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Prediction of chronic kidney disease using urinary dielectric properties and support vector machine

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**ABSTRACT**

In this study, we aim to classify the urinary dielectric properties of subjects with chronic kidney disease (CKD) and normal subjects, at microwave frequency between 1 GHz and 50 GHz using support vector machine (SVM). The dielectric properties of urine were measured at room temperature (25 \(^{\circ}\)C), 30 \(^{\circ}\)C and body temperature (37 \(^{\circ}\)C). Urinary dielectric behaviour differences were observed between respective diabetic kidney disease (DKD) and non-DKD compared to normal subjects. Two-group classifications obtained the highest accuracy of 75.91% and 70.02%, respectively, in differentiating DKD and non-DKD group from normal group. The highest classification accuracy was achieved at 63.94% for three-group classifications. The best classification accuracies were obtained at 30 \(^{\circ}\)C for two-group and three-group classifications.

**ARTICLE HISTORY**

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**KEYWORDS**

Urinary dielectric properties; support vector machine; chronic kidney disease; classification

1. **Introduction**

Diabetes mellitus (DM), also known as hyperglycaemia, is a common public health concern. The prevalence of diabetes among Malaysian adults aged 18 years and above has increased from 11.6% in 2006 to 15.2% in 2011 (Feisul & Azmi 2012). In the United States, 29.1 million (9.3%) of the population were diagnosed having diabetes in 2012 compared to 25.8 million (8.3%) in 2010 (American Diabetes Association 2014). DM is the primary cause of chronic kidney disease (CKD) among other clinical conditions such as polycystic kidney disease, pyelonephritis, glomerulonephritis, autoimmune disorder and congestive heart failure (Feisul & Azmi 2012; American Diabetes Association 2014).

Urinary glucose measurement is an essential non-invasive approach to test for diabetes. Meanwhile, urinary protein is one of the early signs of CKD. Zürbig et al. (2009) reported that initial pathophysiological changes in kidneys resulting in significant changes of urinary proteins as potential biomarkers for the early stage of CKD. Persistent proteinuria followed by progressively decline of renal function is presentations of CKD. Currently,
urinary test strips that use colour charts to determine glycosuria or proteinuria variability are less accurate compared with those that use numerical readouts (Goldstein et al. 2004). Comparison of the results from urinary test strips with laboratory biochemical analysis is always required. However, diagnosis and prognostication of patients with CKD required monitoring of urinary protein as a standard care. Therefore, this provides the motivation to propose a new application for urinary measurement to address those issues.

Recently, the measurement of dielectric properties has generated interest for clinical utility. The presence of chemical compounds or biomaterials drastically affects the chemical and physical characteristics of the viable fluid. Studies related to aqueous solutions and biological fluids reported dielectric properties change with the presence of biomaterials. The effects of temperature and frequency were determined for the changes of the dielectric properties in glucose (Meriakri et al. 2007; Smulders et al. 2013) and protein solution (Boresch et al. 2000; Matyushov 2012). Liao et al. (2001) found that the dielectric constant increased while loss factor decreased with increasing temperature for glucose solution at 2.45 GHz. The presence of urinary glucose showed different dielectric properties of urine (Lonappan et al. 2004; Lonappan et al. 2007). Bassey and Cowell (2013) reported that the dielectric constant decreased with increasing glycosuria molarity at frequency from 0.1 to 3 GHz. Mun et al. (2015a) found that the urinary dielectric properties changed with different glycosuria levels at frequencies up to 50 GHz. On the other hand, the respective variations of glucose, ionic salt and haematocrit level affect the dielectric properties of blood (Alison & Sheppard 1993; Jaspard et al. 2003; Abdalla et al. 2010). Nandi and Bagchi (1998) discovered that the dielectric constant increased in whale myoglobin solution at low frequency (< 10 MHz), while decreased at high frequency. Proteins such as amino acids (Boresch et al. 2000; Rodriguez-Arteche et al. 2012), horse haemoglobin (Ferry & Oncley 1938; Oncley 1938), bovine serum albumin (Grant et al. 1968), and lysozyme from chicken egg (Wolf et al. 2012) solutions resulted in different dielectric properties compared to water. The potential of urinary dielectric properties to detect different proteinuria level were investigated at different temperature (Mun et al. 2015b). Protein-bound water affects the linear conduction of a solution that causing changes of the overall dielectric properties due to drift scatter motion along the electrical field side (Pethig & Kell 1987; Abdalla et al. 2010).

