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# Coin Based Automated Blood Sugar Level Monitoring System for the Public

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**Abstract:** In this paper, we propose a blood sugar level monitoring system (blood glucose monitoring) for the public which is easy to use, automated, coin based and prints instant results. Blood glucose monitoring is a way of testing the concentration of glucose in the blood (glycaemia). Particularly in the case of diabetes mellitus, a blood glucose test is performed by piercing the skin (typically on the finger) to draw blood and then applying the blood on to a chemically active disposable 'test strip'[1]. Most people with diabetes mellitus are advised to monitor their blood glucose level at least twice or thrice in a day or even more in cases where the patients have very high blood sugar levels. This can be done at home or hospitals. The present cost of monitoring blood sugar level at hospitals in India ranges from Rs 50 to Rs 100. If an individual wants self monitoring of blood glucose level at home, the device named "Glucometer" may cost him up to Rs 2500 (approximately) and the cost of each test strip ranges from Rs 30 to Rs 50. This will be a costly affair for people who are suffering from diabetes mellitus and cannot afford the above luxury. So, we have developed a coin based blood glucose monitoring system for the public. By inserting a Rs 5 or Rs 10 coin, one can easily monitor the blood glucose level. This machine can be placed in public places like municipality offices, community buildings, hospitals, etc. The machine is automated and even an illiterate person can operate it and obtain the test results. We have designed a system which is light weight, compact and user friendly. Also the needles used for piercing is of "one time use", sterile and will be disposed after every single use making the device safe and risk free.

**Keywords:** blood sugar level monitoring, glycaemia, test strip, diabetes mellitus, Glucometer, "one time use", sterile.

## I. INTRODUCTION

Diabetes Mellitus (DM), commonly referred to as diabetes, is a group of metabolic diseases in which there are high blood sugar levels for a prolonged period [2]. The symptoms of high blood sugar levels include frequent urination, increased thirst and increased hunger. If left untreated, diabetes can cause further complications. [3] Acute complications include diabetic ketoacidosis, nonketotic hyperosmola coma or death [4]. Serious long term complications include heart diseases, stroke, chronic kidney failure, foot ulcers and damage to the eyes [3].
Diabetes is caused either due to insufficient insulin produced by pancreas or the cells in the body not responding to the insulin properly [5].

There are three main types of diabetes mellitus:

- Type 1 DM results from the pancreas's failure to produce enough insulin. This form of DM was previously referred to as "insulin-dependent diabetes mellitus" (IDDM) or "juvenile diabetes". The cause is unknown [3].
- Type 2 DM begins with resistance to insulin, a condition in which cells fail to respond to insulin properly. As the disease progresses, a lack of insulin may also develop. This form was previously referred to as "non insulin-dependent diabetes mellitus" (NIDDM) or adult-onset diabetes the primary cause is excessive body weight and inadequate exercise [3].
- Gestational diabetes is the third main form and occurs when pregnant women without a previous history of diabetes develop high blood sugar levels.

Type 1 DM may be treated with insulin injections. [3] Type 2 DM may be treated with medication and with or without insulin doses. [7] Gestational diabetes usually resolves after the birth of the baby. [8] For treatment and maintaining healthy levels of glucose/sugar in the body, one has to monitor blood sugar levels frequently. According to World Health Organization, DM has become one of the most fatal diseases in the world if left untreated and without frequent monitoring of the same.
As of 2015, an estimated 415 million people had diabetes worldwide, [9] with type 2 making up about 90% of cases. [10][11] This represents 8.3% of the adult population, [12] with equal rates in both men and women. [13] Diabetes at

 

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least doubles the risk of early death. [3] From 2012 to 2015, approximately 1.5 million to 5 million deaths each year resulted from diabetes. [7][9] Figure 1 shows the most significant symptoms of diabetes. Table 1 shows the comparison between type 1 and type 2 diabetes. [10] Figure 2 shows the rates of diabetes worldwide in 2000.

Table 1 Comparison between Type 1 and Type 2 Diabetes

| **Feature** | **Type 1 Diabetes** | **Type 2 Diabetes** |
|---|---|---|
| **Onset** | Sudden | Gradual |
| **Age on Onset** | Mostly in Children | Mostly in Adults |
| **Body Size** | Thin or Normal | Often Obese |
| **Ketoacidosis** | Common | Rare |
| **Autoantibodies** | Usually present | Absent |
| **Endogenous Insulin** | Low or Absent | Normal, decreased or increased |
| **Concordance in Identical Twins** | 50% | 90% |
| **Prevalence** | ~10% | ~90% |

Table 2 Epidemiological studies of type 2 diabetes in Northern region of India

| **North India** | | **Urban** | | | **Rural** | | |
|---|---|---|---|---|---|---|---|
| **Place** | **Year of Publication** | **N** | **Age** | **Prevalence (%)** | **N** | **Age** | **P (%)** |
| Chandigarh | 1966 | 3486 | 30+ | 2.9 | - | - | - |
| Lucknow | 1973 | 2190 | 20+ | 1.1 | - | - | - |
| Delhi | 1974 | 2291 | 20+ | 2.7 | - | - | - |
| Delhi | 1986 | 6878 | 20+ | 3.1 | - | - | - |
| Delhi | 1991 | 2572 | 20+ | 4.1 | 992 | 20+ | 1.5 |
| Delhi | 1991 | - | - | - | 999 | 20+ | 0.4 |
| Punjab | 1994 | - | - | - | 1100 | 30+ | 4..6 |
| Srinagar | 2000 | 1538 | 40+ | 5.2 | 4045 | 40+ | 4.0 |
| Delhi | 2001 | 532 | 18+ | 10.3 | - | - | - |
| Delhi | 2001 | 2300 | 20+ | 11.6 | - | - | - |
| Jaipur | 2003 | 1091 | 20+ | 12.3 | - | - | - |
| Jaipur | 2004 | 458 | 20+ | 16.8 | - | - | - |
| Rajasthan | 2004 | - | - | - | 882 | 20+ | 1.8 |
| Delhi | 2005 | 2122 | 20-59 | 15.0 | - | - | - |
| Jaipur | 2007 | 1127 | 20+ | 20.1 | - | - | - |
| Nagpur | 2007 | - | - | - | 924 | 30+ | 3.7 |

