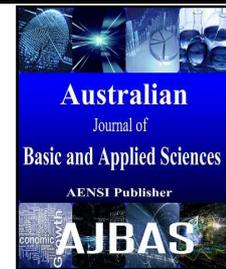




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# A Research Perspective on Ubiquitous Healthcare for Diabetic Patients

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### ABSTRACT

Healthcare systems are prone to change in response to new demographic factors that include an aging society, increasing number of chronic diseases and a growing concern of individuals in managing their own health. The age of wearable computing is upon us. We've been able to shrink computing power from something the size of a room to a box that sat atop a desk, to a smaller box that fits in the palm of our hand, to now an even smaller box we can wear on our bodies. But they're still boxes, more or less: Rigid devices that stick out because they don't conform to the human shape. Diabetes mellitus (DM), commonly referred to as diabetes, is a group of metabolic diseases in which there are high blood sugar levels over a prolonged period. Symptoms of high blood sugar include frequent urination, increased thirst, and increased hunger. If left untreated, diabetes can cause many complications. Diabetes mellitus is a significant and growing global health problem, recognized by the World Health Organization and the IDF. Diabetes is not a curable or controllable disease. But through proper food intake, balanced medication and continuous long term observation the progression can be delayed. This paper explains the origin, symptoms, causes and the ill-effects of Type-2 diabetes. It focuses mainly on the various diabetes management techniques that are employed widely to assist type-2 diabetic patients. We have also proposed an innovative temporary tattoo based diabetes self management scheme that provides a cost-effective way to monitor diabetic patients.

### INTRODUCTION

Diabetes, the most common endocrine disorder, is characterized by elevated levels of sugar in blood due to absence of insulin (type 1) or resistance to its action (type 2). The disease is characterized by metabolic abnormalities and by long-term complications involving the eyes, kidneys, nerves and blood vessels (Zhao, Y.J., 2005). In type 2 diabetes, obesity leads to insulin resistance in the peripheral tissues, so the disease usually has an insidious onset later in life (American Association of Diabetes Educators, 2015). The current expenditure on diabetes treatment in India is approximately 95 USD (Rs. 6,000) person/annum as per IDF atlas, 2014. Besides expenditure, there is a huge requirement for trained workforce at all levels; paramedical workers, doctors, podiatrists and more. While the National Diabetes Control Program is well on its way, lack of specialized human resources is making it lag behind. Lack of awareness about diabetes and its complications, delayed diagnosis, myths surrounding diabetes management and dependence on quacks for treatment makes diabetes detection and management difficult. Uncontrolled levels of blood sugar can lead to tissue damage throughout the body, from eyes to toes. As a doctor, the biggest challenge is to make the patients understand nature of the disease, dispel myths surrounding the diet and medication and ensuring compliance to the medical regime. The risk factors for diabetes in India include age, family history, central obesity, physical inactivity and sedentary living, insulin resistance, urbanization, stress. While HbA1c is the gold standard test around the world

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for insulin initiation and intensification, it is not easily available to a large section of Indian population. Even after the diagnosis, monitoring of diabetes is very poor. Most of the patients initially visit a doctor and then discontinue their therapy once their symptoms are controlled.

## **II. Domain Ontology:**

### **2.1. Etymology:**

Diabetes comes from Greek, and it means a "siphon". Aretus the Cappadocian, a Greek physician during the second century A.D., named the condition *diabainein*. He described patients who were passing too much water (polyuria) - like a siphon. The word became "diabetes" from the English adoption of the Medieval Latin *diabetes*. In 1675, Thomas Willis added *mellitus* to the term, although it is commonly referred to simply as diabetes. *Mel* in Latin means "honey"; the urine and blood of people with diabetes has excess glucose, and glucose is sweet like honey. Diabetes mellitus could literally mean "siphoning off sweet water". In ancient China people observed that ants would be attracted to some people's urine, because it was sweet. The term "Sweet Urine Disease" was coined.

### **2.2. Epidemiology:**

Diabetes, a condition in which the body has lost the ability to produce, or to correctly utilize insulin, is the eighth-leading cause of death by disease in the world. In 2013, according to the International Diabetes Federation, an estimated 381 million people had diabetes. Its prevalence is increasing rapidly in developing countries which follow the trend of urbanization and lifestyle changes, perhaps most importantly a "Western-style" diet. According to the Indian Heart Association, India is the diabetes capital of the world with a projected 109 million individuals with diabetes by 2035. It is estimated that every fifth person with diabetes will be an Indian. Nearly 44 lakh Indians in their most productive years — aged 20 to 79 years — aren't aware that they are diabetic, a disease that exposes them to heart attack, stroke, amputations, nerve damage, blindness and kidney disease. The International Diabetes Federation has been observing November 14 as World Diabetes Day at a global level since 1991, with co-sponsorship of the World Health Organization.

