Automatic calculation of insulin dose for proteins and lipids

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Abstract

Diabetes Mellitus 1 (DM1) is a chronic autoimmune disease characterised by insulin deficiency and hyperglycemia, people who suffer from this illness are called diabetics and are distinguished by having abnormal blood sugar levels. When unchecked, type 1 diabetes mellitus can cause severe damage to the patient's health and in extreme cases can lead to mortality. Monitoring the disease requires a great deal of effort, as patients must perform frequent blood tests and administer insulin in order to compensate possible blood sugar spikes. Insulin dosages are not easy to calculate, as even the most experienced diabetics can become easily overwhelmed by the amount of information necessary in order to produce an adequate dose. While carbohydrates continue to be the primary nutrient affecting blood sugar levels, previous research has shown that fat and protein can also have a drastic effect when it comes to increasing glycaemia, sometimes producing even worst effects.

Tools that can aid patients in monitoring the condition of their disease, while also being able to relieve them of certain related tasks, can drastically improve disease management. MyDiabetes is a mobile application designed to help people who suffer from type 1 diabetes mellitus, it can aid patients in managing their condition by allowing them to create records of meals, administered insulin, exercise, and blood sugar levels. Right now, the application is able to perform insulin calculations based on carbohydrates, but it lacks the necessary conditions in order to process fats and proteins. The main goal of this work is to create an automatic conversion system of fats and proteins into a corresponding dose of insulin, taking into account the meal entered by the user. The second objective, is the creation of an alarm system, to alert the user of the need to administer insulin corrections.

When the new version of the application was complete, it was presented to 15 users for testing, followed by a questionnaire to evaluate the features implemented and its overall usability. Although the feedback received was mixed, the results obtained showed that, in general, both the implementation of the notification system and bolus calculator were well accepted. Although, some issues were raised concerning the number of insulin compensations, quantities and timings. These issues were then discussed amongst us, together with an endocrinology doctor, and appropriate changes were made in the application. There is still much that can be done in order to improve the MyDiabetes application and increase user adherence, but the results obtained are promising and serve as a basis for a future implementation.

Resumo

Diabetes Mellitus 1 (DM1) é uma doença auto-imune crónica caracterizada por deficiência de insulina e hiperglicemia, as pessoas que sofrem desta doença são chamadas diabéticas e distinguem-se por terem níveis anormais de açúcar no sangue. Quando não controlada, a diabetes mellitus tipo 1 pode causar danos graves à saúde do paciente e, em casos extremos, pode levar à morte. Monitorizar a doença requer um grande esforço, uma vez que os doentes devem realizar testes à glicose frequentemente e administrar insulina para compensar possíveis picos glicémicos. As doses de insulina são difíceis de calcular, pois ate os diabéticos mais experientes podem ficar facilmente sobrecarregados com a quantidade de informação necessária para produzir uma dose adequada. Embora os hidratos de carbono continuem a ser o principal nutriente que afecta os níveis de açúcar no sangue, estudos anteriores demonstraram que a gordura e a proteína também podem ter efeitos drásticos na glicemia, por vezes produzindo resultados piores.

Ferramentas que podem ajudar os pacientes a monitorizar o estado da sua doença, ao mesmo tempo que os aliviam de certas tarefas relacionadas, podem melhorar drasticamente a gestão da mesma. A MyDiabetes é uma aplicação móvel concebida para ajudar as pessoas que sofrem de diabetes mellitus tipo 1, pode ajudar os pacientes com a gestão da doença, permitindo-lhes criar registos de refeições, administração de insulina, exercício e níveis de açúcar no sangue. Neste momento, a aplicação é capaz de efectuar cálculos de insulina com base em hidratos de carbono, mas faltam-lhe as condições necessárias para processar gorduras e proteínas. O objectivo primario deste trabalho é criar um sistema de conversão automática de gorduras e proteínas numa dose correspondente de insulina, considerando a refeição introduzida pelo utilizador. O objetivo secundario, é a criação de um sistema de alarmes, para alertar o utilizador para a necessidade de administrar correções de insulina.

Quando a nova versão da aplicação foi concluída, foi apresentada a 15 utilizadores para testes, seguido de um questionário para avaliar as características implementadas e a sua usabilidade. Embora o feedback recebido seja misto, os resultados obtidos mostraram que, em geral, tanto a implementação do sistema de notificações como a calculadora de bólus foram bem aceites. No entanto, algumas questões foram levantadas relativamente ao número de compensações de insulina, quantidades e tempos do bólus. Estas questões foram debatidas entre nós, juntamente com um médico endocrinologista, e as respetivas alterações foram feitas na aplicação. Ainda há muito a fazer de forma a melhorar a MyDiabetes e aumentar a adesão dos utilizadores, mas os resultados obtidos são promissores e servem de base para uma implementação futura.

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Aos meus pais, aos meus avós, e a minha tia. . .

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Listings

Acronyms

AI Artificial intelligence

ADA American Diabetes Association

APN Associação Portuguesa de Nutricionistas

CH Carbohydrate

CU Carbohydrate Unit

CGMs Interstitial Continuous Glucose Monitors

CSII Continuous Subcutaneous Insulin Infusion

CSV Comma Separated Value

DAO Data access object

DM1 Diabetes Mellitus 1

DWB Dual-Wave Bolus

FCUP Faculdade de Ciências da Universidade do Porto

FII Food Insulin Index

FPU Fat-Protein Unit

GI Glycaemic Index

GOe Global Observatory for eHealth

HbA1c Glycated Haemaglobin

ICR Insulin-to-Carbohydrate Ratio

ID Identification Number

IDF International Diabetes Federation

ISF Insulin Sensitivity

IT Instituto de Telecomunicações

MDI Multiple Daily Injections

NFC Near field Communication

NWB Normal-wave Bolus

OND Observatório Nacional da Diabetes

ORM Object-relational mapping

RCSP Rede de Cuidados de Saude Primarios

SNS Serviço Nacional de Saude

SUS System Usability Scale

SWB Square-Wave Bolus

UI User Interface

XML Extensible Markup Language

WPTS Warsaw Pump Therapy School

Chapter 1

Introduction

Diabetes Mellitus is a lifelong condition that is characterised by high blood sugar (glycaemia) levels in individuals afflicted by it. People that are diagnosed with diabetes, especially Diabetes Mellitus 1 (DM1) (the more aggressive form of this disease), need to eat healthy, exercise regularly, and carry out frequent blood tests to ensure their blood glucose levels stay balanced [67].

Although diabetics receive education about the disease, it often becomes complicated to carry out the entire disease management process in an effective way, especially, when they must keep records about blood sugar levels and other relative information. These can be made on paper, and although it is a somewhat simple and effective way, it has some drawbacks. Paper records can be lost or misplaced, thus, requiring the person to create new records. Paper is frail and can be damaged over time, making it difficult for the person to read the information. These setbacks suggest a better and more efficient way of doing this, and a more digital approach might be the solution. The Global Observatory for eHealth (GOe) defines the concept of mHealth, or mobile health, as the practice and medical treatment assisted by mobile devices such as **smartphones**, patient monitoring devices, among other wireless devices [57].

Unlike a conventional cell phone, whose main capabilities are making calls as well as allowing text messaging, a smartphone, also, includes other more advanced features. Most of these devices allow users to surf the Internet, send emails, take pictures, while also playing multimedia content. Modern smartphones that include dedicated operating systems, Android or IOS, allow the installation of apps, applications that bring even more functionalities.

This makes them the ideal mobile device, as there has been an increasing amount of mHealth smartphone applications related to the management, and patient monitoring of this disease. One of the key features of these applications is providing advisory services, which aim to increase patient self-management skills, by storing personal data such as glucose, haemoglobin A1c or glycated haemoglobin (HbA1c), blood pressure, body weight, and facilitating patient decision by utilising pre-stored algorithms [28]. Given their condition, diabetics must take insulin in order to ensure normal body function, these algorithms do the necessary calculations for insulin dosage based on patient data found in the application. Mosa et al. [52], concluded that the use of medical applications by health professionals and patients is extensive, as well as the amount of applications that are available. In addition, his report also mentioned the importance that smartphones can have in patient education, disease management, and remote patient monitoring. A major drawback, despite the abundance of applications related to diabetes management, is that only a few of them are designed to aid patients with DM1 in calculating their insulin dose, thus simplifying the everyday decision-making process (by the patients) [64].

There is, therefore, a need for diabetes oriented mHealth applications, with solid mechanisms that can aid in patient monitoring and management, while also being able to perform the necessary insulin dosage calculations, thus, facilitating the decision making process.

1.1 Motivation

In our work, we aim to create an **automatic system for converting fats and proteins into the corresponding dose of insulin**, taking into account the meal inserted by the user. The basis of this will be an algorithm that will be incorporated in the MyDiabetes [18] application, designed to help people who suffer from diabetes mellitus. Evidently, there is no perfect solution that can provide adequate treatment to everyone. Each person is unique, thus, having different reactions to carbohydrates, fats, proteins, insulin, etc. This means, what could be a solution for a specific person A, may not be a solution for a different person B. This makes it difficult, and at the same time, ineffective, to have a single patient profile. Therefore, the key point here, is to consider each person's specific patient profile in order to provide the most adequate treatment.

MyDiabetes is an application, in the scope of mHealth applications, for people suffering from DM1. The application is being developed in order to allow greater glycaemic control to patients. Monitoring, by the person with DM1, is important to ensure good glycaemic control. MyDiabetes aims to help in the daily monitoring of its users, while also being a way to determine the factors that can influence their glycaemic control

Diabetes mellitus, commonly known as diabetes, is a chronic disease that occurs when the pancreas's production of insulin (the hormone responsible for regulating blood sugar) is non-existent/insufficient or when the body cannot effectively use the insulin it produces. This is equivalent to an increase in blood glucose (sugar), what we call hyperglycemia, which in the long run can mean various complications in the body [16]. The following is a brief description of each type:

- **Type 1:** Type 1 diabetes is the result of an autoimmune reaction, which occurs when the body itself attacks the insulin-producing cells of the pancreas. The *beta* cells, responsible for the insulin production, produce thus little or no insulin. Insulin is the hormone responsible for the transport of sugar (glucose) to the cells, as well as serving as food for them. If insulin is prevented from performing its function, sugar accumulates in the blood, and consequently leads to cell death due to lack of food, which can cause health problems.

Patients affected by this type are insulin-dependent. Despite this, it is possible for them to enjoy a long and healthy life, maintaining the levels of sugar in the blood (by taking insulin), complementing with a good diet and practice of physical exercise [13, 63].

- **Type 2:** Unlike type 1, type 2 diabetes occurs when the pancreas does not produce enough insulin or when the body is unable to use the insulin produced efficiently. Patients affected by this type of diabetes are not insulin-dependent, except in degraded cases. It is the most frequent form of diabetes and is associated with less healthy lifestyles. Both type 1 and type 2 diabetes can begin during childhood and adulthood. Management can be done in more ways than in type 1, such as medication, diet and exercise [58, 72].

- **Gestational diabetes:** During pregnancy, a woman's body must produce more insulin in order to meet extra needs. When the body is incapable of doing so, it can develop gestational diabetes. Gestational diabetes means high blood sugar (glucose) levels, this can cause problems not only to the mother but also to the fetus (since extra blood glucose goes through the placenta). Glucose means energy, due to receiving more energy than it needs, the baby's body will store this energy as fat. Macrosomia is a condition, resulting from gestational diabetes, where a newborn is much larger than average. This can lead to injuries during birth, respiratory complications, and obesity in child life accompanied by a possibility of type 2 diabetes in adult life [3, 66].

Data from the Observatório Nacional da Diabetes (OND) [14], concluded that, in 2018 the estimated prevalence of diabetes in the Portuguese population aged between 20 and 79 years (7.7 million individuals) was 13.6%, i.e., more than 1 million Portuguese in this age group have this pathology. Besides the growing impact on the number of cases, diabetes also assumes a significant role in the causes of death, having been at the origin of 3.8% of the deaths that occurred in 2017. Globally, figures from the International Diabetes Federation (IDF) estimate more than 463 million adults affected by diabetes in 2019, and projects more than 578 million by 2030 [35]. One caveat though: of these 13.6%, a large part are type 2, which can be more easily managed.

The OND also analysed the impact of diabetes on primary health care: in 2018, 862,197 users with diabetes were registered in the Rede de Cuidados de Saude Primarios (RCSP) of the Serviço Nacional de Saude (SNS) of mainland Portugal, out of a universe of 11,649,429 registered users. In the same year, the number of users with diabetes who used the services of the RCSP of the SNS of mainland Portugal (with at least one medical appointment registered in the system) was 715,712. The total number of diabetes medical appointments carried out by the SNS in 2018 was 2,126,287. In 2016 there were 2,138,478 of these consultations and 2,079,814 in 2017. We have more than double the appointments for the number of registered users that have diabetes.

1.2 Research question

The major concern is that for now, there is no good solution for the insulin dosage problem. Diabetes mellitus type 1 patients must administer insulin compensations in order to maintain proper glycaemic levels, these compensations are usually calculated based on carbohydrates to insulin ratios while not considering other nutrients such as proteins, and fats. The current solution, the one advised by medical specialists, is to meticulously check glycaemic values and administer insulin accordingly. Some diabetes-oriented applications already have a system developed to help patients perform their glycaemic control but are limited, and thus, less effective. There is, therefore, a need for an insulin dosage algorithm, that includes all the important nutritional information concerning user meals, that would improve glycaemic control and minimise glycaemic analysis by the user. This being said, with this work, we aim to answer the following question:

- Improving the MyDiabetes application by implementing an automatic insulin conversion system based on carbohydrates, fats, and protein: how can this aid patient self-management?

Each person is unique, a treatment that could work for a specific person or group of people, may not be effective for a different person or group of people. Second, being able to find an equilibrium between the amount of information requested to the user, and the quality of the solution given by the application based on that information. Does more information mean better solutions? How much information is too much information? These questions will impose a *threat* to our work.

1.3 Our approach

With this work, we aim to solve the insulin dosage problem via an insulin calculation system, which will help the user in administering the correct insulin dosages based on his patient profile information and meal nutritional information. This is one of the most crucial aspects of diabetes management systems, as there is a need to provide the user with suitable information that will help him maintain glycaemic control, while also being able to offer post-meal monitoring to ensure there are no late glycaemic fluctuations. The initial approach is to use existing insulin conversion algorithms, which already include proteins and fat in their calculations (e.g., Pańkowska [60]). The use of these novel insulin conversion algorithms will add more functionality to the application while increasing treatment effectiveness, adaptations will have to be made in order to make it compatible with different insulin administration methods (e.g., insulin pump and multiple daily injections). Lastly, the development of a notification system, which will seek to address the issues regarding the post-meal period. This updated notification system will align with the existing notification system already in use in the MyDiabetes application, the idea is to warn the user for insulin compensations, possibly in the long postprandial period, given past meal records.

1.4 Organization

Besides the introduction chapter, this thesis consists of six more chapters. The chapters are:

- Chapter 2: In this chapter, we will discuss all the research material that was examined in order to better understand the problem at hand. We will also assess the current research material available, to solve said problem.
- Chapter 3: In this chapter, we will discuss the state of the art of type 1 diabetes mellitus-oriented mHealth applications. Although the applications presented can exhibit different functionalities from the MyDiabetes application, they are also intended to assist patients with their meal planning.
- Chapter 4: In this chapter, we will review the current status of the MyDiabetes application. We will start by examining its functionalities, while also addressing missing features as well as improvements that could be made. This chapter will give us a better understanding of the application, while also serve as a point of comparison after the implementations to be made.
- Chapter 5: In this chapter, we will discuss the implementations made to the MyDiabetes application, this is based on the information discussed in chapters 2, 3, and 4. We will start by examining the implemented algorithm, we will then address the notifications system and the improvements made to the information screen and default meals.
- Chapter 6: In this chapter, we will review the results of the questionnaires created, in order to assess the usability of the implemented functionalities. We will also assess the opinions of diabetics in whether the added features are useful, and if they can help improve the overall application accomplishment rate.
- Chapter 7: In this chapter, we will reflect over the work that was accomplished, talking about the success of the tasks at hand and the difficulties associated. This chapter is a review of all the work that was accomplished since day one, up to the final stages of this dissertation. To finish the chapter, we will address future work to made in order to further improve the application.

Chapter 2

Managing DM1: One Meal at a time

Human beings cannot exist without food, the human body requires a minimum amount of nutrients in order to properly function, allowing people to maintain day to day activities. In patients affected by Diabetes Mellitus 1 (DM1), a concern is to be able to know, approximately, how much insulin should be administered for a given meal. Naturally, this depends on the meal's composition, quantity, and nutritional value. The ingestion of some foods will require the patient to administer more insulin, while others require less or no insulin compensation. Therefore, meal planning plays a big role in diabetes treatment and is a cornerstone of diabetes management.

