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ScienceDirect
Medical Engineering & Physics 29 (2007) 824–827
Medical Engineering & Physics
www.elsevier.com/locate/medengphy

Communication

A new approach to diabetic control: Fuzzy logic and insulin pump technology

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Received 19 April 2006; received in revised form 27 August 2006; accepted 31 August 2006

Abstract

Diabetes is a major health problem. Since the utilisation of insulin in the 1920s there have been myriad problems in developing suitable technologies to formulate and administer correct dosages to temper this metabolic disease. From multiple daily injections, nasal inhalations and enzymatic supplementation these artificial shortcuts still do not have the ability to fully replicate a 'normoglycaemic' state of being.

In this paper, we sought to explore the use of insulin pumps and the application of fuzzy logic technology to act as an 'artificial pancreas' in diabetic patients. This paper builds on our previous work [Grant P, Naesh, O. Fuzzy logic and decision-making in anaesthetics. J Roy Soc Med 2005;98(1):7–9 [review]].

Keywords: Insulin pumps; Insulin dependent diabetes mellitus; Fuzzy logic; Artificial pancreas

1. Introduction

Diabetes is a mounting problem, not only in the UK and western world, but also in developing countries, which are adopting a more western lifestyle and diet [1]. The major aim of therapy for this chronic condition is to attempt to normalise the individual's blood glucose to optimal levels, which in turn will have implications for their health and reduce future complications.

In this review, we want to look at the use of special pumps, which have been developed for the continuous subcutaneous infusion of insulin [2]. Such pumps have been around for some time and allow the patient to control their blood glucose level in a more stable manner than multiple daily injections of insulin. More importantly though we look at the emergent technology of 'fuzzy logic' which when applied to insulin pump technology is set to enhance glycaemic control even further.

2. Insulin pump technology

An insulin pump is a small, wearable device, which contains a reservoir of short-acting insulin. It is attached to the patient via simple tubing and a subcutaneous needle. These pumps are not automatic but are programmed to deliver insulin constantly at varying rates, which can be determined by the patient. This replaces the traditional system of several self-administered injections throughout the day.

The disadvantages of multiple daily injections of insulin are that usually three or more injections are needed daily and intermediate and long-acting insulins must be used as the basal component. Absorption of the modified insulins has been shown to vary from 19 to 55% in the same individual, resulting in variable glucose excursions [3]. However, the absorption of the soluble, short-acting insulins that are used in continuous insulin pumps varies by less than 3% daily [4]. The number of patients using such pumps varies around the world. In Germany and the USA, approximately one in eight insulin dependent diabetics use them, whereas in the UK it is only 1 in 1000.

The most commonly cited problem with insulin pumps is the risk of diabetic ketoacidosis (DKA). If there are any

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1350-4533/$ – see front matter © 2006 Published by Elsevier Ltd on behalf of IPEM.
doi:10.1016/j.medengphy.2006.08.014

faults with the pump or it becomes disconnected there is no long acting insulin in the patients system to cope with acute stresses and the risks of hyperglycaemia and DKA rise [5]. However, developments in pump technology are making the risks less likely and so long as the patient tests their blood glucose regularly and has spare insulin and a syringe available this should not be a problem [5]. Current models have electronic memory, multiple basal rates, several bolus options, a safety lockout feature, and even remote control. Modern infusion sets have soft cannulas and quick-release options.

Ultimately the hope is that pump technology can be improved to such a standard that it can overcome traditional, erratic human control; forgetting insulin doses, consuming alcohol, being subject to acute stresses and improve overall glycaemic control by being more flexible. In essence by behaving like an 'artificial pancreas'. Currently the pumps work by the individual setting a baseline insulin rate for the daytime and nightime in responses to changes in BM (blood glucose level), in much the same way as an intravenous sliding scale.

