MEDICAL INFORMATION SYSTEM FOR DIAGNOSING DIABETES MELLITUS AND HEARING DISORDER IN CHILDREN

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Abstract: *Late complications of diabetes mellitus, like cardiovascular disease and hearing loss are well-known in case of older people with longstanding disease period. However, in children these complications are not always obvious, because children are in their developing years and their parameters are changing continuously. It is assumed though that a direct relation exists. The Biomedical Engineering Laboratory of BUTE and the Heim Pál Hospital for Sick Children from Budapest has proposed to investigate the problem in a joint research program. The paper is focused on the first step of the mentioned research topic, presenting a medical information system, developed for monitoring and diagnosing diabetes mellitus and hearing disorder in children. It is presented the mathematical reasoning how the diagnostic rule-base of the database with more than 5000 measurement values of 110 children was implemented as well as the advantage of the user-friendly interface and the security conditions.*

Keywords: *computer aided diagnosis, diabetes mellitus, hearing disorder, medical information system.*

1. INTRODUCTION

Nowadays health experts refer to diabetes mellitus as the "disease of the future". The World Health Organization (WHO) newest statistics shows that 4 % of the adult society of the world suffers from diabetes mellitus, [1]. Prognosis (Table 1) warns that by the year 2025 the number of diabetics will increase to 300 million worldwide.

Therefore more and more scientists are dedicating their research on the study of diabetes mellitus.

The health problems of today's patients are more numerous and complex, thus increasing the responsibilities of doctors. Treating patients and staying up-to-date in medical field are almost impossible without the support of information technology. Treatment and research of diabetes mellitus is no exception.

From the engineering point of view, during the last 50 years a variety of models have appeared, focusing mainly on the interaction between glucose and insulin [2-7], and strategies have been designed and applied to the problem [8-11].

It is well-known that diabetes mellitus generates complications on the long run like hearing loss, cardiovascular disease or eyeshot degradation. However, in children and youngsters these effects are not always obvious, because the rapid changes in parameters of a well developing active child. It is assumed though that a direct relation exists.

Table 1. Prognosis of encountering diabetes mellitus on different regions of the world by the year 2025.

Region	Diabetes type 1 (%)	Diabetes type 2 (%)
World	0,20	1,75
Africa	0,07	6,82
Asia	0,13	1,40
N-America	0,58	4,68
S-America	0,26	2,30
Europe	0,47	3,14
Oceania	0,43	2,64

The Biomedical Engineering Laboratory of BUTE and the Heim Pál Hospital for Sick Children form Budapest have proposed to investigate the question in a joint research program. Building up a medical diagnosing information system for diabetes mellitus and hearing loss, based on a vast database, the identification and the modeling of the mentioned diseases as a multivariable system will be made and the direct relation will be searched.

The paper is focused on the first step of the mentioned research topic, presenting the medical information system, which was built for monitoring and diagnosing diabetes mellitus and hearing disorder in children.

After a brief description of diabetes mellitus and hearing loss, mainly focused on the description of the parameters used for monitoring and diagnosing, the system itself is presented: how the data are divided, the decision-trees used for realizing the diagnosing part, and finally results of diagnosing diabetes mellitus and hearing disorder are described.

It must be mentioned, that in case of hearing disorder the subjective pure tone audiometry has been implemented, while in case of objective methods we didn't finish testing the efficiency of the Brainstem Evoked Response Audiometry (BERA) diagnose.

2. MONITORED PARAMETERS FOR DIAGNOSING DIABETES MELLITUS

Diabetes mellitus is a complex metabolic disorder characterized by high blood glucose level in its untreated form, followed by variable micro and/or macrovascular complications (late complications). This is due to the absolute or relative insulin deficiency. It is not a uniform disease, includes all those conditions where blood glucose is high. In healthy people the blood glucose is normalized by the continuously excreted endogenous hormone, the insulin, which most important metabolic task is to transport sugar from the blood stream into the cells where it is converted into vital energy.

Two main types of diabetes mellitus are known: type 1 and type 2 [12], [13].

