Spectral Analysis of Blood Flow Waveform for Blood Glucose Level Detection - Preliminary Study

Jae J. Im and Sang H. Nam

Department of Biomedical Engineering, Inje University
607 Obang-dong, Kimhae, Kyungnam, KOREA

Abstract - Development of a noninvasive measurement for the blood glucose level was performed by extracting a frequency components from the blood flow velocity waveform during an OGTT (Oral Glucose Tolerance Test). The index, \( P_G \), was obtained by calculating the ratio of changes in the power spectrum of the waveform to the changes in the level of blood glucose. They were classified into three groups, normal, diabetics with and without showing neuropathic subjective symptoms. The resulting indices calculated were \( P_G(N) = 1.0 \pm 0.2 \), \( P_G(DN^+) = 0.1 \pm 0.08 \), and \( P_G(DN^-) = 0.3 \pm 0.1 \). The conclusions drawn from the experiment indicated that the spectral analyses of the blood flow waveform could be used as a significant indicator for the blood glucose level.

INTRODUCTION

Blood glucose level affects the compliance of the blood vessels and viscosity, and it finally causes the resistance changes to the blood flow. Therefore, an analysis of the variability on the characteristics of the blood flow waveform may provide the significant information regarding blood glucose level, which is affected by the hormonal and neural controls[1,2].

Among various methods of measuring blood glucose level, OGTT is prevalent as a biological measurement method. Also, diabetic patients show blood glucose level 15% lower than the plasma glucose level, but the capillary glucose appears to have a level of 8% higher than the venous glucose level[3]. From these point of view, the characteristics between flow dynamics of the blood and the variability of the blood flow velocity could provide the pathological information regarding imbalance of the homeostasis. These changes can be obtained by analyzing periodicities of the blood flow waveforms[4].

The objective of the experiment was to establish the relationship between blood glucose level and the frequency components of the blood flow waveform obtained from a finger using an LDV (Laser Doppler Velocimetry).

METHODS

Experimental Design

The experiment was devised with eighteen subjects who were known to normal, diabetic neuropathy with subjective symptoms (DN+), and diabetic without subjective symptoms (DN−). After the OGTT, the velocity changes of the blood flow were obtained using an LDV (ALF400-Advance) from each subject (6 subjects for each category).

The experiment was performed at eight chronological events (every 30 minutes for the duration of the experiment). At each event blood was sampled and the blood flow data were collected at a sampling rate of 5 Hz for the duration of 7 minutes. Spectral analyses of the blood flow waveforms were performed using a 2048-point FFT algorithm.

Data Analysis

After the program has stored the data, laser doppler parameters and the frequency components of the blood flow waveforms were calculated. Laser doppler parameter, \( F \), obtained from the experiment was

\[
F = \sqrt{\omega^2 P(\omega) \, d\omega}
\]  

where, \( P(\omega) \) was a power spectral density at frequency \( \omega \). The peak power spectrum and the integral power spectrum were obtained in the frequency ranges 0.02-0.16 Hz. The index, \( P_G \).
Spectral Analysis of Blood Flow Waveform for Blood Glucose Level Detection - Preliminary Study

Jae J. Im and Sang H. Nam

Department of Biomedical Engineering, Inje University
607 Obang-dong, Kimhae, Kyungnam, KOREA

Abstract - Development of a noninvasive measurement for the blood glucose level was performed by extracting a frequency components from the blood flow velocity waveform during an OGTT (Oral Glucose Tolerance Test). The index, \( P_g \), was obtained by calculating the ratio of changes in the power spectrum of the waveform to the changes in the level of blood glucose. They were classified into three groups, normal, diabetics with and without showing neuropathic subjective symptoms. The resulting indices calculated were \( P_g(N) = 1.0 \pm 0.2 \), \( P_g(DN^+)=0.1 \pm 0.08 \), and \( P_g(DN^-)=0.3 \pm 0.1 \). The conclusions drawn from the experiment indicated that the spectral analyses of the blood flow waveform could be used as a significant indicator for the blood glucose level.