Table 3 Epidemiological studies of type 2 diabetes in Southern region of India

| **South India** | | **Urban** | | | **Rural** | | |
|---|---|---|---|---|---|---|---|
| **Place** | **Year of Publication** | **N** | **Age** | **Prevalence (%)** | **N** | **Age** | **P (%)** |
| Hyderabad | 1966 | 21396 | 20+ | 4.1 | - | - | - |
| Chennai | 1966 | 5030 | 20+ | 5.6 | - | - | - |
| Pondicherry | 1968 | 2694 | 20+ | 0.7 | - | - | - |
| Hyderabad | 1972 | - | - | - | 2006 | 20+ | 2.4 |
| Gangavati | 1990 | - | - | - | 765 | 30+ | 2.2 |
| Trivandrum | 1991 | - | - | - | 1488 | 20+ | 1.3 |
| Chennai | 1992 | 900 | 20+ | 8.2 | 1803 | 20+ | 1.3 |
| Chennai | 1997 | 2183 | 20+ | 11.6 | - | - | - |
| Chennai | 1999 | 1198 | 20+ | 7.6 | - | - | - |
| Trivandrum | 2000 | 518 | 20+ | 12.4 | - | - | - |
| Bangalore | 2001 | 1359 | 20+ | 12.4 | - | - | - |
| Chennai | 2001 | 1668 | 20+ | 13.5 | - | - | - |
| Hyderabad | 2001 | 1427 | 20+ | 16.6 | - | - | - |
| Chennai | 2003 | 1262 | 20+ | 12 | - | - | - |
| Chennai | 2006 | 2350 | 20+ | 15.5 | - | - | - |

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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Godavari | 2006 | - | - | - | 4535 | 30+ | 13.2 |
| Kochi | 2006 | 3069 | 18-80 | 19.5 | - | - | - |

Table 4 Epidemiological studies of type 2 diabetes in Eastern and Western regions of India

| India | | Urban | | | Rural | | |
|---|---|---|---|---|---|---|---|
| **Place** | **Year of Publication** | **N** | **Age** | **Prevalence (%)** | **N** | **Age** | **Prevalence (%)** |
| Eastern Region | | | | | | | |
| Kolkata | 1975 | 4000 | 20+ | 2.3 | - | - | - |
| Kolkata | 1991 | - | - | -8.2 | 2375 | 20+ | 0.8 |
| Guwahati | 1998 | 1016 | 20+ | 11.7 | - | - | - |
| Kolkata | 2001 | 2378 | 20+ | - | - | - | - |
| Western Region | | | | | | | |
| Mumbai | 1963 | 18243 | 20+ | 1.5 | - | - | - |
| Mumbai | 1966 | 3200 | 20+ | 2.1 | - | - | - |
| Ahmedabad | 1991 | - | - | - | 1294 | 20+ | 3.9 |
| Mumbai | 2001 | 520 | 20+ | 7.5 | - | - | - |
| Mumbai | 2001 | 2084 | 20+ | 9.3 | - | - | - |
| Sindhudurg | 2006 | - | - | - | 1022 | 20+ | 9.3 |

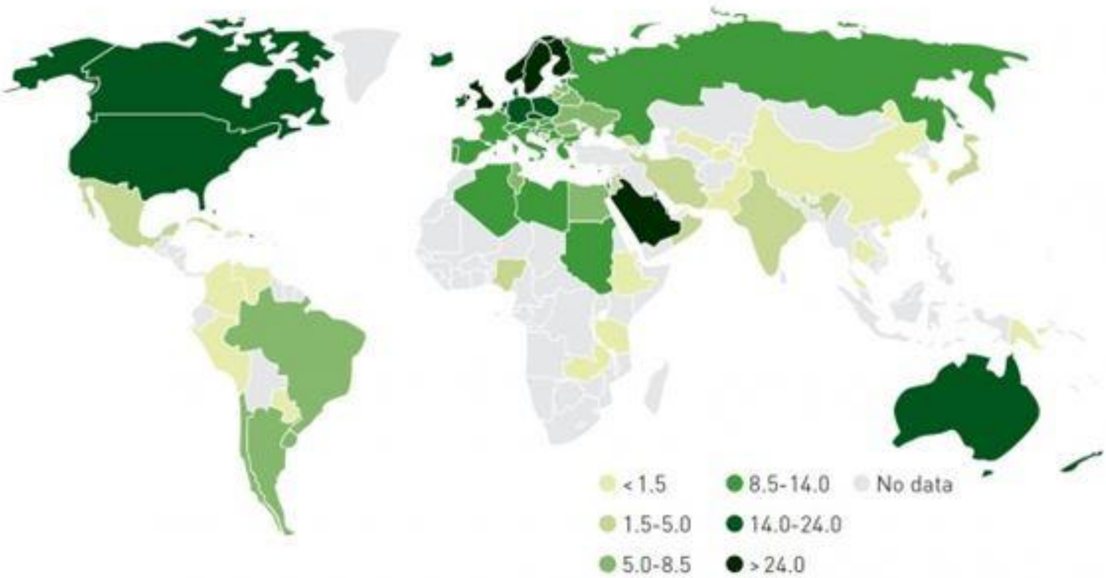


Fig. 7 New case of type 1 diabetes in children 0 to 14 years per 100,100 children per year, 2011

Figure 3 shows prevalence estimates of diabetes for 2007. Figure 4 shows DM deaths per million persons in 2012. Figure 5 and Figure 6 show diabetes prevalence in India among males and females respectively (as per 2014 study). [15] Table 2, table 3 and table 4 show Epidemiological studies of type 2 diabetes in Northern, Southern Eastern and Western regions of India. Figure 7 shows new case of type 1 diabetes in children 0 to 14 years per 100,100 children per year, 2011. [14] Figure 8 shows global prevalence estimates of diabetes by 2025.

As per graphical and statistical data presented above, there is a serious need for blood sugar monitoring and treatment at the right time and with the right approach. Figure 9 shows the unrelenting march of diabetes. [16] We have developed a coin based, automated blood glucose monitoring system. Sterile needles are loaded into the machine for pricking the finger of a person. Up to 96 needles can be loaded into the machine at a time and the needles are of one time use thereby eliminating the risk of any infections. A person can monitor blood glucose level in just 2.5 to 3 minutes after initializing the machine by inserting a coin through the coin slot. We have used glucometer strips for blood sample collection which is directly connected to the glucometer and instant values appear on the LED/LCD display and printed report is generated. Once the strips become empty, there is a signal for reloading the strips. Also, a warning signal pops up as soon as the number of needles reaches a specified minimum level. Even a poor person can insert a coin and monitor the blood glucose level and obtain an instant report.

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ISO 3297:2007 Certified

Vol. 5, Issue 10, October 2016



Fig. 1 Most significant symptoms of diabetes

Since these machines are placed in public places, anyone can access this facility with ease. Also, it is user friendly and a fast paced result is obtained thereby reducing the time spent in the queue.

## II. BACKGROUND

Self monitoring of blood glucose level is essential to optimise glycaemic control in diabetes mellitus. Since the proposed model in this paper will be easily accessible to the public, user friendly and inexpensive, self monitoring can be augmented. Also printed reports can be generated which can be filed and a consultation with a diabetologist or a physician could almost make a person live a healthy and risk free life.

