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Development of a fuzzy expert system for the nephropathy control assessment in patients with type 2 diabetes mellitus

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ABSTRACT

Diabetic nephropathy is a life-threatening complication if not controlled properly. Early detection and effective control prevent its progression. In this study, the development of a Fuzzy Expert System (FES) is proposed to help doctors assess the nephropathy control in patients with Type 2 Diabetes Mellitus (T2DM). The study is based on a FES that was developed with the use of Clinical Practice Guidelines (CPG), data bases and the expertise of a team of doctors. It considers the use of input variables such as Glomerular Filtration Rate (GFR), serum creatinine, blood glucose, Type 2 Diabetes Mellitus Age (T2DMA), uric acid, hypertension and dyslipidemia. All these factors, give an efficient nephropathy control assessment. Sixty tests were performed using the expertise of a team of doctors, the expected results were compared with those estimated by the FES (using the same cases), and it was observed that the FES succeeds in up to 93.33% of the cases. The response surface analysis shows that GFR, serum creatinine and hypertension have a greater impact in the nephropathy control. This system supports the doctors in nephropathy control, but it does not estimate the renal failure stages. Nephropathy control is a clinical problem that includes uncertainty and inaccuracy, so the use of a FES is recommended to overcome this problem, since fuzzy systems help to assess the inherent uncertainty degree.

1. Introduction

Nephropathy in patients with diabetes is a lethal complication of diabetes mellitus and it is the main cause of End-Stage Renal Disease (ESRD) in developing countries (Bojestig, Arnqvist, Hermanson, Karlberg, & Ludvigsson, 1994), early recognition and diagnosis of renal changes increase the opportunity of preventing the initial progress of nephropathy (Remuzzi, Schieppati, & Ruggenenti, 2002). Besides the economic costs of its treatment, the impact in the diabetic patients general welfare and besides the fact that usually means a concurrent progression in microvascular complications, diabetic nephropathy represents in its end-stage, the final complication of the patient, and the best therapy results to be prevention (Guzmán et al., 2009).

Early detection of this disease, allows doctors recommend the required measures for its risk reduction, specifically in adoption of multifactorial interventions targeting the main risk factors (hyperglycemia, hypertension, dyslipidemia, and smoking), and use of agents with a renoprotective effect. This pays off in reducing morbidity and mortality associated with this major health problem (Gross et al., 2005; Martínez-Ramírez et al., 2008). The increasing incidence of ESRD is also driven by better treatment and improved prognosis, which has led to longer survival times for patients on dialysis (Barnett, 2006). Renal disease constitutes a public health problem both nationally and internationally, and it is estimated that nowadays there are more than 60,000 patients under treatment, and this number is increasing at a rate close to 10% per year (Laris-González, Madero-Rovalo, Pérez-Grovas, Franco-Guevara, & Obrador-Vera, 2011). The Family Medicine Unit-Number 1 in its DiabetIMSS department provides structural and multidisciplinary

Abbreviations: ANN, Artificial neural networks; CIs, confidence intervals; CPG, clinical practice guidelines; ES, Expert system (s); ESRD, End-stage renal disease; FES, Fuzzy expert system; FL, Fuzzy logic; GFR, Glomerular filtration rate; T2DM, Type 2 diabetes mellitus; T1DM, Type 1 diabetes mellitus; T2DMA, Type 2 diabetes mellitus age.

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health care to patients with diabetes mellitus. This program includes medical consultations and educational sessions for one year, with the objective of controlling patients (Figueroa-Suárez et al., 2014; León-Mazon, Araujo-Mendoza, & Linos-Vázquez, 2012).

Evaluation and diagnosis of diseases, present in some cases an overwhelming work of seemingly contradictory information or unusual ways (Miller, 1994). Therefore, the doctor needs help to establish the diagnosis and appropriate therapy, especially on rare diseases, or when the patient's symptoms can lead to different interpretations (Alonso-Amo, Pérez, Gómez, & Montes, 1995).

Modern medicine faces the challenge of the acquisition, analysis and application of the large amount of knowledge needed to solve complex clinical problems. The development of medical Artificial Intelligence has been linked to the development of programs that try to help the doctors formulate a diagnosis, the making of therapeutic decisions, and predict results (Ramesh, Kambhampati, Monson, & Drew, 2004).