INTRODUCTION

Blood glucose level affects the compliance of the blood vessels and viscosity, and it finally causes the resistance changes to the blood flow. Therefore, an analysis of the variability on the characteristics of the blood flow waveform may provide the significant information regarding blood glucose level, which is affected by the hormonal and neural controls[1,2].

Among various methods of measuring blood glucose level, OGTT is prevalent as a biological measurement method. Also, diabetic patients show blood glucose level 15% lower than the plasma glucose level, but the capillary glucose appears to have a level of 8% higher than the venous glucose level[3]. From these point of view, the characteristics between flow dynamics of the blood and the variability of the blood flow velocity could provide the pathological information regarding imbalance of the homeostasis. These changes can be obtained by analyzing periodicities of the blood flow waveforms[4].

The objective of the experiment was to establish the relationship between blood glucose level and the frequency components of the blood flow waveform obtained from a index finger using an LDV (Laser Doppler Velocimetry).

METHODS

Experimental Design

The experiment was devised with eighteen subjects who were known to normal, diabetic neuropathy with subjective symptoms (DN+), and diabetic without subjective symptoms (DN-). After the OGTT, the velocity changes of the blood flow were obtained using an LDV (ALF400-Advance) from each subject (6 subjects for each category).

The experiment was performed at eight chronological events (every 30 minutes for the duration of the experiment). At each event blood was sampled and the blood flow data were collected at a sampling rate of 5 Hz for the duration of 7 minutes. Spectral analyses of the blood flow waveforms were performed using an 2048-point FFT algorithm.

Data Analysis

After the program has stored the data, laser doppler parameters and the frequency components of the blood flow waveforms were calculated. Laser doppler parameter, \( F \), obtained from the experiment was

\[
F = \sqrt{\alpha^2 \cdot P(\omega) \cdot d\omega}
\]

where, \( P(\omega) \) was a power spectral density at frequency \( \omega \). The peak power spectrum and the integral power spectrum were obtained in the frequency ranges 0.02 - 0.16 Hz. The index, \( P_g \).
was calculated as the ratio of changes in the power spectral coefficients as a energy distribution to the dosage of glucose during OGTT.

\[ P_g = \frac{\Delta \text{Power Spectrum}}{\Delta \text{Glucose}} \]  

(2)

RESULTS AND DISCUSSION

The representative power spectra are shown in Fig. 1, which reflect the changes of blood glucose variability 60 minutes after the OGTT.

The results reveal that the energy of the waveform is concentrated at the frequency range of \(0.02 \sim 0.166\) Hz and \(0.8 \sim 1.1\) Hz for the normal subjects, while the spectral energy is distributed almost evenly throughout the frequency range \((0.2 \sim 1.25\) Hz) for the diabetic patients with neuropathic subjective symptoms.

As can be seen in Table I, the index value becomes lower for the patients having diabetes and neuropathic symptoms. These variability of the indices could possibly diagnose the progress of the diabetic mellitus.

<table>
<thead>
<tr>
<th>CONDITION</th>
<th>INDEX</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>(P_g(N))</td>
<td>1.0 ± 0.20</td>
</tr>
<tr>
<td>Diabetic w/o Neuropathy</td>
<td>(P_g(DN^-))</td>
<td>0.3 ± 0.10</td>
</tr>
<tr>
<td>Diabetic Neuropathy</td>
<td>(P_g(DN^+))</td>
<td>0.1 ± 0.08</td>
</tr>
</tbody>
</table>

CONCLUSION

The conclusion drawn from calculating power spectral density function and the index, \(P_g\), are (1) the differences in blood flow before and after the OGTT reflects the abnormality in the autonomic nervous system which controls the vasomotion of the blood vessel, (2) the spectral analyses of the blood flow waveform is a valuable indicator for the blood glucose level detection.

Moreover, this experiment could be expanded to study the effect of autonomic nervous system which regulates the variability of the blood flow in the physiological aspects of blood circulation.

REFERENCES