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THE ANALYSIS OF MULTIPLE WEARABLE DEVICES TO PREVENT AND MANAGE TYPE 2 DIABETES MELLITUS

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ABSTRACT

This thesis focused on introducing and analyzing wearable devices used in the prevention and management of the diabetes mellitus type-2. Diabetes mellitus is a chronic metabolic and endocrine abnormality, and timely intervention and prompt treatment can significantly reduce the mortality and morbidity rates associated with this preventable disease.

The objective of the thesis was to analyze wearable devices used in the management of Type 2 diabetes mellitus and its present status in healthcare thoroughly. The second objective of this thesis was to critically compare and analyze the selected wearable gadgets about certain qualitative parameters including duration of action, adverse effects and cost-effectiveness.

Initially, a total of 50 studies were selected for this thesis. However, with the application of well-defined inclusion and exclusion criteria, 13 studies were included. Qualitative methods were then used for a comparative analysis with a special emphasis on the nugget's efficacy, benefits and demerits.

The results of the qualitative analysis revealed noticeable advantages of wearable devices over other traditional available modalities of treatment. These advantages included cost-effectiveness, personalized approach to diabetes management, improved adherence, minimal maintenance requirement and reduced finger stick test requirement.

Keywords: wearable devices in diabetes, medical wearable tools, wearable gadgets in the treatment of type-2 diabetes mellitus, continuous glucose monitors, insulin biosensors, smart applications in type-2 diabetes

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APPENDICES

1 INTRODUCTION

This thesis will critically analyze and investigate the various wearable gadgets available in the worldwide market to manage and treat Type 2 Diabetes Mellitus. The contents of this thesis will expand to encompass all the merits and potential disadvantages of these gadgets in the effective control of random blood glucose levels in type-two diabetic patients.

Type 2 Diabetes Mellitus (also called adult-onset diabetes) can be defined as an endocrine abnormality initially characterized by insulin resistance (decreased response of target tissues to increased levels of insulin) and in later stages by beta cell exhaustion leading to a significant reduction in the physiological production of insulin hormone (Galicia-Garcia et al., 2020). The primary topic of discussion will be wearable devices used to treat Type 2 Diabetes Mellitus. It can be defined as an endocrine disorder that is heavily influenced by genetic predisposition and certain external factors like diet, sedentary lifestyle, and presence of other comorbidities like hypertension, and fatty liver obesity (Westman et al., 2021).

Type 2 diabetes mellitus has been declared endemic in many regions of the world. This is the 9th most common mortality-causing disease in the population above 40 years old. 1.2 million deaths are associated with this lethal malady and its impediments (Khan et al., 2020). Additionally, 462 million individuals across the globe—or—6.28% of the global freight, are troubled by this fatal disease (Khan et al., 2020). It is anticipated that the statistics will even rise in the next 20 years due to elevating peril factors such as immobile lifestyles, rancid fat, highly refined meals, and a reduction in workouts (Himanshu et al., 2020)).

The commissioning party for this thesis is Xamk Active Life Lab situated in 2018. The lab strives to contribute the personal and organizational prosperity through research-based robustness, amenities, scrutinies, investigations, and instructions. This platform rationalizes particular cumulation and interpretations for healthier well-being applications and clinical achievements for its patients.

There are zillions of treatment facilities accessible in this revolutionized epoch of Artificial Intelligence and automation. These include certain wearable devices that have revolutionized traditional treatment strategies and have proven efficacious in monitoring and controlling blood glucose levels and simultaneously preventing the emergence of any cardiovascular complications (Peng et al., 2023). These devices include insulin pumps, blood glucose meters, smart insulin pumps, smart watches, activity trackers and CGMs (Continuous glucose monitors).

The objective of this thesis is to analyze wearable devices used in the treatment of Type 2 diabetes and its present status in healthcare thoroughly. This paper focuses on examining the applications, challenges, and potential benefits of these wearable tools, explicitly focusing on individuals of all age groups diagnosed with Type 2 diabetes. Moreover, another aim of this paper is to critically compare, analyze and evaluate these wearable devices to various parameters including duration of action, side effects, cost-effectiveness and easy availability in the market.

This thesis aims to adequately answer three important research questions as follows:

Q1: Does the use of wearable devices prevent Type 2 diabetes?

Q2: How do wearable devices help to manage different conditions related to Type 2 diabetes?

Q3: What are the pros and cons of wearable devices in today’s era of Artificial Intelligence for the public?

To answer these questions, a qualitative research analysis is conducted via the utilization of data collection. A detailed search is conducted for studies published in peer-reviewed journals and indexed between 2014 and 2024. Various search engines and databases are utilized including Pubmed, Google Scholar, Scopus, Science Direct, MedLine and Cochrane with a search strategy compiling all key terms. Initially, a total of 55 relevant studies were selected. However, after the application of well-defined inclusion and exclusion criteria, only 13 studies were chosen to be analyzed. These studies were then subjected to thorough analysis and evaluation to identify various wearable devices and the efficacy of these devices to maintain a moderate level of blood glucose over a long period.

The theoretical framework of this thesis is divided into two parts. The first part aims to identify and introduce various wearable devices available in the market for the treatment of Type 2 Diabetes Mellitus. The second part will be focused on conducting a competitive analysis of these devices on the basis of efficacy, the level of control over blood glucose, duration of action, cost, adverse effects, accuracy and clinical outcomes. The main idea behind both of these theoretical components is to shed light upon these various wearable devices that are backed by modern technology advancement and how these devices have modernized the mainstay treatment of chronic metabolic disorders like Type 2 Diabetes Mellitus.

This thesis is limited only to Type 2 diabetes and the wearable devices specifically designed to manage this disorder.

Several limitations surfaced during the process of selection of studies and conduction of comparative analysis of this thesis. At the moment, there are numerous wearable gadgets available in the commercial market for the management of Type 2 diabetes mellitus. A few of these tools have been tested and their efficacy has been proven by the positive results and satisfaction of users. However, we faced a limitation of literature deficiency on the efficacy of a few of the newer devices that were introduced in the market recently. These especially include Artificial Intelligence-based devices and wearable lenses. Although these wearable tools have been included in this thesis, it should be highlighted that insufficient literature was available on these interventions.