The solving method is with fuzzy logic-based Expert System (ES). The main idea of an ES is that, expertise, which is the vast body of knowledge about the specific task, is transferred to a computer from a human being. This knowledge is stored in a computer and the users can use it for specific advice. The computer can make estimates and come to a specific conclusion (Liao, 2005). Fuzzy Logic (FL) is a special many-valued logic addressing the vagueness phenomenon and developing tools for its modeling via truth degrees taken from an ordered scale. It is expected to preserve as many properties of classical logic as possible (Novák, 2006). FL is a data processing methodology that allows ambiguity and therefore, is particularly suitable for medical applications, it is highly advisable when trying to model imprecise information and to make rational decisions in an uncertainty environment (Sproule, Naranjo, & Türksen, 2002; Zadeh, 1988). The FL system that was used is the Mandani type, which is based in three blocks: (1) Fuzzification: it transforms a nonfuzzy set into a fuzzy set or increasing the fuzziness of a fuzzy set (Zadeh, 1975). (2) Inference mechanism: it considers the membership levels of the input variables and supported in inference rules, it gives an output. (3) Defuzzification: it's a transformation between fuzzy and real data, this process it makes the fuzzy system output can be interpreted giving concrete values (Martin & Sanz, 2007; Rondeau, Ruelas, Levrat, & Lamotte, 1997).

Response surface methodology is a set of mathematical and statistical techniques which are useful for the modeling and analysis of problems where an interest response receives the influence of diverse variables, and the objective is to maximize such response (Montgomery, 2004).

Worldwide research of diverse types of ES and fuzzy systems has been carried on; in the studies it can see the impact that this discipline has in the medicine. Devi and Nagaveni (2010) develop a system that predicts the diabetic nephropathy risk based on the GFR. This system brings to patients according to their renal status, so doctors can make appropriate recommendations. The work of Narasimhan and Malathi (2014) focused on a classification of the risk of diabetic nephropathy using FL. Performance indicators are: precision of classification = 98.88%, specificity = 71.42 and sensitivity = 99.61. Lucarelli and Castiello (2011) present a study with fuzzy systems to make predictions in the Immunoglobulin A Nephropathy (IgAN) prognosis. This model is compared with an Artificial Neural Network (ANN) to measure its precision. The reliability percentage for the fuzzy model is of 56.12% and reliability of the ANN is of 53%. Ahmed, Kabir, Mahmood, and Rahman (2014) develop a model that predicts the health of a patient's kidneys. With this system is showing a reliability of 86.7%. Hashemi and Javidnia (2012) propose a model with four expert sub-systems. The first makes an evaluation of the body weight, daily energy and the macronutrients needs. The second part assesses hyperglycemia and hypoglycemia levels. The third part proposes the self-control for blood glucose. The fourth part recommends nutritional facts for people with a diabetes-related disease. Roventa and Rosu (2009) propose a medical ES with visual proLog 5.2. The system makes a differential diagnose among the main renal diseases. Gawedal, Jacobs, and Brierlt (2003) propose a work with a FL approach, for the automatic administration of drugs in patients with kidney problems. Mancini et al. (2007) developed an automatic system that stabilizes blood pressure during dialysis, the analysis of this system revealed that its use helped decrease in a 39.1% the hypotension episodes compared with other treatments. Akgundogdu, Kurt, Kilic, Ucan, and Akalin (2010) develop an adaptive neuro-fuzzy inference system that makes a failure diagnosis in renal disease. This system reaches a 100% of effectivity when it is applied. Soman, Zasuwa, and Yee (2008) design three systems; an anemia management program in renal disease, a monitoring vascular system and a nephrology ES. The three systems support doctors when making decisions about treatments and health advice to patients.

Research works mentioned above, provide insight into the benefits that could be obtained with computational decision support systems, these studies have provided vital information concerning the ES application in medicine and specifically in nephropathy control of patients with T2DM. The objective of this research is to develop a FES that helps doctors assess nephropathy control in patients with T2DM.

2. Method

This research was submitted for approval of the Local Committee for Research and Ethical Research in Health 3102, H. Gral. Zona Num. 8, Veracruz Sur, with the registration number R-2014-3102-26. Every procedure was developed according to what it is stated in the Regulations of the General Health Law in research for health. The FES uses the toolbox of Matlab for the development of the FL model. The methodology that was applied in this research is shown in the following stages:

2.1. Variables selection

The variables used in this research result from a thorough analysis made with the team of doctors from DiabetIMSS department. Input variables are explained below:

(1) GFR: provides an excellent measure of the filtering capacity of the kidneys, the normal level of the GFR varies according to age, gender, and size of the body (Levey et al., 2003). According to DiabetIMSS department, a normal GFR in young adults is approximately between 120 and 130 mg/dL and decreases with age. A GFR level smaller than 60 mg/dL, represents the loss of half the level of a normal renal function in adult people. Below this level, prevalence of chronic renal disease increases.

(2) Serum creatinine: concentration of serum creatinine is widely used and commonly accepted to assess the renal functioning. The correct use of the estimated value of serum creatinine depends on knowledge about physiology, pathophysiology of glomerular filtration, metabolism, creatinine renal handling, and the methodology of creatinine measurement. Despite its limitations, serum creatinine is a useful tool, especially if it is supported along with other tools for evaluation of renal function (Perrone, Madias, & Levey, 1992).

(3) Uric acid: according to Cameron (2006) experimental evidence and some clinical data suggest that uric acid may be a factor in progressive renal damage, either directly or through the renal vascular damage, or both.