Data classification is the most intensively studied method in statistics and decision science. It has been applied in disease diagnosis (Polat et al. 2008; Karabatak & Ince 2009; Barakat et al. 2010; Ganji & Abadeh 2011), credit evaluation and image recognition (Michie et al. 1994). Support vector machine (SVM)-based classification method has been widely used to classify urinary proteins of kidney disease (Haubitz et al. 2005; Kistler et al. 2009; Alkhalaf et al. 2010; Gronwald et al. 2011) and diabetes (Ban et al. 2010; Roshan et al. 2011). SVM classifier is proposed to be able to distinguish between malignant breast tissue (Kerhet et al. 2006; Laufer & Rubinsky 2009; Grewal & Golnaraghi 2014), prostate cancer (Shini et al. 2011) and brain injury tissue (Gonzalez et al. 2013) by measuring its electrical impedance properties. Kerhet et al. (2006) concluded that considering the dielectric properties of breast tissue as priority in classification database has increased the classification probability value between a tumour and normal breast tissue.

In this study, we measured the urinary dielectric properties of subject groups, which involved subjects with CKD and normal subjects at room temperature (25°C), 30°C and body temperature (37°C), respectively, between microwave frequency ranging from
1 GHz to 50 GHz. CKD subjects were further classified into diabetic kidney disease (DKD) and non-DKD. SVM-based classification was applied to classify urinary dielectric properties among subject groups and the effect of temperature was determined.

2. Material and methods

2.1. Subjects selection and urine collection

A total of 329 subjects aged between 20 and 80 years were recruited in this study. Out of these, 232 subjects with CKD whose estimated glomerular filtration rate (eGFR) <60 ml/min per 1.73 m² for at least 3 months were recruited from the outpatient clinics of the University of Malaya Medical Centre (UMMC). CKD subjects were further classified into DKD of n = 102 and non-DKD (n = 130) subject groups. DKD subjects were recruited with the following criteria: fasting plasma glucose >7.0 mmol/L and HbA1c >6.0%. The remaining 97 subjects were healthy subjects who were recruited at the University of Malaya, Malaysia as normal subjects. Normal subjects recruited were those without history of kidney or bladder-related diseases. Exclusion criteria involved normal subjects with albuminuria, glycosuria or haematuria. Medical ethics was approved by the Institutional Ethics Review Committee, UMMC. Written informed consent was obtained from each subject to participate in this study. Clinical characteristics of the subjects are summarized in Table 1.

60 ml of random spot mid-stream urine samples were collected from each subject. The urine samples were collected using sterile urine containers. The chemical variables of the urine samples were measured using the routine methods of clinical biochemistry and microscopy tests for urinalysis at the Division of Laboratory Medicine, UMMC. The collected urine samples were stored at a temperature of 4°C. The measurement of urinary dielectric properties was conducted in not more than 4 hours from the time of collections. No preservatives were added to the urine samples upon collection. Table 2 shows the urine characteristics of the subject groups.

| Table 1. Clinical characteristics of DKD, non-DKD and normal subjects. |
|-----------------------------|-----------------------------|-----------------------------|
| Subject                     | DKD                         | Non-DKD                     | Normal                     |
| Gender (Male/ Female)       | 68/34                       | 79/51                       | 51/46                      |
| Age (years)                 | 65 ± 10                     | 64 ± 12                     | 27 ± 8                     |
| Systolic BP (mmHg)          | 147 ± 20                    | 137 ± 19                    | 115 ± 10                   |
| Diastolic BP (mmHg)         | 74 ± 13                     | 72 ± 14                     | 72 ± 7                     |
| Serum creatinine (µmol/L)   | 248 ± 149                   | 218 ± 107                   | <115                       |
| eGFR (ml/min per 1.73m²)    | 21 ± 12                     | 27 ± 16                     | >90                        |