Another limitation that was faced in the course of this thesis is the inadequate evaluation of the publication biases of the studies conducted. The prevalence of studies with preferable or favourable results and outcomes to be published more frequently than those with non-significant or negative outcomes is known as publication bias (van Aert et al., 2019). The evaluation of the publication bias was beyond the scope of nature of this thesis, however, light should be shed on the fact that publication bias does impact the authenticity of the results and may promote ideas without the presence of core evidence (Ayorinde et al., 2020). Lastly, a few database limitations were also encountered during the process of selection of studies based on the inclusion and exclusion criteria. The databases searched might have included only some pertinent studies, which would result in an incomplete retrieval of the literature.

2 BRIEF INTRODUCTION OF VARIOUS WEARABLE DEVICES USED TO PREVENT AND MANAGE TYPE-2 DIABETES MELLITUS

The management and cure of type-2 diabetes mellitus includes a broad spectrum of pharmacological and non-pharmacological agents. In this modern era of artificial intelligence and technology, wearable tools and gadgets have added new freedom, privacy, and independence for type-2 diabetics (Rodriguez-León et al., 2021). Patients of chronic diseases like type-2 diabetes mellitus no longer have to gravely depend upon their physician for adequate and effective management of their disease as these wearable devices offer a non-invasive and budget-friendly option for optimum monitoring and control of their blood glucose levels in the normal physiological range which is 80-110 mg/dl (Ahmed et al., 2023).

These devices have been associated with reduced levels of fasting and random blood glucose. This led to a noticeable reduction in the complications of type-2 diabetes mellitus (Zimmet et al., 2014). Examples of such tools include continuous glucose monitors and insulin pumps, smart t-shirts, wearable intraocular lenses, insulin biosensors, AI-backed Applications, and other online applications that help patients track their physical activity. A total of 9 wearable devices have been chosen as a topic of discussion in this thesis. The following sub-chapter will provide a brief introduction and a comparative analysis of these wearable devices that are used widely in the management and cure of type-2 diabetes mellitus.

Table 1- A quick overview of the main benefit, preventative and curative roles of various wearable devices used in the prevention and cure of diabetes type-2.

WEARABLE DEVICES	PREVENTIVE ROLE	CURATIVE ROLE	MAIN BENEFIT
CGMs and insulin pumps	nil	Manages glucose levels in the normal physiological range (Martin et al., 2019)	Automatic device prevents episodes of hyperglycemia (Martin et al., 2019)
Insulin Biosensors	nil	Keeps insulin level regulated (Sabu et al., 2019)	Automatic device prevents episodes of hyperglycemia and hypoglycemia (Sabu et al., 2019)
Smartwatches	Pop-up notifications about daily exercise (Almujally et al., 2023)	Medication reminders	Aids in achieving lifestyle modifications (Almujally et al., 2023)
E-nose	Detects VOC in expired air, hence, helps in early diagnosis (Maqbool et al., 2023)	nil	Early diagnosis and prompt treatment reduce mortality rates (Maqbool et al., 2023)
AI-Apps	Nil	Treatment plans tailored to patient's unique needs (Kaur et al., 2019)	Personalized approach to diabetic type-2 treatment (Kaur et al., 2019)
Telehealth Apps	Nil	Treatment plans tailored to patient's unique needs (Piet et al., 2023)	Cost-effectiveness
Thermal Camera	Prevents occurrence of diabetic foot (Zhang et al., 2017)	nil	Reduces incidences of leg or limb amputations from diabetic ulcers (Zhang et al., 2017)
Smart Contact Lens	Detect early signs of diabetic retinopathy (Elsherif et al., 2022)	Acts as a portal for drug delivery in the eye	Reduces incidences of diabetic retinopathy and cataracts (Elsherif et al., 2022)
Smart T-shirt	Detects early signs of cardiac arrhythmia (Romano et al., 2024).	nil	Prevents cardiovascular complications of type-2 diabetes mellitus (Romano et al., 2024).

2.1 Wearable insulin biosensors

This newly introduced wearable gadget is of utmost importance for the recording of accurate insulin levels in the plasma of diabetic patients. The information collected is then utilized in the calculation of daily insulin dosage for type-2 diabetics who inject insulin to achieve good glycemic control (Sabu et al., 2019). The goal of these biosensors is of immense importance as their use ensures that the insulin levels in the serum of a type-2 diabetic patient are kept within a normal physiological range (Valkova et al., 2022).

Any deviation from this range can lead to lethal complications owing to hypoglycemia or hyperglycemia. Hypoglycemic states can lead to palpitations, tachycardia, irritability, sweating, feelings of anxiety, and dizziness (McCall, 2012). Similarly, a hyperglycemic condition can also lead to undesirable results which include blurred vision, increased thirst, and an increased urine frequency. Mismanagement in the dosage of insulin can easily lead to such unwanted consequences and hence in a predisposed individual may also lead to few morbid complications like frequent infections, cardiovascular abnormalities including unstable angina and coronary artery atherosclerosis, and fatty liver disease (Farmaki et al., 2020). These wearable sensors are often worn in the upper mid-arm and are recommended by physicians to be worn at all times of the day (Saha et al., 2023)

These biosensors are of various types; however, the two most important ones are Aptamer-based and MIP-based (Molecularly imprinted polymer). Aptamers are single-stranded nucleic acids that possess the ability to recognize certain proteins, owing to their high affinity (Ning et al., 2020). In this case, this particular protein is insulin and these aptamer biosensors are known to provide reliable and accurate measurement of serum insulin levels. Immunoglobulin A3, or IGA3, is a well-known example of an aptamer-based biosensor that has demonstrated encouraging outcomes. IGA3 biosensors have been shown through experimental data to detect blood insulin levels as low as 1.6 pmol/L (Wu et al., 2023).