Good diabetes management can be defined as the process of self-monitorization accompanied by good dietary habits, physical exercise, and insulin use. Establishing good practices in diabetes self-management is crucial for patients afflicted by this disease, if left unchecked, DM1 can lead to serious long-term health conditions such as heart complications, kidney problems, nerve damage and sight loss [75]. Good dietary habits and healthier food choices, that are lower in saturated fat and salts, can help with blood pressure, while controlling carbohydrate intake can lead to improved glycaemia and weight. Physical activity is important, as it is associated with many well-established health benefits, such as improved cardiovascular fitness, better bone health and enhanced psychological well-being [79]. According to the American Diabetes Association (ADA), most adults with DM1 should undergo 150 minutes of moderate to intense aerobic exercise per week [2]. Moderate to high quantities of aerobic exercise are associated with considerably lower cardiovascular and overall mortality risks in type 1 but also type 2 diabetes [69]. For people affected by DM1, aerobic training can lead to improvements in cardiovascular fitness, lipid levels and endothelial function, while also decreasing insulin resistance [71]. Still, an effective balance of food intake and insulin dosing is required to maintain euglycaemia before, during, and after the exercise [13].

Choosing the appropriate insulin treatment is imperative given the nature of this disease. Patient education and disease education play an important role in all of this, learning about the disease and establishing a partnership with the physician can be crucial in improving one's self-management capabilities, and lead to better results in disease treatment [61].

This chapter will cover all the research that was carried out in order to fully comprehend the concepts associated with diabetes management, and the importance of meal planning when tackling the disease. All the information discussed here will prove essential to the development of this project, besides giving a better understanding of the work in hand.

2.1 Insulin

Insulin is a hormone made in the pancreas, which is an organ that aids with digestion. Diabetics have complications associated with the production and use of insulin by their bodies, thus, requiring insulin injections. This is especially true for those with DM1, while only some with type 2 diabetes require this treatment (since their body can still produce some insulin). There are two insulin administration mediums, pen and pumpDM1. The patient, along with the healthcare team, will discuss the most adequate insulin administration method based on current condition and other parameters (e.g., age, health issues) [24]. Synthetic insulin is produced in laboratories using bacterial cells that have been genetically modified to produce human insulin [47]. It exists in five different forms, all of which with different effects, and thus, work differently in managing a person's diabetes. Comprehending the different types of insulin and how they affect diabetes management is important, as it can help to better understand the disease. Below is a brief description of each type:

A **Rapid-acting insulin:** Rapid-acting insulin, sometimes known as fast-acting insulin, is taken right before meals acting very quickly, it is usually taken alongside an intermediate- or long-acting insulin. Doses depend on how much carbohydrates are ingested [24].

B **Short-acting insulin:** Short-acting insulin, also known as **bolus** insulin, is comparable to rapid-acting insulin, but slightly slower. Due to this, patients should administer short-acting insulin approximately 25 minutes before eating, although, it can be taken after or during the meal [12, 23, 24]. It is used to compensate the glycaemic spike that can occur after a meal.

C **Mixed insulin:** This form of insulin is a mix between short- and long-acting insulin, it is taken before meals and eliminates the need to follow up with a background insulin. This type of insulin can also help people who have trouble reading the correct directions and dosages [24, 47].

D **Intermediate-acting insulin:** Intermediate acting insulin, also known as a background or **basal** insulin, is taken once or twice a day. The main function of this type of insulin is keeping blood glucose levels stable during periods of fasting, such as sleeping. While fasting, a person's liver continuously secretes glucose into the bloodstream. Basal insulin maintains glycaemia levels under control, without it, glucose levels would rise at an alarming rate [24].

E **Long-acting insulin:** Long-acting insulin is slower than intermediate insulin but is processed by the body in a similar way. It is usually taken once a day, at the same time each day, being usually effective for 20 to 24 hours [12, 23, 24, 47].

Insulin has three characteristics: **onset**; **peak time**; and **duration**. Bellow is a brief description of each type, accompanied by figure 2.1, which serves as a visual aid to better understand the behaviour of these characteristics in the different insulins.

- **Onset:** This corresponds to the time, after entering the bloodstream, for which the insulin is at maximum strength in terms of reducing blood glucose levels.
- **Peak time:** This is a period before the insulin reaches the bloodstream and begins lowering blood sugar.
- **Duration:** How long insulin continues to lower glycaemia.

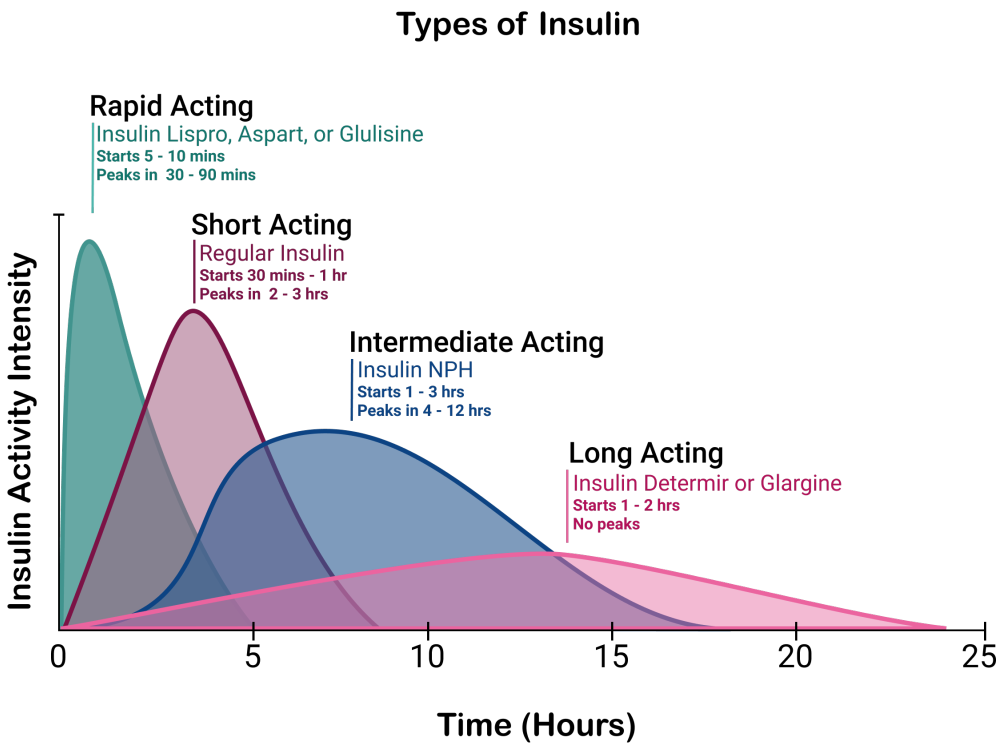


Figure 2.1: Graph demonstrating these characteristics on different insulin types [73].

Regarding insulin therapy, there are two forms, conventional and intensive. Conventional therapy consists of injecting insulin twice a day, this approach is often chosen by people that have a relatively regular routine and prefer to inject their insulin at the same time each day. For people who have DM1, conventional insulin therapy is much less effective at controlling the disease when compared to intensive insulin therapy, therefore, it is usually only considered an option when the latter is not an option [36].

Intensive insulin therapy is more data oriented, relying on information such as a person's blood sugar levels, meal composition and quantity and physical activity levels. This allows insulin to be flexibly and spontaneously adjusted. Insulin is injected as needed, the amount of insulin depends on blood sugar levels, the time of day and physical activity. Also, intensive insulin treatment is proven to improve psycho-social functioning, while also lessening the risks of chronic complications related with diabetes, such as vision impairment, kidney problems, and nervous system disorders [34, 36].

Regular blood sugar monitoring is key, as it allows diabetics to understand the increases in glycaemic levels and its causes, like eating different foods, medication, or physical activity. The information obtained by regular blood sugar monitoring is of great importance, not only for the patient but to the physician as well. Together, they can establish measures in order to improve the current diabetes healthcare plan [30]. Insulin can then be delivered via Multiple Daily Injections (MDI) or by using Continuous Subcutaneous Insulin Infusion (CSII), commonly known as an insulin pump. Both MDI and CSII follow a common insulin routine known as a basal-bolus insulin regimen [34, 36]. A basal-bolus routine involves taking **intermediate-acting insulin** to maintain glycaemic levels stable during periods of fasting, while also preventing glycaemic rises by injecting doses of **short-acting insulin**, these glycaemic rises are due to meals.

This is similar to how the human body behaves in healthy individuals, hence, it is the main advantage of this therapy, as it allows individuals who suffer from diabetes type 1 to closely match how their body would release insulin if it was able to [23]. Despite this, there is a challenge associated with intensive insulin therapy, as patients are required to have high self-monitorization skills for it to give the best results. Since not everyone has those capabilities, the use of technologies that could support patients in collecting and storing their physical, blood glucose, and meal information's could help addressing this challenge and at the same time improve disease management.

2.2 Carbohydrate counting

Carbohydrate (CH) counting is a method for managing diabetes mellitus. It consists in matching insulin requirements with the amount of CH obtained from food. According to the Associação Portuguesa de Nutricionistas (APN), CH counting is a food planning tool used for people with diabetes mellitus that focuses on CH as the nutrient with the greatest impact on postprandial glycaemia and aims to optimise glycaemic control [27]. With this in mind, diabetics who use CH counting are expected to accomplish three major goals according to this method:

1. Identify foods that contain CH
2. Calculate the amount of CH that those foods contain
3. Establish how much insulin to take based on the amount of CH consumed

For people with DM1, aligned with an intensive insulin treatment, it can be an especially effective way of managing the condition. There are three levels of carbohydrate counting, levels 1, 2, and 3. The following will be a brief description of each level as discussed in the article *Using carbohydrate counting in diabetes clinical practice* by Gillespie et al. [32].

- **Level 1:** This is the most basic level, it is designed for people with type 1, type 2, or gestational diabetes mellitus who desire a simpler method of choosing foods, that have difficulties associated with their current meal planning approach, or whose intake of carbohydrates is inconsistent. At this level, patients begin to take their first steps towards establishing good carbohydrate counting practices. This is done by learning which foods contain carbohydrates, carbohydrate choices, and how to start counting carbohydrates. Patients are also encouraged to keep food records and identifying portion sizes, based on weighing and measuring the amounts of food they eat.
- **Level 2:** This level is designed for those who want a more advanced training on the subject and that have understood level 1. At this level, patients continue to develop their record-keeping capabilities while also learning to identify blood glucose patterns that are related to their food, diabetes medications, and physical activity. Finding and interpreting these glucose patterns is important, as the obtained data can be crucial for when taking appropriate action. This is called pattern management.
- **Level 3:** This is the most advanced level, designed primarily for people with type 1 diabetes mellitus who are receiving intense insulin therapy, that could be, via multiple daily injections of insulin or by using continuous subcutaneous insulin infusions by using an insulin pump. Patients start to use carbohydrates-to-insulin ratios to match the amount of insulin given before meals, and sometimes snacks, to the amount of carbohydrates that will be consumed. For this level, patients need to have become skilled at levels 1 and 2, it is also required for them to have good knowledge in insulin adjustments for altering basic daily doses. In addition to this, they must have mastered insulin supplementation (adding or subtracting insulin at mealtimes to help correct premeal blood glucose levels).

An Insulin-to-Carbohydrate Ratio (ICR) specifies the number of grams of carbohydrate covered by each unit of insulin (rapid- or short-acting). A typical insulin-to-carbohydrate ratio is 1 unit of insulin for every 15 g of carbohydrate [26]. Nevertheless, each person is different, thus, the ratio can vary from person to person, besides this, a person's own ratio can change over time or from meal to meal (e.g., a person may need 1 unit of insulin for every 10 g of carbohydrate at breakfast but 1 unit for every 15 g of carbohydrate at lunch). Physical activity, insulin that is already in the system, and fluctuations in hormone levels are conditioning factors that can affect this ratio. From a medical standpoint, blood glucose and meal records are important and can help determining a patient's insulin-to-carbohydrate ratio [26]. Bellow is a table with the pros and cons of carbohydrate counting.

Pros	Cons
Nutrition labels on packaged foods make it easy to count carbohydrates [48]	Tracking carbohydrates alone does not equal a healthy diet [48]
Food information available online	It is easier to rely on packaged food that has nutrition labels than whole foods like fruits and vegetables, which do not have carbohydrates listed on them [48]
Keeping a target carbohydrate number in mind is a tangible measure of how much to eat [48]	Some foods may not contain carbohydrates, but can be high in protein, calories or fat, such as bacon or beef. This makes the tracking procedure difficult when only counting carbohydrates [48]
Meal flexibility	
Carbohydrate counting can be helpful for those looking to control carbohydrates intake [48]	

Table 2.1: Pros and cons of carbohydrate counting

To conclude, carbohydrate counting is not an easy task. It requires the person counting to verify the food nutritional information, weigh the food, and proceed in making the necessary calculations in order to obtain the approximate insulin value. All this effort can make the whole process unbearable for some people and involves continuous learning in order to perfect. People need to educate themselves about carbohydrates, learn how to adjust insulin doses, and be dedicated to monitor blood glucose levels frequently [74]. Additionally, health experts should advise patients about the proper way to employ the method as a nutritional strategy to control blood glucose [15]. The ADA recommends carbohydrate counting for people with DM1 on intensive insulin treatment, as it can help in achieving optimum glycaemic levels. Nonetheless, the ADA recommends that when consuming a mixed meal that contains not only carbohydrates, but also fats and protein, insulin dosing should not be based solely on carbohydrates. This is a downside of the method, as keeping track of carbohydrates alone does not necessarily mean a healthier diet, and thus, reflects in good glycaemic control [29].

2.3 Fat, protein, and glycaemic index

Carbohydrates play an important role as the main nutrient affecting meal planning in DM1, with carbohydrate counting being the main and most used meal planning tool for meal insulin dosing.

The ADA [1], refer to carbohydrates as being the predominant macro-nutrient affecting postprandial glucose control and the primary determinant for calculating mealtime doses in DM1. Nevertheless, as we have discussed in section 2.2, tracking carbohydrates alone has its limitations.

Recently, several studies have raised the question of the importance of other nutrients present in meals that can contribute to a glycaemic increase, such as proteins and fats. According to the ADA, diabetics that have mastered carbohydrate counting should receive education about the glycaemic impact of fat and protein [1]. This new evidence, allied to the use of continuous glucose monitoring devices, has shown that fat, protein, and glycaemic index (GI), can significantly affect postprandial glucose levels. These new findings reinforce the need to develop alternative mealtime insulin dosing algorithms, while also having important implications for nutrition education and counselling in patients with diabetes.

This section consists, mainly, in a systematic review of the literature conducted by Bell et al., in order to study the effects of fat, protein, and GI and their implications in DM1 management. With this article, the author seeks to address the following questions:

1. What effects do GI, protein, and fat have on acute postprandial glucose concentrations in type 1 diabetes?
2. What meal insulin dosing strategies work best for GI, protein, and fat in type 1 diabetes?

Before we get into the questions addressed above, it is important to understand the different units of measurement that can be applied to blood glucose levels. There are two different ways of measuring blood glucose levels. It can be measured in terms of molar concentration, measured in mmol/L, or in terms of mass concentration, measured in mg/dL. Most blood glucose meters are preset to take one or the other measurement. This prevents accidental value changes that can be fatal [6]. Different geographic areas may use different measurements, much like in some countries the driving is performed on the right-hand side. This information is relevant as throughout this section the two measurement units will be presented.

2.3.1 Fat

Fat can have a significant effect on postprandial glycaemic levels. In order to address this issue, the author reviewed seven studies carried out in order to examine the effects of dietary fat on postprandial glycaemia in 103 subjects with type 1 diabetes. All studies added fat to the test meal, while the amount of fat added to the control meals ranged from 6.6 to 52 g. In all studies it was possible to conclude that dietary fat modified postprandial glycaemia. However, one study found that glucose concentrations did not increase [44]. The author believes this is due to the duration of the monitoring period, which was only 3 h. It is also believed that fat can have a delaying effect on the postprandial glycaemic peak, as two studies reported that the addition of dietary fat lowered glycaemic levels in the first 2-3 h [44, 45]. This could be due to fat delaying gastric emptying[1], one study demonstrated that the gastric emptying rate was significantly reduced in the first 2 h after consuming a high fat meal [44].

[1]Gastric process consisting in moving the contents of the stomach into the duodenum [37]

Evidence collected by the author suggests that mixed meals, high in fat and containing carbohydrates, cause sustained late postprandial hyperglycaemia. This goes in accordance to what we discussed in section 2.2. Two studies were analysed by Bell et al., the first showed that the addition of at least 35 g of dietary fats significantly increased postprandial glucose concentrations by 2.3mmol/L at 5 h (roughly 42mg/dL). Note that, a postprandial blood glucose level higher than 10.0mmol/L (180mg/dL) can be considered hyperglycaemia [25], as this value may vary from person to person. The second proved the addition of 50 g of fat caused considerable hyperglycaemia over 5h. These values are important, as they can be used in order to establish meal related parameters when developing prandial insulin dosing algorithms, besides having significant scientific value that demonstrates the effect of dietary fat in postprandial glycaemia levels.

Hibbert-Jones [33], on an article written for the *Practical Diabetes* magazine, also studied the effect of fat and protein on the glycaemic response of a meal. Her conclusions are in line with those discussed above by Bell et al., and are as follows:

- Fat reduces the postprandial glucose response 2-3 hours after eating and delays the peak glucose response due to delayed gastric emptying.
- Fat causes delayed hyperglycaemia 3-5 hours after eating.
- Additional insulin may be required for high fat meals which can increase glycaemia.

They also noted that, there are marked inter-individual differences in the effect of fat on postprandial blood glucose concentrations, this means the same amount of dietary fat can have different effects in different individuals. Also, they concluded that further research is needed in order to identify the amount of fat which affects glycaemia and whether the type of fat makes a difference.