Type 1 diabetes mellitus usually occurs before the age of 35 and most often it is of autoimmune origin. That means that insulin-producing cells

of the pancreas are destroyed by endogenous antibodies produced by the immune system [1], [12], [13]. Thus the pancreas is no longer capable to produce the hormone required by the cells. Consequently, for people with this form of the disease insulin is vital and they have to use it for their whole lives.

Type 1 diabetes (insulin dependent - IDDM) has a very prompt start with alarming symptoms and short medical history. Patients have good appetite at the beginning, still loose weight, drink a lot and have polyuria. Later on, they loose appetite, have difficulties with breathing, become dehydrated and acidotic.

Laboratory test results are typical - severe metabolic acidosis is detected, blood glucose is usually extremely high (25-55 mmol/l) - insulin or C-peptid levels are very low, typical antibodies are detected. Once the alarming metabolic changes are corrected, the child's glycaemic status can be well maintained with regular subcutaneous insulin administration.

Type 2 diabetes mellitus is more frequent, counts for 90- 95 percent of all diabetics. It mainly affects adults aged over 40, although young people and overweight young adults are also developing this form of diabetes with increasing frequency. In type 2 diabetes, the body does produce insulin, but this is not effective enough due to decreased sensitivity of the hormone (insulin resistance) [1], [12], [13]. This also leads to high blood glucose levels.

Type 2 diabetes (non insulin dependent - NIDDM) is even more difficult to handle. It is not rare that by the outbreak of symptoms severe side effects are already present. This is due to the fact, that non-insulin dependent diabetes develops on a very strong genetic background and environmental factors also affect it very much. The huge changes appearing in the past 40-50 years in our life-style and eating habits led to fat, malnutritioned, nonactive population. Everyday stress adds to the risk factors enormously. Diagnosis is more difficult than in IDDM, large scale screening tests are needed in teenage population to rule out those at high risk or persons already having the disease.

As a result, we have taken into consideration more parameters in case of diabetes mellitus as it is necessary to diagnose, to also be able to investigate the connection with hearing disorder. The implemented parameters for the information system are:

- ABPM (Sistole, Diastole);
- Astrup (Ph, Be, Beecf) values;
- C-peptid value;
- Endomysial antibodies (EmA);
- Epilepsy;
- Glucose level;
- HbA1c;
- Antropometric parameters (heigh, mass, BMI);
- Lipids (Cholesterol, Triglyceride, HDL);
- Neuropathy;
- Thyroid hormons (T3, T4, TSH).

3. DETECTION OF HEARING DISORDER

Hearing is the function of the ear by which sound is perceived. The ear has three parts: external, middle and inner ear. Sound waves are picked up and are directed by the external ear to the eardrum (middle ear) and cause vibration on it. The malleus, incus, stapes in the middle ear transmit sound from the eardrum across the middle ear and vibrate against the cochlea. Tiny hair cells in the fluid, inside the cochlea, vibrate and generate nerve impulses which then travel to the brain. As a result of all these functions, the auditory sensation appears, [14].

Methods detecting hearing disorder can be divided in two main categories: "subjective" or "objective" methods.

The "subjective" methods to detect hearing loss are:

- Pure tone audiometry;
- Speech audiometry.

The "objective" methods are:

- Acoustic impedance measurement;
- Electric response audiometry (ERA);
- Oto-acoustic emission.

In our work (after several medical consultations) we have focused only on the implementation of the pure-tone audiometry and on the most widely used ERA method, the Brainstem Evoked Response Audiometry (BERA). Namely, we believe that if there is a direct relation between diabetes mellitus and hearing disorder, it can be detected by these two hearing loss detection methods.