Research have demonstrated that insulin levels as low as 81 fmol/L can be detected by MIP-based biosensors (Psoma et al., 2023). These insulin biosensors are backed up by advanced technology and have shown promising results by offering a comparative better control of the glycaemic index of a diabetic patient. A unique feature of this wearable gadget is its customized approach as it can be customized to the patient's requirements and hence also offers another valuable parameter incorporation. This parameter is the diet and exercise component, which are immensely important for a type-2 diabetic patient as lifestyle modifications are usually considered as 1st line treatment in this chronic illness.

The recent insulin biosensors introduced in the pharmacological market carry along with them an important feature of monitoring the consumer's daily activity via the number of steps that the person walked and also by the variations in the baseline heart rate (Alanzi et al., 2023). This approach keeps the consumer updated about their level of activity in the day and urges them to move more in an attempt to stabilize their blood glucose levels via non-pharmacological ways while simultaneously respecting the privacy of the patient. Some newer models of these insulin sensors are combined with CGMs (continuous glucose monitoring) tools. These products have also proven to be rather efficacious as they regulate two key parameters involved in diabetic control: insulin and blood glucose levels (Klonoff et al., 2017).

2.2 Insulin Pumps and Continuous Glucose Monitors

Both of these gadgets are some of the oldest wearable tools available in the commercial market for the management of Type 2 Diabetes Mellitus (Klonoff et al., 2017). Insulin pumps and Continuous Glucose Monitors are often used in conjunction with each other and are often regulated in a negative feedback manner (Umpierrez et al., 2018). The goal of CGMs is to continuously check the patient's blood glucose level, ideally every five minutes (Pauley et al., 2022).

Commercially available CGMs include the ones with a disposable implant which are worn by the patient usually in the upper arm. Typically, adhesive tape is used to apply these disposable sensors to the patient's skin; they should be changed every three to four days (Vettoretti et al., 2019).

Another type of sensor is called an implantable sensor. Eversense E3 CGM system is a prime example of an implantable sensor (Walsh et al., 2015). These sensors are used for long-term purposes and are composed of fluorescence-based technology. Both types of these sensors work to provide a correct estimate of the blood sugar levels of the user (Wang et al., 2022). These sensors are linked via a wireless transmitter to a mobile application/ software. Hence, they function to keep the patient updated about their glucose levels and the need for insulin administration if required (Marks et al., 2021). This is immensely important as it prevents the incidences of hyperglycemic coma and other complications (Nakamura et al., 2015).

Continuous Glucose Monitors are FDA (Food and Drug Administration) approved and are becoming increasingly in demand due to the provision of a customized and private diabetes management approach for patients (Martin et al., 2019). Currently, type-2 diabetics' most popular wearable device is the Dexom G4 Platinum Professional CGM, which needs to be calibrated twice a day by the user (Nakamura et al., 2015).

One example of how continuous glucose monitors (CGMs) might be used to improve societal growth is illustrated by a 2019 study Merickel et al. included in this thesis. 36 drivers participated in a clinical trial led by Merickel and his colleagues; 20 of them had been diagnosed with diabetes, while the remaining 16 were controls. The blood glucose status of these drivers was assessed in the study using CGMs (Continuous Glucose Monitors); a value of less than 70 mg/dl was classified as hypoglycemic, and a value greater than 300 mg/dl as hyperglycemic.

The studies' findings showed a strong correlation between elevated rates of traffic accidents and risky driving behaviors and abnormal physiological values of blood glucose levels.

It was concluded that diabetic drivers should be encouraged to wear a CGM and an associated insulin pump to prevent any future traffic accidents resulting in casualties (Merickel et al., 2019).

Insulin pumps have actively revolutionized traditional subcutaneous insulin therapy. They serve as an artificial pancreas and tend to automatically adjust the serum glucose level by altering the insulin dosage injected (Nimri et al., 2020). For patients suffering from the advanced stages of type-2 diabetes, insulin delivered in the form of subcutaneous injections multiple times in the day was the mainstream treatment (Meneghini, 2013). Its traditional manual method carries along with its risk of non-stringent glucose control as oftentimes patients forget to administer the dose of this anabolic hormone which results in sudden fainting, dizziness, and vertigo episodes (Home et al., 2020)

This is particularly dangerous in cases where the patient is driving or conducting other crucial work, for example working with heavy machinery etc. Insulin pumps have yielded an easy solution to all of these problems. These pumps are coordinated with the CGMs (continuous glucose monitors) and any measurement of high blood sugar level from the CGM serves as an effective stimulus for these pumps to administer a small dose of subcutaneous insulin (Freckmann et al., 2021). Most of these pumps also feature a manual setting that allows users to change the dosage of insulin injected in accordance to their daily routine, dietary habits, and physical exercise (Seidinova et al., 2018).

Almost 90% of the insulin pumps available in Finland come with already-linked GCM (Continuous Glucose Monitoring) devices (Freckmann et al., 2021). Moreover, insulin pumps come in two varieties. First are the tubed insulin pumps which are characterized by a thin-walled tube that is directly connected to the cannula under the patient’s skin to administer insulin dosage effectively (Berget et al., 2019). These tubes are connected to a reservoir and require changing every 2-3 days. However, the other type of insulin pumps are called patch pumps as they feature no external tube and are attached to one’s skin by use of adhesive tape (Reznik et al., 2013). However, both types of pumps carry along with the feature of connection with a mobile application that allows the user greater control over their diabetes management (Miller et al., 2015). Moreover, these pumps also have an incorporated alarm system that alerts the consumer in cases where the reservoir runs out of insulin or there is miscommunication with the adjacent Continuous Glucose Monitors (McAdams et al., 2016).

The concurrent use of CGMs and insulin devices has shown promising efficacy. Studies conducted have revealed that in 81.1%, the use of these wearable devices has reduced the incidences of hypoglycemic episodes (Ghazanfar et al., 2016).

2.3 Smartwatches featuring mobile-based apps and web-based interventions

The first line treatment of for Type 2 diabetes is not the prescription of pharmacological agents but is urging the patient to introduce various lifestyle modifications (Borse et al., 2021). These modifications include changing dietary habits and incorporating fruits and vegetables in their diet, advising the patient to quit smoking and any other illicit drug use, and recommending the patients to change their sedentary lifestyle and incorporate walks and exercises in their regime to combat the risk factors of the disease that they are diagnosed with (Uusitupa et al., 2019). Lifestyle modification is not an easy task and requires constant efforts by the patients and their families to accomplish. The introduction of diabetes smartwatches was another attempt to aid the patient in accommodating these lifestyle changes (Kim et al., 2022).