Since high fat meals are often consumed during the evening, at dinner, prolonged hyperglycaemia may not be detected until morning of the next day. However, another important issue that we need to refer is the increased possibility of hypoglycaemia given this delay. These are two significant concerns directly affecting prandial meal strategies for glycaemic control in type 1 diabetes. Hibbert-Jones et al., have addressed the problem of hypoglycaemia stating that *"substituting foods with lower fat alternatives would therefore require less insulin"*. According to the author, the reduction of the amount of insulin administered would eliminate the need for the person to eat to avoid hypoglycaemia in the early postprandial period, and reduce the need for additional insulin to correct a high glucose in the late postprandial period.

In a study Desjardins et al. [20], which had as one of its objectives to examine the association between post dinner dietary intake and the occurrence of non-severe nocturnal hypoglycaemia, concluded that there is a significant association between post dinner fat consumption and higher rates of nocturnal hyperglycaemia as well as hypoglycaemia. The author also demonstrated that overnight glycaemic control is still sub-optimal, ergo, further research is required in order to better address this concern. This also means that future prandial strategies must also consider early hypoglycaemia as an obstacle to overcome in order to achieve better results in the management of the disease.

2.3.2 Protein

As with fat, protein can also drastically affect postprandial blood sugar. Similarly, Bell et al. [7] examined seven studies which addressed the effect of dietary protein on postprandial glycaemia in 125 subjects with type 1 diabetes. The test meal carbohydrate content was kept consistent throughout, while six studies added protein which increased energy content. All studies reported alterations in postprandial glycaemic levels with the addition of protein, while one study reported significant differences when compared to the rest [31]. A research by Smart et al. [70], concluded that the addition of 35 g of protein to 30 g of carbohydrates significantly increases blood glucose levels by 2.6 mmol/L (approximately 46 mg/dL) at 5 h postprandial. This is comparable to what we have seen in subsection 2.3.1 with the addition of dietary fat to the meal, furthermore, combining dietary protein with fat, or vice versa, has an increased effect on glycaemic levels, with the author reporting an increase in blood glucose concentrations of 5.4 mmol/L (97 mg/dL) at 5 h postprandial. This is the sum of the individual increases for protein and fat.

Only one study, conducted by Paterson et al. [62], examined the effects of protein in the absence of carbohydrates and fat. The results where conclusive and it was found that the addition of 12.5-50 g of protein did not significantly affect glycaemia, however, the addition of 75-100 g significantly increased glucose concentrations, reaching a peak at 5 h postprandial. This also caused an increase in glucose concentrations equal to administering 20 g of carbohydrates given without insulin. The results presented in this study suggest that protein has different effects when consumed with and without carbohydrates.

In all seven studies, the consensus was that there were variations in glycaemic levels in the late postprandial period. When protein was consumed alone, glucose concentrations began to rose after 100 min for protein concentrations of over 75 g. Three studies found that for meals where protein was consumed alongside carbohydrates there was an increase in blood sugar concentrations, approximately 3-4 h after the meal [54, 70, 80].

Following the information that has been discussed throughout this subsection, we can conclude that protein has a similar effect to fat on postprandial glycaemia, although it differs when consumed alone or alongside other nutrients, more specifically, carbohydrates or fat. A smaller amount of protein will affect blood glucose levels when consumed with at least 30 g of carbohydrates, while when consumed alone, a diabetic would need to ingest over 75 g of protein for it to affect glycaemia. This suggests a lighter control on protein when compared with fat, nevertheless, since almost all meals are mixed meals, we must take this into account when developing prandial insulin dosing strategies.

2.3.3 Glycaemic Index

Glycaemic Index (GI) is a rating system for foods containing carbohydrates. It can show how quickly each food would affect the body's blood glucose levels when it is eaten by itself [78]. Carbohydrate based foods can be broken down quickly by the body and can cause a rapid increase in glycaemic levels, these types of foods are classified as high ranked GI foods (e.g., sugar, white bread, potatoes, and white rice), while low and medium GI foods are broken down more slowly and cause a gradual increase in blood sugar levels over time (e.g., fruits and vegetables, wholegrain foods) [65]. The glycaemic index can aid people affected by DM1 in achieving better control over blood glucose levels by explaining what foods have lower GI index. It should be noted that, people may know what foods have lower GI and still experience difficulties compensating the insulin necessities these provoke. Nevertheless, it is still a help in comprehending glycaemic rises and the effects that foods may have. Glycaemic index has been associated with variations in postprandial glycaemia, understanding how GI can affect post meal blood glucose levels is an important step in achieving better prandial glycaemic control, while also helping to develop more complete and efficient meal insulin calculation strategies.

In order to address the effects of GI on postprandial glycaemia, Bell et al. [7] reviewed seven studies which examined the effects of GI on 98 individuals with DM1. These studies compared high versus low GI foods. All studies where conclusive in demonstrating that low GI foods and meals have a better impact on post meal glycaemia, producing lower glycaemic responses. Nonetheless, three studies suggested that the risk of mild hypoglycaemia is greater with low GI foods [42, 51, 53], the time interval of the hypoglycaemic occurrences was not reported. One study, however, reported that low GI foods are more capable of causing early hypoglycaemia, demonstrating a correlation between GI and time to hypoglycaemia, with each unit of GI increasing the delay in hypoglycaemia of 1 min [51]. These studies where conclusive and are consistent with the knowledge of reduced overall glycaemic response obtained from low GI foods.

2.3.4 Insulin dosing strategies for protein, fat and GI

Subsections 2.3.1 and 2.3.2 where important to understand the predicament of not including proteins and fats in the general insulin calculation algorithm. In this subsection, however, we will discuss novel insulin dosing strategies that already include fat and protein, and the effect these have when compared with those that only consider carbohydrates. First, we will examine the algorithm developed by Pankowska et al., that uses an additional calculation for the inclusion of proteins and fats, and finally, we will look at another algorithm, reviewed by Bell et al., the Food Insulin Index (FII) that calculates the insulin demand for individual foods and mixed meals.

2.3.4.1 Warsaw Pump Therapy School Algorithm (WPTS)

Pańkowska et al. [60], assessed the impact of a fat-protein meal on postprandial hyperglycaemia, and the effectiveness of a computed insulin dose for both CH and fat-protein, in controlling postprandial glycaemia. The results were conclusive, proved that the inclusion of protein and fat in the overall insulin calculation algorithm has a significant effect in reducing and controlling postprandial glycaemic levels.

For this purpose, the authors conducted a randomised open-label study, organised at the Warsaw Medical University, Department of Paediatrics. The participants were all children and adolescents between the ages of 12-18 years old, with DM1, and with a CSII system. A pizza meal was served to all participants, it was made up of dough and dressing, its nutritional value was of 46.8 CH, 33.1 g of fat, and 25.4 g of protein. Carbohydrate content was transformed into units, in which 1 carbohydrate unit (CU) is equal to 10 g = 40 kcal of CH; while the fat-protein unit (FPU) was defined as 100 kcal of fat and protein. In total, pizza nutrients accounted for 4.5 CU and 4.0 FPU.

The patients were treated using an insulin pump and were divided into two experimental groups, control Group A and control Group B. Patients in Group A received dual-wave insulin boluses for their pizza dinner. A Dual-Wave Bolus (DWB) is an insulin administration mechanism implemented in contemporary insulin pumps, it can deliver a combination of an instant insulin bolus followed by a Square-Wave Bolus (SWB) [40], a square-wave bolus delivers a single bolus evenly over an extended period, from 30 minutes to 8 hours [50].

For patients in Group A, the insulin dosage was calculated using the following algorithm:

$$\frac{n \cdot \mathrm{CU} \times \mathrm{ICR} + n \cdot \mathrm{FPU} \times \mathrm{ICR}}{6\ \mathrm{h}\ (\text{Dual-Wave Bolus})} \tag{2.1}$$

For patients in Group B, the following algorithm was used:

$$n \cdot \mathrm{CU} \times \mathrm{ICR} \tag{2.2}$$

n is different, and is used to represent the number of carbohydrate units and food-protein units respectively, ICR represents the insulin-to-carbohydrate ratio. The algorithm used for the control Group B did not include the adjustment for the fat-protein content included in the meal, although the postprandial glycaemic levels were higher in comparison to the experimental Group A, the number of hypoglycaemic episodes during the 360 min postprandial was zero in comparison to the four that occurred in Group A. This is one of the major limitations encountered, the addition of fat tends to decrease the glycaemic response in the early postprandial period in people with T1D, thus increasing the risk of hypoglycaemia.

Nevertheless, the results obtained, concluded that the average glucose values between 2 and 6 hours after the meal were lower in Group A, treated with dual-wave insulin boluses plus the novel insulin formula (WPTS). The improvements introduced by Pańkowska et al., to the total insulin dose formula, showed significant results regarding the control of postprandial glycaemic levels, which shows that there is a need to consider fat-protein elements when calculating postprandial insulin dosing.

2.3.4.2 Food Insulin Index

Bell et al. [8], have developed a study in order to compare the postprandial glycaemic responses in adults with DM1 who used both CH counting and the FII. The FII is a novel algorithm of ranking foods that evaluates the insulin response in healthy subjects to an isoenergetic reference food. According to Bell, by using food energy as the constant, the FII encompasses all foods, and not only those with sufficient carbohydrate content. Hence, all meal components and their metabolic interactions can be considered, allowing a more complete approach to determining insulin demand. The FII algorithm is believed to be a more accurate predictor of postprandial insulin responses to composite meals than carbohydrate counting, this is based on previous studies in healthy people [4]. In people with DM1, the FII is associated with improved postprandial glycaemia without the risk of hypoglycaemia compared with carbohydrate counting [5]. Essentially, the FII assigns an insulin ranking to each food, according to the results obtained by its algorithm. Foods with higher insulin ranking require the diabetic to use more insulin in order to compensate glycaemic rises. The figure bellow, contains a scatterplot which represents the relationship between the insulin index of foods, and their insulinogenic index[2].

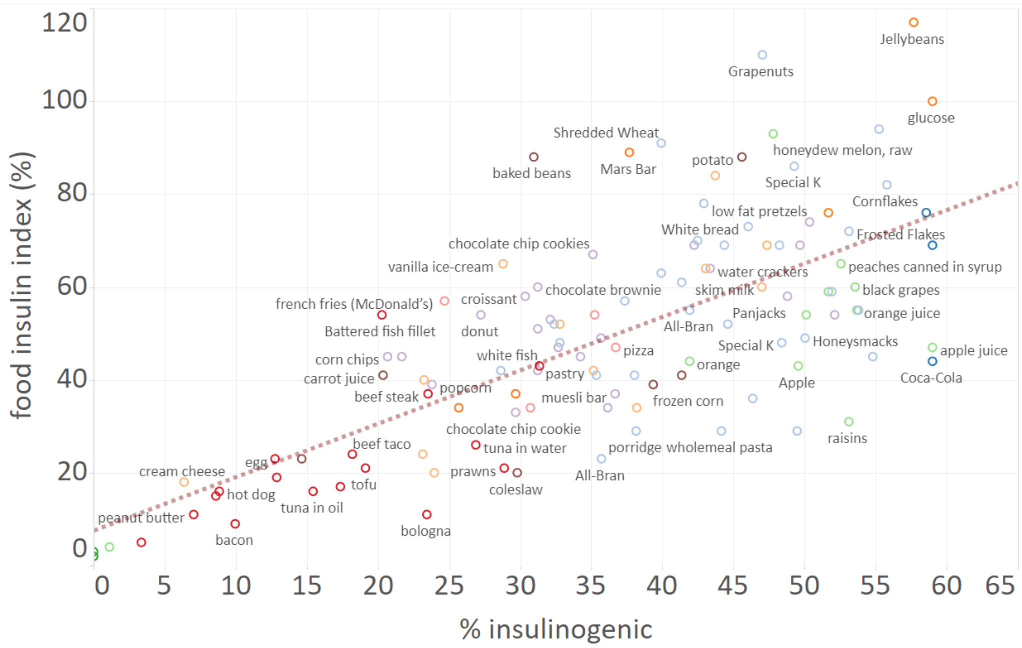


Figure 2.2: Insulinogenic foods and FII [39]

[2]How this food stimulates the production of insulin

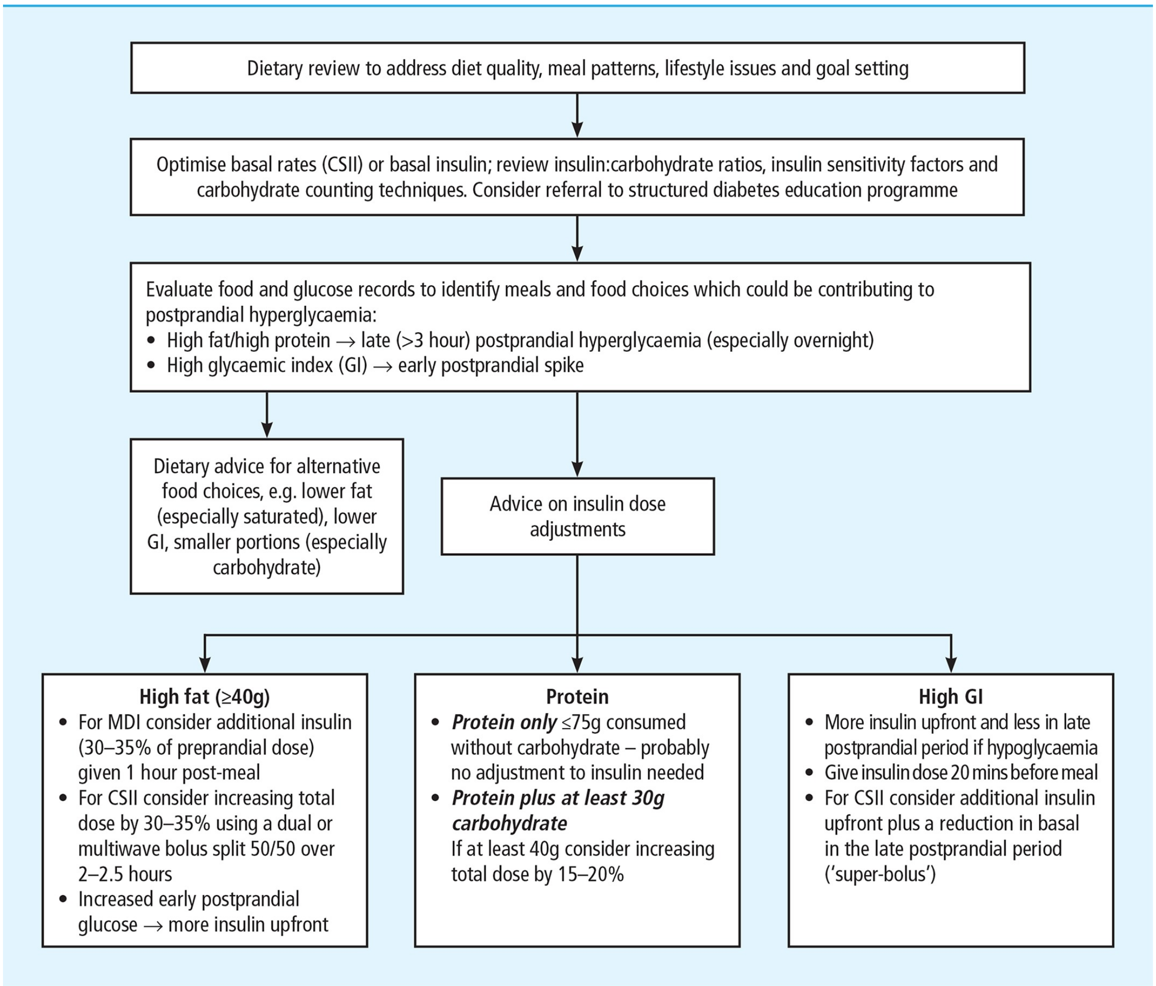


Figure 2.3: Flow diagram obtained by Bell et al. [7]

The diagram displayed in the figure above, was obtained by Bell et al. after their systematic review of the literature in order to study the effects of fat, protein, and GI in DM1 management. These conclusions can be translated into a decision tree of advice diabetics can take in order to better manage their meals.

During this chapter, we understood the concept of insulin, why certain diabetics need to administer insulin, the different types of insulins and their effects on blood sugar levels. After that, we discussed why CH are considered the number one nutrient affecting glycaemia, and what strategies exist in order to mitigate glycaemic rises caused by CH (e.g., CH counting). Although CH is considered the primary nutrient affecting glycaemia, we examined that, several recent studies have raised the question of the importance of other nutrients present in meals that can contribute to a glycaemic increase, such as proteins and fats. Finally, we debated current insulin dosing strategies for proteins, fats, and glycaemic index, such as the Warsaw Pump Therapy School (WPTS) algorithm, and the FII. In the next chapter, we will discuss applications in the scope of the MyDiabetes application, how these applications are performing meal insulin calculations, and how they assist patients in managing their condition.

