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Research Article

Integrative Diabetes and Cardiovascular Diseases

Supporting on-going Diabetes Management: The Need for Frequent, Reliable Information, Decision Support and Guidance to Empower People with Diabetes

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Abstract

As noted by the World Health Organization (WHO) diabetes is a silent epidemic, and by 2020 there will be a 54% rise in the total number of individuals diagnosed with this disease. Moreover, diabetes is the most prevalent chronic disease globally today. What these figures underscore is that the current approaches to prevention and management of diabetes appear to be flawed and thus not delivering the desired results. While it is well recognized that early detection and proactive management of diabetes is essential, this paper suggests a technology solution to assist a key patient frustration around diet and meal planning; namely a solution that can frequently provide reliable information, decision support and guidance to empower people with type 2 diabetes.

Keywords: Diabetes, Chronic disease management, Value-based care, Mobile health, Power-knowledge, Australian healthcare system, World Health Organization(WHO), Glycosylated haemoglobin (HbA1c), Organization of Economic Cooperation & Development (OECD), BMI (Body mass index)

Introduction

Currently, chronic diseases such as diabetes, obesity and cancer, rather than infectious diseases, are not only increasing but also account for the largest part of most healthcare budgets, thereby placing a significant burden on healthcare systems. By definition, chronic diseases are incurable and hence, once an individual contracts a specific chronic disease, he/she must live with it for the rest of his/her life. This translates into a life-long interaction with the healthcare system and on-going monitoring and management of an individual's lifestyle particularly, various health and wellness aspects including diet, exercise and medication intake. To do this effectively and efficiently is especially desired for by the two key stakeholders in chronic disease care, the patients and their clinical care team.

Arguably, the most prevailing chronic disease today is diabetes. The WHO notes that diabetes is a silent epidemic, and by 2020, there will be a 54% rise in the total number of individuals diagnosed with this disease [1-3]. These are alarming figures and have significant repercussions for quality of life of individuals and their families as well as for the financial stress of healthcare systems globally.

Today, early detection and proactive management of diabetes are well recognized as best strategies to combat this chronic disease [4]. Moreover, an essential treatment focus is to provide patients with diabetes appropriate monitoring to enable better assessment and tighter control of blood glucose and thereby preventing further complications [5]. In addition, it is prudent to adopt a cost effective solution that is convenient to both patients and clinicians, as well as least disruptive to patient lifestyle [6]. Thus, the DiaMonD (Diabetes Monitoring Device) solution was developed for patients to facilitate patient empowerment and self-management with their diabetes care [7-10]. Concisely, the solution utilizes pervasive mobile technology to transfer critical information between patients and providers so that expeditious monitoring may ensue. Based on trial data, this solution has been shown to be successful in assisting to lower down and sustain lower HbA1c values (the universally recognized marker for diabetes) in trials in Canada and the US [5] (Appendix 1).

Based on these results, we wanted to further understand the challenges patients and their care teams had with sustaining good glucose control and managing diabetes with a view to trying to develop more technology solutions to support people along this journey. We contend that such pervasive technology solutions that can enable ubiquitous (anytime, anywhere, anyplace) monitoring and management of people with diabetes while simultaneously and continuously educating and motivating them should be a prudent part of any diabetes management program. Furthermore, we wanted to understand the impact of such a solution and unpack, more systematically, critical user issues, key barriers and facilitators, as well as the potential for using generated data for developing a better understanding of individuals' diabetic issues. This in turn could lead to better population health protocols and strategies to prevent or stem the escalating increase and prevalence of diabetes. The result would enable a deeper understanding of diabetes in general, which could perhaps assist at a public health level with regard to better containment and management of this and other chronic diseases as well as the individuals' own ongoing care. In addition, recognizing logically at least, that better data and information should facilitate and support both better management and decision making for both patient users and their clinical care team, we also wanted to understand what aspects of data capture and consequent analytics might be useful to assist in superior on-going monitoring, management and decision making for patients with diabetes. Hence, we conducted multiple surveys across US, Canada and Australia to try to capture some patient perspectives and based on these survey results we propose some opportunities for designing and developing suitable technology solutions.

Given that healthcare costs are an important aspect of all healthcare agendas today, we frame our recommendations against a value-based paradigm, as we believe this a responsible approach to take. Moreover, a key emergent aspect of the study was the power-knowledge dynamics that exists between patients and their clinical care team. We expanded on this finding, noting how it might influence adoption and use of the technology solution. In particular, we noted that when developing technology solutions, it is important to engage both user groups, and without clinician support and engagement, it is unlikely that patients will be willing to adopt or use a technology solution.

In the following sections, we first provide a background, which highlights the key issues around value-based healthcare, chronic disease and diabetes, the Australian healthcare context, power-knowledge and data analytics before presenting the research method, key findings, discussion and conclusions.

Background

In this section, we highlight the key areas in the literature that we have drawn upon to develop our model and solution.

Value-based care

Healthcare delivery especially in the OECD countries today is facing many challenges, most notably aging populations, rise in chronic diseases and escalating healthcare costs [11]. The US is facing the steepest increases with predictions for healthcare costs being 20% of GDP by 2020 [12,13]. To address this, many experts are recommending a shift to a value-based healthcare focus rather than current systems such as fee for service or managed care [12,13] (Appendix 2 provides a summary of key aspects of the value-based agenda for healthcare). At the centre of a value-based approach, the focus is on ensuring for all patients superior access and quality while also minimizing costs. We believe responsible development of any healthcare solution should at the very least examine the possible impact of the proposed solution on access, quality and cost of healthcare, as this can have significant and far reaching consequences to an already challenged healthcare system, and thus, we also examined our preferred solution in this context.