These digital healthcare technologies work in several ways all focused on creating awareness and educating the patient throughout their journey of treating type-2 diabetes via non-pharmacological approaches (Cahn et al., 2018). A few noticeable examples include tracking of blood glucose levels with reference ranges, educational brochures, interactive surveys, pop-up reminders for exercises and insulin administration, and videos through various applications aimed at diabetes education (Kaufman et al., 2010). This education includes teaching the patients how to self-monitor their blood glucose levels, which foods they need to avoid to prevent an insulin spike, pop-up reminders to the user to complete daily missions constructed to guide the user towards a positive lifestyle change (Flemming et al., 2020).

2.4 Diabetic Sensor- A IoT-Based Sensor Used for Diagnosis of diabetes mellifluous

‘The "Diabetic Sensor," sometimes known as the "E-Nose," is an electrochemical sensor that detects the presence of specific substances in exhaled breath using IoT (Internet of Things) software applications (Maqbool et al., 2023). Previous research has shown that the amounts of these specific volatile chemicals in the exhaled air of a diabetic and a healthy person differ significantly (Kou et al., 2017). One of these volatile organic molecules is acetone, a ketone body that is detected in much higher concentrations in the bodily fluids and breath exhaled by patients with diabetes and pre-diabetes.

Apart from the acetone levels, serum amylase has also been found recently to carry some potential for diabetes diagnosis (Maqbool et al., 2023). Studies are still being carried out to establish the significance of E-nose testing in earlier diagnosis of Type-2 Diabetes Mellitus. However, we can conclude with full surety that regular introduction and utilization of these diabetic sensors will provide primary prevention in this endemic of type-2 diabetes mellitus affecting more than 6.28% of the global population (Khan et al., 2020).

2.5 AI-backed Smart Applications for Better Control Of Type-2 Diabetes

In today’s modern era of advancements and technology, Artificial Intelligence devices and tools have gained unprecedented fame for their non-invasive and easy approaches (Shumba et al., 2022). Such an approach was proposed by Maqbool et al., in 2023, where she introduced a smart application that is to be worn by type-2 diabetics. This application will measure blood glucose levels by non-invasive techniques (quite different from the traditional finger prick test) (Alsareii et al., 2022).

This will be accompanied by the measurement of the user’s vital signs via the IoT (Internet of Things) technology. These baseline signs include mean aterial l pressure, surface temperature, blood oxygen saturation, heart rate, and pulse rate via a wristband that the patient would be required to wear (Almujally et al., 2023).

Later, this data will be fed into software backed by ML (machine learning) for analysis. This analysis includes immediate identification of any deranged results or the presence of any abnormalities. In cases where the results coincide with those of a diabetic person, this Artificial Intelligence application will provide a personalized plan tailored to the patient's individual unique needs and requirements (Rghioui et al., 2020).

3 INNOVATIVE TECHNOLOGIES FOR DIABETIC HEALTH MONITORING

New technologies for diabetes healthcare are changing how patients manage their condition. Telehealth apps provide remote counseling and ongoing assessments, making healthcare easier for people with diabetes. Detailed thermal imaging provides a noninvasive method for the early diagnosis of diabetic foot injury, which is a common and serious complication.

Wireless smart contact lenses represent a breakthrough in the diagnosis of diabetic retinopathy and enable real-time glucose monitoring directly to the eye. T-shirts equipped with sensors are able to detect physiological changes indicative of diabetes complications, and ensure timely intervention and positive outcomes, as these improvements represent steps essential to improving the lives of diabetics, health care with the ability of equipment to deliver faster and more accurately.

3.1 Telehealth applications

These include numerous wearable devices that come in the form of patches, wireless chest straps, upper arm and upper thigh bands, and clothing-based monitors (Piet et al., 2023). The usage of these devices has been implicated in the advanced stages of poorly controlled Type 2 Diabetes, where the risk of development of cardiovascular complications is markedly elevated. In these stages, the above-mentioned wearable gadgets measure the user's blood oxygen levels (saturation), heart rate, and ECG (electrocardiogram) measurements (Dal Canto, et al., 2019). These recordings can be easily viewed on a mobile application that is linked to these wearable devices. Hence, any derangement of the cardiovascular parameters in a type-2 diabetic can easily be picked up by these devices and alert the user to visit their nearby healthcare facility as soon as possible (Piet et al., 2023).

Another comparable wearable device that is on the market is known as a "Dynamometer." This device was recently introduced to evaluate a subject's hand grip strength to determine their blood sugar concentration (Kaur et al., 2019). Although the idea is relatively new, its non-invasive nature and time-saving qualities are making it more and more popular (Hamasaki et al., 2021). Since exercise and regular movement are crucial for the cure and management of type-2 diabetes, some wearable devices have been developed to assess your health and movement levels. These include hip-worn straps and shoe insoles (Piet et al., 2023).

Finally, a type-2 diabetic patient can also utilize a Bioimpedance Scale to track the effectiveness of their medication and the advancement of their illness (Lokpo et al., 2023). A bioimpedance device assesses a patient's body composition, concentrating on their body fat reserves (Rodriguez-León et al., 2021). Recently, this scale has been recommended by endocrinologists to measure the two important parameters involved in the treatment of type-two Diabetes Mellitus: body fat and blood glucose measurement (Oyanagi et al., 2023).

3.2 Thermal camera for the detection of diabetic foot

Diabetic foot ulcer is a very common complication in advanced cases of type-2 diabetes mellitus affecting 19-34% of patients in their lifetime (Zhang et al., 2017). Early diagnosis and prompt treatment of this complication is of utmost importance as it can avoid otherwise debilitating operations like amputation of the said limb/ foot (McMillan et al., 2018).