| Table 2. Urine characteristics of DKD, non-DKD and normal subjects. |
|-----------------------------|-----------------------------|-----------------------------|
| Subject                     | DKD                         | Non-DKD                     | Normal                     |
| Protein (g/L)               | 2.71 ± 1.11                 | 2.15 ± 1.30                 | –                          |
| Glucose (g/L)               | 3.08 ± 2.70                 | –                           | –                          |
| Creatinine (µmol/L)         | 6417 ± 3421                 | 6649 ± 3755                 | 9669 ± 2129                |
| Urea (mmol/L)               | 152 ± 59                    | 172 ± 61                    | 203 ± 136                  |
| Cl⁻ (mmol/L)                | 77 ± 31                     | 86 ± 41                     | 111 ± 65                   |
| Na⁺ (mmol/L)                | 79 ± 32                     | 83 ± 46                     | 99 ± 67                    |
| K⁺ (mmol/L)                 | 28 ± 16                     | 33 ± 14                     | 35 ± 27                    |
2.2. Urinary dielectric properties measurement

The urinary dielectric properties were measured using Agilent E8364C personal network analyzer (Agilent Technologies, Santa Clara, CA) connected to standard voltage between 230 and 240 V (AC) and with 50 GHz flexible cable open-ended coaxial slim probe. The system was calibrated with standard references such as air, short circuit and deionized water, and electronic-calibration (E-Cal) was used as the refresh calibration standard.

Before the measurements were conducted, the urine samples were gently stirred to avoid precipitation after refrigeration. The samples were found no presence of air bubbles in the solution upon stirring. The urine samples were heated to room temperature (25°C) using a water bath (Memmert WNB7, Duesseldorf, Germany) with a precision of ±0.1°C. Movement of the probe and test table was avoided during the measurements. The overall measurement setup is similar to that reported in Mun et al. (2015b), as presented in Figure 1. The experiments were repeated by measuring the urine samples at 30°C and 37°C, respectively.

2.3. Support vector machine (SVM)

SVM is a classification technique that was first pioneered by Vapnik (1995) for pattern classification and nonlinear regression. It implements the method of structural risk minimization and is able to provide a good generalization performance on pattern classification (Haykin & Network 2004). The decision function of a linear hyperplane separation is

\[ w^T x + b = 0, \]  

(1)

where \( x \) is an input vector, \( w \) is an adjustable weight vector and \( b \) is bias. Let the training sample, \( X = \{x_1, x_2, ... x_n\} \) and \( d_i \) as the desired output

\[ w^T x + b \geq 0 \quad \text{if} \quad d_i = +1; \]  

(2)

\[ w^T x + b < 0 \quad \text{if} \quad d_i = -1. \]  

(3)
The optimal hyperplane function represents multidimensional linear decision function is

\[ g(x) = w_0^T x + b_0. \]  

(4)

The results of classification must satisfy the following inequality for \( d_i = +1 \) and \( d_i = -1 \):

\[ d_i(w_0^T x_i + b_0) \geq 1, \quad i = 1, 2, 3, \ldots n. \]  

(5)

Consider support vector \( x^{(s)} \) for \( d^{(s)} = +1 \). By definition, the following function obtained:

\[ g(x^{(s)}) = w_0^T x^{(s)} \pm b_0 = \pm 1, \]  

(6)

when \( d^{(s)} = \pm 1 \).

Given equation of optimal hyperplane is related to desired algebraic distance, \( r \):

\[ r = \frac{g(x^{(s)})}{\|w_0\|} = \begin{cases} 
\frac{1}{\|w_0\|} & \text{if } d_i = +1 \\
-\frac{1}{\|w_0\|} & \text{if } d_i = -1 
\end{cases}. \]  

(7)

The margin of separation is between the hyperplane and the closest data point, \( p \). From the equation above, it follows that

\[ p = 2r = \frac{2}{\|w_0\|}. \]  

(8)

Hence, the Euclidean norm of weight vector, \( w \) is maximized as the goal of an SVM.

For nonlinear classification, inner-product Kernel is developed. It converts nonlinear input data into high dimensional linear feature space. The three types of inner-product Kernels functions as shown in Table 3 are commonly used for SVM.

### 2.4. Classification model

SVM-based classification of urinary dielectric properties was performed using the LIBSVM tool in Matlab software (version 2010a). A total of 10 variables from the urinary dielectric properties dispersion of the measured frequency ranging from 1 GHz to 50 GHz were used. Classification was accomplished based on three-fold cross validation method. Two-thirds of the database was used as the training set and the remaining one-
third was used for validation. The classification was repeated three times based on different training and validation sets from the same database. The prediction accuracies were calculated by averaging the results of the three test sets. RBF kernel, \( K(x, x_i) = \exp(-\gamma \|x - x_i\|^2) \) was applied with the parameter, \( \gamma \in [0.1, 10] \) were tested in the system to determine the optimal classification accuracy. Classification models were generated based on the respective urinary dielectric constant and loss factor at 25°C, 30°C and 37°C, respectively. The classifiers were applied to the database to predict the disease of the subjects based on different urinary dielectric behaviours.