Diabetes mellitus

Diabetes mellitus is one of the leading chronic diseases whose frequency continues to rise rapidly despite all attempts to stem this disease. The total number of people with diabetes worldwide is estimated to rise to 366 million in 2030 from 171 million in 2000 [14,15]. Moreover, for every person diagnosed with diabetes, it is estimated that there is another who is yet to be diagnosed, which doubles the number of diabetes sufferers [15]. If uncontrolled or poorly managed, diabetes typically leads to a variety of unpleasant complications, including: chronic vascular and kidney diseases, strokes, heart attacks, eye diseases and neuropathy and for some individual's amputations of extremities and limbs [16,17]. Moreover, diabetes and its complications incur significant costs for the health system, namely, costs incurred by careers, government, and the entire health system [18]. Currently, costs for diabetes, for example, in Australia are estimated to be around $14.6 billion (Australian dollars) per annum [17]. This figure excludes additional costs; namely, societal costs that represent productivity losses for both patients and their careers [18]. Taken together, this makes identifying suitable solutions to support cost effective on-going management of diabetes a strategic necessity both in Australia and globally.

Diabetes has several forms (Type 1, Type 2 and GDM), which require nuances in treatment, although all are concerned with blood glucose levels and the body's inability to process the glucose in the blood. Type 1 diabetes is essentially an autoimmune condition that causes the immune system to destroy cells in the pancreas that produce insulin [15]. It usually presents in childhood or early adulthood but can occur at any age [14]. Type 2 diabetes is the most common form of diabetes [14]. It is often preventable, as it is often associated with lifestyle factors [14]. Essentially in type 2 diabetes, insulin production by the pancreas becomes progressively slower and key organs in the body become resistant to the effects of insulin [14]. The least well researched type of diabetes is the third type, gestational diabetes mellitus (GDM).

Gestational diabetes mellitus (GDM) is a common form of diabetes that presents in pregnancy, sometimes with symptoms but often diagnosed in otherwise normal women on routine screening tests. GDM is more common in older women, in those with a family history of diabetes, in those who are overweight, and in those of non-Caucasian heritage [19,20]. Maternal complications of GDM can be serious and include polyhydramnios and premature labour, maternal hypertension, low birth weights and stillbirth [21]. It recurs in subsequent pregnancies in 30- 80% of women, the incidence varying with ethnicity, being lower in Caucasian women [22].

Treatment of women with GDM aims to control maternal, and therefore fetal hyperglycemia and the associated tendency of fetal hyperinsulinemia, which is at the root of the fetal complications [23]. After many years of uncertainty as to the value of such treatment in GDM, two key trials have now shown benefit for both mother and offspring for antenatal initiation of lifestyle modification and glucose monitoring, coupled with insulin therapy as necessary [24,25]. Antenatal treatment of detected mild GDM was also associated with improved health status for women during the antenatal period and at 3 months after birth, with less postnatal depression [24]. Specifically, there is agreement in the literature that specific self-management activities including glucose monitoring, dietary restrictions, and exercise regimes can result in good outcomes for mothers and babies, suggesting that self-management behaviours can be critical [21,24]. More recently, in Australia, there has been a lowering of the threshold level for when a pregnant woman is now classified as having GDM, which has immediately led to a significant increase in the number of women now diagnosed with GDM over and above the growing trend that has been occurring [26]. This change in classification makes it even more pressing to find a suitable solution.

Irrespective of the type of diabetes, glucose control, diet and exercise are essential elements of any care protocol and these aspects often can be challenging for people with diabetes to manage on a regular basis.

Power-knowledge

Integral in the use of many technology solutions in healthcare is the adoption and embracement of the solution by both clinician and patient. However, we also note that there is, in the clinician-patient relationship critical power-knowledge dynamics, in which the clinician has more power and domain knowledge (i.e., specific knowledge that experts have such as medical knowledge around diabetes) than the patient.

Lamb and Kling [27] distinguish between power-based and influence-based agency, but others such as Wickramasinghe and Lamb [28] have taken a Foucauldian power-knowledge perspective to unravel the underlying dynamics of agency, especially in healthcare contexts, noting the special role of physicians as knowledge worker agents. That is, while physicians are agents and hired to perform certain tasks, they also have unique expertise and thus can influence decision making and outcomes. In contrast, patients have a power dependency on their doctors as they go to their doctor to access their expertise and help and hence are in some sense at an inferior power level due to their inferior domain knowledge. Other scholars e.g., Agarwal [29] and Goh [30] have turned to Petty and Cacioppo's Elaboration [31] Likelihood Model (ELM) to assist in understanding the essence of persuasion, be it central (appeals to logic or reason) or peripheral. In this sense, advice from physicians can be appreciated as powerful central input (especially when data driven) given their position, expertise and respect. Central route induced changes are generally considered more stable (and, thus, more predictive of sustained behavioural change) since they demand more deliberate and reasoned considerations. The patient's motivation (as a moderator in the ELM) would be considered especially high given the overt attention of pregnant women to physicians' advice; i.e., pregnant women tend to try to follow all the advice provided by their doctors. Peripheral persuasion in the form of encouragement by family and friends would also be expected to be generally supportive.