An experimental study supervised by Fraiwan et al., in 2017 used 3 CCD cameras (with their temperature-sensitive properties) to take pictures of the suspected diabetic foot. The images taken were then subjected to intense acquisition, image segmentation, and analysis. The results of the images were then compared with similar foot images taken from a non-diabetic individual. The results showed noticeable differences in the two images owing to peripheral neuropathy and lower temperatures in a diabetes patient (Feldman et al., 2019). This non-invasive and quick method has received much praise from all around the world as it prevents amputation operations that often lead a patient to disability and dependence on others.

Gracia et al., in 2019 also proposed the idea of using the facial texture analysis feature of CCD cameras to diagnose type-two diabetes mellitus. However, the outcomes of this clinical trial were rather ambiguous and still require more trials and literature to establish something solid.

3.3 Wireless smart contact lens for diagnosis of diabetic retinopathy

Diabetic eye disease includes retinopathy and cataract formation. Approximately 5.06% of type-2 diabetes mellitus patients will develop reduced vision and blindness owing to this disease in their lifetime (Teo et al., 2021). However, early diagnosis of danger signs and immediate intervention can prevent the incidence of blindness in these individuals (Keum et al., 2020).

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Wireless Smart Contact Lense is yet another wearable device that can be used for the diagnosis as well as treatment of ocular disorders in these patients (Elsherif et al., 2022). These lenses are non-irritative and inert in nature and can be used for the purpose of drug delivery in the eye as well. They have a special programming sequence that allows them to be connected to a mobile application and they work by measurement of glucose and sorbitol (another type of sugar in the body) in the aqueous humor (Moreddu et al., 2019). These lenses have a dual function and also work to provide best corrected visual acuity as well in type-2 diabetics (Teo et al., 2021).

3.4 Smart t-shirts for Detection of Diabetic Complications

Smart t-shirts have flexible sensors embedded within their material, especially in the precordial region (Romano et al., 2024). These sensors work by measuring the heart rate of the patients and detecting any abnormalities in the cardiovascular system for example presence of any murmur or any signs of cardiac decompensation or arrhythmias (Makroum et al., 2022). In cases of any abnormalities, the T-shirt immediately alerts the user and those around him/her by a beeping sound altering them to transfer the patient to a healthcare facility as soon as possible.

However, the usage of these smart clothing articles is not prevalent yet because of their expensive nature. The lowest price of such T-shirts is 500 dollars and it is out of the budget for a lot of individuals (Khundaqji et al., 2020).

4 COMMISSIONING PARTY:

Xamk Active Life Lab was founded in 2018 to promote individual and organizational well-being through research-based fitness testing, coaching, and services. Equipped with the facilities of Saimaa Stadium, the lab offers essential instruments for a variety of fitness services, including body composition and endurance testing. Workplace groups can benefit from "Hyvinvointi Startti," a program designed for personalized health assessments. The company also provides a guided introduction to the smart room, fostering a relaxed approach to well-being examinations and encouraging the community sharing of physical and mental health. (Xamk n.d.)

Modern fitness centres and testing labs promote well-being at Saimaa Stadium. Anyone looking to improve well-being and solve work challenges can consult coaches, well-being coordinators, and professionals in many fields. Their approach promotes data-driven service. The company uses specific criteria to assess client well-being. Individualization occurs when well-being interventions are tailored to client needs and data. (Xamk n.d.)

5 RESEARCH METHODS AND DATA COLLECTION

A detailed review is being carried out on papers that have appeared in journals that had peer review and indexed from 2014 to 2024. The databases queried comprise PUBMED, Google Scholar, MedLine, and COCHRANE, using a search method that combines all essential terms. These terms were ‘wearable devices in diabetes mellitus’, ‘medical wearable tools’, ‘wearable gadgets in the treatment of type-2 diabetes mellitus’, ‘Continuous glucose monitors’, ‘insulin biosensors’, and, ‘smart applications in type-2 diabetes’. The acquired researches were amplified by citation tracking and cross-referencing systems. The search data was on April 14, 2024. Following the thorough initial review and screening, related conducted studies were explored and incorporated with the selected interventions.

A. Inclusion Criteria

The inclusion criteria were developed according to the PICO criteria described below.

P (POPULATION) - Patients diagnosed with type-2 diabetes mellitus

I (INTERVENTION) - Wearable Devices for the management and cure of type-2 diabetes mellitus

C (COMPARISON) - Other methods of treatment of type-2 diabetes mellitus (conventional/ traditional methods of treatment available)

O (OUTCOME) - Improved Glycemic Control/ presence of blood glucose levels within the normal physiological range.

A few other inclusion criteria included:

1. Study done on human adults and children.

2. Studies were indexed after 2014.

3. Only studies in the English language were included.

5.1 Data collection

We We used a qualitative research method based on interpretivism to ensure our data collection was detailed and organized. Interpretivism values the importance of context and personal viewpoints, aiming to understand social phenomena from the perspectives of those involved.

Following this approach, we reviewed qualitative research published in peer-reviewed journals from 2014 to 2024. Our sources included PUBMED, Google Scholar, MedLine, and COCHRANE. We used a thorough search strategy to find all relevant terms related to our research.

Our search terms included "wearable devices in diabetes mellitus," "medical wearable equipment," "wearable devices in the treatment of type-2 diabetes mellitus," "insulin biosensors," "continuous glucose monitors," and "smart applications in type-2 diabetes." These terms covered a broad range of topics related to wearable technology in diabetes management. This search resulted in 13,719 research articles.

We aimed to gather a wide range of qualitative insights on the use and impact of wearable technologies in diabetes management. Our approach included not just database searches but also methods like reference analysis and source comparison, which helped us find additional relevant studies beyond the initial results. This thorough process ensured we collected comprehensive and relevant literature within the specified time frame.
After an initial review, we found 55 studies that seemed relevant to our research goals. However, only the top thirteen studies met our strict criteria, ensuring they were highly relevant and significantly contributed to our research.

We completed the search by April 14, 2024, ensuring our review included the most recent and relevant literature. By aligning our data collection with interpretivism and rigorous search techniques, we aimed to capture the varied perspectives and outcomes related to the use of wearable technology in diabetes management.

