# Overview and Multi-Criteria Analysis of Glucometers for Telemonitoring of Patient with Diabetes Mellitus

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## Abstract

**Background:** The telemonitoring is more and more used for compensation of diabetes in the last decade. Doctors are able to get an accurate and reliable data in real time using the telemonitoring. A remote monitoring affects the attitudes and behavior of patients and potentially improves their state of health. Conclusions of many studies show additional clinical implications of telemonitoring. But it has not been possible to generalize those conclusions yet.
**Objectives:** The aim of this study was to create an overview of current glucometers available on the market. And select those which would meet the required parameters for using in the telemonitoring with automatic data sharing.
**Methods:** The research is focused on researches from technical and grey literature and on websites of producers and medical device dealers. The questioning will be carried out in the Czech and English language. Multi decision making method helps to select a suitable glucometer.
**Conclusions:** Fifty five glucometers from nineteen producers have been found in the researches and by market survey. The summary table with all important parameters can be seen in the preview. Conclusions of the Multi decision making analysis showed using of Diamond Mini from ForaCare Inc. producer which is the most suitable for the project of the telemonitoring with automatic data sharing. It is necessary to consider the safety of sending data, data sharing and personal data protection before this glucometer will be used in our project.

## Keywords

Diabetes mellitus, telemonitoring, self management, glucometer, smart phone

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## 1 Introduction

The World Health Organization states in its report [1] the 1.7% prevalence of diabetes mellitus disease for the year 2000 and predicts prevalence of 4.4% for the year 2030. The data are worldwide and refer to all age groups. The number of patients is expected to increase from 171 million in the year 2000 to 366 million in 2030. The WHO predicts rise in direct costs for treatment of diabetes from 2.5% of the annual national budget to 15% in connection with increasing number of diabetic patients. Diabetic patients often suffer also from other diseases which results in decreasing quality of life together with rising costs of provided health care.

The telemonitoring is more and more used for compensation of diabetes in the last decade[2]. Doctors are able to get an accurate and reliable data in real time using the telemonitoring. A remote monitoring affects the attitudes and behavior of patients and potentially improves their state of health [3]. The telemonitoring has an incentive

 

and educational effect for the patients [4]. Conclusions of studies focused on the impact of telemonitoring show additional clinical implications of telemonitoring. But it has not been possible to generalize those conclusions yet [5].

The telemonitoring is based on communication between sender and recipient in real time. This allows an immediate reaction of the doctor to the patient's impulse. The patient uses an interactive device which transmits data via the Internet to the doctor for checking patient's biological parameters. Then the doctor evaluates this data and makes decisions for the following steps [6]. Telemonitoring and gathering the data must not bother patients in terms of physical activity, time etc. Ideally this should be completely automatic [4, 7, 8].

Smart phones with installed applications which contain tools allowing the collection, evaluation and sending data to a doctor can be used for automatic operations [7, 9]. There are currently more than 137 mobile applications available for self-control of the diabetes [10]. The most important parameters are the level of glucose in blood, the dose of insulin, the physical activity and the diet [5]. The patient has to fill in manually most of these parameters in his diabetic diary.

Our goal is to create a telemonitoring system which would measure the patient's data and send them to a server as much as possible automatically. The goal is the patient should do the same procedures in the treatment of diabetes such as being without the use of telemonitoring. It should be possible to infer the influence of the telemonitoring to the compensations of diabetes on the basis of the feedback from patients and evaluation of their health status. Hence it is necessary to select such a technical device which allows automatic data sharing without additional burden for the patient

The aim of this study was to create an overview of current glucometers available on the market. And select those which would meet the required parameters and system of telemonitoring described above. Desired parameters are: detection of glucose in blood from 1.1 mmol/l to 33.3 mmol/l (it corresponds with 18 mg/dl to 594 mg/dl) and possibility to share data with a smart phone.

## 2 Methods

The survey was focused on researches from technical and grey literature and on websites of manufacturers and medical device dealers. Search keywords were: a glucometer, the measurement of blood glucose, ketones measurement, measurement + diabetes, glucose monitoring, regulation of glucose, glucose measurement, overview of glucometers, evaluation of glucometers, tests of glucometers. The questioning was carried out in the Czech and English language. The search was particularly focused on glucometers currently offered for sale. A summary table has been created and filled in with found devices and their parameters.

