Non-invasive Fourier Transformed Infrared Spectroscopy for the Measurement of Submucosal Tissue Glucose Concentration—Application of Chalcogenide Optical Fiber System

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Recently, innovative methods for non-invasive blood glucose monitoring are being developed. The most promising technologies for use in a non-invasive blood glucose monitoring system are, 1) near-infra red light (NIR), 2) far-infra red (FIR) radiation spectroscopy, 3) radio wave impedance, 4) optical rotation of polarized light and 5) fluid extraction from skin.

In 1978, Kaiser indicated the possibility of the non-invasive method of glucose measurement, by analyzing the infra-red absorption spectrum through attenuated total reflection (ATR) prism [1]. In this article, we report the results of our experiments on quantitative analysis of glucose concentration by Fourier transformed infrared spectroscopy with an ATR prism. In principle, the light from the nichrome emitter was introduced into a sample cell, reflected by the ATR prism repeatedly, and finally detected by nitrogen cooled mercury copper tellurium (MCT) detector.

By using Fourier transformed infrared spectroscopy (FT-IR), we examined, therefore, the infra-red absorbbance of glucose solutions with various concentrations at the wave numbers from 400 to 4300 cm^{-1}. Glucose had a characteristic absorbance at peaks with wave numbers 1033 and 1080 cm^{-1}, possibly due to the stretching motion and rotation of the pyran ring. Measured signals were proportional to glucose concentrations as predicted by Lambert-Beer's law. Red blood cell corpuscles, albumin, globulin and cholesterol interfered with absorbance spectrum of glucose and shifted the baseline upwards significantly. To eliminate these interferences and then measure glucose concentrations quantitatively in serum and blood samples, the feasibility of the difference absorbance with fasting sample as an individual characteristic was studied. Blood and serum glucose concentrations could be measured quantitatively or monitored if the baseline drift and interferences were subtracted [2].

The characteristic absorbance specific to glucose molecule was also observed in the spectra through mucous membrane of the lip. However, these glucose specific peaks significantly varied with the interferences and the pressure variation of ATR prism attachment to mucous membrane, so that the peak intensities at 1033 and 1080 cm^{-1} were poorly correlated with the blood glucose concentration [3].

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To make easy attachment of ATR prism to mucous membrane of lip and easy control of the attachment pressure, we have applied the chalcogenide optical fiber system (Spectra Tech company, California, USA) connecting with FT-IR. Since infra-red light emission is gradually absorbed during

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passing through the optical fiber, in this experiment, therefore, we have applied new FT-IR spectroscopy with high resolution ($0.25cm^{-1}$) and significantly higher signal-noise ratio (0.01%). Chalcogenide ATR prism is built in the tip of the optical fiber. The light is introduced through optical fiber, reflecting by ATR prism, and passed through optical fiber back to the detector. The optical fiber tip with ATR prism is placed on the mucous membrane of lip to make attachment pressure constant (Figure 1).

Because of the characteristics of the optical fiber, the peak intensity of 1033 cm^{-1} varied significantly. Therefore, in this experiments, we used the peak intensity at 1080 cm^{-1}. Spectral changes caused by various pressure of ATR prism attachment to mucous membrane of lip were also observed at glucose specific bands at 1080 cm^{-1}, but the changes were very small, as compared with these of previous experiments. As a result, highly significant correlation between the difference absorbances with fasting level and increases in blood glucose concentrations above fasting level were observed with this optical fiber system (Figure 2).

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In conclusion, by using Fourier transform infra-red spectroscopy with ATR prism, firstly, glucose has characteristic absorbances at the wave numbers of 1033 and 1080 cm^{-1} and the absorption intensities are proportional to glucose concentrations. Secondly, glucose concentrations in the serum and whole blood samples could be measured quantitatively, if the base-line drifts and interferences other than glucose were subtracted. Thirdly, by using optical fiber system to make the attachment pressure of ATR prism to mucous membrane of lip constant, glucose concentrations in mucosal epithelium could be measured or monitored non-invasively, by analyzing difference absorbance spectra through mucous membrane of lip.

References

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