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Feasibility Study of a Urine Glucose Level Monitor for Home Healthcare Using Near Infrared Spectroscopy

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Abstract— **Urine glucose level monitoring technique using near infrared spectroscopy in conjunction with the chemometric method was newly developed aiming for the use of home health care. The calibration models were obtained by the partial least square method and their validity were assessed using albumin added glucose solution and urine samples. From the results obtained, it was clearly demonstrated that the present method had a capability of predicting urine glucose level with reasonable accuracy (standard error of prediction; 22.3 mg/dl, correlation coefficient; 0.99) and appeared to be a useful means for long-term home health care.**

I. Introduction

ALTHOUGH there are several drawbacks of urine glucose test compared to blood testing [1], daily monitoring of urine glucose level has still been widely used as a rough indicator of high blood glucose levels [2]. For this purpose, there are several kinds of commercially available items such as test strips [3], a pen-shaped enzyme sensor [4] and a sensor system installed in a toilet [5]. Among these, the third one would be an ideal type for long-term home health care, however, there are several drawbacks [5] such as a limited sensor life (4 months or 700 measurements), cumbersome maintenances and a high cost. To overcome these practical drawbacks, we have developed a new technique for measuring urine glucose concentration using near infrared spectroscopy. In this paper, some results of the preliminary experiments carried out for assessing feasibility of the new technique are described.

II. Materials and Methods

For measuring urine glucose level, FTIR spectroscopy in conjunction with the chemometric method of partial least squares (PLS) was adopted and its feasibility was assessed by the preliminary experiments described below.

A. Calibration using Glucose solution

To determine an optimum wavelength range, experiments of calibration by PLS regression using glucose solutions were carried out. Altogether 164 samples with various glucose concentration (0-150 mg/dl) were prepared by dilution. Near infrared spectra of each sample were collected over the spectral range of 1100-1830 nm and 2000-2500nm using a FTIR spectrophotometer (Spectrum One NTS; Perkin Elmer Co. Ltd., USA). The region between 1830 nm and 2000 nm was excluded because of the dominated water adsorption. Using these data, PLS calibration models were generated by the PLS Toolbox 3.5 of MATLAB (Eigenvector Inc., USA). The leave-one-out cross validation method was applied to obtain the Standard Error of Calibration (SEC) for assessing the validity of the model.

B. Validation using Albumin-added Glucose solution

To evaluate the accuracy of the model for predicting glucose concentration, 49 samples with various glucose concentration (0-150 mg/dl) were prepared. In these samples, as one of typical urine substances, appropriate amount of Bovine Serum Albumin (BSA) was added to be the concentration of 300 mg/dl (highest level of urine protein). Near infrared spectra of these samples were collected in the same way, and the glucose concentration was predicted using the model obtained by the experiments mentioned above. Accuracy of the model was assessed by the values of the Standard Error of Prediction (SEP) and the correlation coefficient (r).

C. Calibration and Validation using Urine sample

Calibration and validation studies were conducted using urine samples. Total volume of about 400 ml of urine was collected from a young healthy adult in a day. To obtain urine samples with various glucose concentration level (0-600 mg/dl), appropriate amount of glucose was added. Altogether 126 samples were prepared and the glucose concentration of the samples (measured Glu conc.) was determined using an automatic analyzer (DRI-CHEM 7000; Fujifilm Medical Co. Ltd., Japan). 116 samples were used for obtaining PLS calibration model and 10 samples were used for the accuracy assessment.

III. Results and Discussion

A. Calibration using Glucose solution

Fig. 1 shows the result of PLS regression using the data obtained by the spectral range of 1100-1830 nm. As shown in this figure, quite good linear relationship (r=1.00) and the low

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value of SEC (1.6 mg/dl) were obtained, indicating validity of the PLS model obtained. On the other hand, the values obtained by the spectral range of 2000-2500 nm were worse (r=0.57, SEC=26.1 mg/dl). Based on these results, the spectral range of was fixed to 1100-1830 nm for the following experiments.

B. Validation using Albumin-added Glucose solution

Fig. 2 is the result of the accuracy assessment using BSA added Glu soln. As mentioned before, the PLS model used in this experiment was obtained by Glu solution samples (without albumin). However, the value of SEP and r are still remained within high level (5.2 mg/dl and 0.99, respectively). This suggests the robustness of the obtained model for interferential substances.

C. Calibration and Validation using Urine sample

In Fig. 3, the PLS calibration model obtained by the urine samples is shown. Compare to the result obtained by the Glu solution samples (Fig. 1), the SEC increased (13.0 mg/dl). The main reason of this result is, of course, the existence of many kinds of substances in urine, *e.g.,* urea, creatinine, protein, and so on. However, the SEP between predicted and measured Glu concentration was 22.3 mg/dl (see Fig. 4). This value is much lower than the value reported by Pezzaniti et al [11] (4.3 mmol/l = 77.4 mg/dl). This difference may cause from the difference in the used spectral range. They used the range of 2100-2400 nm because they tried to measure not only glucose but also other four analytes, *i.e.,* urea, ketone, creatinine and protein.