Entered parameters were: designation of the glucometer from the manufacturer; manufacturer; measuring range; measuring time; amount of the blood sample; blood draw location, glucometer memory size; weight; battery life; the ability to share data with a computer and connection specification; the ability to share data with smart phone and again connection specifications. These parameters were obtained from glucometer manuals. The availability on the Czech market, the indicative price and a link to the source are parameters stated in the comments.

The final product will be selected on the basis of a Multi decision making method of selected glucometers. This method is a simple and fast tool. Its conclusions should be objective decisions if comparable items are chosen. The criteria weight calculation formula (1) [11] has been used for assessment in this method. A represents the criteria weight, f is a number of preferences and n is a number of criteria.

$$A = \frac{2 \times f}{n \times (n-1)} \tag{1}$$

## 3 Results

### 3.1 Glucometers Overview

Fifty five glucometers from 19 manufacturers have been found in the researches and by market survey. Their list with all important parameters can be seen in the preview in the table in attachment. All glucometers detect level of glucose in the blood in the range from 1.1 to 33.3 mmol/l. Producers state that 42 devices are able to analyze the blood sample within 5 seconds, 11 devices should analyze the sample up to 10 seconds, two blood glucometers have not got this parameter specified. The memory size to store the measured data ranged from 99 to 4000 records. In some cases it is limited by memory of a smart phone to which the glucometer is connected. 20% of the glucometers state the minimum quantity of the blood sample of 0.3 $\mu$l, 22% states the quantity of 0.5 $\mu$l, 25% of 0.6 $\mu$l. One device required 2 $\mu$l of the sample and another one has no information about the sample quantity in its manual. The weight of the two glucometers was less than 20 grams; the weight of almost 70 % glucometers with battery was between 20 and 60 grams. 35 glucometers which represent more than 63 % of products allow blood draw from alternatives locations. Ten devices allow sampling from a thigh or a calf. Twenty models are available on the Czech market. Forty five devices have possibility of connection to a computer. Thirteen products via a USB cable, two by bluetooth. Another two glucometers is possible to connect via a special connector (e.g. used in iPhones). There are only three models which offer sharing data with smart phones – one via bluetooth and two via a special connector.

Only three glucometers have met the primary parameters – Diamond Mini a iDiamond form ForaCare Inc. and iBGStar glucometer from the producer Sanofi Aven-

 

Table 1: Evaluation of parameters of selected glucometers.

| Evaluated criteria | Diamond Mini | iDiamond | iBGStar |
|---|---|---|---|
| C1 | 10 | 10 | 5 |
| C2 | 10 | 0 | 0 |
| C3 | 10 | 0 | 5 |
| C4 | 10 | 5 | 5 |

tis. These were subsequently assessed by the multi decision making.

### 3.2 Selecting of Glucometer by Using the Multi Decision Making

Evaluating parameters for Multi decision making are:

- The availability of glucometer on the Czech market (marked C1).
- Possibility to connect devices with a smart phone via bluetooth (marked C2).
- An alternative sampling point of blood (marked C3).
- Equipped with a USB connector (marked C4).

Each parameter was rated from 1 to 10. Where number 10 is a maximum value. More satisfied parameters more assigned points. The Table 1 shows evaluation of parameters.

Criterion C2 – the possibility to connect devices with a smart phone, gives 3 preferences. The others received one preference. The criteria order was given. The criteria weights were calculated using the formula (1) [11]. Importance of each criterion was taken into consideration in the evaluation of parameters of selected glucometers (Table 2).

Conclusions of the Multi decision making analysis showed using of Diamond Mini from ForaCare Inc. producer is the most suitable for our project. This device gained more than double points in comparison with the competitors (Table 3).

## 4 Conclusions

The aim of the study was to carry out an overview of the currently available glucometers on the market. It is possible that not all glucometers were included in this thesis. Reason for leaving out some products is due to orientation on the Czech or English speaking market. Another reason could be difference in search expression. 55 devices from 19 producers were involved in the overview. Only three products have met requirements for using in the telemonitoring with automatic data sharing. Conclusions of the Multi decision making analysis showed the most universal and usable device which is Diamond Mini from ForaCare Inc. producer.

Before this glucometer will be used in this project, it is necessary to consider the safety of sending data, data sharing and personal data protection.