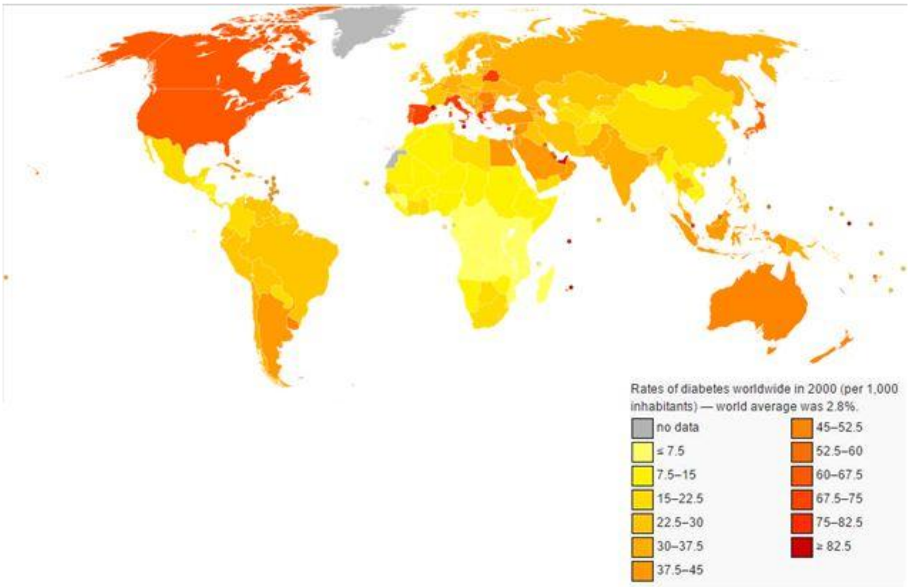


Fig. 2 Rates of diabetes worldwide in 2000

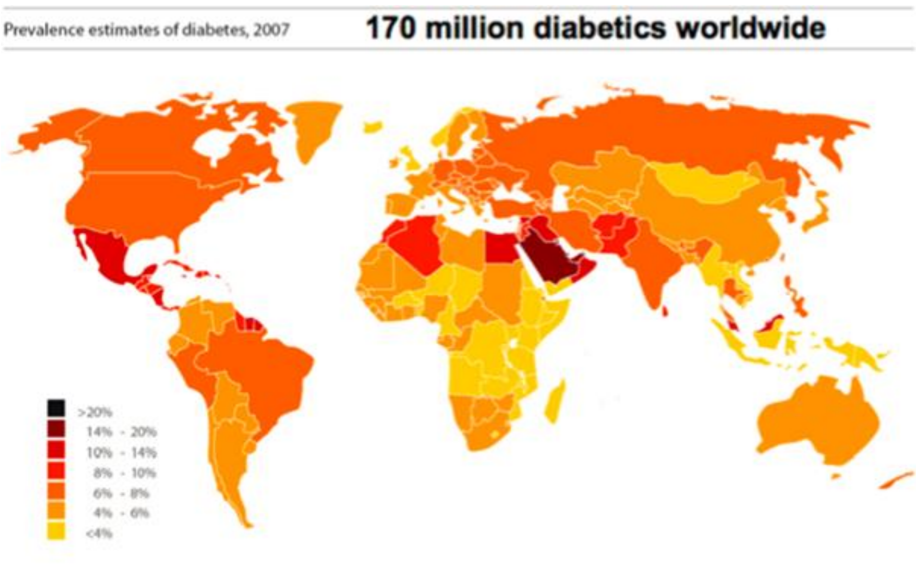


Fig. 3 Prevalence estimates of diabetes for 2007

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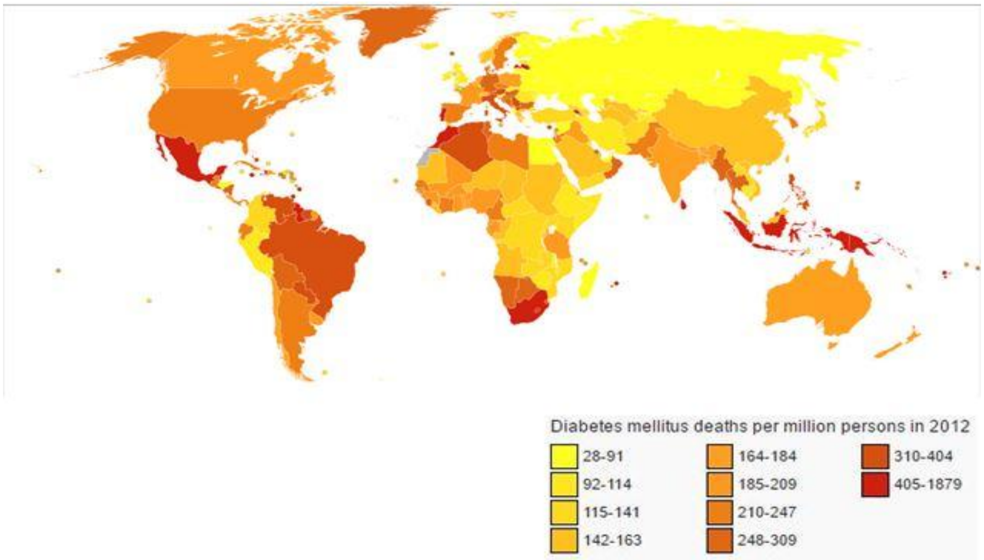