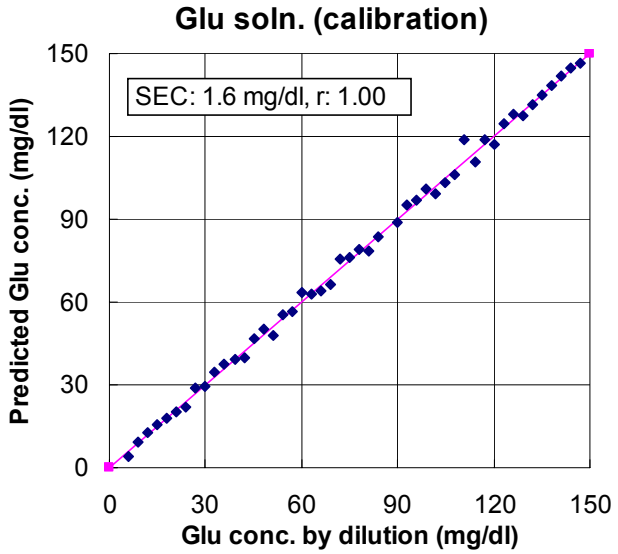

Fig. 1 NIRS predicted vs. reference values for glucose calibration using glucose solution samples.

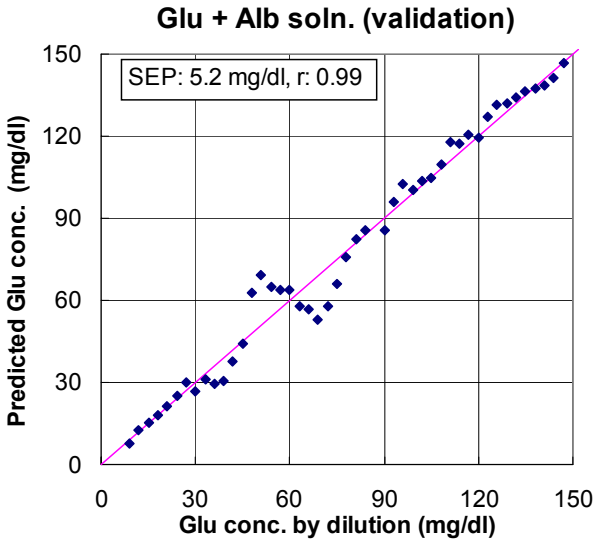

Fig. 2 NIRS predicted vs. reference values for glucose model validation using albumin-added glucose solution samples.

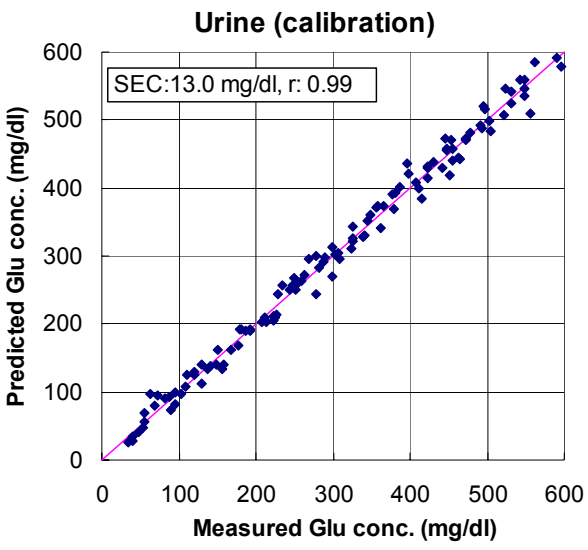

Fig. 3 NIRS predicted vs. measured values for glucose calibration using urine samples.

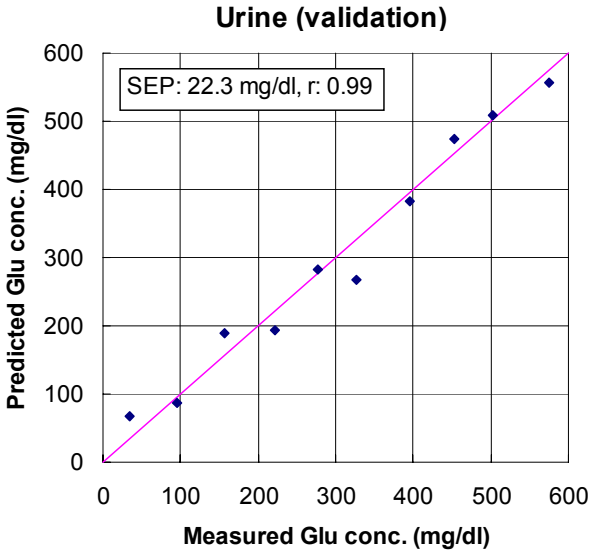

Fig. 4 NIRS predicted vs. measured values for glucose model validation using urine samples.

Improvement in accuracy of the present method will be achieved by increasing the number of urine samples for the PLS calibration. The problems to be solved for the home healthcare use will be (i) reduction of the number of the wavelength for spectral collection, (ii) shift of the present complicated optical system to the convenient LED-photo diode multi-array sensor system, and (iii) development of a urine sampling system which could be installed in a toilet.

IV. Conclusion

A new technique for measuring urine glucose concentration using NIRS in conjunction with PLS was developed. Feasibility of the method was verified by the preliminary experiments using glucose solution and urine samples. From the results obtained, it was clearly demonstrated that the present method had a capability of predicting urine glucose level with reasonable accuracy (SEP; 22.3 mg/dl, correlation coefficient; 0.99) and appeared to be a useful means for long-term home health care.

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