Data analytics

Data analytics is a process of collecting, cleansing, transforming, and modeling data towards discovering useful information and recommending, predicting, and supporting decision-making [32]. Health data analytics is a promising area to mine the trove of patient data available for research, medical decision-making, and healthcare policy making [33]. Data analysis can provide a solution to the increasing demands from consumers for enhanced healthcare quality and increased value, leading to new scientific discoveries, and better medical treatment. Data analytics is broadly classified into four types: descriptive, diagnostic, predictive, and prescriptive [34].

We contend that several techniques of data analytics could be used in the context of supporting better monitoring, management and subsequent treatment of patients with diabetes. *Descriptive analytics* uses reporting tools and techniques to know the past and to classify and categorize historical data [32]. For example, descriptive analytics could be used to answer questions like, "What is the age distribution of GDM patients?".

Diagnostic analytics uses tools such as visualization to explain the why question [32]. For example, descriptive analytics is used to answer questions like, "What factors preceded patients who developed diabetes?".

Predictive analytics utilizes the data to predict a likely event to be experienced [32]. Predictive analytics could be used to answer questions such as "What is the likelihood that someone of a particular demographic type will develop GDM?".

Finally, *Prescriptive analytics* is used to identify and then to recommend an optimal solution [32]. Prescriptive analytics thus, could be used to answer questions such as "What can a person do to avoid developing diabetes related complications?".

For all the four types of analytics, consistent, complete, and accurate patient data are critical. Further, disciplines such as computer science, engineering, and genetics have developed visualizations to improve presentation, analysis, and understanding of data. Visual analytics is the science of analytical reasoning, facilitated by advanced interactive visual interfaces in order to facilitate reasoning over, and interpretation of, complex data by visualization [35]. Machine learning, pattern recognition, and data mining are various data analytics methods used for capturing and disseminating patient conditions to clinicians in real-time decision support. The outcomes of healthcare data analytics such as hospital readmissions [36] and treatment responses [35] are often of great practical importance. Hence, it is likely that a technology solution that systematically captures key data of patients ongoing and in real time, could have many benefits on analysis to support better decision making and consequent care management.

Thus, technology and digital health solutions can provide some assistance around monitoring and management as well as persuasion or supporting behaviour changes.

Method

The aim of our study was to determine by surveying and interviewing various cohorts of people with diabetes, what resources or supports are required to help them achieve and maintain good diabetes self-care practices and how amenable they would be to technology support solutions. Inclusion factors consisted of having type 2 diabetes and being diagnosed for at least 2 years. 20 patients in Canada, US and Australia respectively were surveyed. In addition, we limited the age to between 40-65 years.

Methodology

A mixed-method approach was adopted. We designed two surveys one for healthcare providers and one for patients with diabetes to test what each group finds most helpful for maintaining tighter blood glucose and better diabetes care. In addition, we interviewed representatives from healthcare care teams (i.e., endocrinologists, dieticians and diabetic educators) as well as several patients. To pilot our surveys, we distributed them via a digital network to diabetes specialists or diabetologists across Ontario, Canada. We have also run two similar pilot projects in US and Australia to further test the items for any cultural and /or language differences. As we wanted to understand the on-going management and self-care issues, we focussed on individuals who had diabetes for at least 2 years. The rationale for such selection was that by that time these individuals may have to a greater or lesser extent, got over the initial "shock" of diagnosis and at times overwhelming aspects of initially having to change their lifestyle or behaviours.

Results

Based on initial data collected for a population of 100 respectively for Australia, Canada and US, we found that on running non parametric tests (Whitney-Mann U), there were no differences across gender, race or marital status regarding the various aspects of self-care, however on running a Kruksal-Wallis test, results suggested that there were some significant differences in self-care that was related to education. First, differences were significant with reference to both dietary control and health care use. Moreover, there was an interesting U-curve relationship between education and dietary care suggesting that those with some college education were the worst with dietary care (worse than grade school and high school educated) and that dietary care got better as the level of education improved thereafter. Differences were also significant regarding health care use by patients with varying levels of education, but the results were not so clear, as were observed for dietary care. Finally, regarding BMI, essentially, there were no significant findings related to BMI and use of self-care methods.

Based on the answers to the open ended questions, we found that all people with diabetes irrespective of ethnicity, country or gender found it challenging on an on-going basis to control and manage their diet plans, navigate through packed foods and understand how these might impact their sugar levels and to balance eating out. Many of these individuals, before being diagnosed with diabetes had enjoyed eating but post diagnosis had found eating, meal planning and grocery shopping to be a chore and the enjoyment around eating had gone. In addition, they commented on the need for regular guidance, information and support in making prudent meal choices. Other frequent comments focussed on exercise and in what types of exercise they should engage and/or the need to have more choices of different types of exercises. A final area of note was around scheduling of regular appointments and the difficulty at times to get speedy/timely advice from their clinical care team.

From the clinical care team side, noted concerns were around funding and staff shortages that prevented expeditious responses, given the volumes of patients. Dieticians noted that meal planning on an on-going basis was a challenge for many people with diabetes.

Discussion

From the findings gained from our surveys we noted the three key areas the surveyed people with diabetes wanted: meal planning and diet, exercise and scheduling appointments. Each of these three areas can be addressed with technology support solutions as noted in table 1. Of these three, the one that also had the highest priority from the clinical care team was around better diet and meal planning, especially from the dieticians. Given this, we propose a smart fridge [frequent, reliable, information, decision support and guidance to empower] for people with diabetes. To develop this solution we believe it is essential to adopt a design science research methodology.