### **2.3. Manifestation:**

The classic symptoms of untreated diabetes are weight loss, polyuria, polydipsia and polyphagia. Symptoms may develop rapidly in Type-1 diabetes mellitus while they usually develop much more slowly and may be subtle or absent in Type-2 diabetes mellitus. Several other signs and symptoms can mark the onset of diabetes, although they are not specific to the disease. In addition to the known ones above, they include blurry vision, headache, fatigue, slow healing of cuts, and itchy skin. Prolonged high blood glucose can cause glucose absorption in the lens of the eye, which leads to changes in its shape, resulting in vision changes. A number of skin rashes that can occur in diabetes are collectively known as diabetic dermadromes.

### **2.4. Repercussion:**

Almost every organ in the body can be adversely affected with the onset of diabetes, say medical specialists. But with timely intervention and care, the disease can be kept under check. Diabetes is one of the diseases that affect the endocrine system. The pancreas produces the hormone insulin. In Type 2 diabetes, insulin is still produced but the body becomes resistant to it. Endocrinologists can help patients manage their diabetes, by prescribing insulin and/or medications, and offering diet plans. Diabetics should avoid painkillers. They should watch out for swelling of the feet, extreme fatigue, weakness and breathlessness. Obese children should also be screened for diabetes.

## **III. Adjudicating Diabetes:**

### **3.1. Conviction:**

The average normal person has an average fasting glucose level of 4.5 mmol/L (81 mg/dL), with a low of down to 2.5 and up to 5.4 mmol/L (65 to 98 mg/dL). Doctors can determine whether a patient has a normal metabolism, prediabetes or diabetes in one of three different ways - there are three possible tests: **The A1C test,**

### **The FPG (fasting plasma glucose) test and the OGTT (oral glucose tolerance test):**

#### **3.2. Reiterating Blood Sugar Test:**

Blood sugar monitoring is important for people with type 2 diabetes. The recommendations for how often you should test are based upon individual factors such as type of treatment (diet versus oral medication versus insulin), level of glycated hemoglobin (A1C), and treatment goals. A healthcare provider can help you determine how frequently to test.

### **3.3. Apprehension:**

The results of blood sugar testing tell you if your diabetes treatments are on target. However, blood sugar results can be affected by activity levels, foods eaten, and medications. To interpret results, it is important to consider all of these factors. You should review your blood sugar results regularly with a healthcare provider. Ketones are acids that are formed when the body does not have enough insulin to get glucose into the cells, causing the body to break down fat for energy. Ketoacidosis occurs when high levels of ketones are present and can lead to serious complications such as diabetic coma.

### **3.4. Parameters of Interest:**

The gold-standard fluid for diagnostics is blood, however, blood analysis requires invasive sampling, which is undesirable for long-term continuous use. In recent years, significant effort has been focused on sampling and analysis of alternative body fluids, such as interstitial fluid, tears, saliva, and sweat. The transition from blood to other body fluids provides a less invasive means of sampling, which in turn may provide a route to facilitate longer-term continuous monitoring. Analysis of sweat loss and sweat composition can also offer valuable information regarding hydration status and electrolyte balance. Tears are another body fluid in which many proteins and electrolytes are normally present. Glucose is one of the most important biomarkers present in tears, and may be useful in personal monitoring of diabetes. The six new possible ways to test blood glucose include contact lens, saliva, acetone in the breath, earlobe, the light through the skin and the coil between the eyelid and the eye. In recent years, a number of different types of wireless networks have been investigated and employed in health-care applications.

## **IV. Presiding Diabetes Management:**

Disease management is defined as “a system of coordinated health care interventions and communications for populations with conditions in which patient self-care efforts are significant. Such programs emphasize the empowerment of patients to manage their own care and to use evidence-based guidelines to help them stay as healthy as possible.

### **4.1. A Consensus of Taxonomy:**

To help frame subsequent analysis, CITL derived the following taxonomy of ITDM technologies, which is described in detail below:

- Technologies used by payers
- Technologies used by providers
- Disease registries
- Clinical decision-support systems
- Technologies used by patients
- Self-management
- Remote monitoring
- Integrated provider-patient systems

### **4.2. Glucose Monitoring Techniques:**

Blood glucose monitoring is a way of testing the concentration of glucose in the blood (glycemia). Particularly important in the care of diabetes mellitus, a blood glucose test is performed by piercing the skin (typically, on the finger) to draw blood, then applying the blood to a chemically active disposable 'test-strip'. Different manufacturers use different technology, but most systems measure an electrical characteristic, and use this to determine the glucose level in the blood. The test is usually referred to as capillary blood glucose.