Chapter 3

State of the art

A smartphone is relatively simple to use and easy to gain access to. It has become a necessity in people's lives and in today's market there are many shops dedicated to selling these devices. Almost all of them have access to the internet, and with a few clicks, a user can search the web for information about almost anything. This, aligned with the fact that it is basically a miniaturised computer with sensors and a computational capacity that allows it to run applications, makes them a powerful tool that could be used to provide personalised health monitoring, decision support, and education in a convenient manner to patients living with a chronic disease, such as diabetes mellitus. Smartphone-related applications are rapidly developing in relation to communication, information processing, design, features and connectivity with other devices (e.g., health monitoring wearable devices) [41]. Rapidly evolving technologies such as Continuous Subcutaneous Insulin Infusion (CSII), Interstitial Continuous Glucose Monitors (CGMs)[1], and Bluetooth enabled smart pens for insulin delivery tracking and insulin dosing support are all part of the modern treatment and monitoring of Diabetes Mellitus 1 (DM1) [41].

Health data tracking and evidence-based decision support through the use of mobile applications should help facilitate self-management in DM1. A smartphone application that could integrate text message feedback from a certified diabetes education service can lower Glycated Haemaglobin (HbA1c) levels in adults with DM1 who initially have high glucose levels. Smartphone applications could also help with reducing the risk of hypoglycaemia by improving symptom recognition and patterns recognition [41]. Also, it would be ideal if a diabetes management application, in addition to being able to store meal, exercise, HbA1c, and weight records, could also provide support regarding insulin dosage calculations based on nutritional intake, since this is seen as one of the most complicated aspects of the disease.

In this chapter, we will mainly discuss applications developed to provide support to people suffering from DM1 and understand how these applications can somehow improve the quality of life of said people and help with the management of the disease. We will also discuss fitness and nutrition-oriented applications, as these can be considered predecessors to diabetes management

[1] Measures the interstitial glucose level, which is the glucose found in the fluid between the cells [56].

applications. Both of these will be discussed more in dept in sections 3.1 and 3.2.

3.1 Fitness related health applications

Fitness applications, although not primarily intended to help with type 1 diabetes mellitus, are perfectly usable for that purpose. Previously, we have discussed how Carbohydrate (CH) counting is the number one method for prandial insulin dosing, and subsequently, achieving glycaemic control. As such, diabetics may find that these applications could in fact help them by displaying carbohydrate content, approximately, in their meals. Most fitness related applications have a food database that allows users to check the number of calories and other related nutrients such as carbohydrates, fats, and protein. This allows them more control over what they eat and aids them in reaching their goals (e.g., weight loss, muscle gain). Most smartphone users download fitness related applications, or health applications, and most of these are geared towards people living with DM1. DM1 is a disease that is particularly suited for smartphone-based support, this is due to the difficulty associated with glucose monitoring, insulin dosing, carbohydrate counting and lifestyle management.

3.1.1 MyFitnessPal

MyFitnessPal is a fitness oriented mobile application, dedicated to promoting a healthier lifestyle by helping users keep track of their caloric intake and level of exercise. With it, it is possible to keep a record of daily meals using an extensive database with multiple entries of different foods, from vegetables to meat and fish, as well as premade meals. All these entries are accompanied by their respective nutritional information, which include calories, fat, protein, vitamins, iron and calcium. Users can also scan the barcode that is found on food packaging, the application will then convert the read data into the respective nutritional information. Besides food, this application can also monitor daily exercise, cardio and strength.

Key features of this application include:

- Food database: Use of a food database with nutritional information and pre-made meals.
- Exercise records: Users can record the amount of exercise preformed.
- Meal records: Users can consult and register meal information.
- Relative information related to good eating habits and physical activity.

3.1.2 Carb Manager

Carb Manager, much like MyFitnessPal, is an application dedicated to promoting a healthier lifestyle by providing tools that can assist its users in maintaining a low-calorie diet, as well as the possibility to examine detailed nutritional information about consumed foods. The application contains an advanced food tracking system, users can keep meal records by entering the information directly, searching the food database, or by taking a picture, the application has Artificial intelligence (AI) implemented that can process an image and register the food displayed (although this may not be the most accurate way). The application can notify the user, by issuing alerts, if nutritional limits are being exceeded, since it also automatically tracks carbohydrates, fats, and protein with its macro calculator.

It comes bundled with plenty of information regarding low-carb articles, recipes, meal planning and videos aimed at helping users achieve their goals, while also allowing them to connect external devices in order to track fitness activity. In conclusion, it is a very powerful and complete application that can be used by anyone that wants to improve their eating habits and nutrition, while also enhancing physical activity levels, but is especially beneficial to users afflicted by DM1.

Key features of this application include:

- Food database: Use of a food database with nutritional information and pre-made meals.
- Exercise records: Users can record the amount of exercise preformed.
- Meal records: Users can consult and register meal information, use of AI in order to assist users in registering their meals.
- Relative information related to good eating habits and physical activity such as videos, articles, and recipes.

3.1.3 MyPlate Calorie Tracker

MyPlate Calorie Tracker is a health and fitness mobile application, much like MyFitnessPal and Carb Manager, developed to be a tool that can provide its users with the necessary information and assistance so they can achieve their nutritional goals. The application provides an extensive, and comprehensive, food database with over 2 million entries and users can also use a built-in bar code scanner to track and find food easily, provided the item is registered in the database. Users can create their own custom meals, this is especially useful for those who have the habit of eating the same meals everyday (e.g., breakfast or during an afternoon snack). One of the main objectives of this application is providing information relative to key meal nutrients, such as fats, protein and carbohydrates. Though, it can also provide detailed information about other secondary nutrients such as fibre, sugar and sodium. Lastly, users are capable to set reminders in order to keep track of when they must eat their meals.

All this nutritional information and capabilities are accompanied by fitness aid and assessment, the application allows users to log their workouts and, as with food, has a broad fitness related database built for exercise tracking. To conclude, it is a very capable and extensive application that can help both diabetics looking for something to aid them with their meal planning, and people looking to improve their physical conditioning.

Key features of this application include:

- Food database: Use of a food database with nutritional information and the ability to build a custom meal.
- Exercise records: Users can record the amount of exercise preformed and the application has support for exercise mediums.
- Meal records: Users can consult and register meal information, use of a built-in bar code scanner to easily register food items.
- Relative information related to good eating habits and physical activity, community based assistance.

3.2 Diabetes related applications

John, et al. [28], refer to diabetes as being one of the most popular chronic clinical conditions targeted by mHealth, followed by depression and asthma. Therefore, this subsection will address a few mobile, diabetes oriented, health applications, and examine how these compare to the MyDiabetes application. Jimenez et al. [38], conducted a study in which the objective was to investigate and identify several diabetes management and self-help applications through a Google search, these applications were then characterised in terms of their features, such as: medication management, blood-glucose self-management, physical activity, diet and nutrition, and weight management. Jimenez et al. [38], concluded that of the features described above, the most prevalent were: nutrition or diet-related, and physical activity tracking. Given the nature of this work, it is also important to see how applications can deal with more advanced issues, such as assisting with insulin calculations and post-meal patient monitoring.

During March of 2021, a search was conducted in the Android (i.e., Google Play Store) smartphone application platform store for content related to exercise and diabetes, with special emphasis on applications designed for individuals who suffer from DM1. In order to do this, the terms *exercise*, *nutrition* and *diabetes* were entered into the search bar of the Android store website. In total, roughly 250 applications were found. Of these 250, those with a user ranking of 4.5 stars or more were filtered. Lastly, the remaining applications were filtered based on their number of downloads. The number of downloads can be used as a metric to analyse how appealing an application is, and as such, serve as a decision support parameter. In the end, only 5 applications were available, namely: **mySugr**, **Diabetes:M**, **Glimp**, **Diabetes**, and **Beat Diabetes**. These final applications were then reviewed based on five parameters: diet and nutrition, physical activity, notifications and warnings, meal insulin calculations, and application price.

3.2.1 mySugr

MySugr is an application created for people with diabetes, it acts as a diary of the disease. It allows the monitoring of several indicators, such as glucose levels, administered insulin, medication, food consumed and meals. The data can be later analysed in graph form, or exported to Comma Separated Value (CSV)[2]. One of the major concerns we have found while using the mySugr application is its usability.

1. **Diet and nutrition**
    - There is no food database with nutritional information.
    - Users can choose the type of food, meat, vegetables, fish, etc., but this information is not food specific nor it has influence on the final insulin calculus. Its purpose is only to keep a record of types of food the user has eaten.
    - Nutritional information like fats, carbohydrates, proteins, etc., have to be entered by the user. Information is then displayed in the app.
    - The application keeps a record of previous inputted meals and their information.
2. **Physical activity**
    - Physical activity tracking, amount of exercise performed.
3. **Notifications and warnings**
    - Can notify the user based on previous entries. Although the notification system exists, it is primitive. mySugr calls these notifications *reminders* and much like other aspects of the application they have to be defined by the user, a more correct approach would be to launch alarms automatically when necessary.
4. **Meal insulin calculations**
    - Insulin calculations are based, solely, on carbohydrates.
5. **Application price**
    - The application is free to download.

3.2.2 Diabetes:M

Diabetes:M is a mobile health application designed to help people afflicted by Diabetes Melitus. It acts as a disease management tool, allowing users to better control their blood sugar levels. With this application, users can create their personal profile and input personal data relative to their condition. It is compatible with not only diabetes type 1, but also with type 2 and

[2]Text files with regulated format, where values are separated by commas.

gestational diabetes. Its a more complete management and self-monitoring tool, in comparison with the application discussed in the previous section. Diabetes:M already incorporates the insulin conversion algorithm established by Pankowska et al. [60], although it has some limitations, mainly, in patients who use multiple daily injections as their main form of treatment.

1. **Diet and nutrition**
   - The application has a food database with different foods and pre-made meals, these are accompanied by nutritional information.
   - If a given meal or food is not registered in the food database, users can choose to save a record with their given meal while also recording the nutritional information of said meal. The application allows scanning the packaging barcode. In terms of registering meal information, its a very complete application in this aspect.
   - Nutritional information can be filled automatically by the application, if present in its database, or by user input.
   - The application keeps a record of entered meals and their information.
2. **Physical activity**
   - The application is able to track the exercise duration and type, this can include basketball, aerobics, soccer, martial arts, cycling, etc., and also allow users to leave a comment related to said exercise.
3. **Notifications and warnings**
   - The application is able to notify the user based on previous entries. After creating a meal record, the application while calculate the respective insulin dosage for that meal, if one or more postprandial insulin compensations are necessary, the application will designate alarms to warn the user of those compensations. Users can also create their own alarms.
4. **Meal insulin calculations**
   - Diabetes:M utilises the algorithm developed by Pankowska et al. [60] in order to perform meal to insulin calculations. This is a more complex algorithm that besides carbohydrates, also includes proteins and fats.
   - The application is friendly to users that use pen and pump, but for users that use pen its not as good as to ones that use pump.
5. **Application price**
   - The application has a free version, which is more limited, and a paid version which adds extra functionalities.

3.2.3 Glimp

Glimp is a mobile application developed to manage DM1 and designed to be compatible with 3rd party sensors such as the Abbott FreeStyle Libre, Libre Pro, MiaoMiao and BluCon. By using Near field Communication (NFC)[3] technology, glimp reads sensor data and then displays this information on the smartphone screen. Glimp is not approved by Abbott, and, as such, users should use the application with caution as the sensor readings are not guaranteed to be the most accurate. A different application from those we saw before, glimp is intended to be used with a glucose sensor and provides the user data obtained from that sensor such as HbA1c, insulins, calories, carbohydrates, fat and protein, instead of being more meal oriented.

In order to check blood sugar levels, diabetics must perform a finger-prick test. A finger-prick test consists in collecting a blood sample from the fingertip which will then be placed in a blood testing meter or other testing device. The Abbott FreeStyle Libre is a diabetes management system designed so that diabetics do not have to prick themselves every time they want to measure their glucose values. The system consists of a sensor that is placed on the body of the person, and a reading device that is used to read sensor data. Glimp, essentially, eliminates the need to have the sensor reading device and allows people to use their smartphone to do the readings instead. Most people that use this system, prefer to use their own mobile device to the readings instead of using the Abbott reading device. This is both convenient and cheap, as the reading device is somewhat expensive.

1. **Diet and nutrition**
   - Nutritional information tracking such as carbohydrates, fats, and calories.
2. **Physical activity**
   - Physical activity tracking, amount of exercise performed.
3. **Notifications and warnings**
   - Warnings and notifications about HbA1c levels, fats, and proteins.
4. **Meal insulin calculations**
   - The application does not perform insulin calculations.
5. **Application price**
   - The application is free to download.

[3] Enables short-range communication between compatible devices.

3.2.4 Diabetes

Unlike some other applications, Diabetes functions as a diary for glycaemic levels. The application is very simple, when opened, it automatically records the current date and time (based on the smartphones date and time) and the user just inserts his blood glucose level. Each record may be associated with a tag, description, and weight information. Information stored in the application may be viewed in the form of a graphic or in a statistical manner (e.g., mean, minimum, maximum). Bluetooth devices can be connected to the application and data can be imported or exported to CSV or Extensible Markup Language (XML). Users can also create reminders via the user menu.

1. **Diet and nutrition**
    - No food database.
    - Meal information and entries are not supported.
    - Blood glucose tracking.
2. **Physical activity**
    - No physical activity tracking.
3. **Notifications and warnings**
    - Simple reminders created by the user.
    - No notifications about blood sugar levels.
4. **Meal insulin calculations**
    - The application does not perform insulin calculations whatsoever.
5. **Application price**
    - The application is free to download.
    - The application has a paid version which removes advertising and adds features.

3.2.5 Beat Diabetes

Beat diabetes is a mobile application created by a team of physicians working in the field of diabetes. The application is focused on providing disease-related information rather than serving as a tool to help manage the disease. As such, users will not find the typical capabilities of a regular diabetes self-management application, but instead, will be able to review information regarding the disease, and information concerning good dietary habits and physical activity.

The main features of this application include information about the best and worst foods for diabetics, tips about controlling blood sugar levels, strategies to improve physical activity, and a description of complications regarding diabetes and the timeline of their appearance.

1. **Diet and nutrition**
   - Relative information about good eating habits, foods, and recipes.
   - No food database available.
   - The application does not support entering meal information.
2. **Physical activity**
   - Information regarding physical activity and exercises.
   - The application does not support physical activity tracking.
3. **Notifications and warnings**
   - No notifications and warnings.
4. **Meal insulin calculations**
   - The application does not perform insulin calculations based on carbohydrates or other nutrients such as proteins or fat.
5. **Application price**
   - The application is free to download.

Functionalities \ Applications	mySugr	Diabetes:M	Glimp	Diabetes	Beat Diabetes	MyDiabetes
Food database	✗	✓	✗	✗	✗	✓
Meal tracking	✓	✓	✗	✗	✗	✓
Carbohydrate tracking	✓	✓	✓	✗	✗	✓
Fat tracking	✗	✓	✓	✗	✗	✓
Protein tracking	✗	✓	✓	✗	✗	✓
Cholesterol tracking	✗	✓	✓	✗	✗	✓
Physical activity tracking	✓	✓	✓	✗	✗	✓
HbA1c tracking	✓	✓	✓	✓	✗	✓
Meal to insulin calculator	✗	✓	✗	✗	✗	*[4]
Warnings and notifications	✓	✓	✓	✓	✗	**[5]

Table 3.1: Comparison of the applications discussed above

To conclude, today there is a lot of availability when it comes to diabetes-oriented applications, some can really help their users by serving as a personalised assistant and providing important information in order to improve the management of the disease. Nevertheless, patients should consult their physician prior to choosing one of these applications, as some of them may not be

[4] To be developed with this work.

[5] The application already has notifications and warnings but this system will be further developed with this work.

the best in helping them with their condition. Users should be well informed when choosing and should go for those most highly regarded. In the applications we reviewed above, all except one had already developed a system were insulin was calculated using both carbohydrates and fats. Therefore, there is still room for growth in this regard.

Chapter 4

MyDiabetes: Current status analysis

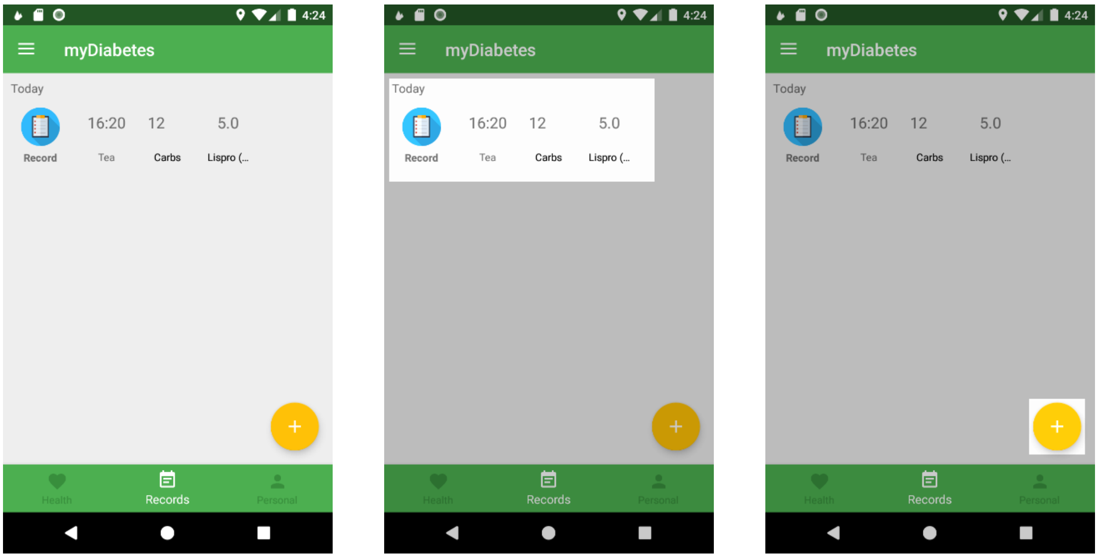
In this chapter, we will proceed in reviewing the state of the MyDiabetes application before implementing the functionalities discussed during the introduction. As mentioned in chapter 1, MyDiabetes is a mobile application designed to help people who suffer from Diabetes Mellitus 1 (DM1). It serves as a "personal assistant", enabling users to record past meals, performed exercise, and insulin administrations. The application is also able to notify the user of future insulin injections and calculating insulin dosages. The application was conceived at the Faculdade de Ciências da Universidade do Porto (FCUP), and is a joint project with the Instituto de Telecomunicações (IT). Through the course of its existence, the application has been developed by multiple people, each adding new features or improving existing ones. All of these developments lead us to the point in which we find ourselves today and which we will elaborate on. The focus of this review will be, specifically, on the aspects of the application that are directly to the future work.