Design science research methodology (DSR)

Design science is an important and legitimate research paradigm in information systems [37]. Design science research involves constructing a wide range of socio-technical artefacts, such as new software, processes, algorithms or systems intended to improve or solve an identified problem [35]. The design science guidelines originated from information-systems design theory originally proposed by Walls [38] as "a prescriptive theory which integrates normative and descriptive theories into design paths intended to produce more effective information systems." Eventually, Peffers [39] expanded design theory into a design science research methodology by incorporating the principles, practices and procedures required to carry out research by applying design science theory. They suggested that design science theory as a methodology, needs to be consistent with prior literature, provide a nominal process model for doing design science research, and provide a mental model for presenting and evaluating design science research [39]. Moreover, Hevner and Wickramasinghe [40] noted that in healthcare contexts use of design science research methodology was especially prudent for fine tuning innovative solutions.

Von [41] presented seven guidelines for understanding, executing, and evaluating design science research. Various studies [42-45] have used these guidelines for building algorithms and systems. The three-cycle view captures the design science research idea to refine the artefact design iteratively through several interconnected *design*, *relevance*, and *rigor* cycles as illustrated by Hevner [46]. The improved four-cycle model of IS design science research for capturing the dynamic nature of IS artefact design is illustrated in figure 1 [47]. This refinement is intended to increase both the artefact's effectiveness to address the real-world problem as well as its knowledge contributions over several iterations. The fourth cycle in the DSR model, termed as *change and impact* cycle, is to better capture the dynamic nature of artefact design for dynamic real-world contexts. The design of a smart fridge using design science research is further discussed in table 2, while figure 1 depicts the design science research methodology.

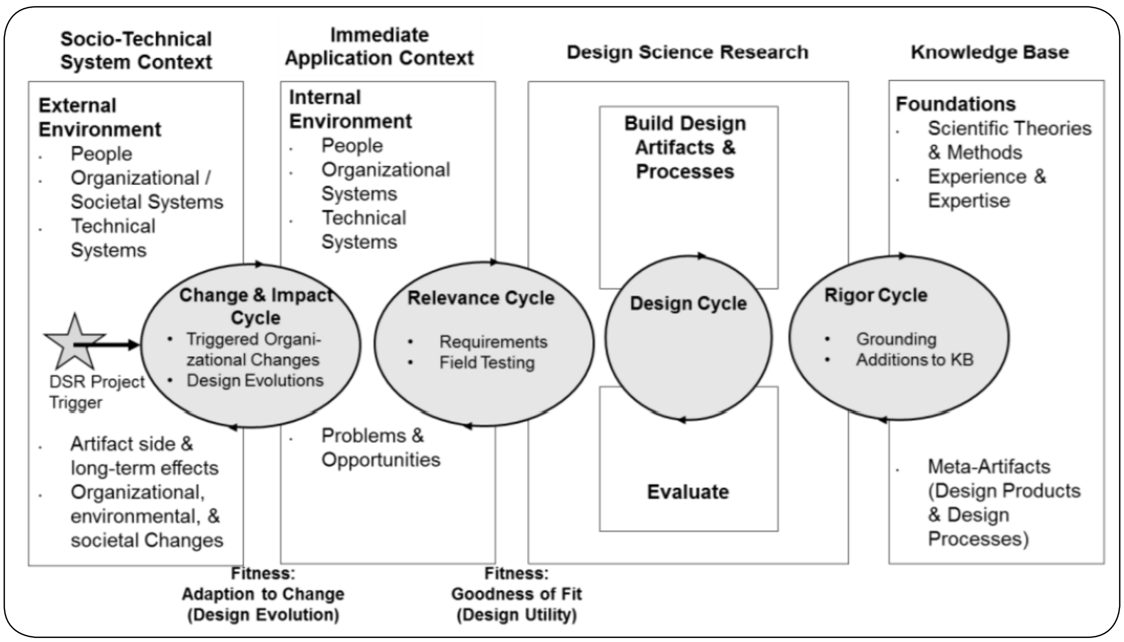

Figure 1: Four-cycle model of IS design science research [47].

To develop the smart fridge solution consistent with a DSRM (Design science research methodology). The first phase includes storyboarding the technology solution idea and then presenting it back to the user/patient. Currently, we are in the process of iterating in this cycle of showing the storyboard to a few selected volunteer patient users and tweaking the design once this cycle is completed. On the completion of the design cycle then we move to prototyping the solution and on the completion of prototyping, then again sharing this with the user for further input. Finally, a clinical trial will be launched to confirm usability, fidelity and proof of concept; i.e., that the solution does provide/support tighter glucose control and thereby better clinical outcomes.

Answers to the posed research questions

This study set out to try to understand the key frustrations for people with diabetes and why they may become non-complaint or what are the challenges to maintain good blood glucose levels. Based on our short survey we have found that a key area is focussed around meal and diet planning and have suggested that a suitable technology solution that can provide frequent, reliable information, decision support and guidance, that will assist in empowering people with diabetes. Table 2 and 3 provides more specific answers.

