Dielectric Properties of Urine for Diabetes Mellitus and Chronic Kidney Disease between 0.2 GHz and 50 GHz

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Abstract-**This paper investigates the dielectric properties of urine among normal subjects, subjects with diabetes mellitus (DM) and subjects with chronic kidney disease (CKD) at microwave frequency between 0.2 GHz and 50 GHz. The measurements were conducted using open-ended coaxial probe at room temperature (25°C), 30°C and human body temperature (37°C). Statistical significant differences in dielectric properties were observed across temperatures among normal, DM and CKD subjects. Significant differences were reported across subject groups at 25°C, 30°C and 37°C respectively.**

Keywords-**dielectric properties, urine, diabetes mellitus, chronic kidney disease**

I. Introduction

Recently, dielectric properties measurement is generating interest for clinical utility. Dielectric properties are categorised in terms of dielectric constant (ε') and dielectric loss factor (ε'').ε' and ε'' measure polarization and heat dissipation of material respectively in the presence of electromagnetic field that affected by electric field. Generally, dielectric properties are affected by temperature, frequency, composition and orientation.

Previous studies had reported that the dielectric properties changed with tissue type [1, 2] and biological fluid [3-8].Gabriel, Gabriel [1] and Gabriel, Lau [2] reviewed frequency and temperature dependency of dielectric properties with tissues. They reported that the dielectric behaviors were changed due to different water content and blood infiltration rate within tissues [1, 2]. Dielectric properties were varied with different hematocrit, ionic salt or glucose level in blood [6, 9, 10]. Lonappan, Bindu [4] pointed out that the presence of glucose in urine (diabetes mellitus) caused increment of dielectric constant at frequency up to 3GHz.

Chronic kidney disease (CKD) is a disease that is presence of proteinuria followed by progressively decline of renal function (increment of serum creatinine level)[11]. Monitoring urinary protein is required as a standard care of diagnosis and prognostication of patients with CKD. Studies had investigated the dielectric properties of protein solution from animal hemoglobin [12, 13], bovine serum solution [14], whale myoglobin [15] and chicken lysozyme [16]. Nandi and Bagchi [15] found that the dielectric constant increased with concentration of whale myoglobin solution at low frequency while decreased at high frequency up to 1GHz at 20°C.

In this study, we aim to investigate dielectric properties of urine among normal subjects, subjects with diabetes mellitus (DM) and subjects with chronic kidney disease (CKD) at room temperature (25°C), 30°C and body temperature (37°C) respectively between microwave frequency of 0.2 GHz and 50 GHz. Statistical analysis will be conducted to determine the significant difference in dielectric properties across the temperatures and subject groups.

II. Methodology

A total of 51 subjects were recruited in this study.50ml random spot urine samples were collected from 20 normal subjects as the control group, 15 diabetes mellitus (DM) patients with glycosuria and 16 chronic kidney disease (CKD) patients with proteinuria. Medical ethics approval was obtained from the Institutional Ethics Review Committee, UMMC, Malaysia before carrying out the study. All subjects were given of informed consent before the urine collection. Fresh urine samples were collected and stored in refrigerator at temperature of 4°C before measurement within 4 hours. No preservatives were added to the urine upon collection.

Open-ended coaxial slim probe with computer controlled network analyzer (PNA Agilent E8364C)) in frequency range between 0.2 to 50 GHz was used to measure the dielectric properties in terms of dielectric constant (ε') and dielectric loss factor (ε''). The network analyzer was calibrated with reference air, short circuit and deionized water before measurement. Refresh calibration type was set by using e-calibration as standard.

Urine samples were heated to room temperature (25°C) using water bath with a precision of ± 0.1°C and the samples were gently stirred. The dielectric probe was cleaned and sterilized using alcohol wipe before each measurement.

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Experiments were repeated by heating urine sample to 30°C and 37°C respectively. Three measurements were recorded at each temperature.