Pure-tone audiometry is used to get the subject's threshold (slightest perceptible sound) for pure tone. The hearing loss is measured in decibels

(dB). Various frequencies (60, 125, 250, 500, 2000, 4000, 8000 Hz) are selected and the dB varies until the examinee reports can hear the sound. The threshold for each frequency is recorded. The entire range of audible pitches is tested and plotted on an audiogram, which discloses deviations from the normal values. The basic conductive type audiograms are presented in Fig.1, and they are, [16]:

a. High sound loss with highly right descent inclination;
b. High sound loss with abrupt descent run;
c. Circumscribed hearing loss;
d. Increased circumscribed hearing loss;
e. High sound loss with table formation;
f. Basocochlear-type hearing loss;
g. Panocochlear-type hearing loss;
h. Mediocochlear-type hearing loss.

The greater the number of decibels, the greater the hearing loss is, [15].

BERA is an objective method of measuring or testing hearing. Objective audiometry is necessary in some cases, like the infants, who couldn't contribute, or some adults, who perhaps don't want to contribute. There are two main goals of BERA investigation:

- Assessment of hearing threshold;
- Differential diagnostics of neurological disorders;

BERA measuring needs about 30 minutes while sound impulses are entered into the patient's ear, who lies without moving or perhaps sleeps. Low intensity sound impulses are emitted in the ear, starting form 80 dB and decreasing in 20 dB until 20 dB, [15]. The graph obtained for the first 10 ms (250 points) is analyzed and gives important information about the auditory nerve and about the lower part of the brainstem. To be precise, the obtained diagram must record at least 2048 samples in a measurement. Samples containing too much noise are artefacs, so they are dropped away. The measurements are always repeated to check the reproductivity of the diagram by calculating cross correlation.

A typical BERA diagram consists of 7 waves (Fig.2). These waves can be associated with well defined parts of the auditory nerve (I. Nucleus acusticus, II. Nucleus cochlearis ventralis et dorsalis, III. Oliva superior, IV. Lemniscus lateralis, V. Colliculus inferior, VI. Corpus geniculatum mediale, VII. Radiatio thalamo-corticalis), so the BERA diagram gives a functional map of the auditory nerve.

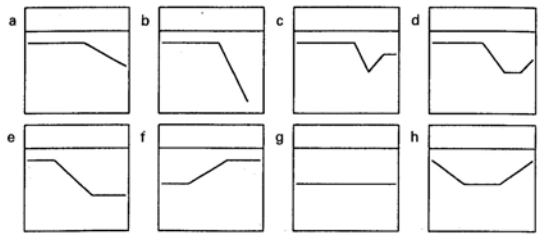

Fig. 1. Basic conductive type audiograms.

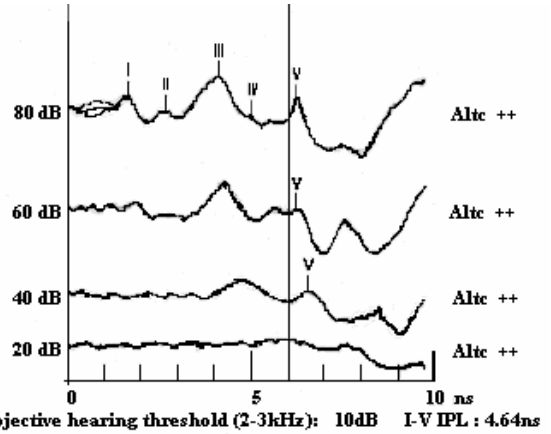

Fig 2. BERA results of an 11 month child.

The waves can be characterised by their latency time (2~8 ms) and amplitude (10~1000 nV), [16].

The most essential parameter is the I-V interpeak latency. Reducing the intensity of the stimulus, the latency times get longer, and the amplitudes get smaller. This change can be displayed on the intensity-latency graph. Reaching the hearing level, no response is evoked, BERA waves disappear. Hearing level defined this way can be compared to subjective hearing level on 2kH. Subjective hearing level lower than 20 dB signs central problem.

4. MEDICAL INFORMATION SYSTEM DEVELOPMENT AND RESULTS

2.1. *Database Management and Monitoring Diabetes Mellitus and Hearing Disorder*

To create the database of our software we have collected more than 5000 measurements of 110 children. The measurements were carried out in the Heim Pál Hospital between 1999 and 2003.