3. Results

3.1. Overview

Tables 4 and 5 show the mean and standard deviation of measured urinary dielectric properties for DKD, non-DKD and normal subjects at different frequency points. The cross-comparisons of urinary dielectric properties for different subject groups at respective temperature of 25°C, 30°C and 37°C are presented in Figure 2. According to Figure 2, an ‘inflexion’ frequency point was determined at about 7 GHz for the urinary dielectric constant and 27 GHz for the loss factor, respectively. These findings are in agreement with the study by Mun et al. (2015b). The urinary dielectric properties of DKD and non-DKD subjects were found to be higher than normal subjects at frequencies below the ‘inflexion’ point, while lower than those of the normal subjects at frequencies above the ‘inflexion’ point. The urinary dielectric properties showed more differences between normal and non-DKD, compared to DKD subjects. The urinary dielectric properties decreased and increased with temperature at frequencies below and above the ‘inflexion’ point, respectively. The strength of urinary dielectric properties differences between subject groups was found affected by the temperature of urine (Mun et al. 2015a; Mun et al. 2015b).

3.2. Classifications

To avoid bias due to the mean differences of urinary dielectric properties between subject groups, classifications of urinary dielectric behaviour were performed using a total of 10 different variables of frequencies points with an interval of 5 GHz at the microwave frequency ranging from 1 GHz to 50 GHz. RBF kernel with \( \gamma = 0.5 \) was found to show optimal performance in the classifications of urinary dielectric behaviour at the frequency range between 1 GHz and 50 GHz.

3.3. Two-group classifications: DKD vs normal and non-DKD vs normal

The classification results of dielectric properties between DKD vs normal and non-DKD vs normal at 25°C, 30°C and 37°C, respectively, are summarized in Tables 6–8. Overall, higher accuracies were obtained using urinary dielectric constant compared to loss factor. The highest classification accuracy of 75.91% and 67.30% was achieved at 30°C for dielectric constant and loss factor, respectively. Higher accuracies were found in classification of DKD than non-DKD from normal subjects.
### Table 4. Mean and standard deviation of urinary dielectric constant of DKD, non-DKD and normal subjects at different frequencies.

<table>
<thead>
<tr>
<th>f (GHz)</th>
<th>25°C</th>
<th>30°C</th>
<th>37°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DKD</td>
<td>Non-DKD</td>
<td>Normal</td>
</tr>
<tr>
<td>5</td>
<td>73.77 ± 0.13</td>
<td>73.72 ± 0.05</td>
<td>73.76 ± 0.05</td>
</tr>
<tr>
<td>10</td>
<td>62.82 ± 0.09</td>
<td>62.80 ± 0.12</td>
<td>62.82 ± 0.06</td>
</tr>
<tr>
<td>15</td>
<td>50.70 ± 0.09</td>
<td>50.69 ± 0.13</td>
<td>50.71 ± 0.06</td>
</tr>
<tr>
<td>20</td>
<td>40.36 ± 0.08</td>
<td>40.33 ± 0.11</td>
<td>40.35 ± 0.05</td>
</tr>
<tr>
<td>25</td>
<td>32.29 ± 0.07</td>
<td>32.25 ± 0.14</td>
<td>32.39 ± 0.06</td>
</tr>
<tr>
<td>30</td>
<td>26.48 ± 0.12</td>
<td>26.42 ± 0.25</td>
<td>26.49 ± 0.07</td>
</tr>
<tr>
<td>35</td>
<td>22.13 ± 0.12</td>
<td>22.11 ± 0.14</td>
<td>22.14 ± 0.08</td>
</tr>
<tr>
<td>40</td>
<td>18.88 ± 0.15</td>
<td>18.87 ± 0.16</td>
<td>18.90 ± 0.08</td>
</tr>
<tr>
<td>45</td>
<td>16.41 ± 0.22</td>
<td>16.36 ± 0.36</td>
<td>16.44 ± 0.11</td>
</tr>
<tr>
<td>50</td>
<td>14.50 ± 0.22</td>
<td>14.41 ± 0.62</td>
<td>14.56 ± 0.20</td>
</tr>
</tbody>
</table>

### Table 5. Mean and standard deviation of urinary loss factor of DKD, non-DKD and normal subjects at different frequencies.