One-way ANOVA test of SPSS Statistic 21.0 (SPSS, Inc., Chicago, IL) was used to determine the significant differences of dielectric properties across the temperatures and subject groups. The level selected for statistical significance was set at probability value <0.05.

III. Results

Figure 1 shows the average dielectric properties of subject groups with respect to frequencies from 0.2 to 50 GHz at temperature 25°C, 30°C and 37°C respectively. In general, dielectric properties changed with frequency and temperature. In comparison between subject groups, more differences were observed between normal and CKD subjects than between normal and DM subjects.

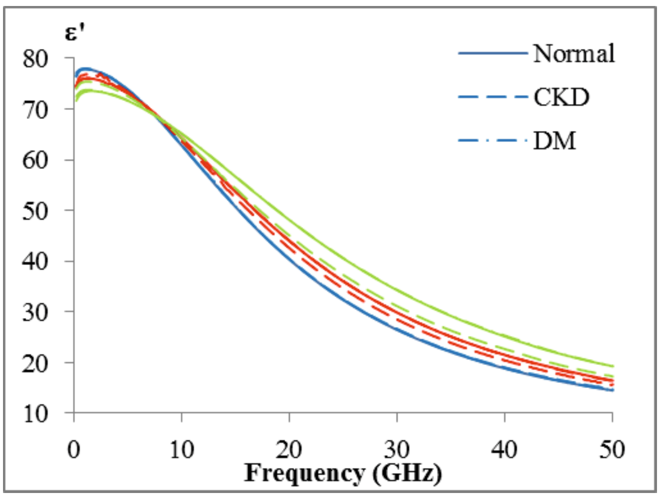

Fig. 1 Average dielectric constant of subject groups at 25°C (__), 30°C (__), and 37°C (__)

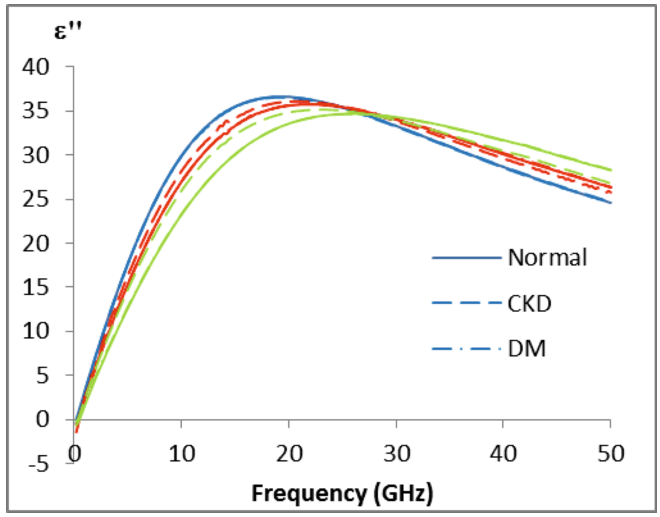

Fig. 2 Average dielectric loss factor of subject groups at 25°C (__), 30°C (__), and 37°C (__)

Statistical significant differences ($p<0.05$) in dielectric properties were observed across the temperatures among normal subjects, DM subjects and CKD subjects. Table 1 to Table 6 shows F number and p value of dielectric properties across subject groups at different microwave frequencies. Significant difference ($p<0.05$) in dielectric properties were reported across the three subject groups at the respective temperature.