Fig. 4 DM deaths per million persons in 2012

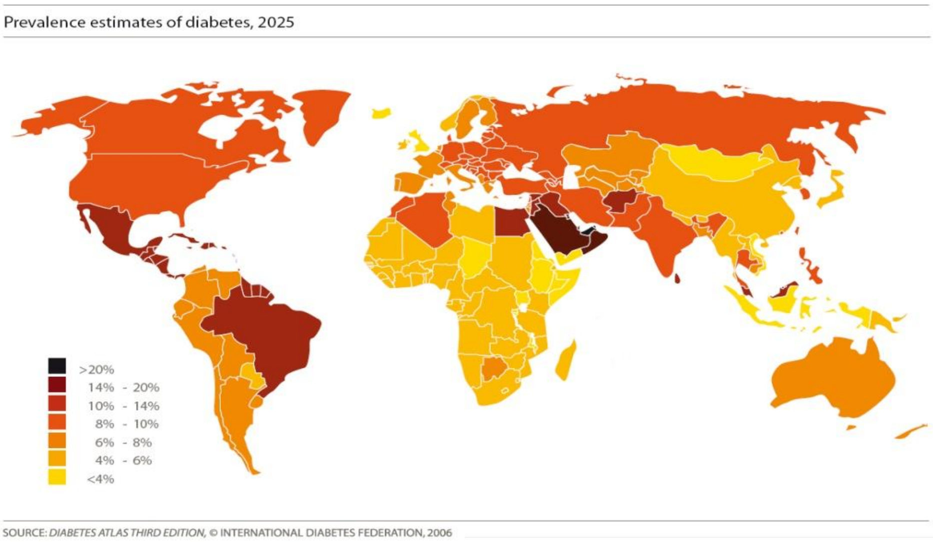


Fig. 8 Global prevalence estimates of diabetes by 2025

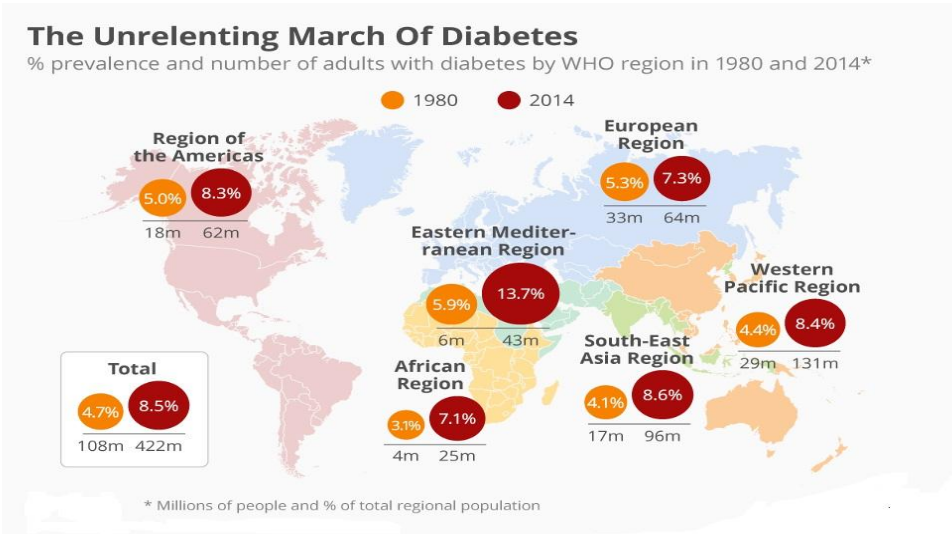


Fig. 9 the Unrelenting March of Diabetes

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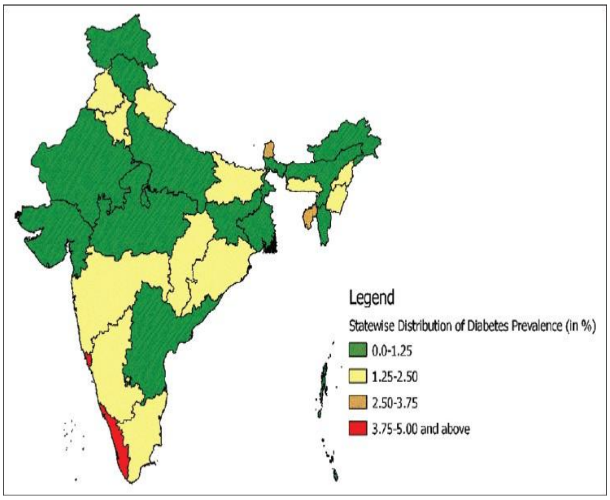


Fig. 5 Diabetes prevalence in India among males (as per 2014 study)

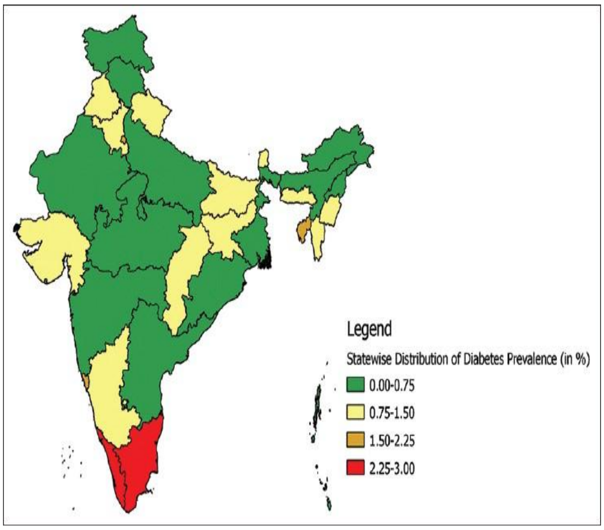


Fig. 6 Diabetes prevalence in India among females (as per 2014 study)

## III.METHODOLOGY

### A. Schematic Diagram

The schematic diagram of the coin based automated blood sugar level monitoring system is as shown in figure 10.

It consists of a programmable coin acceptor [16] into which a person can insert Rs 5 or Rs 10 coin (for rural and urban areas respectively) in the coin slot. By inserting the coin, the system gets initiated and is ready to perform. The coin collector collects the coin and can be emptied from time to time. A microcontroller is used to dictate the actions to each and every device of the system, thus making blood glucose level monitoring completely automated.

We have designed a cylindrical needle package as shown in figure 11 which consists of twelve 22mm x 15 mm slots. It is designed to be 320 mm in length and 170 mm in diameter. The cylinder can hold a maximum of 96 sterile, one-time use needles for piercing (each of the 12 slots can hold a maximum of 8 needles). The cylinder is rotated by 22.5 degrees each time to pick a new sterile needle. We have employed a robotic arm as shown in figure 12 to fetch the needle from the slot in the cylinder, to place it in the needle holder and dump the pin into the bin after usage.

Once an appropriate coin is detected by the coin detector, the system is initiated and a sterile needle is fetched from the cylindrical package and is placed in the needle holder by the robotic arm. And the person is asked to press the button in the needle and consequently his/her finger is pierced from which a drop of blood can be used to measure blood glucose level.

Our system consists of a glucometer which is loaded with test strips and one strip pops out each time. Now the person can place the pierced finger on to the test strip and blood glucose value is obtained and displayed on the display screen of the glucometer (the unit being mg/dl).

The test report can be obtained from the printer which is employed in the system as shown in the schematic diagram. We have employed an LCD instruction display to guide the user for self monitoring of the blood glucose level. We have also provided a bin to collect the used test strips and needles to avoid infections. The system also has power and reset buttons. The system needs an AC power supply. The whole system is controlled by a timer and each person gets about 2 to 3 minutes to monitor his or her blood glucose level. The timer is vital in order to make our system systematic and to reduce the “stand in queue” time of the public.

### B. System Design and Working

In this section, we discuss in detail, the system design and the working of each and every entity we have mentioned in the previous section.When a person inserts a coin, the system is initiated or ready to use. For this purpose, we have made use of a programmable coin detector/acceptor (which can accept up to three different types of coins) as shown in figure 13 and we employ a coin collector for collection or deposition of coins which can be emptied from time to time. The machine indicates when the coin collector is full and cannot accept any more coins. The connections to the programmable coin detector/acceptor are as shown in figure 14.

When the system is initiated, the servo motor rotates the cylindrical needle package by an angle of 22.5 degrees each time. The construction and dimensions of the needle package is as shown in figures 15. Figure 16 shows the cut section view of the cylindrical needle package. Each hollow cuboidal slot attached to the cylinder of the needle package consists of 8 sterile needles. Figure 17 and figure 18 show the cuboidal slot and the sterile needle used in the process (before piercing). The nose of the needle pops out of the cylinder so that it can be pulled down by the robotic arm and into the needle holder.

