Millimeter-Wave Non-Invasive Monitoring of Glucose in Anesthetized Rats

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***Abstract*—The realization of a non-invasive monitor for determining blood glucose concentrations in human subjects is a prescient driver for many new techniques spanning optical, chemical, electronic and radio sensors. Microwaves offer the possibility of simple, compact, non-invasive, and continuous measurement of glucose level in the superficial tissue without significant heating, tissue labeling, or any short or long term deleterious effects on the subject. This paper demonstrates what we believe is the first correlative measurement of real time millimeter-wave (MMW) absorption with glucose and insulin levels in a live animal, the anesthetized rat. The authors use a commercial vector network analyzer and a simple non-invasive waveguide probe to monitor transmission and reflection of Ka MMW band (26-40 GHz) through the ear. The data shows good correlation between MMW absorption and levels of insulin, glucose and saline (control).**

I. Introduction

COMPACT, transportable and continuous monitoring of blood glucose levels without the need for invasive sampling of the blood is a “Holy Grail” for biomedical companies trying to develop technologies to help diabetic patients, especially during sleep periods. MMW transmission through in vitro human blood samples has been shown to vary with glucose concentration due to correlative changes in the complex refractive index [1].

II. Results

We have developed a very simple waveguide-to-waveguide active transmission probe that can clamp on the ear, finger webbing, or any loose skin fold, and can be continuously monitored by a vector analyzer to measure changes in transmission or absorption of the incident millimeter-wave power. Using power levels well below the safe exposure limit of 1mW/cm^2, we have been able to record significant changes in the absorption and reflection coefficient (magnitude and phase) of signals between 27 and 34 GHz measured through the ear (including the skin and underlying perichondrium) during 1-ml intraperitoneal injections of glucose and insulin in anesthetized rats. The injected amounts of glucose (1-2 g per kg of body weight) and insulin (0.25-2 Units per kg of body weight) produced the changes in the blood glucose level that are within the range of fluctuations observed in diabetic patients. As a negative control, the same rat was injected with 1 ml of saline.

The changes observed (increase in millimeter-wave transmission after glucose injection and decrease in transmission after insulin injection), are consistent with the reported decrease in millimeter-wave conductivity and index of refraction of in vitro blood samples with increasing glucose concentration [2] and follow a Cole-Cole model for dielectric change with frequency. The relatively slow time constant (15-20 minutes) for the observed changes relates to the speed of glucose/insulin absorption from the intraperitoneal space and into blood circulation. A much slower drift in the transmission seen after the saline injection is consistent with fluctuations in the body temperature and respiration rate during the experiment. Reflection measurements showed similar changes, but with much poorer signal-to-noise ratio. Phase comparisons were also made, but they too suffered more variation with time than simple transmission magnitude plots.

III. Summary

These experiments provide one of the first demonstrations of real time non-invasive monitoring of glucose concentration in vivo using millimeter-wave signals. Follow-up experiments will correlate the MMW data with actual glucose concentration in the blood of awake animals and will carefully investigate the possibility of the confounding influence of glucose-coupled biochemical and/or physiological parameters.

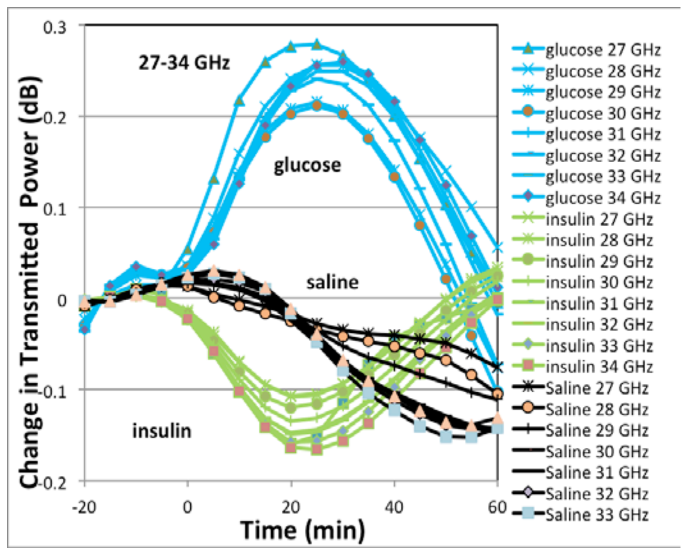

Fig. 1. Change in millimeter-wave transmission through the animal ear as a function of time for various frequencies between 27-34 GHz. At time t=0 injections were given of: 2g/kg Glucose (blue), 1 ml Saline (black) and 2 Units/kg Insulin (green). Typical absorption time is 20 minutes. Note that the levels track the expected shift in absorption due to change in the imaginary part of the index of refraction, consistent with prior data from published millimeter wave measurements on blood glucose (see text).

References

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