Results are stored in a database built under Microsoft Office Access platform using Open DataBase Connection (ODBC). This open structure gives the opportunity for further

development of the system, even for Internet Protocol (IP) based networks, or for Local Area Networks (LAN).

Data are structured on two levels: on the first the personal data of a child is stored, while on the second his/ her measurement values. The database is using the social security number of a person as primary key. The measurement value types in case of diabetes mellitus are presented by Fig.3.

To optimize the storage capacity of the database, a new table was created for each different set of measurements. As a result, empty fields and memory allocation are avoided.

Some of the monitored parameters can be controlled only showing their numerical values, but in some cases graphical interpretation is required (like the percentile curve in case of diabetes mellitus, or different measurements in case of hearing disorder).

A very important feature of the implemented software is the prediction of the mentioned diseases. For example, in case of diabetes mellitus each child has his own attendance note-book, what every child has to complete on his own. Unfortunately, sometimes cheated results are entered. Therefore, the system must have its capability to filter out the wrong entered values. Consequently a correct monitoring should be obtained. This feature is realized by analyzing the existing values and the diagnostic rule-base.

Another advantage of the system is its user-friendly interface. The software is not created for IT specialists, therefore this is also a very important feature.

2.2. *Diagnosing Diabetes Mellitus*

Diagnosing diabetes mellitus and hearing disorder is discussed separately.

In case of diabetes mellitus, the implemented diagnostic rules, even the graphical percentile curve, are mostly based on mathematical relations and as a result a decision tree can be realized (Fig.4). According to the WHO's latest recommendations, the following figures describe carbohydrate metabolic status:

Fasting glucose levels

- Normal fasting glucose:
  < 6,0 mmol/l
- Impaired fasting glucose:
  6,1-6,9 mmol/l
- Diabetes mellitus:
  ≥ 7mmol/l

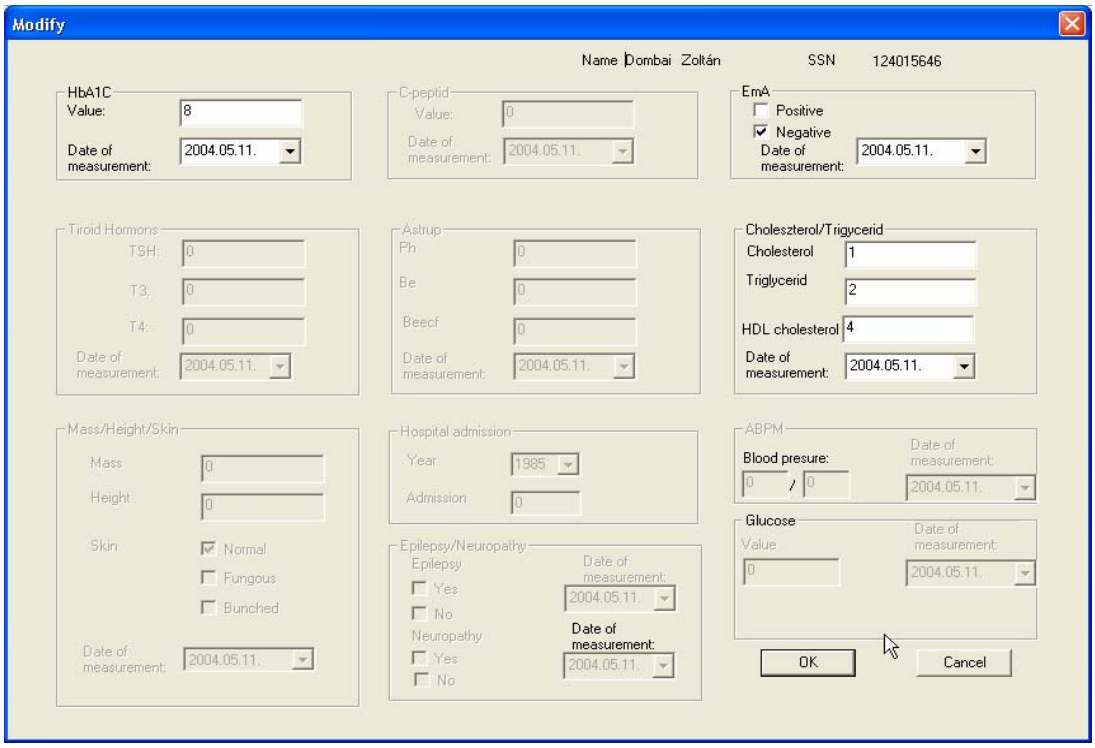

Fig.3. Entering selected measurement values in case of Diabetes mellitus.