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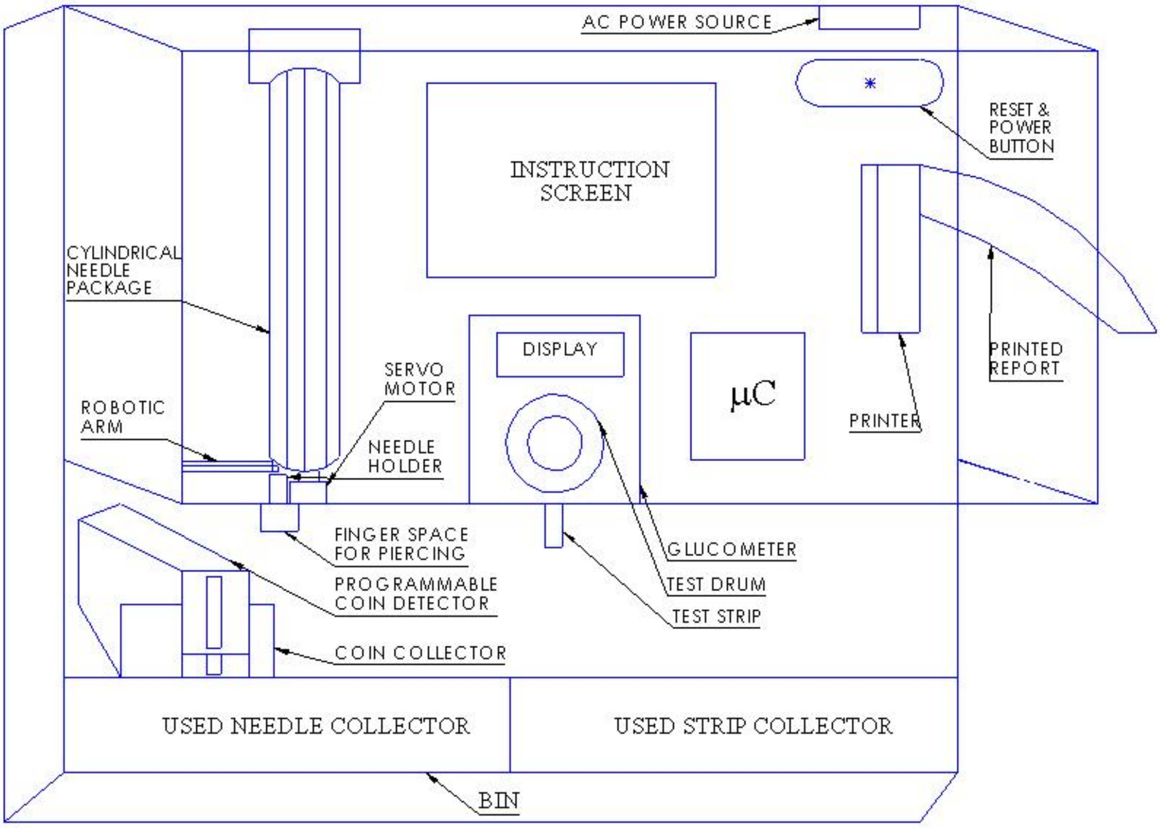


Fig. 10 Coin based automated blood sugar level monitoring system

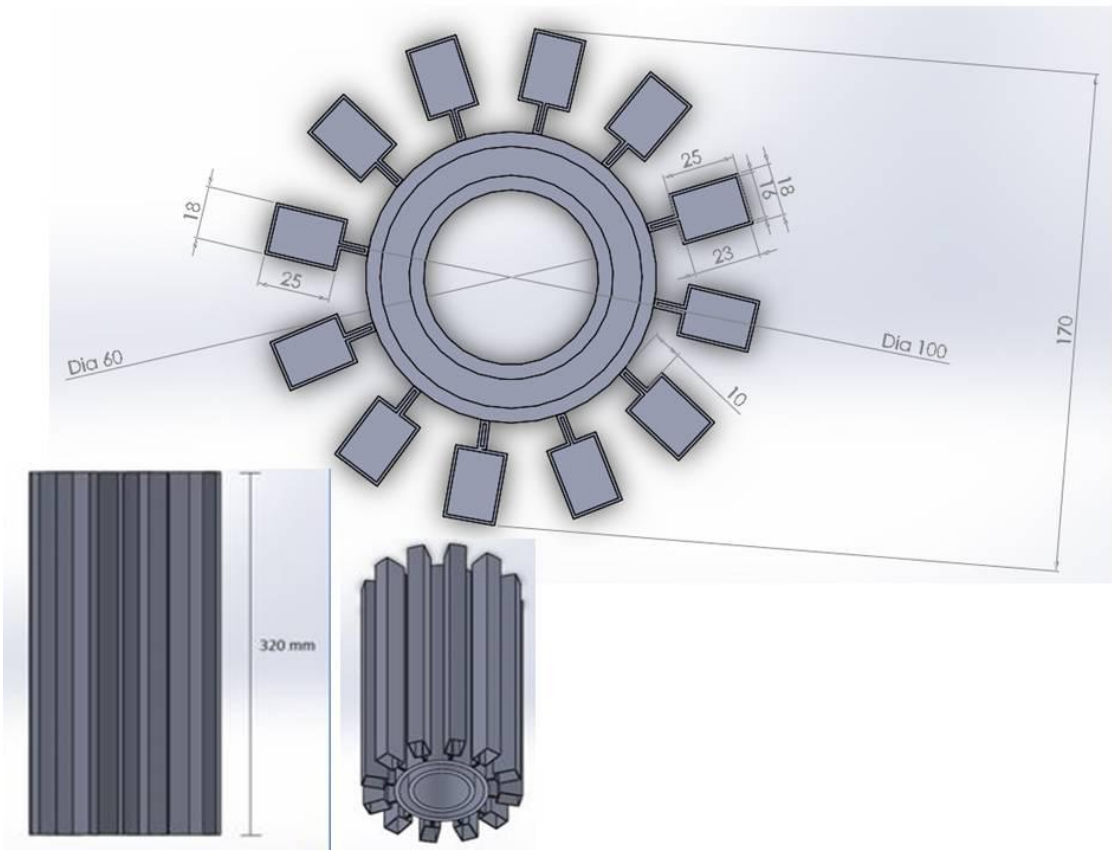


Fig. 11 Cylindrical Needle Package

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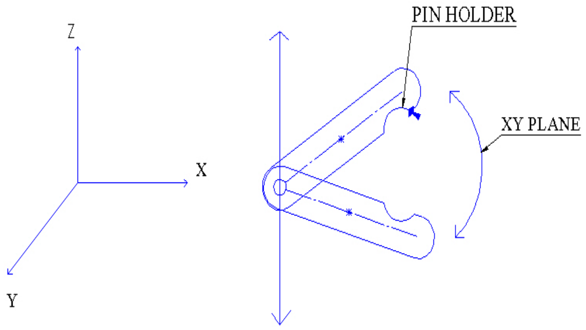


Fig 12 Robotic Arm

The robotic arm and the needle placed in the needle holder are as shown in figures 12 and 19 respectively. Within 3 to 4 seconds after the coin is inserted, a sterile needle is fetched and placed in the needle holder. The person has to now place the finger at the space provided for piercing as shown in figure 10 and here the person gets his or own time to press the button in order to pierce a finger. This is essential in order to allow proper piercing. And once the button is pressed, a test strip comes out of the glucometer. Once the finger is pierced and the blood comes out, it has to be placed on the test strip which absorbs the blood by capillary action and the blood glucose level in mg/dl is displayed on the glucometer screen. All these functions are controlled by the microcontroller. Also, there is a LCD instruction screen which guides the user throughout the process of self monitoring and is as shown in figure 20. The printer generates a report with date, time and blood glucose value. After a period of 2-3 minutes, the entire system goes into sleep mode in order to save power and the process continues with each insertion of coin by users. A reset button is provided in order to reset the system if anything goes wrong in the process of monitoring. A power button which is essential is provided to shut down the system completely.