As said before, two major functions of this application are:

1. Being able to perform meal insulin calculations based on meal records.
2. Being able to notify the user on future insulin intakes.

The first functionality depends on how the application is designed to handle nutritional information such as, carbohydrates, proteins and fat. This data will allow the application to perform the necessary calculations for meal insulin, this is explained with more detail in chapter 2 (subsection 2.3.4) and chapter 5. The second depends on how the application is designed in order to launch alerts and notifications. In the following pages, we will go into detail about both of these functions and how the application is designed to accommodate them.

The MyDiabetes application has been developed to be as user friendly as possible. Upon starting the application, the user is prompted to input his personal information (e.g., weight, height, age, sex) as well as his glycaemic objectives, insulin administration method (e.g., pump or pen) and the type of insulin (refer to section 2.1). After this, he is taken to the “Home” screen, where previous records are available. These could be related to meals, insulin, or glycaemia. The home screen is the first contact that users have with the application, each time they open the app. In this screen, users can check their past records, and by clicking them, they can update that record with new information. MyDiabetes has three types of records, meal records, glycaemia records, and insulin records. If a user performs a meal record, it will contain the meal carbohydrate information, and the amount of insulin for that given meal. If a user performs a blood sugar record, it will contain a blood sugar value. Finally, if a user performs an insulin record, it will contain the type of insulin and the quantity. A user can create a new record by clicking the plus button as shown in figure 4.1c.

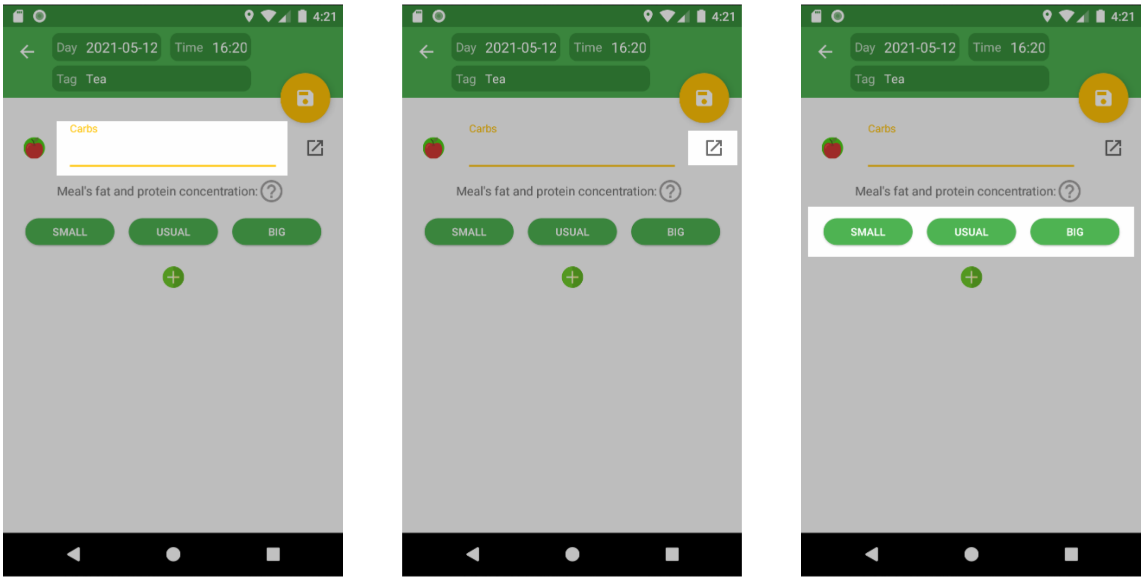


(a) The home sub menu (b) The saved records (c) Button to add a new record

Figure 4.1: Home screen and past records

4.1 Meal record

A meal record is where users will provide the application with information regarding their meals. Users can place the number of carbohydrates of the meal in a textbox displayed on the upper part of their screen as shown in figure 4.2a. Since the application has a food database, users can use it to search for the foods they are currently eating. The database has hundreds of entries. Food items are displayed with their nutritional information per grams or per portions, each portion corresponds to 100 grams. In a previous work, three buttons were implemented in this menu, these buttons were created as a default in case the user does not use the food database.



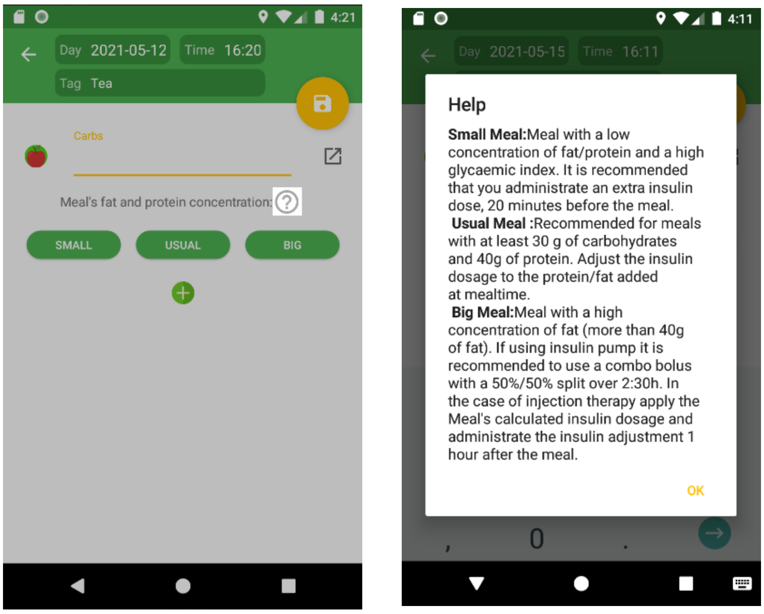
(a) Carbohydrate textbox (b) "Create meal" sub menu button (c) Default meal buttons

Figure 4.2: A meal record and its components

Buttons			
	Small	Usual	Big
Description	Used when the meal's fat/protein content is very small or none.	Used when the meal contains at least 40g protein and at least 30g carbohydrates.	Used when the meal's fat content is at least 40g.
Result	Insulin quantity is calculated using only the carbohydrate content.	Insulin quantity is calculated using carbohydrate content, as well as fat and protein content.	Insulin quantity is calculated using carbohydrate, as well as fat and protein content.

Table 4.1: Description of the functioning of the buttons

A concern that may arise when using the default meal buttons is misinterpretations. Users can look at the buttons and may translate their names as the amount of food they have on their plate instead of that meal's nutritional quantities, which are two very distinct ideas. In order to mitigate this issue, a help button was implemented that can be accessed by the user at any given time. It is shown as a question mark in the interface, when it is clicked, this button makes a box appear on screen with information regarding each button. More is shown on the figure 4.3 bellow.



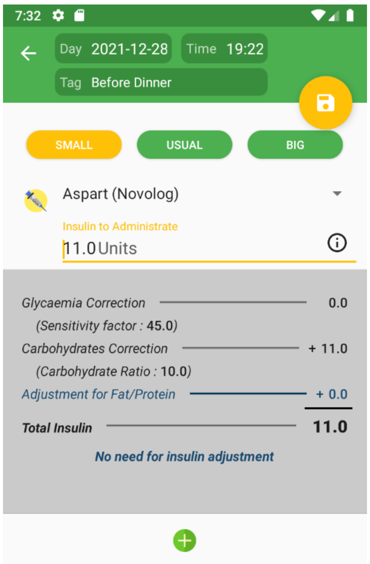
(a) Help button (b) Help pop up screen

Figure 4.3: The buttons' help mechanism

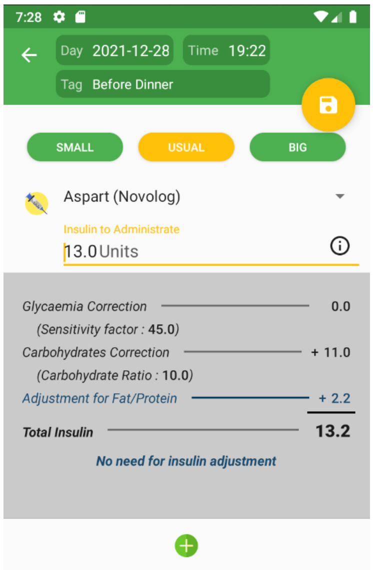
Following what has been said previously, a big problem concerning the MyDiabetes application is that right now the meal insulin calculations are incomplete. Only carbohydrates are being accounted for. Meal insulin can be calculated by carbohydrate counting, or by combining the results obtained from carbohydrate counting and adding an extra calculation for protein and fat. The current version of the MyDiabetes application is capable of performing the necessary calculations for converting carbohydrate content into an acceptable insulin dosage. This means the application is fitted for carbohydrate counting (see section 2.2), but as we have seen throughout this dissertation, counting only carbohydrates, although acceptable, has its limitations as it does not reflect the real insulin dose the person has to take.

In order to facilitate the user's interaction with the application, and simultaneously solve the issue regarding fat and protein calculations, the buttons were implemented in the application's meal menu. This, however, is quite crude. Ideally, the values that should be processed by the application regarding meal information should be as close to the actual nutritional information of said meal. Of course, this is also quite hard due to the precision of the information. Moreover, the calculation of the insulin for the protein/fat intake was still unfinished.

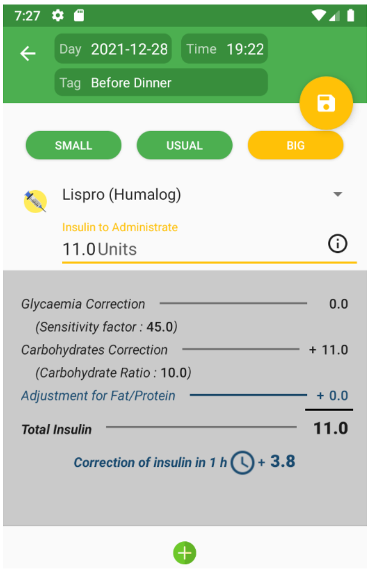
Diabetics can administer insulin in one of two forms, pen and pump (see section 2.1). Insulin injections are taken by patients in a full dose at one point in time, while an insulin pump can be programmed to release the insulin bolus continuously. The figure bellow displays the different results obtained by a user when utilising the default meal buttons with a pen and a pump. When using a pump or a pen, the insulin information screen displays different messages, these messages are intended to aid the user in maintaining normal glycaemia values and future insulin intakes.



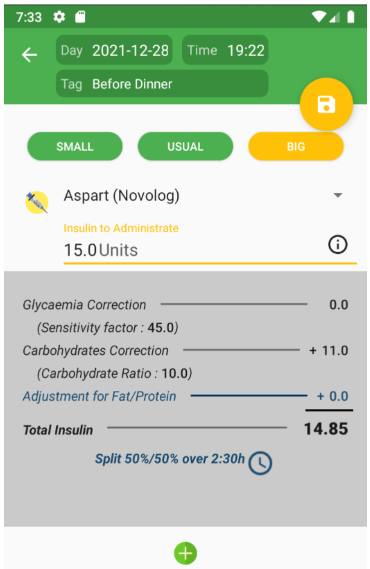
(a) Small meal with pump



(b) Usual meal with pump



(a) Big meal with pen

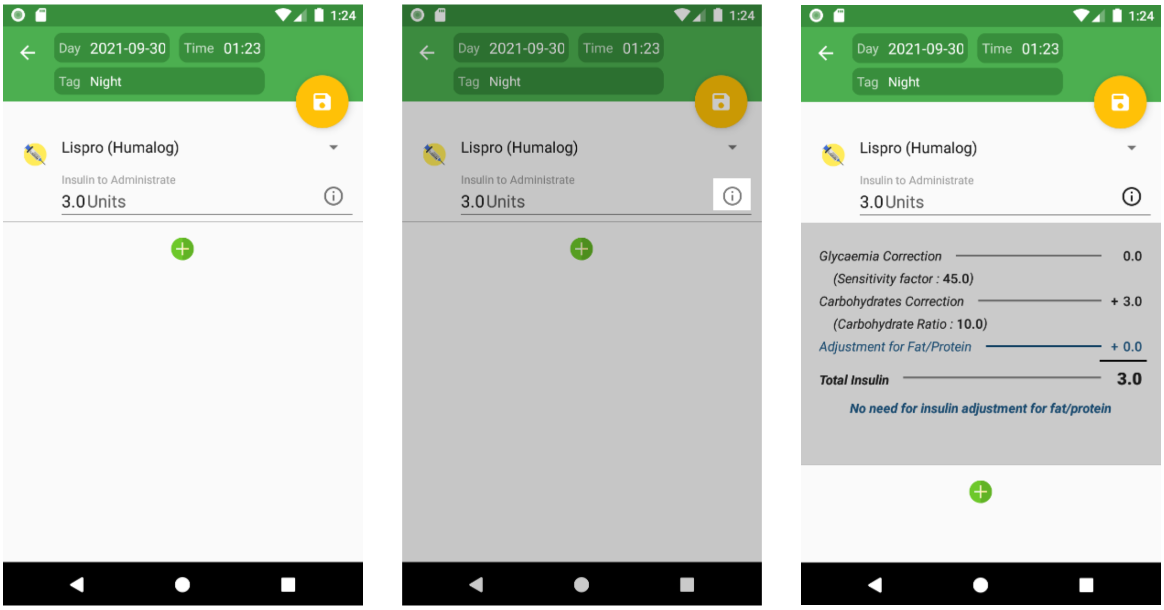


(b) Big meal with pump

Figure 4.5: The meal buttons with their respective results

4.2 Insulin record

An insulin record is used when users want to save the amount of insulin they have administered. When using the meal record and after defining the meal, the insulin record appears automatically and shows the amount of insulin calculated for that meal. In order to verify the insulin quantities, the user can press the info button, displayed in 4.6b. After pressing this button, a cascade styled screen appears displaying the insulin information regarding carbohydrates and the fat/protein adjustments. The total insulin is the sum of the two.



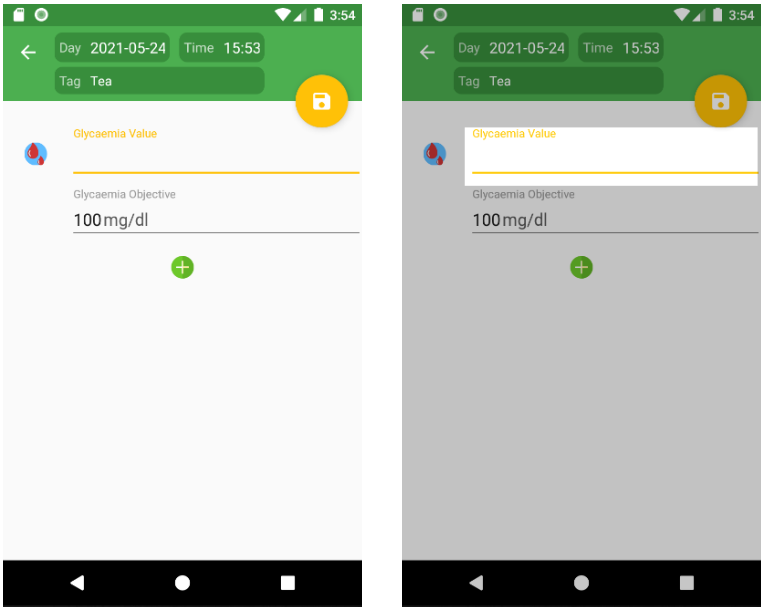
(a) Insulin record (b) Insulin help button (c) Insulin help pop up screen

Figure 4.6: A insulin record and its components

In this version, the application does not display the information regarding fat and protein adjustments as it has not been yet implemented.

4.3 Glycaemia record

A glycaemia record is utilised when users want to save their blood sugar data. After performing a reading, by using an appropriate glycaemia metering device, the user can save his blood sugar level by inserting the value in the textbox displayed on 4.7b. Saving glycaemia values benefits users in two different ways, it is both convenient and helpful. Records can be maintained in the application and the information regarding these records can be checked at any given time. This is convenient, as the information is always there and ready to be accessed by the user. There are still quite a few diabetics that use paper for saving their blood sugar values, the downside being that paper records can be lost or damaged. Smartphones can also be prone to accidents. Still, having your information with you always is a great benefit, and since it is a valuable device, people tend to be more cautious. Being able to emulate this method in the application is a plus, and since it is relatively simple, it becomes a straightforward process.