Today chronic diseases have replaced infectious diseases as one of the top global causes of deaths and morbidity [Centre for Diseases Control http://www.cdc.gov/]. Diabetes is one of the five major chronic diseases and has been termed by the WHO as the silent epidemic [WHO, http://www.who.int/topics/diabetes_mellitus/en/]. By definition, for most sufferers of diabetes (or other chronic diseases), there is no likely cure, which makes prudent management of their condition the key to improving their quality of life. Good management is predicated on pertinent information and germane knowledge [28], which at times is not always easy for these patients to access and/or acquire. As the preceding study has served to illustrate, pervasive mobile solutions have the potential to support appropriate self-management. Self-management is not only important as it empowers patients having diabetes while acknowledging their central role and responsibility for managing their healthcare. Moreover, an active participation of people with diabetes in the self-management is an integral and recognized strategy for managing their condition and reaching improved treatment outcomes [1-4].

An important aspect, which was further identified in the preceding study, revolves around the patient and provider, their respective roles and influences with regard to adoption of new technology. As such, clearly the patient plays a very active and empowered role in his/her care and treatment. However, the role of the clinician/provider as the care provider should not be forgotten. In many ways, the physician directly or indirectly plays dual roles as a potential adopter and/or an influencer of the technology. Given the expertise and regard patients generally have for their medical provider, it is reasonable to expect that the provider's recommendations and advice, not only about a treatment protocol but also about a technology to be used within this care path, will have an influence on the technology being ultimately tried and even adopted by the patient. Conversely, a technology solution will be less likely to be adopted if the patient's doctor was not supportive of the solution. This then raises several key questions concerning patient adoption and the potential dual roles of the physician as both an adopter and an influencer. Integral to this appears to be an apparent power-knowledge dynamic.

Thus, the suggested solution presented above should be examined from both patient and clinician perspectives for the acceptance of this technology as a tool to facilitate and support the on-going treatment of diabetes. Based on the response to the questionnaire regarding use of the solution if clinicians had not recommended its use, it was evident that clinician support of the solution was important. Moreover, we found that clinicians were not so comfortable to treat patients using technology solutions they didn't not support. Thus, our study provides directional data to highlight that these are important considerations and should be considered in future research. In particular, we assert that the adoption of a technology solution by a patient is highly influenced by their clinician's endorsement. Thus, patients are more likely to use solutions that their clinicians endorse rather than solutions that they like and are not endorsed by their clinicians. To investigate this area more closely we believe that Petty and Cacioppo's Elaboration [31] Likelihood Model (ELM) could be helpful to understand the essence of persuasion in this context. Specifically, the two vital questions are: how patients are persuaded and also what persuades clinicians? It would appear from our findings that are important that both patients and clinicians embrace the technology solutions. But when clinicians are on board it is highly likely that patients will be too, while the converse is not so likely to be true. Hence, our study sheds light on our understanding of the clinician-patient relationship. In particular, it suggests to us to frame clinician advice as appealing as possible for persuading patients to either use/non-use the technology. The power-knowledge dynamics show that the professional position that clinicians hold, coupled with their expert knowledge can serve to sway patients' judgments to use/not use a technology solution. This is also an important consideration in designing technology solutions for healthcare contexts.

Value-based care

Given that providing value-based care is on the agenda of most, if not all OECD countries' healthcare agendas, we believe that no study today that proffers a technology solution to facilitate care delivery, should ignore value-based care. Some scholars [11] have noted that value in healthcare consists of addressing key aspects of access, quality, and cost of care, and thus we examined the proposed solution in the preceding study in this context.

Mobile solutions that are designed to support patients with specific chronic diseases, such as diabetes, will enable such patients to follow appropriate treatment protocols for their chronic disease. When they will present for surgery in a value-based bundled healthcare environment, they would not be denied care for being high risk patients. Rather, the healthcare facility will provide compelling evidence to show that they are managing their patients' co-morbidities and that their patients are at an appropriate/acceptable health risk for surgery.

Table 1: Possible roles for technology solutions.

Patient Pain Point	Possible Technology Solution
Meal and diet planning	Many technology solutions currently exist that can assist with diet planning and nutritional guides. In addition there is scope to develop and enhance these further to give more specific and tailored advice and support.
Exercise	Many technology solutions currently exist that provide exercise advice and there are several wearable devices that can track exercise and steps.
Appointment Scheduling	Calendar reminders and scheduling assistants are possible; however connecting these to specific clinical care team members may be more challenging.

Table 2: Design science research guidelines.

Design Science Research guidelines	Smart Fridge
Guideline 1: Design as an Artefact	A convenient and innovative mobile solution to support people with diabetes manage their meals, grocery shopping and eating habits to assist in optimising blood glucose control. It also has the potential to support a value-based care agenda as it can increase access, has the potential to increase quality of care and more especially timeliness of feedback and does not appear to impact costs of care delivery; ie care to administer diabetes is unchanged. If anything it has the potential to reduce them by preventing more serious problems from occurring.
Guideline 2: Problem Relevance	To provide in a timely fashion anywhere, anytime key data to facilitate better decision making. To provide an appropriate technology solution that can support self-management around food and meal choices.
Guideline 3: Design Evaluation	It is necessary to include dieticians and potential patient users at various points in the design and testing of the solution. This is an iterative process and concluded when all are satisfied that the solution is fit for purpose.
Guideline 4: Research Contributions	Users' perspectives of the mediating role of the solution should be explored.
Guideline 5: Research Rigor	Theoretical foundations and conceptual models drawn from information systems, chronic disease management protocols, healthcare quality and safety need to be addressed including the potential to extend and modify current care paths and protocols.
Guideline 6: Design as a Search Process	The design must comply to meet with ethics and other requirements and one must ensure full and complete risk mitigation in such a context.
Guideline 7:	Internal communication: Present the technology solution to clinically-oriented users through focus groups, simulations exercises, brainstorming meetings, as well as technical and managerial meetings.
Communication of Research	External communication: Progress and findings need to be reported to professional groups and be peer-reviewed and assessed.