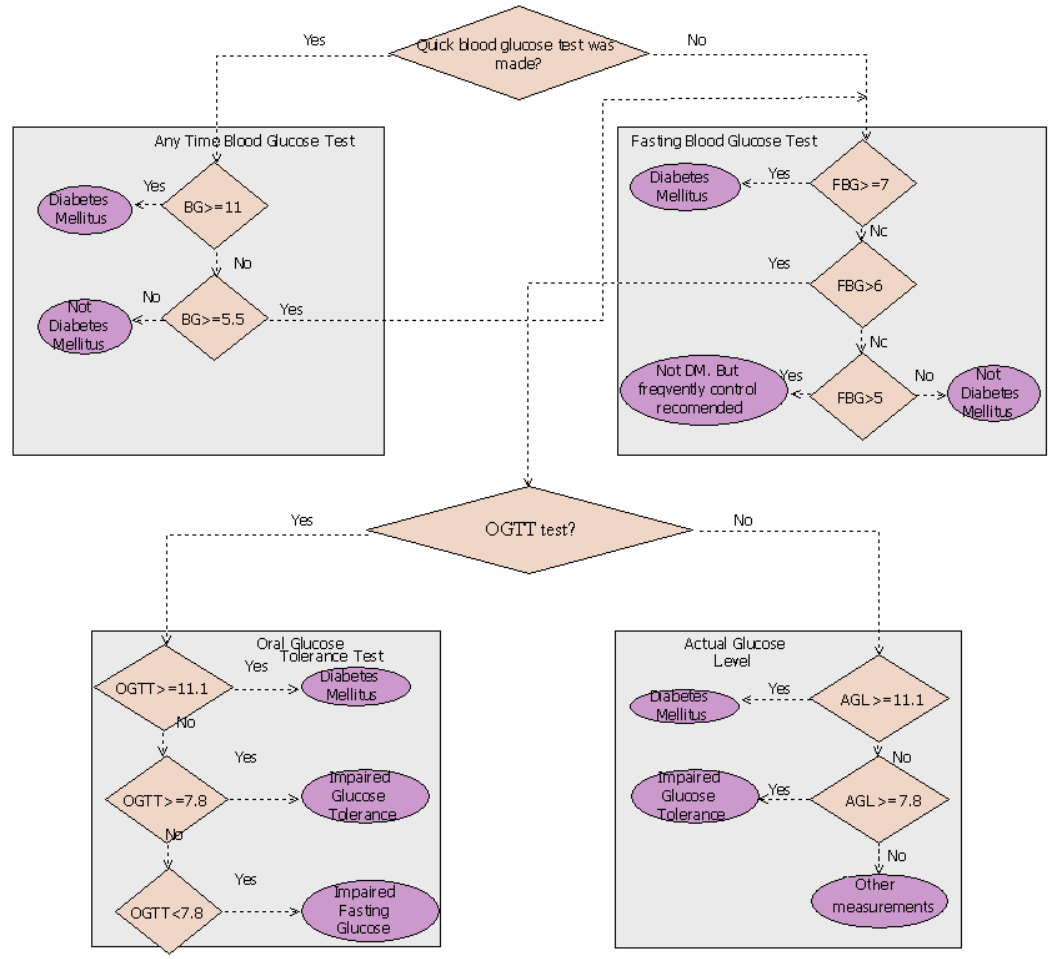

Fig.4. Decision tree of diagnosing diabetes mellitus.