Fig. 13 Programmable Coin Detector

An alarm system is developed in order to sound an alarm when the coin bin and bin used to collect the used needles and strips are full.

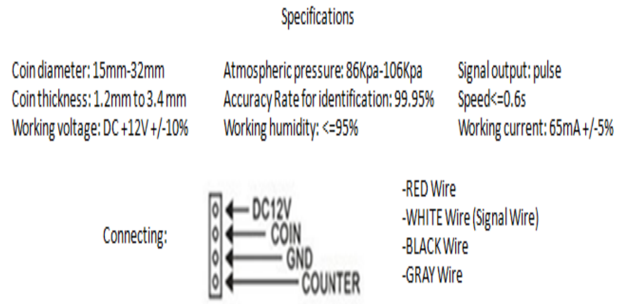


Fig. 14 Connections to the programmable coin detector/acceptor

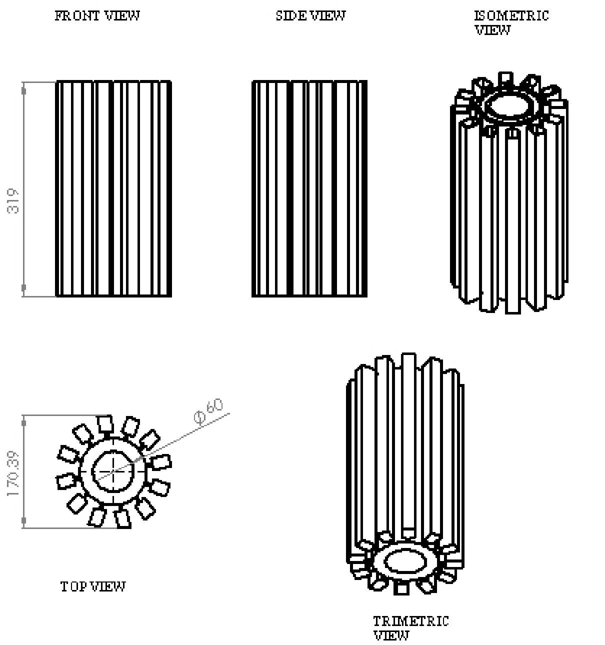


Fig. 15 construction and dimensions of the needle package

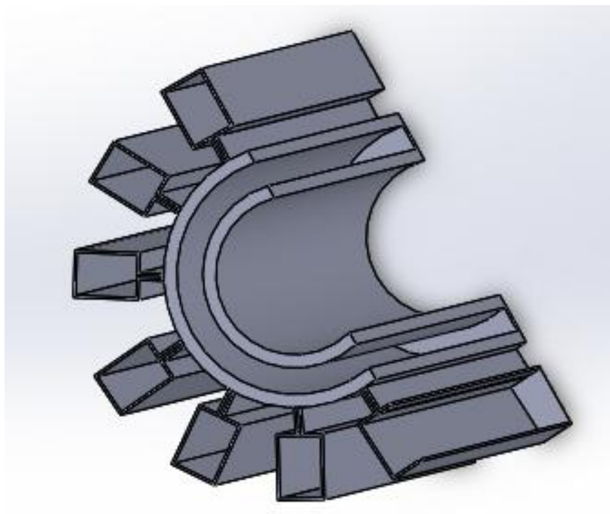

Fig 16 Cut section view of the cylindrical needle package

An alarm system is also provided in order to indicate when the test strips and needles are empty and need replacement. A provision is made to replace the cylindrical needle package and the cylindrical drum holding the test strips after they are empty.

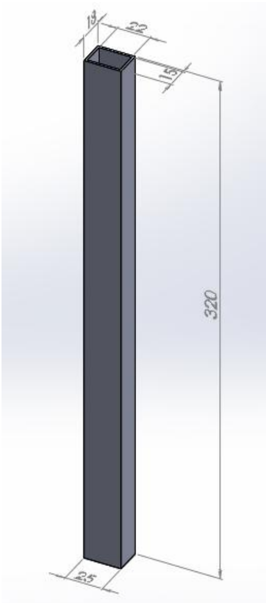


Fig. 17 Cuboidal slot

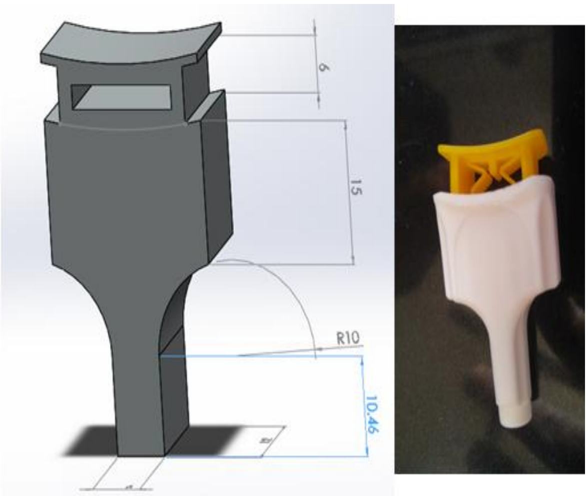


Fig. 18 Sterile needle package (before using)

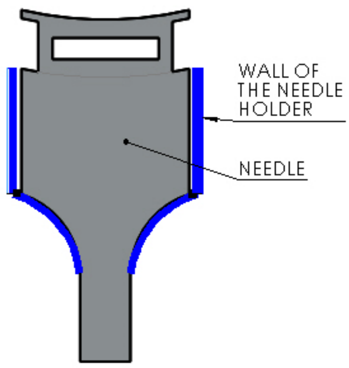


Fig. 19 Needle placed in the needle holder

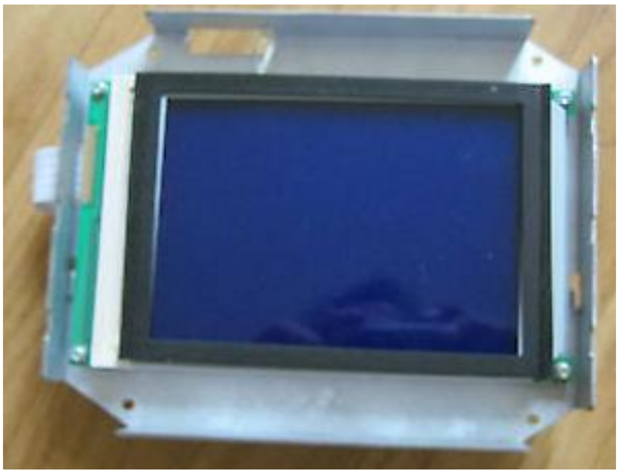

Fig. 20 LCD Instructions Screen

C. Instructions Set (to the Users and Handlers)

a) On the instructions screen:

- Insert coin
- Press here
- Add blood to the strip
- Empty the bin
- Out of needles
- Out of strips
- Time out
- Insert paper roll
- Collect report
- Fatal error
- Out of paper
- Error
- Sorry try again

b) On the glucometer display:

- Insert the test drum
- Error
- Invalid test strip
- Invalid decoder
- Low battery
- Set date
- Set time
- Insert blood
- Processing

## IV. RESULTS

The differences between estimation of glucose in whole blood by glucometer, our device and serum glucose by glucose oxidase method are as shown in the table 5. Figure 21 shows venous blood sampling and our design uses whole blood method of blood glucose monitoring.

Although the whole blood method is not as accurate as venous blood sampling, it is the best method for self monitoring, instant and anytime monitoring of blood glucose level. Our design makes the method of whole blood sampling easily accessible to the public, inexpensive

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and produces printed reports for the consultation with the concerned doctor. The error factor can be corrected. To obtain blood glucose in serum from figures in whole blood, it is multiplied by a factor of 1.15. This error factor may be decreased with improved techniques of whole blood monitoring.

With the development of glucose meters, patients could adjust the dose of their insulin to achieve near physiologic control as possible. Patients with type 2 diabetes could modify carbohydrate intake and exercise to also achieve better glycemic control. The American Diabetes Association (ADA) advises most people with diabetes to maintain blood glucose levels as close to normal as possible. Frequent blood glucose must be interpreted by healthcare professionals so that the patients can be guided toward safer and more targeted glycemic control. So to achieve this, an automated coin based blood glucose monitoring system can be employed and provide open access to public.

A person can monitor his/her blood glucose level as shown in table 6. This can be made possible by following these basic steps in pattern recognition and management:

a) Identify the target blood glucose levels before and after meals (i.e., 80 to 120 mg/dl pre-meal and <140 mg/dl, 2 hours after eating).

b) Perform self-blood glucose monitoring (SBGM) at the same time each day. Record any factors that can possibly influence the blood glucose levels, such as timing of the test in relation to the meal, carbohydrate intake, drug dosage, activity level and illness.

c) Look for patterns of glucose above or below target range on 3 or more consecutive days, or low readings lasting 2 days.

d) Evaluate whether influencing factors may account for glycemic patterns, and

e) Take action if a consistent pattern of glucose levels above or below a target is identified.

## V. DISCUSSIONS

Many people want their glucometers to have laboratory-level accuracy, which is understandable.

But to do so, glucometers would have to have much more complicated technology which could get exceptionally expensive. When it comes to health outcomes, experts agree that accuracy at every blood glucose level is less important than the accuracy at levels for which a wrong number is most likely to cause a clinical error. Those are the results that might encourage you to make a possible harmful decision about not treating hypoglycemia (low blood glucose) or dosing too much of insulin for what appears to be high blood glucose.

Fig. 21 Venous blood sampling

Table 6 Daily self monitoring of blood glucose level to achieve glycaemic control

| Day | Before breakfast | 2 Hours After breakfast | Before lunch | Before dinner | Bedtime |
|---|---|---|---|---|---|
| Monday | - | 81 | 127 | 234 | 92 |
| Tuesday | 128 | 203 | 78 | 281 | 167 |
| Wednesday | 123 | - | - | 170 | 375 |
| Thursday | 93 | - | - | - | - |
| Friday | 45 | - | 153 | 177 | 253 |
| Saturday | - | 135 | - | - | 95 |
| Sunday | 87 | - | - | 107 | 123 |
| Monday | 58 | 163 | 200 | 83 | 132 |
| Tuesday | 113 | 160 | 136 | 335 | 102 |
| Wednesday | - | 156 | - | 143 | - |
| Thursday | 118 | - | - | - | 104 |
| Friday | 74 | 115 | 158 | 202 | 315 |
| Saturday | 267 | 160 | 163 | 210 | 180 |
| Sunday | - | 156 | - | 124 | - |

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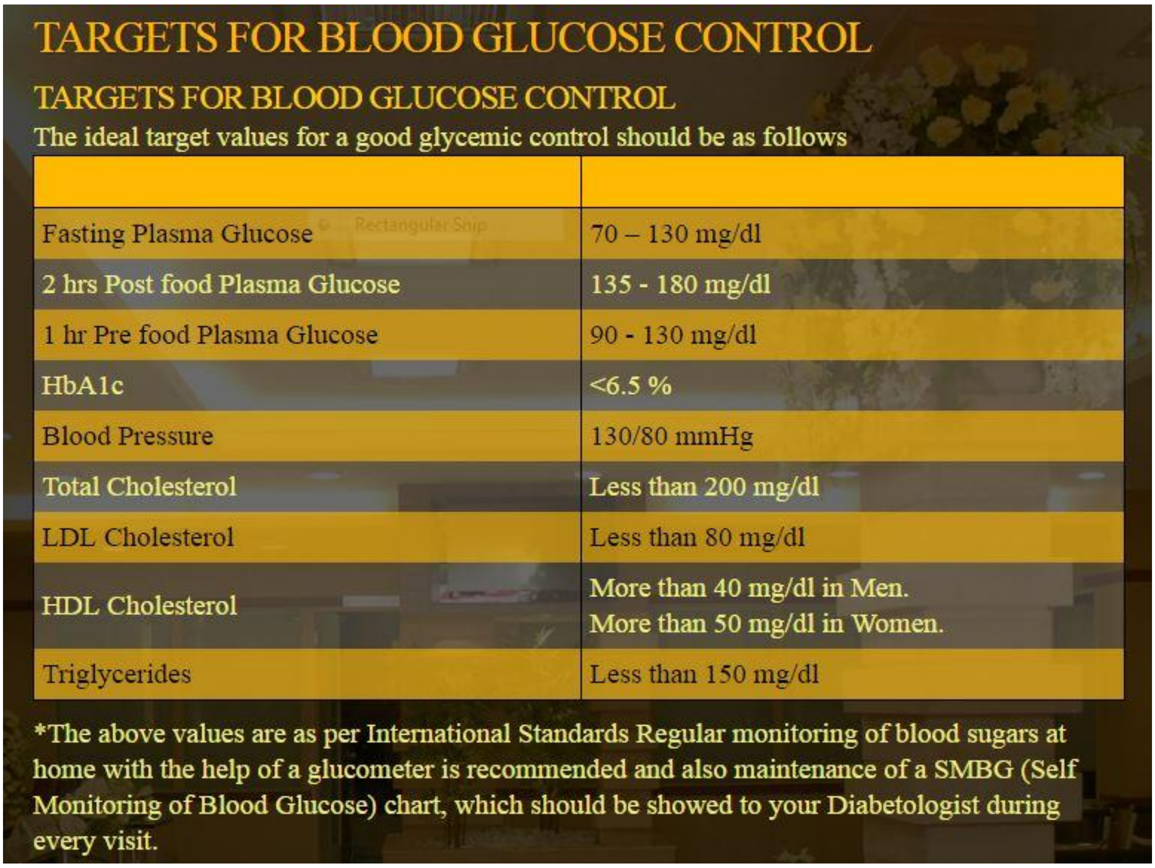
Table 5 Differences between estimation of glucose in whole blood by glucometer, coin based automated blood sugar level monitoring system and serum glucose by glucose oxidase method