Specifically, we noted in our study that the patients received a higher level of access that was 'anytime, anywhere as needed assistance', in which that they could send, update and receive messages via the mobile solution. Moreover, the quality of care was higher as it was more focussed and precise and because the clinicians received timely data and information, to make prompt key decisions about blood glucose level, insulin dosage, as well as diet and exercise. We do note, however, that we did not conduct a formal economic analysis in this study.

Overall, the directional data from the study supports the position that a pervasive solution (the smart fridge) can assist patients to better control their good glucose by enabling them to ensure better food and meal planning. This is prudent and appears to be consistent with a value-based healthcare paradigm. It also enables us in our future studies, to develop hypotheses to test around the central issue of value-based care.

Table 3: Question and answers

Question	Answer
How would the smart fridge enable and support the value-based care paradigm in the context of chronic disease management?	As noted earlier, at the essence of this paradigm is that at all times high quality,access and yet minimisation of cost should permeate all healthcare interventions. By providing in real time advice around diet and meal planning and thereby facilitating better glucose control, the patients' diabetes will be better managed, which in turn shall enable the patient to be at a reasonable risk level rather than a high risk level for healthcare interventions; ie there result many instances today in healthcare where patients with a high risk level due to uncontrolled blood glucose levels are denied surgery until their glucose levels are more tightly controlled. Moreover, this will also facilitate the potential for cost savings by ensuring better glycaemic control.The clinicians also strongly felt that with the technology solution they could provide better care and which was their key goal.
What are the benefits and suitability of such a pervasive technology solution to self-care?	The benefits are many including: i) peace of mind, ii) convenience, especially for busy working individuals, iii) ability to receive immediate feedback and thus make changes and/or modify diet plans accordingly. These were all identified by both patient and clinicians.
What are the key barriers and facilitators?	One of the biggest barriers identified is government regulations and policies. To offer it as an optional solution is not a problem as long as it complies with all regulations. Key facilitators included clinician and hospital executive support.The given data clearly showed that patients were willing to adopt technology recommended by their clinicians. Patients also intimated that if their clinician did not support the solution they would be reluctant to adopt it while clinicians clearly stated they would not be so comfortable for their patients to use a technology solution they did not recommend and support because at the end of the day they bear the risk and responsibility. This would also mean that a key facilitator is clinician support and endorsement as well as hospital executive support.
What are the possibilities of applying the tools and techniques of data science to enable precision healthcare delivery and/or inform public health care initiatives regarding better chronic disease management practices and protocols?	On discussion with clinicians, they believed that collecting the data from all patients would provide deeper insights into diet planning and food choices for people with diabetes,which would in turn help to inform practice protocols and population health initiatives.Significant to the clinicians was the ability, from analysed data, to give them a clear(er) picture of the current state, likely trends and possible impacts.
Are patients influenced and persuaded by their clinician to adopt the solution and is this important in choosing the solution?	Patients noted that if their clinical care team had not used the technology solution, they would not have used the solution even if they found it better than the standard care. Thus, for them it was important that their clinician was also using the technology solution and was supportive to his/her patients, using the solution. Clinicians also remarked that if their patients used technology solutions that they did not recommend, they would not be as comfortable to treat their patients and then would advise their patients to stop using such solutions if they encountered issues. This is why it is essential that when developing solutions clinicians and patients are involved in the design phases.

Data analytics

For healthcare, data analytics is becoming an essential enabler, especially in providing superior chronic disease management. Furthermore, such data on an extended level can have far reaching impact on public health protocols and the delivery of more precision type medicine in the context of chronic disease care and management. We anticipate that data collected around food planning and blood glucose control would be very helpful and powerful to develop more personalized and targeted meal planning for various sub-groups of the population. It will assist all people with diabetes to enjoy their food and to worry less about its impact on their blood glucose; a recurring theme reported to us as a frustration from patients; i.e., the challenges they find with selecting appropriate foods. The use of data analytics can also in the future be extended to other types of chronic disease and meal/diet requirements.

Visualization is one of the most useful ways of diagnostic analytics to explain the why question [34]. With respect to the smart fridge solution, diagnostic analytics and visualization can get into the root cause and detection. Visualization helps to share a clear analysis of the patients and healthcare providers with the quantitative readings of individual blood sugar measurements, qualitative overview of glucose by low, high, and normal levels, frequency of patient monitoring and feedback as well as the consistency of monitoring. Further analysis of these factors can expose potential patterns in behaviour that lead to abnormal glucose levels. By extending the data captured from past medical history; ethnicity and socio-economic status; physical examination outcomes such as height, weight, BMI; laboratory test data on blood glucose levels, insulin intake, HbA1c, liver profile, thyroid and fasting lipids, it is possible to develop a more precise picture of a patients diabetes and thus develop a more tailored treatment regimen. Diagnostic analytics and visualization can also be used to make critical decision support and patient safety support, by maintaining a surveillance dash board with daily entry, documentation and result storage for better care. Diagnostic analytics also has the potential to reduce the impact of cost of care delivery, by preventing more serious problems from occurring.