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Table 2: Criteria preferences.

| Table of preferences | C1 | C2 | C3 | C4 | Number of preferences (f) | Hierarchy of criteria | Scale |
|---|---|---|---|---|---|---|---|
| C1 | x | 0 | 1 | 0 | 1 | 2 | 0.167 |
| C2 | 1 | x | 1 | 1 | 3 | 1 | 0.500 |
| C3 | 0 | 0 | x | 1 | 1 | 2 | 0.167 |
| C4 | 1 | 0 | 0 | x | 1 | 2 | 0.167 |

Table 3: Weight calculation for each criterion of selected glucometers.

| Evaluation the criteria | Scale | Diamond Mini | iDiamond | iBGStar |
|---|---|---|---|---|
| C1 | 0.167 | 1.67 | 1.70 | 0.83 |
| C2 | 0.500 | 5.00 | 0.00 | 0.00 |
| C3 | 0.167 | 1.67 | 0.00 | 0.83 |
| C4 | 0.167 | 1.67 | 0.83 | 0.83 |
| Sum | | **10.00** | 2.50 | 2.50 |

 

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Appendix 1: Glucometers review based on the market research.

| No. | Type of glucometer | Producer | Range of measurements (mmol/l) | Measurement time (s) | Memory range | The size of a blood sample (µl) | Weight (g) with battery | Possibility of connection with computer | Specification connection with computer | Connection with smarth phones | Specification connection with smarth phones | Posibility alternative place of blood sampling | Availability on the Czech market | Place of blood sampling |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | One Touch UltraEasy | LifeScan | 1.1 - 33.3 | 5 | 500 | 1 | 40 | yes | USB cable | no | - | yes | yes | finger, forearm, upper arm, hand, thigh, calf |
| 2 | One Touch Vita | LifeScan | 1.1 - 33.3 | 5 | 500 | 1 | 58 | yes | USB cable | no | - | yes | yes | finger, forearm, upper arm, hand, thigh, calf |
| 3 | One Touch Ultra | LifeScan | 1.1 - 33.3 | 5 | 150 | 1 | 42,5 | yes | USB cable | no | - | yes | yes | finger, forearm, upper arm, hand |
| 4 | One Touch UltraSmart | LifeScan | 1.1 - 33.3 | 5 | 3000 | 1 | 79 | yes | USB cable | no | - | yes | yes | finger, forearm, upper arm, hand, thigh, calf |
| 5 | One Touch Verio Pro | LifeScan | 1.1 - 33.3 | 5 | 750 | 0,4 | 85 | yes | USB cable | no | - | yes | yes | finger, forearm, hand |
| 6 | Diamond Prima | ForaCare Inc. | 1.1 - 33.3 | 5 | 450 | 0,5 | 52 | yes | USB cable | no | - | yes | yes | finger, forearm, upper arm, hand, thigh, calf |
| 7 | Diamond Mini | ForaCare Inc. | 1.1 - 33.3 | 5 | 450 | 0,5 | 27 | yes | USB cable, bluetooth | yes | bluetooth | yes | yes | finger, forearm, upper arm, hand, thigh, calf |
| 8 | iDiamond | ForaCare Inc. | 0.5 - 33.3 | 5 | iphone memory | 0,5 | 34 | yes | iphone connector | yes | iphone connector | not specified | yes | not specified |
