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Automatic classification of glycaemia measurements to enhance data interpretation in an expert system for gestational diabetes

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ABSTRACT

Expert systems for diabetes care need to automatically evaluate glycaemia measurements in relationship to meals to correctly determine patients' metabolic condition and generate recommendations about therapy adjustments. Most glucose meters allow patients to manually label each measurement with a meal tag, but as this utility is not always used, a completion procedure is needed. Classification methods are usually based on predefined mealtimes and present insufficient accuracy that might affect the automatic data analysis. Expert systems in diabetes require a reliable method to manage incomplete glycaemia data so that they can determine if patients' metabolic condition is altered due to a specific meal or due to an extended fasting period.

This paper presents the design and application of a classification module to automatically assign the appropriate meal and 'moment of measurement' to incomplete glycaemia data. Different machine learning techniques were studied in order to design the best classification algorithm in terms of accuracy. The selected classifier was implemented with a C4.5 decision tree with 7 input features selected with a wrapper evaluator and the genetic search algorithm, which achieved 95.45% of accuracy with the training set on cross-validation. The classification module was integrated in the *Sinedie* expert system for gestational diabetes care and was evaluated in a clinical environment for 8 months with 42 patients. A total of 7,113 glycaemia measurements were uploaded by patients into the *Sinedie* system and were completed by the "classification module". The 98.79% of the measurements were correctly classified, while patients modified the automatic classification of 1.21% of them. Classification results were improved by 21.04% compared to a classification based on predefined mealtimes. The automatic classification of glycaemia measurements minimizes the patient's intervention, allows structuring measurements in relationship to meals and makes automatic data interpretation by expert systems more reliable.

1. Introduction

As in other types of diabetes, the prevalence of Gestational diabetes mellitus (GDM) is increasing throughout the world (IDF, 2015). If the new International Association of Diabetes Study Group diagnosis criteria (IADPSG, 2010) –recently proven to be cost effective (Duran, Saenz, & Torrejon, 2014) – are adopted, the prevalence could be doubled. Several adverse outcomes are associated with hyperglycaemia in pregnancy, as foetal macrosomia, shoulder dystocia or caesarean section (Metzger, Lynn, & Lowe, 2008). Although most cases resolve with delivery, both mother and foetus are at a higher risk of developing type 2 diabetes in the future (Boney, 2005; Franks, Looker, & Kobes, 2006).

Maternal glycemic control reduces adverse GDM outcomes (Hartling, Dryden, & Guthrie, 2013) so patients are prescribed to self-monitor their blood glucose (BG) levels with a glucose meter around main meals. Although measurements are stored in the glucose meter memory file, patients usually note down their results in a paper logbook, structuring measurements in relationship to meals. They indicate the specific meal which the measurement is related to (breakfast, lunch or dinner) and whether it was made before (preprandial) or after the meal (postprandial). Clinicians evaluate the patients' measurements each week or every other

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week to determine the appropriate treatment, which consists of nutritional prescription, physical activity and, if necessary, insulin therapy. It has been observed that patients commit errors when manually reporting their BG levels, being the mean values significantly higher than the logbooks' ones (Given, O' Kane, Bunting, & Coates, 2013). Although this could mask a bad glycemic control and make clinicians establish a wrong therapy, they still prefer to examine logbooks instead of meter memory files (Polonsky, Jelsovsky, & Panzera, 2009). The reason might be that logbooks are easier to be reviewed, as they provide structured information that glucose meter memory lacks, like associations of measurements to meals, which are essential to make therapy adjustments. Logbooks also provide additional information such as food intakes, insulin doses or exercise.

Telemedicine allows patients to send their BG data to the system to be remotely evaluated, which avoids unnecessary displacements (Carral, Ayala, del, & Fernández, 2015; Pérez-Ferre, Galindo, & Fernández, 2010) and improves access to specialized care in rural areas (Mohan & Pradeepa, 2014). Furthermore, by a more exhaustive and frequent evaluation of accurate data, telemedicine is capable of improving glycemic control (Wojcicki, Ladyzynski, & Krzymien, 2001) and reducing GDM adverse outcomes (Dalfra, Nicolucci, & Lapolla, 2009; Ferrara, Hedderson, & Ching, 2012). Monitoring data in telemedicine systems should be presented to clinicians organized as they appear in paper logbooks to facilitate their interpretation.