Predictive analytics identify past patterns to predict and understand the future. The value of predictive analytics in diabetes has been emphasized in which prediction is perhaps more important than explanation, considering the daunting cost of delay in diagnosis and treatment [35]. The traditional Bayesian statistical approach uses regression analysis to identify significant predictive factors [48]. One of the important outcomes of predictive analytics using regression would be to determine the long-term risk of type 2 diabetes following a pregnancy complicated by GDM. By assessing what maternal antepartum, postpartum, and neonatal factors are predictive of later development of type 2 diabetes, can lead to long-term follow-up and early intervention to modify and ameliorate their risk over many years [49]. Artificial Intelligence and machine learning for predictions are highly important as a patient's risks of future adverse health events are high. This is because patients with chronic diseases often develop complications in their disease course. For instance, patients with diabetes often have higher risks of stroke, heart disease, eye problems, and renal failure (Centers for Disease Control and Prevention, 2014). Considering risk prediction for a specific adverse health event as a single machine learning task, the key aspect of [33] approach, is to obtain an improved predictive performance for each individual task, by learning multiple related tasks jointly and simultaneously. Thus, developing and utilizing multitask learning strategies to predict multiple patient outcomes based on the data collected is yet another area to explore in future in the context of chronic disease care and management.

When asked, the clinicians in the study were positive about incorporating data analytics. In particular, they were concerned to have the right data to make sound decisions and thereby facilitate better care for their patients. In addition, they were desirous for data to support better protocol developments and support better public health initiatives and care plans.

Conclusions

Current practices and strategies to combat people with diabetes appear to be ineffective in the light of perpetually, escalating numbers of new people, being diagnosed with diabetes. Moreover the cost of treating people with diabetes is becoming significant. This means new solutions and approaches and strategies are required. Even though there are many technology solutions that support blood glucose testing per se based on patients' perspective this is not enough and support and advice around diet, in an on-going fashion, is believed to be an essential enabler for supporting better blood glucose control.

The preceding survey has served to highlight the opportunity for a smart fridge idea to assist people with diabetes, especially around meal planning and food management; an area identified as a major challenge and pain point by the patients surveyed who have had diabetes for at least 2 years. We believe such a solution has the potential to represent a paradigm shift for diabetes care and more generally chronic disease management. It is likely that the consequent paradigm shift in the approach to treating chronic diseases such as diabetes will provide the needed impetus to address the rising costs and provide better means to manage the current state.

By unpacking the smart fridge concept/solution in relation to the principles of value-based care, it is also shown that such pervasive mobile solutions support value-based care delivery by proving greater access and quality of care, while simultaneously reducing costs associated with this care. Furthermore, the contribution of power-knowledge dynamics in the clinician-patient relationships, were identified as an area for the appropriate application of data analytics. Given that diet and food planning are important in many areas of chronic care e.g. oncology, obesity, hypertension and mental health, there is a vast potential to expand the application of dietary planning to the afore-mentioned areas and thereby increase its practical implications and benefits.

Appendix 1: DiaMonD (Diabetes monitoring device)

The DiaMonD solution was developed by Inet Intl. Inc, a Canadian company to provide diabetes self-management and monitoring to all patients suffering from diabetes. Succinctly figure A1 shows the basic solution as developed by Inet. Key aspects of the solution include it is fully HIPAA compliant, totally pervasive which means it works on any mobile platform (Android, IOS etc) and it requires co-use or co-adoption of patient and their clinical care team.

Appendix 2: Key aspects of the value-based care paradigm

To address escalating healthcare costs in the US (and many other OECD countries), many are advocating incorporating a value-based system for healthcare delivery including bundled payments for services.

Existing health status, or pre-existing conditions (e.g. Diabetes or other chronic disease), appears to constrain