| 9 | FreeStyle Lite | Abbot Diabetes Care Inc. | 1.1 - 27.8 | 5 | 400 | 0,3 | 31 | yes | data cable | no | - | yes | yes | finger, forearm, upper arm, hand, thigh, calf |
| 10 | FreeStyle Freedom Lite | Abbot Diabetes Care Inc. | 1.1 - 27.8 | 4 | 400 | 0,3 | 45 | yes | data cable | no | - | yes | yes | finger, forearm, upper arm, hand, thigh, calf |
| 11 | FreeStyle Optimum | Abbot Diabetes Care Inc. | 1.1 - 27.8 | 5 | 450 | 0,6 | 42 | yes | not specified | no | - | yes | yes | finger, forearm, upper arm, hand, thigh, calf |
| 12 | FreeStyle InsuLinx | Abbot Diabetes Care Inc. | 1.1 - 27.8 | not specified | 495 | 0,3 | 66 | yes | USB cable | no | - | no | no | finger |
| 13 | FreeStyle Optimum Xceed | Abbot Diabetes Care Inc. | 1.1 - 27.8 | not specified | 450 | 0,3 | 42 | yes | not specified | no | - | yes | no | finger, forearm, upper arm, hand |
| 14 | FeeStyle Lite | Abbot Diabetes Care Inc. | 1.1 - 27.8 | 5 | 400 | 0,3 | 31 | yes | not specified | no | - | no | yes | finger |
| 15 | Precison Xtra Overview | Abbot Diabetes Care Inc. | 1.1 - 27.8 | 5 | 450 | 0,6 | 46 | yes | data cable | no | - | yes | no | finger, forearm, hand |
| 16 | Accu Chek Performa Nano | Roche | 0.6 - 33.3 | 5 | 500 | 0,6 | 40 | yes | infrared | no | - | yes | yes | finger, hand |
| 17 | Accu Chek Aviva | Roche | 0.6 - 33.3 | 5 | 500 | 0,6 | 60 | yes | infrared | no | - | yes | no | finger, hand |
| 18 | Accu Chek Aviva Combo | Roche | 0.6 - 33.3 | 5 | 1000 | 0,6 | 103 | yes | bluetooth | no | - | no | no | finger |
| 19 | Accu Chek Performa | Roche | 0.6 - 33.3 | 5 | 500 | 0,6 | 52 | yes | infrared, cable | no | - | yes | yes | finger, hand |
| 20 | Accu Chek Mobile system | Roche | 0.6 - 33.3 | 5 | 2000 | 0,3 | 129 | yes | infrared | no | - | no | no | finger |
| 21 | Accu Chek Advantage | Roche | test strips | 5 | 480 | not specified | 60 | yes | data cable | no | - | no | no | finger |
| 22 | Accu Chek Aviva Active | Roche | 0.55 - 33.3 | 5 | 200 | 1 | 57 | yes | infrared | no | - | yes | no | finger, forearm, hand |
| 23 | Contour Link | Bayer | 0.6 - 33.3 | 5 | 480 | 0,6 | 53 | yes | not specified | no | - | no | yes | finger |
| 24 | Contour next USB Meter | Bayer | 1.1 - 33.3 | 5 | 2000 | 0,6 | 34 | yes | USB cable | no | - | yes | no | finger, forearm, hand |
| 25 | Contour XT Meter | Bayer | 0.6 - 33.3 | 5 | 480 | 0,6 | 48 | no | - | no | - | no | no | finger |
| 26 | Contour | Bayer | 0.6 - 33.3 | 5 | 480 | 0,6 | 48 | no | - | no | - | yes | no | finger, forearm, hand |
| 27 | Contour TS | Bayer | 0.6 - 33.3 | 8 | 250 | 0,6 | 57 | yes | data cable | no | - | no | yes | finger |
| 28 | Breeze 2 | Bayer | 0.6 - 33.3 | 5 | 420 | 1 | not spedified | yes | data cable | no | - | no | no | finger |