| **Point of comparison** | **Whole Blood by Glucometer** | **Whole blood by coin based automated blood sugar level monitoring system** | **By glucose oxidase method (venous blood sampling)** |
|---|---|---|---|
| Region of blood collection | Finger (preferred) | Finger (preferred) | IV line of the patient |
| Results | Instant | Instant | Takes time |
| Test strips | Needed | Needed | Not needed |
| Cost | Rs 50 to Rs 100 per test | Rs 5 to Rs 10 per test | Rs 50 to Rs 100 |
| Self monitoring | Yes | Yes | No |
| Automated | No | Yes | No |
| Expenditure for glucometer | Yes (Rs 1000 to Rs 2500 approx) | No (since it is public property, it can be shared) | No |
| Accuracy | Less accurate when compared to glucose oxidase method | Less accurate when compared to glucose oxidase method | Comparatively accurate |
| Printed report | No | Yes | Yes |
| Need for reagents | No | No | Yes |
| Public accessibility | No | Yes | Present only at hospitals and PHCs |


TARGETS FOR BLOOD GLUCOSE CONTROL

TARGETS FOR BLOOD GLUCOSE CONTROL

The ideal target values for a good glycemic control should be as follows

| | |
|---|---|
| Fasting Plasma Glucose | 70 – 130 mg/dl |
| 2 hrs Post food Plasma Glucose | 135 - 180 mg/dl |
| 1 hr Pre food Plasma Glucose | 90 - 130 mg/dl |
| HbA1c | <6.5 % |
| Blood Pressure | 130/80 mmHg |
| Total Cholesterol | Less than 200 mg/dl |
| LDL Cholesterol | Less than 80 mg/dl |
| HDL Cholesterol | More than 40 mg/dl in Men. More than 50 mg/dl in Women. |
| Triglycerides | Less than 150 mg/dl |

*The above values are as per International Standards Regular monitoring of blood sugars at home with the help of a glucometer is recommended and also maintenance of a SMBG (Self Monitoring of Blood Glucose) chart, which should be showed to your Diabetologist during every visit.

Fig. 22 Targets for blood glucose control

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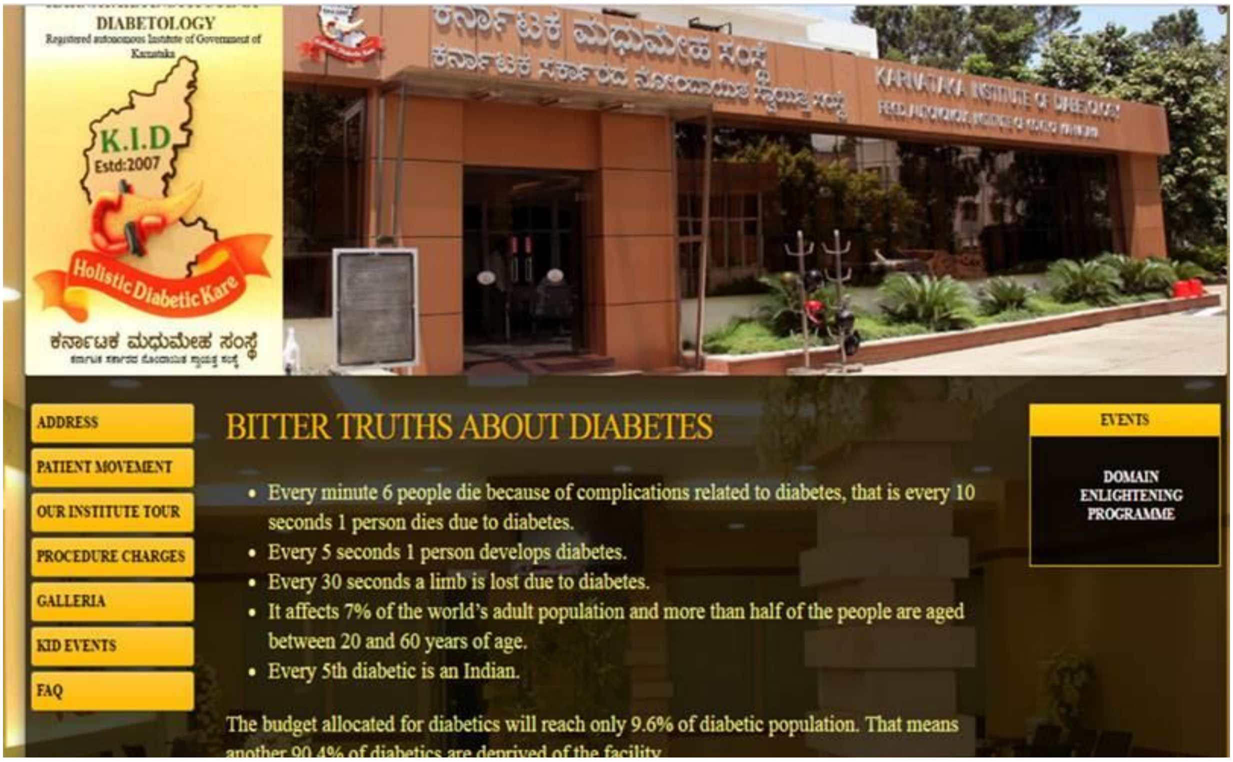

Fig. 23 Bitter truths about diabetes

## VI. CONCLUSIONS

The proposed "Coin based automated blood glucose level monitoring system" would be a boon to the public, who can monitor their blood glucose levels by themselves to achieve glycemic control. It is a compact, inexpensive and user-friendly device for self monitoring of DM. Also the generated reports can be filed and by consultation with a diabetologist or a physician, one can live a healthy life. Figure 22 shows the targets for blood glucose control which are international standards of regular monitoring of blood sugars at home with the help of glucometer [17]. By achieving glycemic control, one can avoid the other adverse effects of DM such as those mentioned in earlier. Figure 23 shows the bitter truths diabetes [17]. As they say "Health is wealth" and "Prevention is better than cure".

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