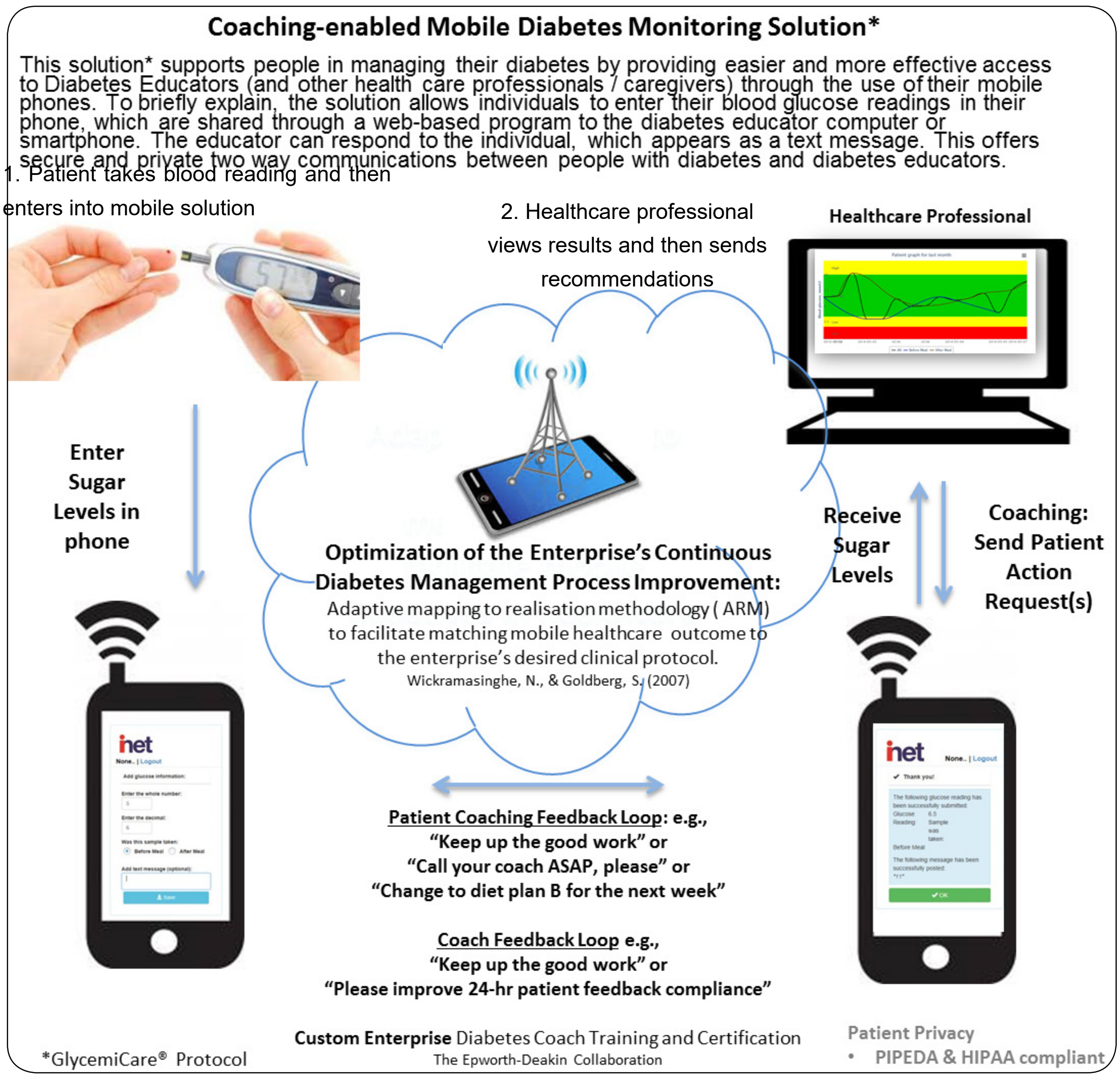

Figure A1: The basic DiaMonD solution (figure provided by Inet Intl Inc.).

patient access to important, but expensive treatments, based on measures of quality and inclusion criteria for treatment. While on the surface these decisions appear scientifically sound, the practical solutions available to the obese, diabetic or elderly with multiple chronic comorbidities or socio-economic barriers and limitations who attempt to achieve better health are limited?. Hence, solutions that assist to support individuals with chronic disease would enable them to have better access to healthcare treatments for specific issues such as a knee replacement in a value-based, bundled care healthcare context.

In 2016, CMS (Center for Medicare and Medicaid Services) has begun a shift in payment from volume to value, aligning 85% of all payments it makes linked to quality or value by the end of this calendar year, with 30% of payments tied to quality or value through Alternate Payment Models (APM). In 2016, the US began shifting to "value-based reimbursement" in the MACRA and MIPS programs with the goals to overcome waste, benchmark all providers' Medicare payments and adjust them based on comparison with peers' clinical outcomes for the same procedures. In addition, the US government is shifting to fixed-price "bundling" for many known treatments, e.g. knee and hip replacements [18,19]. These reimbursement changes are intended to guide providers towards evidence-based medical decisions and procedures. Such evidence-based processes are supposed to be unbiased and scientifically optimized formulations that describe the best way to treat patients for the best overall outcomes.

The US Veterans Administration continuously publishes and updates a compendium of best practice guidelines for many chronic diseases. Most hospitals and payers either adopt or create similar guidelines for their own decisions, and those formulae are typically embedded in hospital/physician EHRs (electronic health records) and financials software to reinforce "positive" behaviours, compliance and, ultimately, outcomes.

Any clinical "centre of excellence" (CoE) will naturally apply or customize the best evidence-based guidelines with its own expertise, with the expectation and intention that such decisions will result in their outcomes and reimbursement being among the most highly ranked, respected, and, hopefully, profitable; i.e., more focused care plans tailored to each patients specific issues will in turn result in better clinical outcomes more efficiently and effectively and thus will save money as an added benefit. Hospitals or physicians, who deliver care at lower levels, may have to settle for average outcomes reimbursement, and poor-performers may be motivated to abandon services they cannot deliver well.

Medicare Access and CHIP Reauthorization Bct of 2015
Merit-based Incentive Payment System
http://www.healthquality.va.gov/guidelines/

An unintended outcome that can and does emerge, however, is that many centers including CoEs will very naturally and quite scientifically correctly decline to provide clinical services to patients who have underlying health issues that are statistically proven to have poor prognoses and outcomes; diabetes being a notable and leading issue. In some cases, there may also be a failure to intervene and mitigate the risks that are preventing the elective procedure that may reduce the patient's pain or improve their function and quality of life.

To date the US healthcare environment has made substantial investments into examining how to create and deliver value-based care. These strategies are now being carefully examined in Australia, which is likely to adopt similar principles and thus all technology solutions are now being viewed in this light.

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