Postprandial glucose levels

- Two hours after eating :
  < 7,8 mmol/l = normal
- Two hours after Oral Glucose Tolerance Test (OGTT):
  ≤ 7,8 mmol/l – < 11,1 mmol/l =
  = Impaired glucose tolerance
- Two hours after OGTT or any time measured:
  ≥ 11,1 mmol/l = Diabetes Mellitus

Although, the decision tree is not so complicated, the importance and the role of the more than 10 parameters in the diagnosing and monitoring procedure of diabetes mellitus (numbered in section 2) is described below.

The C-peptid (connecting peptid) is excreted in equimolar quantities from the pancreas and is easily measured in the peripheral blood. Its level is extremely low in IDDM and could be normal or high in NIDDM.

Hemoglobin (HbA1C), which is glicated, is a good indicator of previous average blood glucose levels. Its normal value is under 6,5 %.

By examining the presence of insulin antibodies it is possible to differentiate autoimmune type 1 or nonimmune type 2 diabetes mellitus. They also play a very important predictive role in the prediabetic phase of the disease.

The ketoacidic state of diabetes, which is a severe metabolic dysfunction often seen at the beginning of type 1 diabetes, or in severely maltreated or non-educated patients can be very well evaluated by Astrup examination (blood gas evaluation). Subtle changes are displayed before clinical symptoms appear, so it is a useful and simple test for predicting further changes in the metabolic status.

It is well-known that there are a number of associated autoimmune diseases which alter the course of IDDM. These conditions may arise slowly, with only few clinical signs, altering gradually the patients' life and metabolic status, but there are others which outbreak quickly, turn carbohydrate metabolism beyond control, and need quick intervention. Most commonly associated diseases are gluten sensitive enteropaty (celiac disease), autoimmune

thyreoiditis leading to hypothyreoidism, and epilepsy.

Gluten sensitive enteropathy may insidiously change a good humored child to a cheerless one, with loss of appetite, or appears promptly together with diabetes outbreak. With malfunction of absorption destabilizes glucose homeopathy. That is why it is included in our routine screening and follow up program in order to be able to rule out the disease as early as possible. The diagnosis is based on the detection of antibodies formed against the endomysium (EmA) of the intestinal wall. This is determined from the blood. In case of positive result, gluten is excluded from the diet.

In case of thyreoiditis the glucose metabolism is also altered, symptoms usually develop gradually. Therefore hormone level measurements (T3, T4. TSH) are also included in the protocol. Once the condition is diagnosed, adequate therapeutic steps are taken until metabolic balance is reached, followed by long term control exams.

The third most frequent associated condition is epilepsy. The cause of this disorder in diabetes is not fully understood, but it is observed that frequency of epilepsy is higher in diabetics than in normal population. Symptoms are very similar to those appearing in severe hypoglycaemic status: loss of conscious, fits, low blood sugar. From the clinical signs it is impossible to differentiate between the two conditions, the therapeutic consequence should be different, that's why it is utmost important to rule out epilepsy.

Late complications of diabetes include macrovascular diseases (as mentioned above), which can start slowly with mild symptoms like slightly elevated blood pressure and pulse. These alterations can be very well ruled out with continuous blood pressure measuring (ABPM). Once even subtle changes are found, medication is prescribed to exclude complications.

These are the parameters taken into consideration in case of diabetes mellitus. The medical information system is capable to diagnose missing parameters. Testing showed that in all cases of the more than 5000 measurements, the diagnosing tool still has an efficiency of 100 % correct diagnose. Diagnose is also reachable form the percentile curves, where the ideal is to follow the 50%-line (Fig.5).

As a result, we can tell that the described system is coming to help the everyday work of doctors and nurses, but the final word is always told by the supervisor (doctor). Consequently, intelligent software was developed, capable to diagnose diabetes mellitus. The class hierarchy of the implemented program is not complicated at all (Fig.6), which is an important remark mostly if we want to modify the program in the future.