3. What is fuzzy logic?

How do you define statements such as 'my blood sugar is on the *low* side', or 'I'm feeling a *bit* hungry'? Fuzzy logic (FL) is simply a conclusion reached by a computer program, which recognises that all values are not absolutes such as yes or no or black and white. FL makes calculations considering varying degrees between absolutes. For example, it may recognise black and white, yet make an evaluation based on a shade of grey which is somewhere in between [6].

It provides a simple way to arrive at a definite conclusion based upon vague, ambiguous and imprecise data. In essence the approach is to solve problems by mimicking how a person would make decisions, only much faster. Consider what happens when you get into a shower and the temperature is too cold, you'll make the water comfortable very quickly with little trouble. FL mimics this kind of behaviour. It is a simple, rule-based system and is empirically based (e.g., if X and Y then Z). FL can be used to monitor biological systems that would be difficult or impossible to model with simple, linear mathematics. It opens the door for control systems that would normally be deemed unfeasible for automation.

FL works through the use of 'adaptive controllers', which use a simplified form of human 'fuzzy' thinking. An adaptive controller is any control system with adjustable inputs and outputs and a mechanism for altering them. It contains two loops, a control loop and a parameter adjustment loop. In practice any kind of automatic system can be set up so long as your goals are defined [6]. An example would be blood pressure (BP) control during surgery. A fuzzy control device can monitor the patient's BP, if it is too *low*, then the intravenous fluids will be run in *faster*, until a *satisfactory* blood pressure value is achieved.

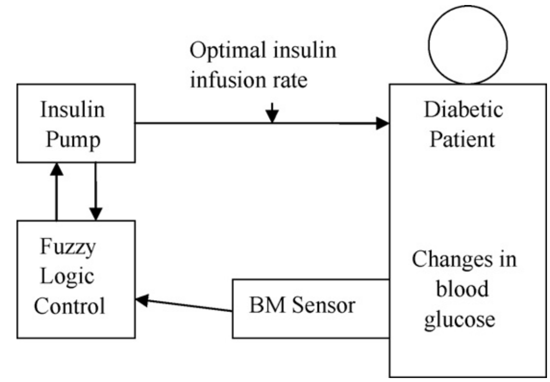

Fig. 1. Demonstrates a closed loop feedback system, which continuously monitors the patient's blood glucose level and adjusts the infusion of insulin to an optimal rate.

3.1. An artificial pancreas? Application of FL to diabetes

Many patients can tolerate high or low blood sugars that others cannot; there is no best fit artificial system for regulating such a flexible biological system and the dangers of sliding scale insulin have been reported elsewhere [7]. Maintaining optimal blood glucose control is difficult for IDDM (insulin dependent diabetes mellitus) patients when typical daily regimens of food, insulin and exercise are altered [8]. By combining continuous glucose sensing with insulin pump technology running on fuzzy logic rules we can offer the hope for development of a closed-loop artificial pancreas in the form of either an external or an implantable sensor, feeding back to an external or implantable pump (Fig. 1).

Otto et al. attempted to develop an artificial intelligence system using FL, which used an implanted blood glucose sensor [9]. The information from this sensor was used to adapt the rate of infusion of insulin and it was assessed to see whether it could cope with responses to common 'inputs' such as daily insulin, food and exercise. Unfortunately however the mean absolute percentage error between the predicted and actual blood glucose values was over 10%. Their prototype was limited by the requirement for a rigid testing schedule, human error and situational circumstances such as alcohol consumption, illness, infection, stress, and significant hormonal imbalances. No significant conclusions regarding model validity could be drawn due to limited evaluation processes and subject sample size in this study, although the prototype has demonstrated viability as a valuable learning tool for diabetic patients.

In one study by Ibbini et al., a closed-loop system was used to control the plasma glucose level in patients with IDDM [10]. This control scheme was based on fuzzy logic control theory to maintain a normoglycaemic average of 4.5 mmol and the normal conditions for free plasma insulin concentration in severe states; in particular, when the diabetic patient is subjected to a glucose meal disturbance or fluctuations in the measured glucose level due to error in the