5.2 Analysis

Wearable devices have completely changed the core foundations of the traditional ways of managing and treating type-2 diabetes mellitus. These devices carry along with them several advantages and disadvantages but something that can be said with utmost surety is that the benefits outweigh the demerits as these wearable gadgets offer greater privacy and self-dependency to the patients. We will start our analysis with continuous glucose monitors and associated insulin pumps.

CGMs major advantage is that they give real-time readings of glucose levels in the blood which plays a significant role in the identification of glucose trends and prediction of any hypoglycemic or hyperglycemic episodes (Rodbard, 2017). Such predictions can easily avoid a potentially dangerous condition and reduce mortality rates as well (Šoupal et al., 2016). A prime example of the utilization of CGMs and attached insulin pumps to avoid undesirable circumstances is when a type-2 diabetic patient is driving and suddenly their blood sugar level drops (Golden et al., 2012). In such life-threatening conditions, a stimulus by a continuous glucose monitor will lead to automatic insulin dosage and adjustment via the pump attached and can work to decrease mortality and morbidity rates as well (Medical Advisory Secretariat, 2009).

Another prime advantage of continuous glucose monitors is the fact that CGMs have almost replaced the centuries-old finger stick test that was widely used to monitor an individual’s blood glucose levels. This replacement has led to a significant decline in complications associated with the finger stick test like the risk of infection resulting from contaminated or unsterilised needles (Olansky et al., 2010). Moreover, there may be residual blood traces in the end cap, which could lead to cross-infection. This process carries the risk of spreading medical conditions, including HIV and hepatitis viruses which can be contracted through infected hands, gloves, equipment, or surfaces (Kost et al., 2009).

The most used continuous glucose monitor, DEXOM-G6 provides the patient with blood sugar level readings every 5 minutes and gives you the option to create customisable thresholds and receive alerts when your readings cross a certain designated range (Davis et al., 2021). This implies that you could be aware that you are out of range before you even start experiencing symptoms, allowing you to take preventative action (Garg et al., 2022). Despite the presence of these advantages, CGMs have drawbacks and might not be the right choice for everyone. First and foremost is the expensive nature of these wearable devices. Depending upon the brand and shelf-life, these gadgets can cost anywhere between $300 to $500 per month (Herzig et al., 2023). For a majority of the population, this can prove to be out of budget especially if the cost is not covered by the insurance and considering the chronic nature of the disorder in the discussion.

Secondly, although CGMs typically tend to provide correct readings, there are certain situations where they don't, especially when there are abrupt fluctuations in glucose levels (Spanakis et al., 2022). Sometimes, it can become an absolute necessity for users to verify readings using conventional finger stick tests. Moreover, since the continuous glucose monitor and insulin pump are required to be worn 24/7, it can become a distressing concern for type-2 diabetics who suffer from some sensory disorders like autism and schizophrenia (Chao et al., 2023). Although very rare, there have been incidences where type-2 diabetics using continuous glucose monitors for the 1st time experienced an allergic reaction (Herzig et al., 2023). Moreover, since this wearable device is backed by technology, real-time glucose measurements from CGM devices may be momentarily unavailable due to signal loss or disruptions (Klonoff et al., 2017). The capacity to combine CGM data with other components of diabetes treatment like subcutaneous insulin injections and pharmacological drugs like metformin may be limited by the incompatibility of certain CGM systems with other diabetes management tools or software.

When it comes to another wearable device, insulin biosensors, certain mixed opinions regarding its efficacy can be found. Although insulin biosensors have a lot of potential applications, it's of utmost significance to remember that they are still in the initial phases of development and could not be generally available to the commercial pharmacological market just yet (Salek-Maghsoudi et al., 2018).

These hormonal biosensors have several well-known benefits, such as being portable, having increased sensitivity, and providing more precise readings for insulin levels in bodily fluids (Kumar et al., 2022).

However, the endocrine nature of the hormone must be highlighted here. This hormone is monitored by certain very specific parameters including glucagon levels, blood glucose levels, melatonin, glucagon-like peptide (GLP-1), leptin, and growth hormone. It is practically impossible to duplicate the body's feedback system and control processes, despite the fact that insulin biosensors have been produced in an effort to imitate these intricate feedback control mechanisms. Moreover, certain insulin biosensors might need to be implanted or used through invasive procedures, which could be irritating or carry a risk of infection (Scholten et al., 2018).

E-noses can allow continuous monitoring of volatile organic compounds (VOCs), offering a more comprehensive picture of changes in metabolism across time than more traditional intermittent monitoring techniques. They are an excellent tool for tracking variations in blood glucose levels several times a day because of their speed and portability (Farraia et al., 2019). The major advantage of this diagnostic gadget is that it is majorly applied to high-risk populations for type-two diabetes mellitus. This group includes women with long-standing PCOS, individuals with a very strong genetic predisposition (especially those patients whose parents also suffer from the same disease), individuals with obesity (especially if their BMR is above 40), sleep apnea and age greater than 40 years (Hasandokht et al., 2023). Recent studies have also analyzed the success of electronic noses as a screening device for early diagnosis of type-two diabetes mellitus so that prompt intervention can be taken and complications can be kept at bay.

However, the usage of diabetic sensors as a definite diagnostic tool is still an ongoing topic of debate among endocrinologists as it offers rather limited specificity and sensitivity (Montuschi et al., 2013). False positive and negative results are one of the main complications of this wearable device which can hinder accurate result measurements. (Vadala et al., 2023). It should also be kept in mind that temperature, humidity, and background noise are examples of external factors that can alter e-nose measurements and compromise the accuracy and dependability of the results (Dragonieri et al., 2017). Another drawback of the usage of electronic noses is that they have a rather limited range of detection of volatile organic compounds. They, unfortunately, don't possess the ability to detect all of the volatile compounds which can lead to false results.

Dynamometers are a prime example of one of the telehealth applications used to enhance lifestyle modifications in earlier stages of type-2 diabetes mellitus. This device can be used to measure muscle strength, which is crucial for diabetics because they run the risk of losing muscle mass and becoming weaker in their muscles. However, muscle strains and other injuries can result from improper dynamometer use or unsupervised strength testing, particularly in those who are not used to resistance exercise (Choe et al., 2021). Light should also be shed upon the fact that dynamometers are mainly used to assess muscle strength; they cannot give complete information regarding fitness or general physical function. To evaluate endurance, flexibility, and balance, further tests could be required (Kaur et al., 2021).

