One is to attach electrodes to stomach serosa by surgical operation. The other is to attach suction electrodes to stomach mucosa by swallowing them. The final method is to place surface electrodes on the abdomen. The first method, though accurate, has generally limited usage, and the second may cause patients' pain. The last one is called electrogastrography (EGG), which is noninvasive and easy to measure, but its measured waveform is difficult to analyze and it is not yet completely understood.⁵

The first EGG was recorded by Alvarez in 1921.⁶ He recorded signals of approximately 0.05 Hz, which was equivalent to 3 cpm (cycles/min). Those were similar to sine waveforms by applying two surface electrodes on the abdomen to which a galvanometer was connected. Since the 1980s, many studies on EGG have been performed and it has been demonstrated in some studies that EGG signals resulted from the contraction of gastric smooth muscle and that a pacemaker existed near the greater curvature of the midcorpus, though some researchers disagree.⁷ An EGG has a rhythm of 3 cpm and a range of 0.5 to 10 cpm.⁸ The EGG signals are generally classified as bradygastria (0.5 to 2.3 cpm), normal (2.4 to 3.7 cpm), and tachygastria (3.8 to 10 cpm). A measured EGG is currently assumed normal if it has 3 cpm in
more than 70% of the measured signals. However, the 3 cpm percentage of EGG varies considerably depending on the relative location of the surface electrodes to the stomach. The commercially available products have only one channel and the EGG signals cannot be monitored in real time while being recorded. Therefore, we constructed a real time four-channel EGG monitoring system which can display up to four channels of EGG signals with two-dimensional (2D) and three-dimensional (3D) running spectra for easy interpretation. Three axes of

the 3D running spectra represent time, frequency, and spectral amplitude.

MATERIALS AND METHODS

The EGG data were acquired from a total of 40 asymptomatic medical college students at Yonsei University averaging 26 years of age. Among them, the EGGs of 20 subjects were measured for both fasting and postprandial, while 20 EGGs were measured for fasting only. EGGs were recorded for 20 minutes each in a slightly-tilted sitting position for fasting and postprandial. The postprandial EGG was recorded immediately after eating a roll of sushi and a cup of water. The recording was begun at least 5 minutes after attaching the electrodes for better signal acquisition. For every EGG recording, each subject's abdomen was cleaned with alcohol, then 6 EGG electrodes, including one reference and one ground, were attached on the abdomen as shown in Fig. 1. The reference electrode was placed midway between the distal end of the sternum and the umbilicus. The four active electrodes were placed around the reference electrode. The distance between the centers of the reference and each electrode was 6 cm. Although there is no standard electrode configuration with respect to uni- or bipolar, number of electrodes, and their location, our electrode configuration was one of

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**Fig. 1.** Positions of the electrodes. The EGG signals were recorded as the potential differences between the reference electrode (Ref) and each of the four surrounding electrodes (Ch1 – Ch4).

**Fig. 2.** Block diagram of the 4-channel EGG system.
the conventional ones.\textsuperscript{11-15}

A four-channel EGG system constructed in this study consisted of hardware and software, including running spectrum analysis (RSA) for easy interpretation of the raw EGG signals. The system was interfaced with a PC through an analog-to-digital (A/D) converter for digitization and processing of the raw data as shown in Fig. 2. The major components of the hardware were auto-balancing circuitry, differential amplifiers, and low and high pass filters. The auto-balancing circuit minimized baseline drift due to motion artifacts such as respiration and movement, etc. Since the amplitude of the EGG signal was very small, ranging from 10 to 100 \( \mu \text{V} \), the EGG system needed a high gain of 39,000 so as to make it, ranging from 1.95 to 3.9 \( \text{V} \), as well as using high precision filters. A sampling rate of 2 Hz was selected for acquiring EGG signals.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig3.png}
\caption{The steps for menu selection.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig4.png}
\caption{Normal EGG signal in each of 4 channels.}
\end{figure}
Fig. 5. Normal 2D spectra in each of 4 channels.

Fig. 6. A typical 3D running spectra of a patient (bradygastria).
For the spectrum analysis, the EGG data were filtered resulting in 0 to 10 cpm using the multi-resolution wavelet method. Then FFT (fast Fourier transform) was performed on each 512 data with 75% overlapping to display 2D or 3D spectra.

Fig. 3 shows each step for menu selection. In the first step, raw EGG or spectrum was asked to select. Then, total or dominant frequency and final 2D/3D view or 3 cpm percentage were requested to select.

The paired-samples t-test was used for statistical analysis using the SPSS (Ver. 8.0) for Windows program.