<table>
<thead>
<tr>
<th>f (GHz)</th>
<th>25°C</th>
<th>30°C</th>
<th>37°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DKD</td>
<td>Non-DKD</td>
<td>Normal</td>
</tr>
<tr>
<td>5</td>
<td>17.69 ± 0.08</td>
<td>17.79 ± 1.66</td>
<td>17.63 ± 0.19</td>
</tr>
<tr>
<td>10</td>
<td>29.92 ± 0.05</td>
<td>29.98 ± 1.0</td>
<td>29.89 ± 0.10</td>
</tr>
<tr>
<td>15</td>
<td>35.50 ± 0.07</td>
<td>35.53 ± 0.49</td>
<td>35.45 ± 0.07</td>
</tr>
<tr>
<td>20</td>
<td>36.60 ± 0.09</td>
<td>36.59 ± 0.19</td>
<td>36.57 ± 0.06</td>
</tr>
<tr>
<td>25</td>
<td>35.42 ± 0.10</td>
<td>35.41 ± 0.19</td>
<td>35.39 ± 0.06</td>
</tr>
<tr>
<td>30</td>
<td>33.32 ± 0.14</td>
<td>33.31 ± 0.26</td>
<td>33.28 ± 0.60</td>
</tr>
<tr>
<td>35</td>
<td>30.98 ± 0.16</td>
<td>30.96 ± 0.34</td>
<td>30.93 ± 0.08</td>
</tr>
<tr>
<td>40</td>
<td>28.67 ± 0.18</td>
<td>28.61 ± 0.51</td>
<td>28.63 ± 0.08</td>
</tr>
<tr>
<td>45</td>
<td>26.56 ± 0.20</td>
<td>26.46 ± 0.65</td>
<td>26.48 ± 0.12</td>
</tr>
<tr>
<td>50</td>
<td>24.64 ± 0.13</td>
<td>24.54 ± 0.59</td>
<td>24.53 ± 0.15</td>
</tr>
</tbody>
</table>
Figure 2. Measured urinary dielectric properties for different subject groups. Comparison of mean urinary dielectric properties between subject groups of (a) DKD and normal, and (b) non-DKD and normal, at respective temperature of 25°C (black), 30°C (red) and 37°C (blue).
3.4. Three-group classification: DKD vs non-DKD vs normal

Tables 9 and 10 show the confusion matrix of the classification for urinary dielectric behaviour among DKD, non-DKD and normal group at 25°C, 30°C and 37°C. Again, the highest classification accuracy was achieved at 30°C (63.94%) for three-group classifications.

Table 9. Confusion matrix of the classification for urinary dielectric constant among DKD, non-DKD and normal group at 25°C, 30°C and 37°C.

<table>
<thead>
<tr>
<th>Comparison groups</th>
<th>$\varepsilon_r'$</th>
<th>$\varepsilon_r''$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DKD vs normal</td>
<td>25 69 8 24.25</td>
<td>39.22 19 73 10 28.43</td>
</tr>
<tr>
<td>Non-DKD vs normal</td>
<td>22 101 7 77.69</td>
<td>80.76 27 95 8 73.08</td>
</tr>
<tr>
<td>Normal</td>
<td>16 17 64 65.97</td>
<td>65.05 12 28 57 58.76</td>
</tr>
</tbody>
</table>

Classification accuracy 55.97 61.67 53.42

Table 10. Confusion matrix of the classification for urinary loss factor among DKD, non-DKD and normal group at 25°C, 30°C and 37°C.