Similarly, another wearable gadget called ‘Bioimpedance Scale' has been gaining much popularity in recent times. This tool is primarily used to assess one’s body composition, including fat mass, protein mass and water content. Hence, it can be concluded with certainty that the benefits of this scale can be appreciated in lifestyle modification treatment modality for type-2 diabetes mellitus. Changes in body composition can be early signs of complications related to Type 2 diabetes, such as peripheral neuropathy or nephropathy. Regular monitoring with bioimpedance scales can help detect these changes early and facilitate timely intervention. However, where these scales carry numerous benefits, light should be shed upon certain limitations that tag along the use of these tools in the management and cure of type-two diabetes mellitus. This expensive gadget is prone to providing false results regarding body composition, especially in individuals with certain body types (like pear-shaped body figures) and certain health conditions like dehydration and generalized edema (Oyanagi et al., 2023).

Moreover, they fail to provide important details like muscle mass and visceral fat etc. This aspect makes their practicality for type-2 diabetic patients very limited and heavy on budget (Solanki et al., 2015).

Smartwatches have massively modernized the treatment modalities for type-2 diabetes (Årsand et al., 2015). They serve to fulfil several purposes including giving medication reminders, tracking one's daily activity through the steps taken, and integrating with health apps to subconsciously urge the user towards a healthier lifestyle with increased adherence to medications (Sehgal et al., 2021). To meet specific needs and preferences of individual patients, smartwatches can be tailored with a variety of features and apps. Due to this adaptability, people with Type 2 diabetes can customize their smartwatch to complement their diabetes care strategy (Maritsch et al., 2024).

People with Type 2 diabetes may find it easier to remember to take their meds on time if their smartwatches have the feature of medication reminders in the form of pop-up notifications (Reeder et al., 2016). Where smart watches and similar wearable gadgets provide numerous undeniable benefits to patients, their access to most of type-2 diabetic patients has been limited owing to the presence of certain financial constraints.

More so, the results of these smartwatches are easily influenced by environmental factors like temperature, humidity and wind, which can result in inaccurate results and performances (Lehmann et al., 2023). Another subtle demerit of this wearable tool is that users can easily get overly dependent and exhibit overreliance on these smartwatches for diabetes treatment and this can potentially lead to a lack of self-monitoring and self-management skills, which are vital for long-term diabetes control (Sehgal et al., 2021).

Smart apps powered by Artificial Intelligence have a lot to offer in terms of improved Type 2 diabetes management. These apps use artificial intelligence algorithms to give diabetics individualized care, ongoing monitoring, and insightful information (Ellahham, 2020). The biggest merit of these technology-based applications is the personalized approach that they offer to each patient's needs. These apps take a record of the user's biophysical profile including weight, height, current BMR, ideal BMR according to age, height and gender and past medical history (Khodve et al., 2023). The application then uses this data to recommend certain dietary and exercise changes for the users which helps the user's immensely in their goal towards better glucose level control (Nomura et al., 2021). The proceeding research buoyed up to assume a more energetic engagement in their health and could discern Type 2 diabetes issues before time. Moreover, the integration of these apps with wearable technology like smartwatches and glucose monitors to escalate suggestion accuracy and provide a complete view of health consultations (Dankwa-Mullan et al., 2019).

These apps scrape together information and retain privacy-linked health data comprising of prescription policies, and personal information containing name, age, address, and bank account information (Yadav et al., 2023). In the bargain, the efficiency of these AI systems and reliability may have built-in limitations principally when evaluating complex health data (Khan et al., 2023).

Smart contact lenses allocate real-time knowledge and estimation of the glucose levels in the aqueous humor (Keum et al., 2020). This detection system has done astonishing work in the reduction of the worldwide prevalence of cecity and impaired visual acuity originating from uncontrolled diabetes mellitus type-2 (Park et al., 2018). The contact lenses provided are highly comfortable and don't necessitate repeated checks and balances or replacements like in the case of CGMS and insulin biosensors (Ioniță et al., 2023).

However, these lenses must be removed at bedtime and at the time of removal and insertion, a good quality contact solution with antibacterial and antifungal properties is used to avoid any chances of eye infection like conjunctivitis and corneal ulcers (Fleiszig et al., 2020). One of the most superior advantages of smart contact lenses over other available diabetes wearable devices is the fact that they are discrete and respect patient's privacy and confidentiality (Park et al., 2018).

They don't tend to draw attention like traditional lancet stick testing when measuring blood glucose levels.

It is important to highlight the drawbacks of this wearable technology, as these drawbacks restrict the frequent use of these gadgets. For many people, especially those with allergies or underlying ocular problems, using contact lenses can be excruciating, inconvenient, and even dangerous in some situations (Ioniță et al., 2023). Immune-mediated ocular allergies may be triggered by these lenses, resulting in symptoms as swelling, discomfort, increased tears, redness, and proptosis (Elsherif et al., 2022).

Furthermore, there is still a great deal of missing data in the literature to definitively prove that smart lens glucose readings yield more accurate findings than conventional lancet stick tests, raising serious doubts about the quality of these tools (Maulvi et al., 2016).

6 RESULTS

Wearable devices have several gain and drawbacks when it comes to treating Type 2 diabetes. These gadgets, which include activity trackers and continuous glucose monitors (CGMs), provide real-time monitoring and feedback to help with improved sugar level management. For example, continuous glucose monitors, or CGMs, offer continuous glucose readings that enable users to immediately modify their insulin dosage, exercise routine, and nutrition. As a result, there is less chance of complications and better glycemic control.

Additionally, we have seen that this wearable technology also has the ability to track physical activity, which motivates people to lead active lifestyles—a vital component of diabetes management. They also integrate easily into daily routines and are convenient and easy to use. Thermal cameras which are able to identify diabetic foot/ ulcer via temperature changes indicative of signs of inflammation or impaired blood flow, also require standardized protocols for usage in diagnosis and management of diabetic complications. Due to insufficient literature and standardized procedures, these cameras are not currently being widely used by type-two diabetic patients.