The use of telemedicine could increase clinician's workload as it favors the generation of a greater amount of data to be evaluated by clinicians. Expert systems can solve the potential increment of clinicians' workload (Klonoff & True, 2009) by automatically analysing patients' monitoring data according to expert specifications (Hernando, Gómez, Corcoy, & del Pozo, 2000). The automatic analysis of monitoring data could optimize clinician's time by notifying which patients are evolving satisfactorily and which ones need a deeper examination. Expert systems, like clinicians, need to analyze glycaemia data in relation to meals to be able to determine patients' condition and to generate specific recommendations about therapy adjustments.

Glycaemia data entry in expert systems can be performed by patients either manually or by uploading the data stored in their glucose meter (El-Gayar, Timsina, Nawar, & Eid, 2013a). The automation of data entry is preferred as it minimizes transcription errors (Given et al., 2013), results in more data captured, simplifies the date entry process and increases patients' satisfaction (El-Gayar, Timsina, Nawar, & Eid, 2013b). One of the problems that expert systems in diabetes have to face is the management of incomplete glycaemia measurements. A measurement is considered incomplete if it lacks its association with a meal or with a moment of measurement. Newer glucose meters can include the functionality to allow registering these data manually, but even if they do, it is a time-consuming task and patients sometimes forget to introduce it. Without an accurate method to manage incomplete glycaemia data, expert systems cannot determine if patients' metabolic condition is altered due to a specific meal that should be adjusted or due to an extended fasting period.

The majority of studies available in literature about expert systems do not explicit describe the method used to retrieve the associated meal and moment of measurement of glycaemia data or how they manage the lack of this information. Some expert systems allow patients to add a meal tag to glycaemia measurements after uploading data from the glucose meter (Cafazzo, Casselman, & Hamming, 2012; Lim, Kang, & Shin, 2011; Quinn, Clough, & Minor, 2008), but it has been observed that sometimes patients forget to label some of the measurements (Mackillop et al., 2014) so they cannot be automatically analyzed. To solve this problem, the expert system can preselect a meal tag for each measurement downloaded and allow patients to modify it. Bromuri et al, preselect glycaemia meal tags based on previous measurements, so, if the last measurement was taken before dinner, an after dinner period is preselected (Bromuri, Puricel, & Schumann, 2016). However, this method might present problems when dealing with repeated or missing measurements, for example if the patient forgets to measure her glycaemia after dinner, she measures it the following day before breakfast and she, by mistake, accepts the preselected meal tag. Some commercial applications automatically classify the glycaemia measurements downloaded by patients according to patient's predefined mealtimes (Sanofi Diabetes, 2015), but this method might present an elevated rate of errors as we will see in the following sections. We propose an innovative method for glycaemia meal tag preselection using machine learning techniques.

This paper presents the methodology to design an automatic classifier to associate the appropriate meal and moment of measurement to each glycaemia data downloaded from a glucose meter, its integration within the *Sinedie* expert system for GDM and the classification results obtained in a pilot study at Hospital de Sabadell with 47 patients for 8 months.

2. Material and methods

This section describes the *Sinedie* expert system and how the automatic classifier is integrated with the BG levels uploading procedure. We explain the two different classification strategies studied to design the classifier: a simple algorithm based on the patient's mealtime schedules, measurements' time and BG level; and a more complex algorithm based on machine learning techniques. Finally, we describe the design of the clinical evaluation experiment.

2.1. Sinedie expert system for GDM

Sinedie is a telemedicine platform enhanced by an expert system to manage the treatment of GDM patients. It aims to improve health care processes by reducing the evaluation time per patient, avoiding unnecessary displacements and improving the access to specialized healthcare. The expert system available in *Sinedie* computes the patients' metabolic condition and generates advice, to both patients and physicians about treatment changes, including the need to start an insulin therapy. The BG classifier presented in this paper was integrated in the *Sinedie* system as a classification module, whose functionality is to assign an appropriate mealtime and a moment of measurement to each incomplete measurement uploaded to the system with the glucose meter. The glucose meter memory file provides information about date and time of each measurement, as well as its value (see Fig. 1). Additionally, patients can enter the corresponding moment of measurement (preprandial or postprandial) or the associated mealtime if they have a glucose meter that allows registering such information. The classifier allows structuring the BG levels obtained from the glucose meter file to be visualized in an e-logbook in *Sinedie* (Fig. 1). This completion procedure is executed in a preprocessing step prior to the automatic data analysis performed by the expert system and it is essential to detect anomalous conditions in patient's health. After each data download, patients verify if the automatic classification is accurate and otherwise correct it.

2.2. Classification problem analysis

A preliminary study (study 1) was carried out to determine which would be the optimal classifier to be implemented in *Sinedie*. As part of this study, we examined measurements' distribution along the day according to time and BG level to analyze the