<table>
<thead>
<tr>
<th>Comparison groups</th>
<th>$\varepsilon_r'$</th>
<th>$\varepsilon_r''$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DKD vs normal</td>
<td>28 73 1 27.45</td>
<td>35.29 19 73 10 18.63</td>
</tr>
<tr>
<td>Non-DKD vs normal</td>
<td>30 100 0 76.92</td>
<td>79.23 15 105 10 80.97</td>
</tr>
<tr>
<td>Normal</td>
<td>16 29 67 69.07</td>
<td>77.31 10 26 61 62.89</td>
</tr>
</tbody>
</table>

Classification accuracy 57.81 63.94 54.16
4. Discussion

In two-group classifications, higher classification accuracies were observed in classification of DKD vs normal subjects compared to non-DKD vs normal subjects. The overall deviations were about 1%–8%. The classification model able to distinguish the respective DKD and non-DKD subjects from normal subjects based on the urinary dielectric behaviours. These indicate the existence of a unique pattern of urinary dielectric properties across the subject groups. Urinary glucose is the essential non-invasive approach for diabetic patients. Previous studies found urinary glucose oxidation increases free charges such as 8-iso prostaglandin F2α in the urine of diabetic patients (Monnier et al. 2006; Wentholt et al. 2008). Dielectric properties increase with the increase of dipoles density of free radicals in glucose bio-oxidation process (Abdalla et al. 2010). Meanwhile, urinary protein is the sign of patients with CKD as the pathophysiological changes in their kidneys. Protein-bound water results the drift scatter motion along the electrical field side that affects the linear conduction of a solution. This subsequently changes the overall dielectric properties (Pethig & Kell 1987; Abdalla et al. 2010).

In comparison between CKD and normal subjects, lower levels of mean urinary creatinine, urea and salt ions were observed in CKD subjects. However, statistical analysis reported no significant differences across the constituents between urine of CKD and normal subjects (Mun et al. 2015b). The presence of urinary glucose and protein significantly changes the urinary dielectric properties.

In fact, the temperature of urine may change between the body (37°C) and room temperature (25°C) during the process of collection to measurement. Temperature variation is an important factor that affects dielectric properties. In this study, the highest classification accuracy was obtained at 30°C, compared to 25°C and 37°C. Overall, the classification accuracies were varied from 0.5% to 10% among different temperatures. The intramolecular hydrogen bonds were stretched between water molecules when the temperature changed. This could affect the changes of dielectric properties (Wentholt et al. 2008). Urine is a complex biological solution that consists of different chemical constituents that can be broadly categorized as electrolytes, as well as organic and inorganic compounds. The combination effects of hydrogen bonds, molecular Brownian movement and ionic conductance are increased with the rise in temperature of urine. Nevertheless, randomizing the agitation of molecules at certain high temperature could reduce the significant effect of the overall biomaterials present in urine. In this study, we showed that the dielectric behaviour of urine was optimal at 30°C for classification, while the accuracies decreased when the temperature reaching at 37°C.

According to Tables 9 and 10, the lowest accuracy was mostly obtained when classifying the urinary dielectric properties of DKD group. The common classification error was that the DKD subjects were misclassified as non-DKD subjects. The classification error between DKD and non-DKD group was >50%. These findings showed more significant effect of urinary protein in dielectric properties changes compared to urinary glucose. This is in agreement with the study by Mun et al. (2015a), which reported less observable dielectric properties changed with urinary glucose concentration especially at low frequency range. We found urinary dielectric behaviour would be able to distinguish the CKD subjects from normal subjects based on different pathological processes. Alkhalaf et al. (2010) discovered different biomarkers were found between type-I and II diabetic patients due to different pathophysiology of the particular DKD. Hence, our study suggests that there is a need for future investigation of type-I DKD patients.
In this study, we demonstrated the potential of using urinary dielectric properties to distinguish CKD subjects from normal subjects. Single spot-urine measurement is insufficient for CKD diagnosis; however, it is certainly important for initial targeted disease screening.

5. Conclusions

SVM-based classification models were applied to classify urinary dielectric properties of CKD. Urinary dielectric behaviour differences were observed for respective DKD and non-DKD compared to normal group. In two-group classifications, the highest classification accuracy was achieved at 75.91% and 70.02% for differentiating DKD and non-DKD from normal group, respectively. As for the three-group classifications, the highest classification accuracy was achieved at 63.94%. $30^\circ$C was found optimal for two-group and three-group classifications. Our study demonstrated the potential of using urinary dielectric properties to distinguish between CKD and normal subjects.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Yip Boon Chong is a medical doctor in the Damansara Specialist Hospital, Petaling Jaya, Malaysia. His research interests mainly include nephrology and general medicine for kidney diseases.
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