| No. | Type of glucometer | Producer | Range of measurements (mmol/l) | Measurement time (s) | Memory range | The size of a blood sample (µl) | Weight (g) with battery | Possibility of connection with computer | Specification connection with computer | Connection with smarth phones | Specification connection with smarth phones | Posibility alternative place of blood sampling | Availability on the Czech market | Place of blood sampling |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | Didget | Bayer | 1.1 - 33.3 | 5 | 480 | 0,6 | 76 | yes | Nintendo integrated card | no | - | yes | no | finger, forearm |
| 30 | SD Codefree | Standard Diagnostics, Inc. | 0.55 - 33.3 | 5 | 500 | 0,9 | 48 | yes | data cable | no | - | yes | yes | finger, forearm, hand |
| 31 | SD-Check Gold | Standard Diagnostics, Inc. | 0.6 - 33.3 | 5 | 400 | 0,9 | 50 | no | - | no | - | no | yes | finger |
| 32 | SeNova | Chdiagnostics | 1.1 - 33.3 | 10 | 250 | 0,6 | 60 | yes | not specified | no | - | no | yes | finger |
| 33 | True2go | NIPRO Diagnostics | 1.1 - 33.3 | 4 | 99 | 0,5 | 17 | no | - | no | - | yes | no | finger, forearm |
| 34 | TRUEresult | NIPRO Diagnostics | 1.1 - 33.3 | 4 | 500 | 0,5 | 47 | no | - | no | - | no | no | finger |
| 35 | TRUEtrack | NIPRO Diagnostics | 1.1 - 33.3 | 10 | 365 | 1 | 47 | no | - | no | - | yes | no | finger, forearm |
| 36 | TRUEbalance | NIPRO Diagnostics | 1.1 - 33.3 | 10 | 365 | 1 | 47 | no | - | no | - | no | no | finger |
| 37 | TRUEread | NIPRO Diagnostics | 1.1 - 33.3 | 10 | 200 | 1 | 47 | no | - | no | - | yes | no | finger, forearm |
| 38 | Clever Chek | BBI Healthcare | 1.1 - 33.3 | 7 | 450 | 0,7 | 70 | yes | USB cable | no | - | yes | no | finger, forearm, upper arm, hand, thigh, calf |
| 39 | Omnitest 3 | B Braun | 0.55 - 33.3 | 3 | 365 | 0,3 | 54 | yes | data cable | no | - | no | no | finger |
| 40 | Omnitest plus | B Braun | 0.6 - 33.3 | 5 | 250 | 1 | 41 | yes | data cable | no | - | no | yes | finger |
| 41 | GlucoMen LX Plus | A. Menarini Diagnostics LTD | 1.1 - 33.3 | 4 | 4000 | 0,3 | 75 | yes | audiojack | no | - | yes | no | finger, forearm, hand |
| 42 | Glucocard MX | A. Menarini Diagnostics LTD | 0.6 - 33.3 | 5 | 500 | 0,3 | 46 | yes | not specified | no | - | yes | no | finger, hand |
| 43 | Glucocard G+ | A. Menarini Diagnostics LTD | 0.6 - 33.3 | 5,5 | 450 | 0,6 | 50 | yes | audiojack | no | - | yes | no | finger, forearm, hand |
| 44 | Glucocard X | A. Menarini Diagnostics LTD | 0.6 - 33.3 | 5 | 360 | 0,3 | 45 | yes | not specified | no | - | yes | no | finger, forearm, hand |
| 45 | Glucofix mio plus | A. Menarini Diagnostics LTD | 1.1 - 33.3 | 4 | 400 | 0,3 | 75 | yes | not specified | no | - | no | no | finger |
| 46 | GlucoMed GM | A. Menarini Diagnostics LTD | 0.6 - 33.3 | 7 | 250 | 0,5 | 39 | no | - | no | - | yes | no | finger, forearm, hand |
| 47 | GlucoRx Nexus | TaiDoc Technology Corporation | 1.1 - 33.3 | 5 | 1000 | 0,5 | 67 | yes | USB cable | no | - | no | no | finger |
| 48 | IME-DC | Arctic Medical | 1.1 - 33.3 | 10 | 100 | 2 | 57 | yes | USB cable | no | - | yes | no | finger, hand |
| 49 | One Touch Ultra 2 | LifeScan | 1.1 - 33.3 | 5 | 500 | 1 | 42 | yes | data cable | no | - | yes | no | finger, forearm, hand |
| 50 | Discreet all in One | Mendor | 1.1 - 33.3 | 5 | 250 | 0,5 | 28 | yes | data cable | no | - | no | no | finger |
| 51 | BGStar | Sanofi Aventis | 1.1 - 33.3 | 6 | 1865 | 0,5 | 48 | yes | not specified | no | - | no | no | finger |
| 52 | iBGStar | Sanofi Aventis | 1.1 - 33.3 | 6 | 300 | 0,5 | 9 | yes | not specified | yes | iphone connector | yes | no | finger, forearm, hand |
| 53 | CareSens N | Spirit Healthcare | 1.1 - 33.3 | 5 | 250 | 0,5 | 50 | yes | USB cable | no | - | yes | no | finger, forearm, hand, thigh |
| 54 | WaveSense Jazz | Aga Matrix, Inc | 1.1 - 33.3 | 4 | 1865 | 0,5 | 48 | no | - | no | - | yes | no | finger, forearm, hand |
| 55 | PURA | Ypsomed | 0.6 - 33.3 | 5 | 500 | 1 | not spedified | yes | not specified | no | - | yes | no | finger, hand |