(a) Glycaemia record (b) Glycaemia textbox

Figure 4.7: A glycaemia record and its components

The glycaemia objective is a threshold set when the user first uses the application, it serves to signal the normal amount of blood sugar for that user. The insulin algorithm uses this threshold in order to provide an accurate calculation, considering the users current glycaemia value and glycaemia objective value. This ca be achieved by reducing or increasing the insulin quantity.

4.4 Conclusion

Although some things are missing, we must consider that the application is being developed over the years and in each of its stages, a new component is implemented or a current one gets improved. In chapter 3, we used a table to demonstrate how detailed the MyDiabetes application is in terms of functionalities, and consequently, we made a comparison with some other diabetes-oriented applications. MyDiabetes was one of the more better ranked applications, compared to the rest of the apps in the table, and second only to Diabetes.M. Although, this was due to not having a full implementation of the insulin calculator algorithm and a notification system. However, both these features are to be implemented with this work.

Chapter 5

Design and Development

The main objective for implementing an insulin calculator is to help the diabetic user to arrive at the most appropriate insulin value to be administered. The addition of this tool to the MyDiabetes application will, in a way, increase the utility and potential value of the application for the user, and helping them with managing their disease. In this chapter, we will discuss the added features and improvements over the previous version of the application.

Each section of this chapter represents a new element that has been implemented, or updated in the application. It will be explained why the new implementations and/or updates were developed, as well as the process that led us to consider these solutions to improve insulin calculations. We expect these updates to have an impact in the user's diabetes management. The new implementations/updates are:

- Implementation of a system to convert proteins and fats, present in a meal, in the respective insulin dose.
- Implementation of a notification system with a timer, to alert the user of the need to administer insulin corrections.
- Improving meal records, by allowing the inclusion of details (further explained in 4)

5.1 Fat and protein conversion system

This section covers the integration of the fat and protein conversion algorithm into the MyDiabetes application. The algorithm is based on the developments made by Pańkowska and Błazik [59] while creating ***Diabetics software***, a nutrition database software and bolus calculator. *Diabetics software* includes an algorithm to calculate mealtime insulin doses. The algorithm is composed of four parts, bellow is a brief explanation of each.

The Warsaw Pump Therapy School (WPTS) algorithm, used in *Diabetics Software*, aims to establish a form of education for patients using an insulin pump. This involves helping patients in achieving a proper mealtime insulin dose. Achieving optimal meal insulin dosing is a key factor in controlling Diabetes Mellitus 1 (DM1). This new model, designed by Pańkowska and Błazik [59], is composed of two parts. The first part is responsible for calculating the Normal-wave Bolus (NWB), the NWB is calculated exclusively from carbohydrates. The second part is responsible for calculating Square-Wave Bolus (SWB), the SWB is calculated exclusively from fat-protein content. The model is able to perform this second calculation due to the addition of a new variable, known as Fat-Protein Unit (FPU). The FPU is a new exchange factor that was added to the food counting system, defined as 100 kcal of fat and/or protein. When calculating the SWB, the system uses the FPU to determine the insulin quantity of the extended bolus. Additionally, the FPU is also used to calculate the duration of the extended bolus.

The higher the FPU content of a meal the higher the time value will be. As referred in chapter 2, fat and protein have a direct effect on the diabetics' glycaemia levels. Additionally, fat can delay gastric emptying, and thus, influence blood sugar rises. Considering these facts, Pankowska and Blazik defined time intervals considering the FPU factor for these kinds of meals. The time interval is then adjusted, as high FPU meals need more time to be processed by the body.

In short, to implement the algorithm we have to follow these steps:

- **Step 1:** Calculation of the Carbohydrate Unit (CU) and FPU total for a particular meal
- **Step 2:** Rounding both FPU and CU in order to facilitate future calculations.
- **Step 3:** Calculation of the needed insulin dose and type of boluses. The Insulin-to-Carbohydrate Ratio (ICR) factor is used in this equation.
- **Step 4:** Calculation of the time length of the SWB.

Further along this section, we will go into more detail on each and every part.

In chapter 2 subsection 2.3.4, we introduced the insulin calculator algorithm and the concepts of FPU and CU. In this section, we will detail these two concepts. FPU and CU are the two main components of the algorithm, one is responsible for the standard bolus, while the other for computing the extended bolus.

Calculating the CU is a relatively simple process. First, we divide the number of total carbohydrates of a meal by 10, since one unit of CU is equivalent to 10 carbohydrates. This then gives us the total amount of CU in a meal, and then is is possible to calculate the normal bolus. The formula for the CU calculations is displayed bellow.

$$CU = \frac{Carbohydrates}{10} \tag{5.1}$$

For calculating the FPU, we take the number of fats and proteins in the meal and multiply them by two different constants each. It is important to understand the origin of these constants in the FPU formula. The constants are 4 for the proteins and 9 for fat. [55]. As one unit of FPU is defined as being 100 kcal of fat and/or protein we divide by 100. The formula is displayed bellow.

$$FPU = \frac{Protein \times 4 + Fat \times 9}{100} \tag{5.2}$$

Both FPU and CU are rounded using the half-piece method [59]. This means the calculated values are rounded to whole or half unit whatever is closest.

One major disadvantage of the Diabetics software, as stated by the authors, is that it does not consider either the target glucose level or the insulin sensitivity in its measurements. The calculations depend solely on CU and FPU information. Meal insulin calculations are recalculated if the meal's content is changed.

The mealtime algorithm developed for the MyDiabetes application, although based on the WPTS algorithm, tries to improve the referred issues. Meal insulin calculations are done considering the user's ICR factor and Insulin Sensitivity (ISF) factor. Additionally, when the user first starts the application, he is prompted to introduce some personal information including glucose targets. One other important aspect is the possibility of adding records of glucose measurements. All of these parameters are taken into account when calculating the insulin dose for the carbohydrates. It is in this sense that we expect the algorithm implemented in the MyDiabetes application to be more robust. We expect the results obtained through our implementation to be closer to what the real value of the insulin dose should be.

After calculating the CU and the FPU, the algorithm developed by Pańkowska and Błazik, uses these values in order to determine the standard bolus and the extended bolus. When this happens, it also calculates the duration for the extended bolus depending on the value of the FPU. Bellow we have a listing that shows the functioning of the algorithm, it features the core logic behind the standard and extended boluses calculations.

```
public void algorithmPankowska() {
    ...
      float cu_perc;
      float carb_units = rounding(getCarbs() / 10);
      float irFactor = 10.0f / getCarbsRatio();

      setStandardBolus();
      setTotalBolus();
      setDurationExtendedBolus();
   ...
}
```

Listing 5.1: WPTS variables and other important functions

The code snippet displayed above contains some variables used by the algorithm, as well as some other important methods used to assign the values calculated to the global variables, responsible for storing the value of the normal bolus, the duration, and the square bolus.

The code snippet displayed bellow, demonstrates the logic behind the calculation of the normal bolus. A key variable we have yet to discuss, which is directly involved in the calculation of the normal bolus, as well as the standard bolus, is the cuperc. The cuperc can be translated as the share of carbohydrate units in the meal. In other words, after adding the FPU with the CU, the cuperc is the percentage of carbohydrates in the result of that sum. The formula for the cuperc is displayed bellow.

$$cuperc = \frac{\text{CU}}{\text{CU} + \text{FPU}} \tag{5.3}$$

```java
public void algorithmPankowska() {
    ...
      // calculating the normal bolus:
      //the values 0.2 and 0.8 are default values of the algorithm
      if(cu_perc < 0.2){
         setNormalBolus(0.0f);
      }
      else if(cu_perc >= 0.2 && cu_perc <= 0.8){
         float temp =  (float) (carb_units * irFactor * (1 - correction));
         setNormalBolus(temp);
      }
      else if(cu_perc > 0.8){
         float temp = (float) (carb_units * irFactor);
         setNormalBolus(temp);
      }
   ...
}
```

Listing 5.2: WPTS normal bolus calculations

By looking more carefully at the conditions of both parts of the algorithm, we can see that although they do different tasks, they are somewhat similar. The most noticeable difference is due to the fact that, the normal bolus calculation uses the percentage of carbohydrates (the cuperc), while the extended bolus calculation uses the FPU for it's first condition. Both parts assess the percentage of each nutrient and define the value of each bolus. If the percentage of carbohydrates, when calculating the normal bolus is negligible, then, the value of the normal bolus is zero. On the other hand, if the percentage of carbohydrates is considerable, then, it uses the amount of CU multiplied by the insulin resistance factor. The algorithm may also use a correction factor depending on the percentage of CU. The hard coded values used above in the if-else condition are the default values defined by the WPTS algorithm. These values represent possible percentages of CU.

```
public void algorithmPankowska() {
    ...
      //calculating the square bolus:
      //the values 0.2 and 0.8 are default values of the algorithm
      if(this.FPU < 1.0){
         setSquareBolus(0.0f);
      }
      else if(cu_perc < 0.2){
         float temp = (float) (this.FPU * irFactor);
         setSquareBolus(temp);
      }
      else if(cu_perc >= 0.2 && cu_perc <= 0.8){
         float temp = this.FPU * irFactor * (1 + correction);
         setSquareBolus(temp);
      }
      else if(cu_perc > 0.8){
         setSquareBolus(0.0f);
      }
   ...
}
```

Listing 5.3: WPTS extended bolus calculations

Following what has been said previously, after calculating the extended bolus, the algorithm then calculates the time length of FPU effect on glycaemic levels, based on the amount of FPU and the percentage of carbohydrates in the meal. In order to attain this value, we use the same conditions defined by Pańkowska and Błazik [59] in their software.

Bellow, we have the conditions defined by the Pańkowska and Błazik in order to define the time length value of the extended bolus:

- FPU $<$ 1.0 $=>$ time = 0h
- cuperc $>$ 0.8 $=>$ time = 0h
- FPU $>=$ 1.0 and FPU $<$ 2.0 $=>$ time = 3.0h
- FPU $>=$ 2.0 and FPU $<$ 3.0 $=>$ time = 4.0h
- FPU $>=$ 3.0 and FPU $<$ 4.0 $=>$ time = 5.0h
- FPU $>=$ 4.0 $=>$ time = 8.0h

One concern that we encountered, which then had to be solved, is the fact that the software developed by Pańkowska and Błazik is targeted at those who use insulin pumps. The values returned by the algorithm may not be the most appropriate for users who use an insulin pen. When a patient decides to perform an insulin injection, he must input the correct insulin dose in the insulin pen. Generally, insulin pens have a knob for adjusting the insulin dose, and a dose window with an indicator displaying the current insulin charge.

Most insulin pens are limited to increments of half a unit of insulin. This means, each time the user rotates the knob, the dose will increase by one. With this in mind, and considering the base algorithm presented above for calculating the insulin dose, changes have been made in order to take this into account.

In the image displayed bellow, we have an example of an insulin pen and its components.

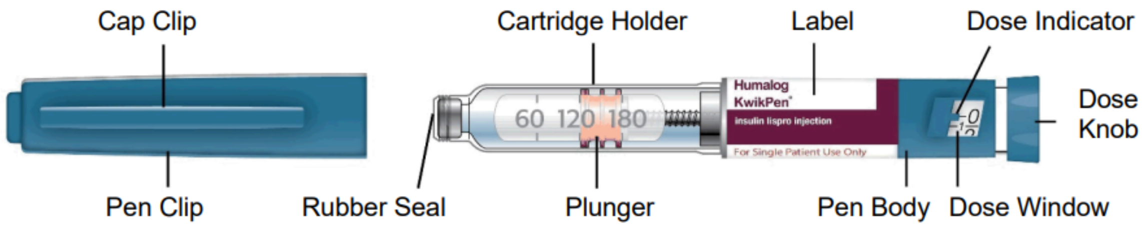


Figure 5.1: A typical insulin pen with its components highlighted [43].

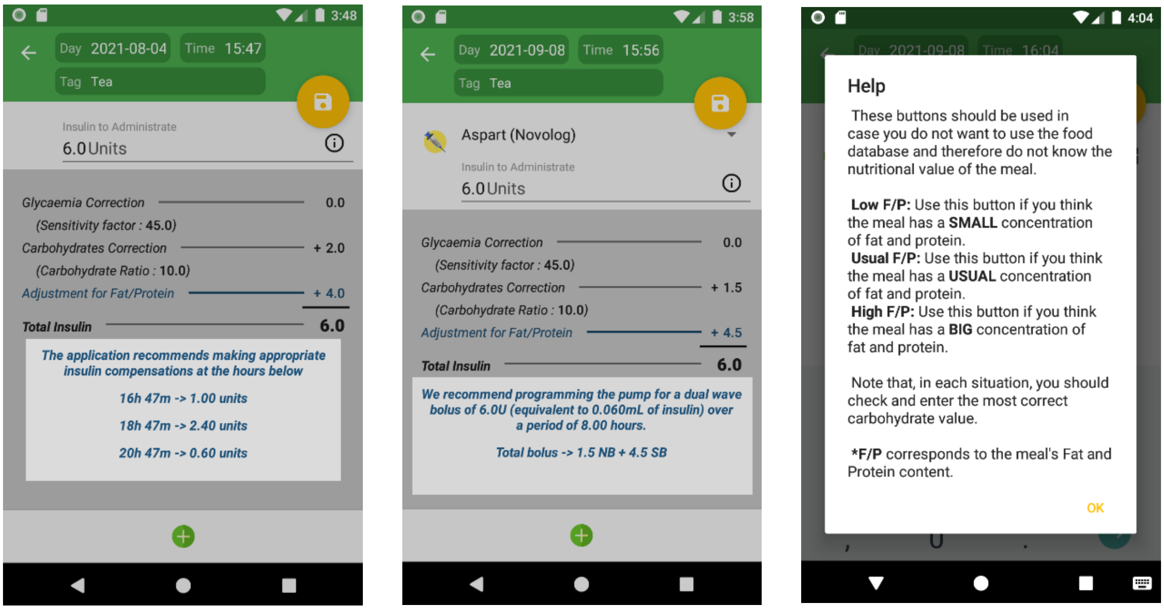
Note that, the WPTS algorithm developed by Pańkowska and Błazik [59] is insulin pump oriented. Insulin pumps are more flexible devices when it comes to programming insulin boluses, when compared to insulin pens. They often allow users to increment their doses in less than 0.5 units per increment. Medtronic, a global leader in medical technology, services, and solutions, has a vast amount of available Continuous Subcutaneous Insulin Infusion (CSII) devices. Diabetics who happen to use a Medtronic pump can program their boluses and increment insulin doses by 0.1, 0.05, and 0.025 units [49].

After calculating the insulin dosage for the meal, the MyDiabetes' bolus calculator rounds this value so it can be used with insulin pens. The mealtime algorithm uses the rounding function of the MyDiabetes application. Both the standard bolus and the extended bolus are rounded using this method. According to Pańkowska and Błazik, both the FPU as the CU must be rounded to half a unit or a unit. For this, we use the rounding function discussed before.

Besides the algorithm and some other bolus related functions, we have also redesigned a few elements of the user interface, as well as the help dialogs explained in the previous chapter. After bolus calculations, one thing that we thought could be improved was the information presented to the user, regarding the calculation of insulin, after the insertion of the meal. When inserting a meal record, MyDiabetes promptly inserts an insulin record which is relative to that meal. After this is done, depending on whether the user uses a pen or pump, and depending on the meal's nutritional quantities, new information regarding insulin administration may appear.

If the user's main insulin administration method is via pen, then, information regarding the time intervals of insulin compensations will be shown. Alternatively, if the user's main insulin administration method is via insulin pump, then, the information that will be shown to the user will be the total insulin dose to be administered, as well as the duration of the extended bolus to be programmed in the insulin pump. Lastly, in case the FPU content is negligible, an alternative message informing the user that there is no need to compensate for fats and proteins will appear.

In this final case, only the insulin quantity associated with the carbohydrates is shown (the rest is zero). This new information can be better examined in the figure bellow.



(a) Information for the pen (b) Information for the pump (c) Information for the buttons

Figure 5.2: Newly added information for the insulin and meal records

5.2 Implementation of the alarm system

Forgetting to perform an insulin compensation can be easy during daily life. Stress, distractions, and work, are impacting factors, that can lead a person to forget or even neglect medication schedule. If not under control, certain areas of a person's life can take priority over diabetes, leading to negative outcomes. Brod et al. [9], have conducted a study to examine issues regarding unintentional dosing irregularities due to memory problems. The objective was to assess how this issue can impact insulin taking behaviour in people with diabetes. According to the authors, unintentional memory issues do impact insulin taking behaviours. These can lead to dosing irregularities and contribute to patient uncertainty and worry, about diabetes management. They also concluded that insulin strategies that assist patients in managing memory related dosing issues, may reduce costs, improve adherence and treatment efficiency. With this in mind, including an alarm system in the MyDiabetes application, and the possibility for a diabetic user to program his own alarms, with a defined insulin quantity and description, can mitigate many of the issues discussed by Brod et al..

Implementing alarms and notifications in the MyDiabetes app can aid users to achieve their glycaemia targets, and increase user interaction. According to Woodward et al. [81], mHealth applications have been shown to help users change their health-care behaviour through personalised goals and self-monitoring. By using push notifications (e.g., reminders for tasks), mHealth apps enable users to more easily self-monitor and, consequently achieve their goals of behavioural change, such as administering insulin on time. Notifications can also increase app adherence and engagement, further aiding users in achieving their health objectives [81]. It is in this sense that we think that the implementation of a system that could do this would bring additional benefits to the application.

