Artificial Intelligence & Machine Learning for Effective Management of Blood Glucose Levels in Patients with Type 1 Diabetes

David Hart

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David Hart
Fundamentals of Computational Intelligence
Flinders University

Hart0373@flinders.edu.au

Abstract

Looking back at the history of type 1 diabetes and the development in technology since the 1960's, the application of artificial intelligence and machine learning capabilities has vastly increased. It is amazing to see developments that have come to light so far that have real world applications and are currently assisting diabetic patients. The purpose of this paper is to outline how artificial intelligence and machine learning capabilities have greatly improved the management of blood glucose levels and insulin management and in patients diagnosed with Type 1 Diabetes.

1. Introduction

Diabetes: by definition is a metabolic disorder that causes abnormal blood glucose levels (BG) regulation where the body either produces little to no insulin (Type 1 Diabetes) or where the body has developed a resistance to insulin (Type 2 Diabetes). At present there is no known cure for diabetes however, effective self-management of the disease can be achieved through actively tracking blood glucose levels, managing physical exercise, diet and insulin control. Without effective management, short term complications include hypoglycaemic (low blood glucose) and hyperglycaemic (high blood glucose) events. In the long-term there are also many associated complications that can develop such as, heart disease, retinopathy, glaucoma, kidney damage, liver damage and nerve damage to name a few.

In December 2020, the National Diabetes Services Scheme (NDSS) documented that there are more than 1.4 million Australians currently living with diabetes with only 9% of diabetics diagnosed with type 1 (Scheme 2020).

2. Current Management / Treatment

For type 1 diabetics, there are two main types of insulin, bolus insulin (rapid insulin) and basal insulin (long lasting insulin). Bolus insulin (aka meal-time insulin) is calculated by an insulin to carb ratio (I:C) which is the amount of insulin needed to cover the amount of carbs to be eaten e.g., 1 unit of insulin for every 12g of carbs. Basal insulin is injected once or twice a day to match the body's natural secretion of glucagon over a 24-hour period.

At current there are two methods for effective insulin delivery in type 1 diabetic patients. Multiple daily injections (MDI) which involves the injection of the two types of insulin (bolus & basal) multiple times throughout the day and Insulin pump therapy which involves a small electronic device that continuously delivers insulin through a small canula. Typically, in today's world insulin pumps are paired with a Continuous Glucose Monitor (CGM) (Bastani 2014).

3. History of the Insulin Pump Therapy

It was in the 1960's where the idea emerged for a continuous insulin delivery device. Arnold Kadish developed this system that together with continuous delivery also had automatic blood glucose sensing. At this time the system was quite large (the size of a backpack) and overlooked as it was impractical for day-to-day use. Nevertheless, this is where insulin pump technology started. Following Kadish's device greater attention was directed to the first computer-controlled pump in 1974. This system was designed to mimic a normal functioning pancreas with a pump that controlled the withdrawal and mixing of insulin or dextrose and a printer and plotter to record minute-by-minute data.

By the 1980's pharmaceutical began investing in the development of insulin pump technology where the first microprocessor-controlled pump was licensed for commercial use and released to the market in 1983. At this time of development many pumps were unreliable, with limited safety alarms, lacked control of safe insulin delivery and offered little flexibility to vary the insulin flow along with many other problems (F. M. Alsaleh 2009).

4. Insulin Pumps of Today

Since the 1980's there have been many advancements in insulin pump technology along with the development of Continuous Glucose Monitoring (CGM). CGM is a small electronic device (sensor) which utilises a small electrode that is inserted below the skin that can measure electronic resistance in interstitial fluid. The sensor is attached to a small radio frequency transmitter which sends the information to a receiver (often a pump or a mobile phone). Through the use of a CGM diabetics can access their blood glucose readings and make decisions in live time without the need of a finger prick.

In today's insulin pump, many safety features have been introduced such as a "suspend on low" feature where the insulin pump will suspend insulin flow should the patient's glycaemia is or is predicted to below a certain security threshold, this was the very first step to achieve a hybrid closed loop system where machine learning was becoming more significant in insulin pump technology. The release of the Medtronic 670g insulin pump brought to the market the new wave of insulin pumps that are capable of increasing or decreasing back-ground insulin flow depending on the user's blood glucose levels. The initial system was configured to be both safe and conservative and a huge step forward to in the reduction of hypoglycaemic events in type 1 diabetic patients (Hovorka 2011).

5. Benefits of Insulin Pump Therapy

There are many benefits as to why someone would choose to use an insulin pump over the traditional method of multiple daily injections. In today's insulin pump therapy, pumps allow for a more tailored and controlled approach in the delivery of insulin allowing the patient to inject fractional amounts of insulin at a time, customised basal rates to match the body's natural secretion of glucagon, fewer injections and finger pricks. An insulin pump combined with a CGM also aids in diabetic implications such as, Dawn Phenomenon, hypoglycaemic unawareness and other diabetic complications that may require a tighter control. Thus, increasing the patient's quality of life (Zisser 2010).

6. A.I and The Hybrid Closed-Loop System

Artificial Intelligence (A.I), was first defined in the 1950's by John McCarthy as "any task performed by a machine that would have previously been considered to require human intelligence". The subbranch of A.I (Machine Learning) has vastly changed the way patients manage type 1 diabetes.