#### **4.2.1. Blood Glucose Meter:**

A blood glucose meter is an electronic device for measuring the blood glucose level. A relatively small drop of blood is placed on a disposable test strip which interfaces with a digital meter. Within several seconds, the level of blood glucose will be shown on the digital display. Needing only a small drop of blood for the meter means that the time and effort required for testing is reduced and the compliance of diabetic people to their testing regimens is improved. Although the cost of using blood glucose meters seems high, it is believed to be a cost benefit relative to the avoided medical costs of the complications of diabetes.

#### **4.2.2. Continuous Glucose Meter:**

A continuous glucose monitor (CGM) determines glucose levels on a continuous basis (every few minutes). A typical system consists of a disposable glucose sensor placed just under the skin, which is worn for a few days until replacement, a link from the sensor to a non-implanted transmitter which communicates to a radio receiver, an electronic receiver worn like a pager (or insulin pump) that displays glucose levels with nearly continuous updates, as well as monitors rising and falling trends. Continuous glucose monitors measure the

glucose level of interstitial fluid. Shortcomings of CGM systems due to this fact are: (i) continuous systems must be calibrated with a traditional blood glucose measurement (using current technology) and therefore require both the CGM system and occasional "fingerstick". (ii) glucose levels in interstitial fluid lag behind blood glucose values

#### **4.2.3. Glucose Sensing Bio-implants:**

A significant improvement of diabetes therapy might be achieved with an implantable sensor that would continuously monitor blood sugar levels within the body and transmit the measured data outside. The burden of regular blood testing would be taken from the patient, who would instead follow the course of their glucose levels on an intelligent device like a laptop or a smart phone.

#### **4.2.4. Non-Invasive Technologies:**

Some new technologies to monitor blood glucose levels will not require access to blood to read the glucose level. Non-invasive technologies include near IR detection, ultrasound and dielectric spectroscopy. These will free the person with diabetes from finger sticks to supply the drop of blood for blood glucose analysis. The five building blocks of exponential technological progress include computing power, data storage, bandwidth, miniaturized hardware and advanced software (Penders, J., 2009).

### **V. Standards Provisioning Diabetes Self Management:**

#### **5.1. SMBG: Self-Monitoring of Blood Glucose:**

SMBG is an important complement to the measurement of A1C levels because it provides the person with diabetes immediate information about their blood glucose levels (Gyselinckx, B., 2005). Unlike A1C monitoring, SMBG provides the person with diabetes a means to distinguish fasting, preprandial, and postprandial blood glucose levels. By delivering information on a person's current blood glucose level, SMBG allows the person with diabetes to monitor the immediate effects of food, physical activity, and medications on glycemic control. SMBG refers both to the act of checking (or testing) blood glucose levels with a blood glucose meter and utilizing the results to make lifestyle and treatment regimen decisions. Unfortunately, some people with diabetes may not understand how to utilize SMBG results in the above-described ways. Thus, there is a need to remedy this through diabetes education.

#### **5.2. WBAN: Wireless Body Area Network:**

In Wireless Body Area Networks, various sensors are attached on clothing or on the body or even implanted under the skin. The wireless nature of the network and the wide variety of sensors offer numerous new, practical and innovative applications to improve health care and the quality of life. Using a WBAN, the patient experiences a greater physical mobility and is no longer compelled to stay in the hospital. These sensor nodes can be worn externally or implanted inside the body to monitor multiple bio-parameters (such as blood oxygen saturation, blood pressure and heart activity) of multiple patients at a central location in the hospital. It is a radio frequency based wireless networking technology (Ragesh, G.K., K. Baskaran, 2012). A WBAN can be used to offer assistance to the disabled (Maloney, J.M., J.T. Santini Jr, 2004). Some popular protocols for WBAN are TMAC, SMAC, ZigBee MAC and Baseline MAC (Maloney, J.M., J.T. Santini Jr, 2004). The technologies employed by Wireless Body Area Network for secure transmission include Radio-Frequency Identification, Wireless Personal Area Network, Ultrawideband technology, Wireless wristband sensor with inertial tracking system and biosensors (Coyle, S., 2014). The standards used in Wireless Body Area Network include Bluetooth, Zigbee, WirelessLAN, Radio frequency transceiver and cellular phone (Cherukuri, S., 2003). Challenges in healthcare application includes low power, limited computation, security and interference, material constraints, robustness, continuous operation, and regulatory requirements.