RESULTS

Fig. 4 shows a typical normal EGG raw signal in each of the four channels and Fig. 5 shows its corresponding 2D spectra. From Fig. 4, 9 to 11 peaks per 200 seconds can be counted resulting in 2.7 to 3.3 cpm, which was inside of the 3 cpm range, respectively. From Fig. 5 to 7, the red and blue colors showed the largest and smallest in magnitude, respectively. In Fig. 5, the two vertical lines parallel to the y-axis indicated the range of 3 cpm, which were 2.4 and 3.7 cpm respectively. The spectrum in each of four channels was in the range of 3 cpm, resulting from the fact that all four electrodes were located above the normal subject stomach. However, this was a rare case and only one or two channels may show this kind of spectrum. Fig. 6 shows a typical 3D running spectrum for a patient (bradygastria). As the main frequency of the EGG signals was about 2 cpm, this was classified as bradygastria.

In this figure, it can be seen that about 5 cpm occurred briefly at 2 minutes after beginning measurement. The 2D spectra in Fig. 5 or the 3D spectra in Fig. 6 were much easier to analyze the EGG than the raw EGGs in Fig. 4 since the former showed the temporal change of the EGG spectrum.

The dimensionless number that represents “power” (log of the microvolts squared) within the different frequency bands was used to calculate the percentages of total power in the various frequency ranges as follows:

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preprandial</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best Ch (N=40)</td>
<td>89.5*</td>
<td>64.4</td>
<td>100.0</td>
<td>12.7</td>
</tr>
<tr>
<td>Ch 1</td>
<td>83.2*</td>
<td>43.1</td>
<td>100.0</td>
<td>16.0</td>
</tr>
<tr>
<td>Postprandial</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best Ch (N=20)</td>
<td>90.4†</td>
<td>63.6</td>
<td>100.0</td>
<td>12.7</td>
</tr>
<tr>
<td>Ch 1</td>
<td>76.5†</td>
<td>19.4</td>
<td>100.0</td>
<td>22.1</td>
</tr>
</tbody>
</table>

* p<0.001 (paired-samples t-test).
† p=0.003 (paired-samples t-test).

Fig. 7. An example of faulty diagnosis using only channel 1 for EGG measurement.
The percentage of 3 cpm EGG

\[
\frac{\text{The power at } 2.4 - 3.7 \text{ cm}}{\text{The total power at } 0.5 - 10 \text{ cpm}} \times 100
\]

Table 1 shows the 3 cpm percentages for normal subjects of the best channel among the four channels and channel 1, whose electrode position was approximately the same as that of the commercially available one-channel system. The “best channel” means the channel showing the highest 3 cpm percentage among the four channels. The average 3 cpm percentage of the best channel and channel 1 for preprandial was 89.5% and 83.2%, respectively, and this was statistically significant (p < 0.001). It was 90.4% and 76.5%, respectively for postprandial, which was statistically significant (p = 0.003). The difference of average 3 cpm percentage between pre- and postprandial seems to be due to the relative position change of the electrode to the stomach after food intake, which shows the necessity of a multi-channel EGG system like the four-channel system developed in this study.

Since the relative position of the electrodes to the stomach for every person is quite different, a one-channel EGG system may lead to a false-positive diagnosis. Fig. 7 shows a good example of faulty diagnosis using channel 1 only for EGG measurement. In this case, the four-channel EGG signals were acquired from a normal subject. As shown in the figure, all the spectra except channel 1 showed normal 3 cpm. This shows again the necessity of a multi-channel EGG system.

Fig. 8 shows both normal and abnormal placement of the electrodes. In Fig. 8A, the EGG signal measuring the voltage difference between channel 1 and the reference would be the largest among the four channels, as the stomach is mostly covered by channel 1 and the reference. In Fig. 8B, the stomach hasn’t been covered by any channel since the stomach was located unusually higher than the normal position. Therefore, no channel can produce accurate EGG signals, resulting in faulty diagnosis. This example also shows the necessity of a multi-channel EGG system.

**DISCUSSION**

Due to the considerably variable positions of each individual’s stomach, accurate EGG measurement depends heavily on the electrode placement on the abdomen. That’s why the currently available one-channel system is inappropriate and a multi-channel one is necessary. Even the four-channel EGG system built in this study failed to accurately measure EGG signals in some cases. Therefore, systems with more than four channels and placement of the electrodes covering the wider abdomen are likely necessary.

As the raw EGG signals were displayed in real time, it was possible to check the data validity, while this was not possible for the commercially available one-channel EGG system due to the fact there was
no signal processing function in real time.

The average 3 cpm percentage of the best channel among the four-channel system showed a statistically significant increase compared to that of one channel both in the preprandial (p<0.001) and in the postprandial (p=0.003) conditions for normal subjects.

In conclusion, a multi-channel measurement system with wider electrode placement is recommended for EGG measurement.

REFERENCES