The hybrid closed-loop insulin pump (MiniMed 670g) was the first insulin pump developed by medical tech company Medtronic Diabetes and approved for use for by the US Food and Drug Administration (FDA) in September 2017 that demonstrated the use of machine learning capabilities to automate the delivery of insulin. The 670g system makes use of their Guardian Sensor 3 technology allowing the user to operate the pump in 2 different modes (manual mode & auto mode).

The auto mode system uses machine learning algorithms that capable of automatically adjusting basal (background) insulin dosages specific to the user based on CGM sensor readings. CGM sensor readings are transmitted to the pump every 5 minutes allowing the pump to deliver an incremented insulin dose. The system is considered a "hybrid" system because it can only automate the delivery of basal insulin, uses must continue to bolus at mealtimes. The 670g system utilises pre-programmed blood glucose target (6.8 mmo/l) to determine the amount of insulin to be delivered. With the pre-programmed target it has been demonstrated through clinical trials that there has been a significant reduction in hypoglycaemic and hyperglycaemic events with a positive impact on overall HbA1c results (Neumiller 2018).

7. Machine Learning Algorithm's

For the closed-loop to operate and adapt to the patient's individual needs, the system utilises a history of glucose trends and takes in the following 3 parameters: eventual glycaemia using CGM feedback, Insulin-on-board and eventual glycaemia in order to affect an insulin delivery.

Eventual glycaemia using CGM, utilises the history of CGM values sent to the pump. The pump then calculates the last sent values and the value the patient is expected to reach after an elapsed 15 minuets if the continues with the current glucose trend.

Insulin-on-board, every bolus or micro-bolus delivered through the pump has an effect on the patient's blood glucose levels and insulin response curve. The curve is used to represent 1 unit of insulin from the time it is delivered to the number of hours the insulin is deemed to be active thus determining the amount of insulin that is to have an effect on the patient's body.

Eventual glycaemia is the glycaemia to which the patient is heading to. It is calculated using the trend for the next 15 minutes plus the effect of the insulin-on-board.

These calculations are merely just the beginning of the hybrid closed loop system (Jesus Berian 2019).

8. Limitations of AI in diabetes care

At this stage two of the most significant limitations with current insulin pump technology are, how to remove the patient's need to administer a meal-time bolus and insulin timing.

Bolus limitations, Current insulin pump technology allows for an automated process in changing insulin delivery amounts based on glucose trends and the secretion of glycogen stored in the liver, however when glucose enters the bloodstream through the consumption of carbohydrates, current technology cannot adjust the algorithm in a suitable time or predict the amount of carbohydrates that has been consumed to match the amount of insulin needed to counteract the rapid change in glucose values that are likely to occur.

Insulin Timing Limitations, insulin timing is the time it takes insulin start becoming active in the body. From the time of injection, the active time of insulin can vary from 2 – 15 minutes depending on the type of insulin the patient is using with peak effectiveness time occurring within 60 minutes. At this stage it is not possible for an insulin pump to know how much insulin is required for such a rapid change in glucose values and how high that change is likely to be. The issue here is, by the time an insulin pump can make these calculations, the body would already be in a hyperglycaemic state (Burren, 2019).

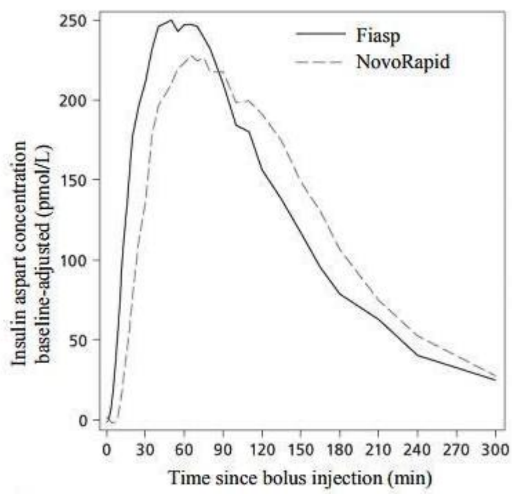

Figure 1. Insulin peak times (Burren, 2019).

9. The Future of A.I in Diabetes Care

The future and advancement of Insulin pumps has a promising outlook with engineers looking to produce the "artificial pancreas" with an aim to mimic a fully functioning and healthy pancreas. One of the key areas in need for further development is for more advanced technology for further prevention of diabetic hypoglycaemic events. Current technology allows for insulin pumps to alert the patient and suspend insulin delivery when the eventual glycaemia is predicted to be below the patients target glucose range. The prevention of hypoglycaemia at this stage is typically managed by the patient by either consuming either a fast-acting source of glucose or by the administration of glucagon.

The key area for future development is for a fully automated insulin pump with capabilities to deliver either insulin or glucagon based on CGM values and blood glucose trends (Farmer, Edgar and Peppas, 2008).

10. Conclusion

Many type 1 diabetics are faced with the mental burden of decision making that comes with the daily management of their blood glucose levels which if not managed correctly can result in many diabetic related complications. This burden of current diabetic management has resulted in as many as 50% of patients who suffer from type 1 diabetes to be diagnosed with anxiety, depression or other mental health illnesses (Carrie M. Bernstein 2017).

Future development of diabetes technology is not only vital to assisting type 1 diabetics in day-to-day life but it is also creating a better quality of life with the potential to delay and prevent further diabetic related complications.

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