#### **5.3. MHealth: Mobile Health:**

MHealth applies the power and reach of mobile communication to health care services (Bandodkar, A.J., 2014). It plays a key role in transforming health care into a more-efficient, patient-centered system of care in which individuals have real-time access to information to support engagement (Asada, H.H., 2003). Use of mHealth spans a broad spectrum of capabilities which can be classified into three levels:

##### **5.3.1. Basic:**

mHealth app with limited features; data is captured manually. Users manually input dietary intake and the application compiles reports on daily calorie, sodium, fat, and carbohydrate intake (e.g., MyFitnessPal, NutritionMenu and MyNetDiary

### **5.3.2. Intermediate:**

MHealth app with limited features; data is captured via biosensors with minimal manual efforts. While still nascent, examples include an inhaler from Propeller Health with a built-in asthma sensor to measure air quality, and BioStamp, a wearable device that can monitor and transmit vital signs.

### **5.3.3. Advanced:**

MHealth app with the ability to capture multiple inputs via biosensors, coupled with intelligent data-processing capabilities. These devices are not yet widely developed; however, one example is Scanadu Scout, a portable device that measures temperature, heart rate, blood oxygen levels, respiratory rate, ECG, and blood pressure. It transmits all this information to a mobile device.

### **5.4. Wearable Sensors:**

Wearable health monitoring systems allow an individual to closely monitor changes in her or his vital signs and provide feedback to help maintain an optimal health status (Yang, B.H., S. Rhee, 2000). If integrated into a telemedical system, these systems can even alert medical personnel when life-threatening changes occur (Thierer, A.D., 2015). A wearable PPG biosensor in the form of a ring has been developed by Yang and Rhee (Kaur, R., 2011). As an article of clothing, a ring is more likely to be worn continuously, making it suitable for continuous monitoring applications. Asada et. al. have further refined the design of the ring sensor to ensure that the PPG signal output is more resistant to noise components due to motion artifacts and changes in ambient light levels for cardiovascular monitoring.

### **5.5. Tattoo-Based Noninvasive Glucose Monitoring:**

The new skin-worn tattoo-based glucose detection system uses a lower current density to extract the ISF glucose followed by selective amperometric biosensing using a glucose oxidase (GOx)- modified Prussian Blue transducer at a low potential as compared to GlucoWatch. Such flexible, low-cost, and aesthetically pleasing iontophoretic-biosensing tattoo platform can be easily mated with the human skin with the least level of intrusion to the wearer's routine. To realize both extraction and sensing operations using such a printable skin-worn tattoo platform, additional Ag/AgCl reverse-iontophoresis electrodes (along with the agarose hydrogel coating) have been incorporated for efficient delivery of ISF close to the working and counter/reference electrodes. The biocatalytic reagent layer was optimized for imparting the sensitivity needed for detecting low (micromolar) glucose concentrations in the extracted ISF14 and high specificity in the presence of common interfering electroactive species.

### **5.6. Electrochemical Sensors:**

Electrochemical sensors involve using electrodes to measure the electrochemical changes that occur when chemicals interact with a sensing surface. Recently, a great deal of effort has been applied to the development of wearable electrochemical sensors through the employment of novel materials, such as conductive polymers and carbon nanomaterials. For instance, carbon nanomaterials present excellent electrical and chemical properties, and they have been extensively explored for the realization of biosensors.

### **5.7. Implantable Sensors:**

It has been shown in continuous monitoring of blood glucose level was enabled by placing an implantable sensor covered with a multilayered membrane in the subcutaneous tissue of the abdomen. Glucose levels were determined every 30seconds and radio transmission of the glucose data occurred every 5 minutes. If this sensor were to be combined with an implantable drug delivery system, such as the one in, a closed feedback loop would be formed for the control of blood glucose levels via the delivery of variable amounts of insulin.

## **VI. Conclusion and Future Work:**

Wellness and health are central to our lives and are major determinants of quality of life. Furthermore, the efficient delivery of effective healthcare is a key societal objective, especially given increasingly limited economic resources. Diabetes occurs almost in people above 45 years and in that age the patient might not have good health. Tracking the diabetic patient's blood sugar/ hydration is very difficult since they are busy in their job. Today's healthcare has become cost-prohibitive and most developed countries are spending a significant proportion of gross domestic product (GDP) on healthcare. Currently most of the healthcare system is in crisis due to challenges including escalating costs, the inconsistent provision of care, medical error, an aging population, and high burden of chronic disease related to health behaviors. Mitigating this crisis will require a major transformation of healthcare to be proactive, preventive and patient-centered, with a focus on improving quality-of-life. Information technology, networking, and biomedical engineering are likely to be essential in making this transformation possible with the help of advances, such as sensor technology, mobile computing, machine learning, etc. Our proposed monitoring system encourages the diabetic patient to wear a BioStamp

tattoo on his/her wrist. This BioStamp tattoo has a glucose sensor and a hydration sensor embedded in it that monitors blood sugar level and body hydration level periodically. This BioStamp also has a Radio Frequency antenna embedded in it, which is capable of sending the measured data to a nearby mobile device using Bluetooth. A detailed description of our BioStamp based diabetes self management can be seen in our next paper.

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