Table 1 F number and p-value of dielectric constant across subject groups at 25°C

Frequency (GHz)	F number	p-value
5	1.613	0.210
15	4.683	**0.014**
25	3.418	**0.041**
35	2.819	0.070
45	2.163	0.126

Table 2 F number and p-value of dielectric constant across subject groups at 30°C

Frequency (GHz)	F number	p-value
5	14.671	**<0.01**
15	16.509	**<0.01**
25	16.532	**<0.01**
35	17.049	**<0.01**
45	17.465	**<0.01**

Table 3 F number and p-value of dielectric constant across subject groups at 37°C

Frequency (GHz)	F number	p-value
5	17.206	**<0.01**
15	16.312	**<0.01**
25	16.274	**<0.01**
35	16.204	**<0.01**
45	15.211	**<0.01**

Table 4 F number and p-value of dielectric loss factor across subject groups at 25°C

Frequency (GHz)	F number	p-value
5	1.370	0.264
15	0.901	0.413
25	3.466	**0.039**
35	4.844	**0.012**
45	6.270	**<0.01**

Table 5 F number and p value of dielectric loss factor across subject groups at 30°C

Frequency (GHz)	F number	p value
5	17.806	**<0.01**
15	17.504	**<0.01**
25	1.664	0.200
35	13.269	**<0.01**
45	13.050	**<0.01**

Table 6 F number and p-value of dielectric loss factor across subject groups at 37°C

Frequency (GHz)	F number	p-value
5	16.951	**<0.01**
15	16.504	**<0.01**
25	14.183	**<0.01**
35	17.874	**<0.01**
45	15.111	**<0.01**

IV. Discussion

According to Figure 1 and Figure 2, a "cross-over" frequency point was observed where dielectric constant was constant at about 7 GHz and loss factor was constant at about 27GHz respectively with changing of temperature. Dielectric properties showed a decreasing trend at frequencies lower than the respective "cross-over" point and increasing trend at the above frequencies from 25°C to 37°C. Relaxation frequency was increased with increased temperature. This is in agreement with the dielectric properties of water [17] since major component of urine is water content. CKD subjects were observed to have the highest and lowest dielectric properties among the subject groups respectively at below and above the "cross-over" point at 30 °C and 37 °C. The presence of protein could affect dielectric properties of solution [15].

As shown in Table 1 to Table 6, the significant difference across subject groups indicates that the dielectric properties could be important parameters to detect glycosuria and proteinuria. In addition, stronger significant differences across subject groups were reported at 37 °C and 30°C.

Table 7 Group pairs that have significant difference in dielectric constant

Frequency (GHz)	25°C	30°C	37°C
5		DM-CKD, N-CKD	DM-CKD, N-CKD
15	N-DM	DM-CKD, N-CKD	DM-CKD, N-CKD
25	N-DM	DM-CKD, N-CKD	DM-CKD, N-CKD
35		DM-CKD, N-CKD	DM-CKD, N-CKD
45		DM-CKD, N-CKD	DM-CKD, N-CKD

Table 8 Group pairs that have significant difference in dielectric loss factor

Frequency (GHz)	25°C	30°C	37°C
5		DM-CKD, N-CKD	DM-CKD, N-CKD
15		DM-CKD, N-CKD	DM-CKD, N-CKD
25	N-CKD		DM-CKD, N-CKD
35	DM-CKD	DM-CKD, N-CKD	DM-CKD, N-CKD
45	DM-CKD	DM-CKD, N-CKD	DM-CKD, N-CKD

The significant difference in dielectric properties for multi-comparison between subject group pairs is shown in Table 7 and Table 8 using post hoc test analysis. Normal, DM and CKD groups were significantly differed from one another at 30°C and 37°C except for normal and diabetes mellitus group (N-DM) group pair.

V. Conclusions

Dielectric properties of urine for diabetes mellitus and chronic kidney disease have been investigated between 0.2 to 50GHz. Dielectric properties of urine showed a decreasing trend and increasing trend respectively at below and above the "cross-over" frequency point from 25°C to 37°C. Significant differences in dielectric properties were reported across temperatures. Graphically, more differences were observed between normal and CKD subjects than between normal and DM subjects. Dielectric properties of CKD subjects were statistically significant the highest and lowest among subjects groups respectively for below and above "cross-over" frequency point at 37 °C and 30 °C except 25 °C. Significant difference between subject groups was found at 25°C, 30°C and 37°C respectively.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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