The first step in developing developing the MyDiabetes alarm system is to create a template in which all alarms will be based on. This is represented by a single class that contains all the information necessary to generate and schedule an alarm. The next includes organising the alarms in a list and display this list to the user, the design should be simple and intuitive and should allow deletion of single or multiple alarms. The final step is characterised by the integration of this system with the meal records section, so that when a user adds a new meal record MyDiabetes generates alarms accordingly.

In short, we need the following elements:

1. A class that will serve as an alarm model.
2. A list where the alarms will be placed and displayed to the user.
3. A database that will maintain and store the alarms.

The Alarm class contains information such as the time and date of the alarm, whether the alarm is a recurring alarm or not, and if so, the days it will repeat. It also has a flag indicating if the alarm is started or stopped. A unique alarm Identification Number (ID) is present, as well as a *'long'* variable which represents the creation of the alarm, it acts similarly to a timestamp and is used by other functions later on. This class also contains the methods responsible for scheduling and cancelling alarms.

Displaying elements in a list or a grid is a very common design pattern in mobile applications, the screen displays a collection of items which the user can scroll through. This collection could be a list, a grid or another structured representation of data. The RecyclerView is a list drawing library that essentially provides a fixed-size window to load a large data-set into, items are created dynamically and inserted into the RecyclerView [68]. In case the views go out of scope (they leave the screen), it can recycle the ones created in the beginning and reuse them to make it seem as if the views were never offloaded. Thus, giving an impression the views were virtually present off screen. RecyclerView was developed to replace the ListView and GridView models, it improves the former increasing performance and reducing battery usage. ListView structures are very capable at displaying similar looking data, although, power consumption wise they lack optimisation. Every time a scroll happens the ListView needs to create newer views, which is a demanding task. Heavier lists with high quantity of items translate into a more resource hungry application. For this reason, and due to it being a more flexible and simple (although powerful) structure, we decided to opt for a RecyclerView list structure for the alarm system menu.

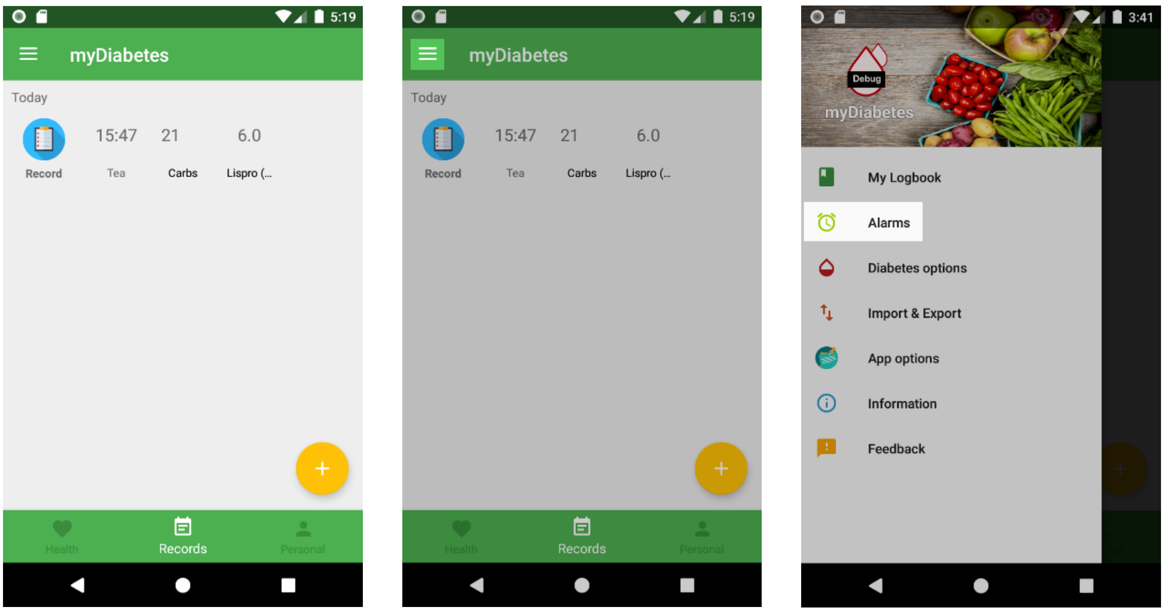
Lastly, we need a way to store and save the alarms list. Android is very flexible when it comes to database management and creation. With the introduction of the API 26, ROOM was added. Android ROOM is an abstraction layer over SQLite and implements Object-relational mapping (ORM) to store data [22]. ORM reduces the amount of code that needs to be written in order to perform database operations. This simplified the process of creating databases and storing application data. Applications that process trivial amounts of structured data can greatly benefit from the persistency of this data locally. This being said, using ROOM to store alarm information on the MyDiabetes application is the better choice both in terms of performance and simplicity.

ROOM has three main components: entity, database, and Data access object (DAO). All three are further explained bellow.

- **Entity:** Entity is a modal class that is annotated with the **@Entity** annotation. The variables in this class are the columns and the class itself is the table. In our implementation this represents the Alarm class.
- **Database:** It is an abstract class where the entities are stored (e.g., alarms).
- **DAO:** This is an interface class that allows us to perform multiple operations in our database.

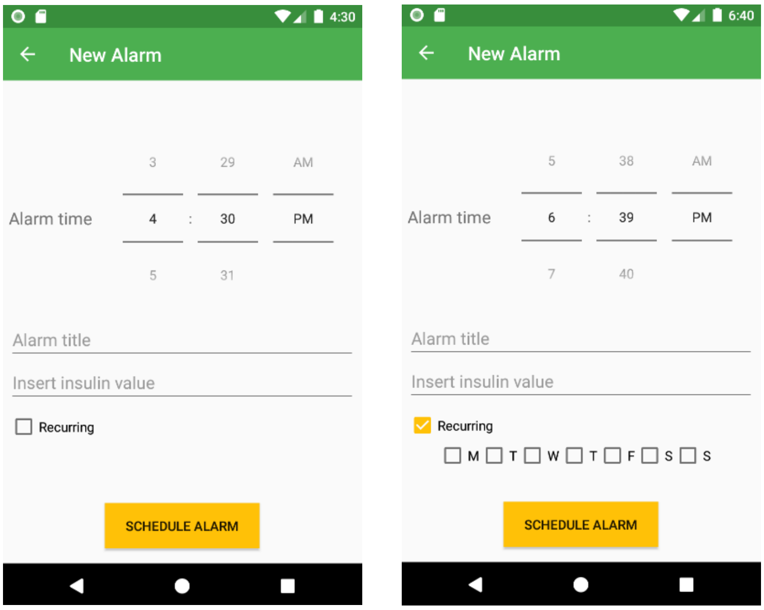
Now that we have covered the more technical part, such as the architecture of the system and how it was implemented, we will discuss the system itself and how it works in the MyDiabetes application.

The alarms menu can be accessed by opening the user drawer and clicking on the "Alarms" entry, next to the alarm clock icon, as displayed bellow.



(a) Home screen (b) The user drawer icon (c) Alarms menu

Figure 5.3: The alarm menu section in the user drawer



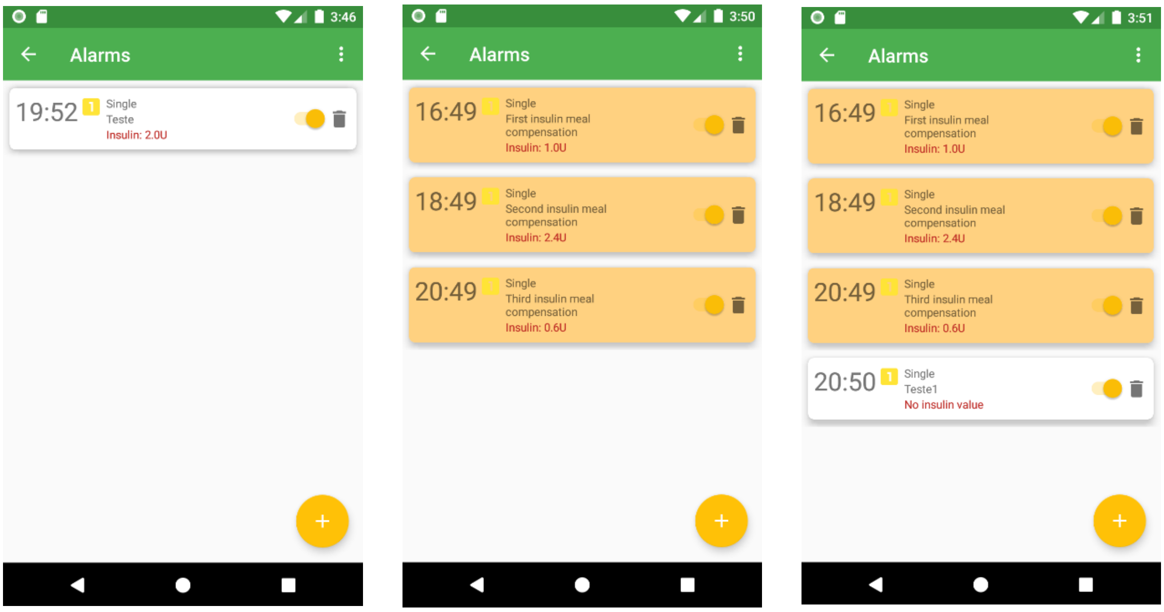
(a) TimePicker and EditTexts (b) Recurring options enabled

Figure 5.4: New alarm menu screen

In the alarms menu there is a button on the bottom left corner where the user can create a new alarm. It is also on this menu that the current created alarms are listed. This means that, if there are any alarms created, they will appear on this screen and with their respective information. When the user decides to create a new alarm, he is taken to the "create alarm" screen. In this screen there is a TimePicker element the user can utilise in order to define the alarm time, and two EditText elements, one for the alarm name and the other for the insulin value. There is also a checkbox that can be clicked in order to define the alarm as a recurring alarm. When clicked, the screen displays seven checkboxes corresponding to the seven days of the week, as seen in figure 5.4.

When the user creates a meal record, he can use the default meal buttons or search the meal database for his meal. When this step is concluded and the record is created, the application will then redirect the user to the records screen and a dialog will appear asking if he desires to create alarms/notifications. A dialog box is a small window that prompts the user to make a decision or insert additional information [21]. It requires users to take additional actions to continue (e.g., yes, no). If the user says yes, the application will then create the necessary alarms that will alert the user of future insulin compensations. These alarms will then be added to the alarms list and can be accessed via the alarms section.

Since the alarms are added to the list and are seen as any other alarm object, it was decided to change the colour of the alarms created by the application so as not to confuse the user.



(a) Manual alarm (b) Generated alarms (c) Mixed alarms

Figure 5.5: A list containing examples of both alarm types

Chapter 6

Results and analysis

This chapter will describe the idealised planning for the study, together with the changes that had to be made to that planning. The results of this study will be analysed in depth, this also involves debating solutions to the problems that have emerged.

Initially, our plan was to perform this questionnaire on the people attending the endocrinology service of S. João's Hospital. Due to medical appointments being on standby, and patients being contacted and examined through the phone, this was not possible. During 2020, the world was struck with the COVID-19 pandemic. Although the current situation is a more stable, we are still living in the aftermath of the virus, people and institutions are required to follow health safety instructions and precautionary measures in order to minimise infection risk. Diabetics are classified as a risk group, naturally, it is safer for them if they do not have to go to hospital.

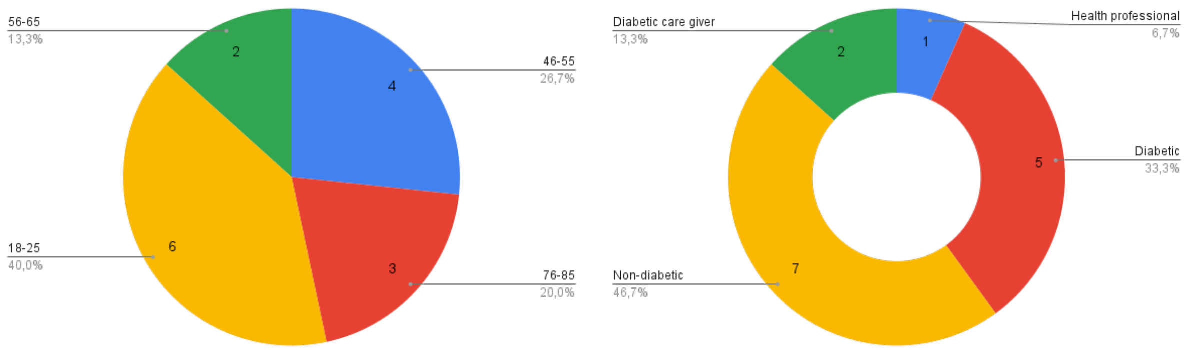
Due to this setback, we had to change our initial planning. This included increasing the target spectrum for the questionnaire, as well as the questionnaire itself. Besides diabetics, we decided to include non-diabetics, health professionals in the field of diabetes, and diabetic caregivers as targets for the questionnaire. We then changed the questionnaire to better accommodate these different groups of people.

The questionnaire itself is divided into three sections, with two key sections. More information regarding the questionnaire can be consulted in appendix A. We established that non-diabetics would only be responsible for giving feedback regarding the usability part of the questionnaire, while the rest would give feedback for every part. On average, each person that was approached to undertake the questionnaire, had about five minutes to interact with the application. We had to carefully plan out the interaction time in order to maintain a good balance between interest and minimum interaction. The MyDiabetes application is currently in closed development, this means that it is not listed in the Google Play Store. For people to use it, they must be part of the MyDiabetes program and be involved in its test phase[1]. They also must sign the Informed Consent form and be fully informed about the methodology to be developed during the study. We approached people which we had some proximity with, because this was the most viable

[1] Endocrinology Service of the São João Hospital, EPE [17]

solution we had, given the current setbacks. The interaction of people with the app, was made on one of our personal devices that had the application installed. Since these people will not be able to keep the application, we tried to take as little time as possible from them during the interview. If a person was asked to use the application for a long period of time before answering the questionnaire, that person could lose interest. On the other hand, if application use time is too small, then that person will not acquire sufficient knowledge to answer the questionnaire in a proper manner.

15 participants were interviewed, ranging in age from 18 to 85. The fact that there was such a wide range of ages made it possible to understand the acceptability of the different functionalities implemented in the application, in different age groups. The percentages these groups occupy in the study, as well as their age range, are represented in figure 6.1.



(a) Ages (b) Types

Figure 6.1: Ages and types of participants

The questionnaire has 18 questions, 8 of them are related to the implementations made in the application, while the rest is related to its usability. The 8 questions related to the application are mixed. Some questions are accompanied by a visual aid (e.g., a screenshot of the application), some are multiple choice, others require the person to perform an association between two premises. Some questions require justification, so to give us a better insight on why the person decided to answer in that manner. As stated before, everyone except non-diabetics answered these questions.

The questions related to the application are:

- Q1: Do you calculate the necessary insulin dose for proteins and fats?
- Q2: Do you understand what the "light", "usual" or "large" buttons are for?
- Q3: If you ate one of the following meals for breakfast, which button would you use given your regular diet?

- Q4: In your daily life would you introduce a detailed meal (making favourites) or would you prefer to use the buttons?
- Q5: Would you like notifications to remind you to reinforce your insulin dose?
- Q6: Would you trust the insulin values presented to you by the app?
- Q7: Is the information regarding the calculation of insulin clear?
- Q8: Does the automation of the insulin calculation process motivate you to make more records?

The answers provided to **Q4 "Do you calculate the necessary insulin dose for proteins and fats?**", show that every single person stated that they did not calculate the insulin dose for proteins and fat. Based on our conclusions, this was due, essentially, for two reasons: First, people do not have the required expertise to perform the calculations; Second, people do not find it helpful to perform said calculations. Although the application bypasses the first problem, by performing the necessary calculations for the diabetic, the second issue persists. One approach that could help in mitigating this problem, is by informing the person while using the application of the importance of proteins and fats and how these nutrients could affect their glycaemia values. A second approach is through encouragement by the respective physician. Extra insulin compensations, and insulin adjustment based on protein and fat calculations, is still a fairly "new" subject. Most diabetics are unaware of the existence of this method when it comes to meal insulin planning. People should be informed about the added benefits of including these nutrients in their insulin calculations and should also be encouraged by their doctor into trying this regime. Without medical advice we do not believe that most diabetics would have the willingness to do exactly this, even if suggested by the MyDiabetes application. Most people already struggle with carbohydrate counting, which is a simpler method, so it is understandable that there exists some resistance in performing these added calculations. The added information and encouragement could possibly increase application usage.

The feedback received to **Q6 "Would you trust the insulin values presented to you by the app?**", demonstrates that the values established by the application when it comes to insulin dosages, although requiring modifications, were well received. Most interviewees trust the calculated insulin dose displayed on the screen when testing the application. This could be due to users identifying the displayed insulin value as a familiar one, or, by trusting the application after knowing the entities behind its development. However, some users were critical of the values shown by the bolus calculator. This was justified due to the values shown being considerably lower than those the users were used to administering for a similar meal. We find this information of great importance, since it opens more room for debate when it comes to achieving an optimal meal insulin value.