The results of ‘Electronic Nose’ can also be labeled as deficient when it comes to the above conducted qualitative analysis. They offer a quick and non-invasive way to identify volatile organic compounds (VOCs), which can be a sign of diabetic metabolic abnormalities, in sweat, urine, or breath. Then, this technology might help with early diagnosis, monitoring the progression of an illness, and assessing the effectiveness of treatment. Moreover, it is plausible that E-noses will not be able to detect all relevant biomarkers or differentiate between different types of diabetes.

There are drawbacks to take into account, though. Because of its high price, some customers might find that their access to these products is limited. Accuracy is another issue, especially with CGMs that don't always give precise readings.This may lead to potentially harmful health outcomes in addition to inefficient medical decisions.

Similarly, the results of other wearable devices including smart lenses, dynamometers, bioimpedance scales and insulin biosensors are rather unclear and lack clear distinction when it comes to blunt efficacy. While smart contact lenses allow non-invasive glucose monitoring, they are still in the early stages of research. Similarly, where precise glucose monitoring is possible with insulin biosensors, they can prove to be rather uncomfortable for the user. Despite the fact that they can measure muscular strength straightforwardly, dynamometers are not suitable for real-time monitoring.

The results of the above conducted qualitative analysis also highlight various merits of wearable tools over other available conventional/ traditional treatment options.

7 CONCLUSIONS

As technology progresses, these devices becoming more precise, trustworthy, and user-friendly. This pattern suggests that in the near future, wearable technology will likely take the role of traditional diabetes treatment techniques. Their ability to track vital indicators, transmit real-time data, and offer personalized insights will enable people with Type 2 diabetes to take control of their health and make informed decisions about their care.

Furthermore, by averting problems and enhancing general health outcomes, wearable technology may lower healthcare expenses. All things considered, the use of wearable technology in diabetes treatment appears to have great promise for improving efficiency, convenience, and patient-centered care.

However, something that can be concluded with assurance is that the numerous wearable devices thoroughly discussed in this thesis might have little to offer if used individually with the exception of CGMs. A way more effective approach is by combining these technologies which could result in an all-encompassing strategy for managing type-two diabetes that would allow for precise, non-invasive monitoring of muscle activity and blood glucose levels.

In conclusion, some issues need to be resolved even if wearable technology has a lot to offer in terms of controlling Type 2 diabetes, including better glucose control and increased physical activity. Cost, accuracy, and privacy concerns are a few of these. The advantages of wearable technology generally exceed the drawbacks; however, cautious planning and close observation are essential to guarantee their safe and efficient application in the treatment of diabetes.

Table 2- A Quick overview of the studies used in this thesis

TITLE	AUTHORS	YEAR OF PUBLICATION	TYPE OF STUDY	MAIN IDEA OF THE STUDY
A Smart Sensing Technologies-Based Intelligent Healthcare System for Diabetes Patients	Maqbool et al.	2023	Qualitative	An Artificial Intelligence (AI)-enabled human-centered smart healthcare monitoring system for management of Type 2 diabetes
DiabeticSense: A Non-Invasive, Multi-Sensor, IoT-Based Pre-Diagnostic System for Diabetes Detection Using Breath	Kapur et al.	2023	Qualitative	Diabetic Sense: a novel, portable, non-invasive system for diabetes detection using breath samples
The Clinical Effects of Type 2 Diabetes Patient Management Using Digital Healthcare Technology: A Systematic Review and Meta-Analysis	Kim et al.	2022	Qualitative	Meta-analysis was done to evaluate the clinical effects of digital healthcare technology for patients with Type 2 diabetes management
Wearable Insulin Biosensors for Diabetes Management: Advances and Challenges	Psoma et al.	2023	Qualitative	Qualitative analysis of a insulin biosensor which is critical for calculating the insulin administration dosage, which is critical for insulin-dependent diabetic patients.
Non-Invasive Wearable Devices for Monitoring Vital Signs in Patients with Type 2 Diabetes Mellitus: A Systematic Review	Piet et al.	2023	Qualitative	Telehealth Applications used in the management of type-2 diabetes mellitus
Wireless smart contact lens for diabetic diagnosis and therapy	Keum et al.	2020	Qualitative	Analysis of smart contact lenses for both continuous glucose monitoring and treatment of diabetic retinopathy
Diabetic foot ulcer mobile detection system using smart phone	Fraiwan et al.	2017	Qualitative	Analysis of a mobile thermal imaging system that can be used as an

thermal camera: a feasibility study				indicator for possible developing ulcers
Non-invasive Diabetes Detection using Facial Texture Features Captured in a Less Restrictive Environment	Garcia et al.	2020	Qualitative	The objective of this research is to develop a non-invasive method for detecting diabetes and investigate the efficacy of utilizing a mobile smartphone as a convenient instrument for taking pictures.
Methods for combining continuously measured glucose and activity data in people with Type 2 diabetes: Challenges and solutions	McMillan et al.	2018	Qualitative	To introduce the new use of constantly measured physical activity from an accelerometer with continuously measured glucose in the management of Type 2 diabetes mellitus
Driving Safety and Real-Time Glucose Monitoring in Insulin-Dependent Diabetes.	Merickel et al.	2019	Qualitative	The purpose of this study is to use wearable and in-car sensor measures of driver physiology and health to solve the demand for driver-state detection.
Performance of the first combined smartwatch and smartphone diabetes diary application study	Årsand et al.	2015	Qualitative	To analyze how smart watches can be used in the lifestyle modification treatment modality of Type 2 diabetes mellitus.

The Benefits of Utilizing Continuous Glucose Monitoring of Diabetes Mellitus in Primary Care: A Systematic Review.	Kieu et al.	2023	Qualitative	Qualitative analysis of the efficacy of continuous glucose monitors in the treatment of Type 2 diabetes mellitus.
Early Detection of Prediabetes and T2DM Using Wearable Sensors and Internet-of-Things-Based Monitoring Applications.	Baig et al.	2021	Qualitative	Wearable technology and Internet-of-Things-based monitoring applications

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APPENDICES