The notification system implemented in the application was well received, almost all participants stated they would like to have notifications to warn them about insulin compensations. Some people stated that, at times, they could forget to perform a compensation or fail to administer it in due time. This can also be applied to measuring blood sugar levels. Although the notifications are designed around administering insulin, they are quite flexible, and can be used to notify the user of anything. This may include measuring glycaemia levels. The answers to question **Q5, "Would you like notifications to remind you to reinforce your insulin dose?"**, are displayed bellow, in figure 6.2.

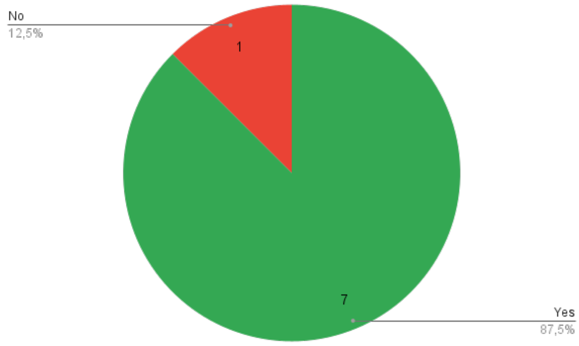


Figure 6.2: Existence of notifications

The last question that was presented, **Q8 "Does the automation of the insulin calculation process motivate you to make more records?**", is related to the implementation of the insulin bolus calculator, as well as the use of notifications to alert the user to perform an insulin compensation. The results obtained for this question are presented in figure 6.3.

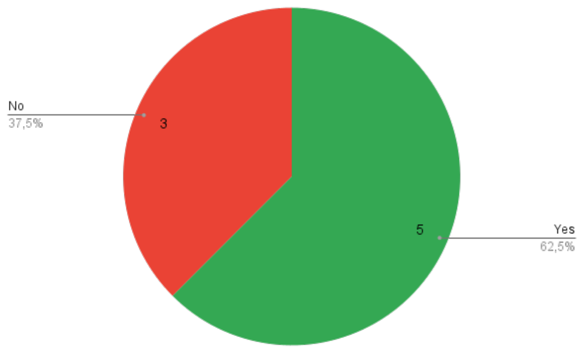


Figure 6.3: Motivation to perform more records

By analysing the data obtained, we can conclude that there is a mixed opinion when it comes to increasing application usage with these new functionalities. Some people involved in the study would agree that they would be enough to motivate them to create new records, others would disagree. We conjecture that with people's willingness to use an application when they are not used to doing so, not necessarily on the implementation itself. One pattern we came to notice, is that people require the application to be simplistic, they enjoyed the features offered but had some difficulty using them. We can support this claim by observing the data related to **Q4 "In your daily life would you introduce a detailed meal (making favourites) or would**

you prefer to use the buttons?", every single person choose the buttons as their preferred method, as seen in figure.

This is related to the simplicity and ease of this method when compared to using the database, we can conclude that further development and research is needed in order to optimise the use of buttons to calculate an insulin dose.

The usability section was mainly designed for non-diabetics, although everyone who participated in the study answered this part of the questionnaire. The answers given where important in evaluating the usability of the application after the integration of the new functionalities implemented. The usability section has 10 questions, and 5 different types of answer for each question. It is essentially a System Usability Scale (SUS) test, it was designed by Brooke et al. to evaluate the usability of a system. One of the primary benefits of using SUS is that the feedback is reliable and repeatable. Each response is assigned a value for the SUS score calculation. The final value evaluates the overall usability of the design solution, in this case, the MyDiabetes application. In order to obtain a score, we must perform the following calculations:

- For each of the odd numbered questions, subtract 1 from the score.
- For each of the even numbered questions, subtract their value from 5.
- Sum the total score of these new values, then we multiply this by 2.5.

Five questions were ranked the highest. These questions are respectively: Q3; Q7; Q9; Q6; Q8. These are all related to the ease of use of the application. By following the calculations explained above, we obtain a SUS score of 62.5. This places the usability of the MyDiabetes application in the "OK" range. Although, we must take into account, that this value is slightly influenced by some of the higher age groups approached to perform the questionnaire. Nevertheless, usability wise, we can conclude that most people who answered the questionnaire did not find it difficult to understand how to work with the application. This means accessing the different functionalities that the MyDiabetes application has to offer, including those that were implemented during this work. The more "negative" opinions came from people at the upper end of the age spectrum, which was to be expected. Younger people are more used to dealing with technology, whereas older people are more unenthusiastic and have a steeper learning curve. This behaviour was expected in people over the age of 65, however, it was possible to observe that people in the 46-56, were experiencing difficulties, using the application. The chart found in the figure bellow 6.4, demonstrates the results of each question. The different coloured bars represent the questions, and how they are distributed by each answer. We can assume that most people that would use the application would enjoy the experience, since most of the answers given were positive.

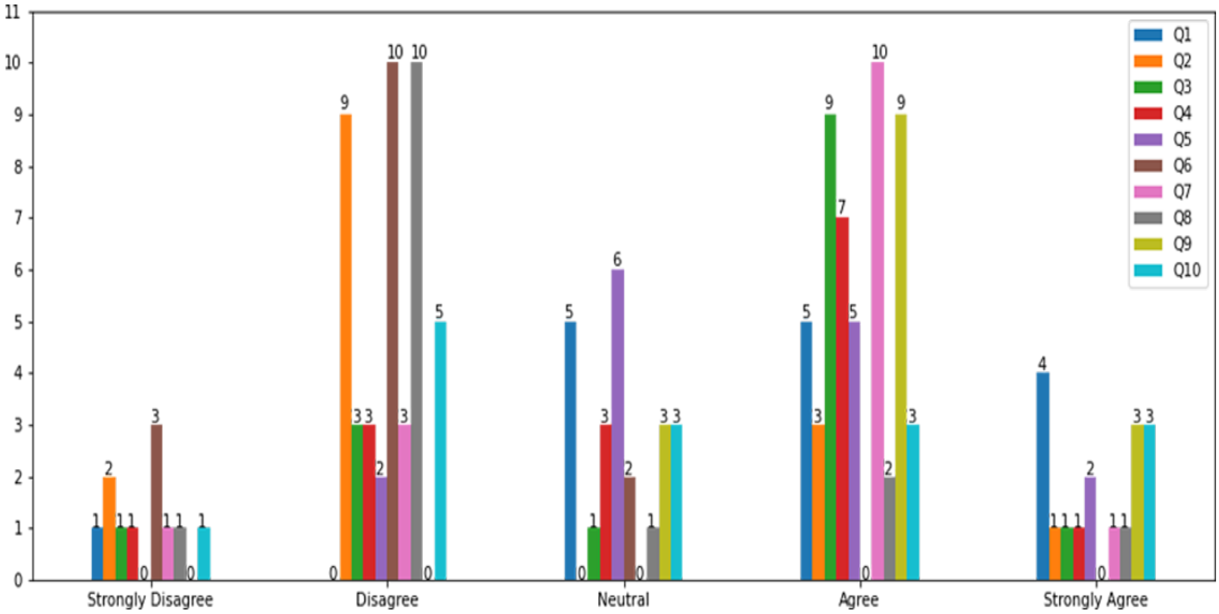


Figure 6.4: Answers to the usability section

6.1 Post-results changes

A major issue that was raised during and after the study, was related to the number of insulin injections suggested by the application. Most diabetic volunteers that performed the questionnaire, stated that the number of insulin injections that was suggested by the application was to high. When the study was initiated, the MyDiabetes application was planned to suggest up to three added insulin compensations for a given meal, depending on the meal's nutritional quantities (e.g., protein, fat, carbohydrates). Considering that most users state to only perform one insulin bolus per meal, and that they are not available to administrate more injections, besides the mandatory ones, this idea had to be revised. Requiring the person to perform more than 1 injection per meal would cause discomfort, specially if they had to do additional blood sugar tests after.

One person that participated in the study stated that, having to perform additional blood sugar tests was worse than extra injections. Possibly due to the nature of the test. When diabetics want to be sure of their glycaemia levels, they perform what is known as the "finger-prick" test[2]. The blood is then used with a testing device that will then show the current blood sugar value. The fingertips are one of the most sensitive areas of the human body [46], and although diabetes can cause some lack of sensitivity in this area due to peripheral neuropathy[3], the person still feels a strong sensation each time they must perform a blood sugar test.

The problem raised, was due to the adaptation of the algorithm developed by Pańkowska and Błazik. As explained in previous chapters, this algorithm is pump oriented, this means its

[2]Consists in pricking one's finger with a needle (known as a lancet) in order to draw blood [76]

[3]Damage to the peripheral nerves, often causing weakness, numbness and pain, usually in the hands and feet[77]

adaptation to insulin pens is quite difficult and would require dividing the dose into multiple injections. MyDiabetes users that have Continuous Subcutaneous Insulin Infusion (CSII) devices can continue to use this algorithm in order to achieve an insulin dose that can be programmed into their devices, while users who are carrying out Multiple Daily Injections (MDI) treatment need an alternative solution. This led us to modify the application in order to better accommodate these types of users. The modifications to the application's bolus calculator, regarding the use of insulin pens, were debated amongst ourselves, based on the feedback received in the study, and the expert opinion of an endocrinologist in the field of diabetes. The physician, Dr.César Esteves from the endocrinology department of Hospital Pedro Hispano, has recently accompanied the MyDiabetes project, and advised us to change the number of compensations, as well as the insulin values that were being calculated. His opinion is in line with the statements received by the people who participated in the questionnaire.

With this in mind, we decided to make the following changes:

- For users whose main method of insulin administration is through CSII, the application will calculate the insulin dose and the duration using the Warsaw Pump Therapy School (WPTS) algorithm. This is applicable to the buttons and detailed meals
- Users whose main method of insulin administration is through MDI, the application will calculate the insulin dose using the new information obtained via the physician. This is also applicable to the buttons and detailed meals.
- An extra insulin dose should be advised to the user, this extra dose should be administered in the 1 or 3 hour post-prandial period, depending on fat-protein quantities.

According to a study developed by [11], people with Diabetes Mellitus 1 (DM1) who are being treated with basal-bolus insulin injections, should be encouraged to carbohydrate counting, and should administer extra insulin units 3h into the postprandial period when consuming a high-fat, high-carbohydrate meal. The results obtained by the author, showed a reduction of plasma triglyceride concentrations and inflammatory markers in DM1 patients. Most diabetics have difficulties when it comes to fat and protein calculations, however, not accounting for these nutrients is associated with raised blood lipids, delayed glucose excursions and increased inflammation. In the opinion of the author, patients should be advised about the importance of the late bolus, not only for glycaemia control, but also to prevent possible negative influences on vascular health.

The new information we obtained, allowed us to establish insulin doses that could be applied to each of the default meal buttons, "light", "usual", and "big", and to the detailed meals. For a "light" meal, we reduced the amount of insulin to be administered to the user and adjust this value considering the basal insulin. For a "usual meal", we administer a dose that is roughly 50%/50%, this means half the dose will be related to the carbohydrates while the other half is related to the proteins and fats. For a "big" meal, we have two different options:

- For a meal that is roughly 40%/60%, the application will calculate the total dose considering the carbohydrates and fat/protein content of the meal. The application will then advise the user to administer this dose right before the meal. This was advised to us by the endocrinology doctor.
- For a meal that is roughly 22%/88%, the application will calculate the dose, and advise the user of an extra insulin compensation of 33% of the calculated dose. This compensation should be given in 3 hours after the meal.

Chapter 7

Conclusions

The aim of this work was to enhance the assistance carried out by the application to the diabetic, more specifically, by improving its ability to help him with mealtime insulin calculations. This was achieved by implementing a novel insulin calculation algorithm, that considers not only carbohydrates, but also proteins and fats. This implementation was the result of several months of analysing background information, as well as a study of the base application, which already contained a insulin calculator for the meal's carbohydrates. Lastly, we created a questionnaire in order to evaluate what was developed. This questionnaire was to be presented to diabetics that could use the application, thus giving them insight about the application's functioning and added features, and then answer the questions.

Due to the current pandemic situation, we had to change our initial plans of recruitment. Most people recruited to utilise the application, and thus perform the questionnaire, were non-diabetics. This, as said previously, was due to the inability to go to hospital and talk to the patients in person, and also to the fact that we lost some contact with the users who were partaking in the MyDiabetes program. These were the main reasons for the low adherence to the questionnaire, and what ultimately lead to the limited number of diabetics.

After the study, the results obtained raised an issue regarding the bolus calculator. People that were inquired stated that the number of insulin compensations, estimated by the application, were too high. This caused us to have to rethink what had been done initially in the MyDiabetes application. We had previously contacted a specialist physician in the area of diabetes, in order to obtain feedback about the implementations made to the bolus calculator. This physician has accompanied the MyDiabetes project since the beginning, and advised us to change the number of compensations, as well as the insulin values that were being calculated. His opinion is in line with the statements received by the people who participated in the questionnaire. The next few days were marked by changes to the code in order to mitigate these issues and make the application more acceptable to its potential users. However, a future study is needed in order to test what has been implemented and fully solve the problem of insulin dosages and time intervals.

7.1 Future Work

Due to the increasing usage of continuous glucose metering devices, it would be advantageous to somehow adapt the My Diabetes application to be able to work with these devices. Users would be able to perform a reading and send it to the application, creating a glycaemia record. The implementation of mechanisms that would enable My Diabetes to use wireless technologies such as Bluetooth or Near field Communication (NFC), would create compatibility with these devices. This would be easier and less demanding than having the user insert the data and creating the record. A major issue we have found, is that people tend to lose interest when asked to perform multiple steps in order to finish a task. By simplifying the application, and designing its functions and its User Interface (UI), to be as user friendly as possible, we can expect to see an increase in application usage.

An important aspect of the MyDiabetes application that should be improved, is better attributing an insulin value to the default meal buttons. In this implementation, we were able to apply a function that would calculate the insulin value for a usual meal based on the meal records available in the application. The value was calculated dynamically and adjusted automatically as the user was making meal records. A somewhat similar implementation could be performed for a big meal, ultimately improving both the buttons. An extra button could also be useful, since this opens more possibilities when it comes to adjusting insulin dosages and times.

A big challenge in optimising the bolus calculator algorithm, is understanding optimal dosages for a given individual, while at the same time, mitigating the rising issues concerning hypoglycaemia. Hypoglycemia can be considered a determining factor when it comes to perfecting mealtime insulin calculations. This becomes more relevant as the nutritional complexity of the meal increases (e.g., contains fats, proteins).

The use of a statistical methods and data analysis may help in atoning this issue. The added ability of analysing user data, and consequently developing a data model, that could predict the occurrence of a hypoglycaemia and adjust the insulin dose accordingly. This would be an excellent tool to add to the bolus calculator. When a hypoglycaemia would be predicted, the application could infer the possible causes and advise the user accordingly. This inference, on a first stage, may be based solemnly on medical knowledge, but could evolve to data mining and machine learning approaches. Naturally, a study would then be necessary in order to generate meaningful insights on the utility of these kinds of solutions.

Appendix A

Questionnaire

In this appendix, we will address the questionnaire used in order to receive feedback on the work that was developed in the MyDiabetes application. The main objective here is to understand if the insulin doses, which are being calculated by the algorithm, are in line with what a diabetic could introduce for a given meal. In addition to this, we will also expect to have a better understanding on the importance of the default meal buttons, and to what extent the implementation of alarms and notifications is important for the user. The answers to this questionnaire can serve as a starting point for refining the application in a future implementation.

A.1 Appendix

The questionnaire was developed via Google Forms [19], a platform developed by Google that is both flexible and intuitive. Google Forms allows an easy creation of any kind of questionnaire that can then be shared via e-mail or by a generated link. The questionnaire itself is divided into three sections:

1. General
2. Application
3. Usability

The application section covers the functionalities implemented in the application, the usability section is related to the usability of the application, and the general section has only two questions age and type of person. We established that diabetics should complete both sections, while non-diabetics would be limited only to the usability part. Google Forms allows this separation via answer conditioning, this means we can establish a condition based on a person's answer (e.g., whenever a person identifies as a non-diabetic, Google Forms guides her to the usability section). We use the "type of person" question in the general section to do this. The questions presented in the questionnaire are as follows, in Portuguese:

- General:

  1. Which situation do you most identify with? (diabetic, diabetic caregiver, non-diabetic, health professional in the field of diabetes)
  2. What is your age?

- Application:

  1. Do you calculate the necessary insulin dose for proteins and fats?
  2. Do you understand what the "light", "usual" or "large" buttons are for?
  3. If you ate one of the following meals for breakfast, which button would you use given your regular diet?
  4. In your daily life would you introduce a detailed meal (making favourites) or would you prefer to use the buttons?
  5. Would you like notifications to remind you to reinforce your insulin dose?
  6. Would you trust the insulin values presented to you by the app?
  7. Is the information regarding the calculation of insulin clear?
  8. Does the automation of the insulin calculation process motivate you to make more records?

- Usability:

  1. I would like to use this system frequently.
  2. I find the system unnecessarily complex.
  3. I found the system easy to use.
  4. I think I would need help from someone with technical knowledge to use the system.
  5. I think the functions of the system are very well integrated.
  6. I find the system very inconsistent.
  7. I believe that people will learn to use the system quickly.
  8. I found the system complex to use.
  9. I was able to use the system with confidence.
  10. I needed to learn several new things to be able to use the system.

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