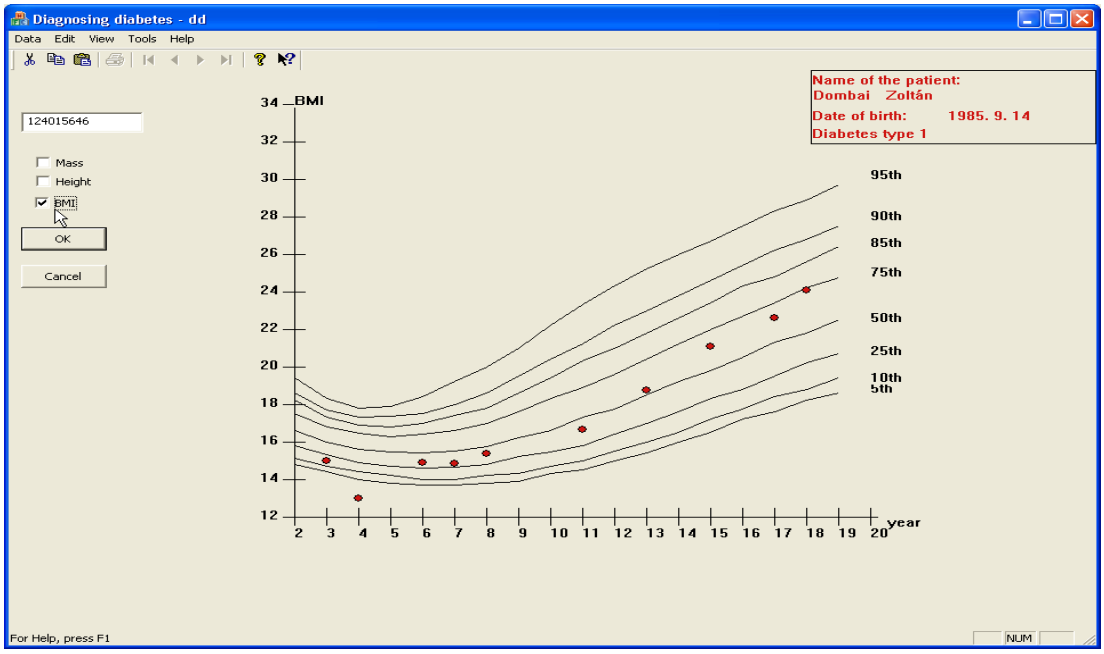

Fig.5. Body Mass Index (BMI) percentil diagnosing and monitoring diagram for diabetes mellitus.

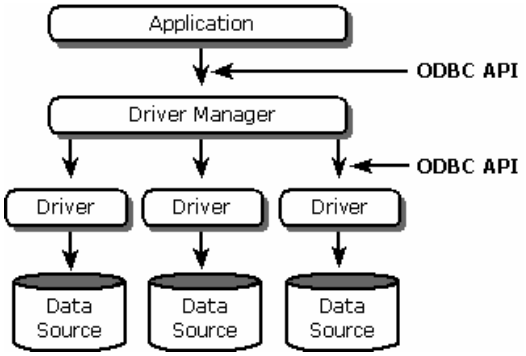

Fig.6. The architecture of the ODBC**.**

2.3. *Diagnosing Hearing Disorder*

To diagnose hearing disorder, the class hierarchy was kept and the same steps were done, as in diabetes. However, only the mentioned two hearing loss methods (pure tone audiometry, BERA) have been implemented.

In case of pure tone audiometry, mostly graphical representation was used, trying to identify one of the normal conductive type audiograms presented in Fig.1. The diagnosing algorithm was also implemented by a decision tree (Fig.7) by comparing relative adjacent points of a measurement every time. Fig.8 exemplifies the case of sensorineural hearing loss.

In case of BERA method, the waves are reproduced on the latency times calculated from the measured BERA diagram. For diagnosing, this value is compared to expected latency times representing the normal hearing population. Latency times measured on the right and left ear are also compared. Difference between the two sides can be found, and that is typical to retrocochlear lesion: the latency of the V^{th} wave is longer then the normal or the opposite side; the I-V interpeak latency is longer then the normal or the opposite side; the amplitude of the V^{th} wave is smaller then the I^{st} wave. With other rules other hearing defects (e.g. recruitment) can be detected.

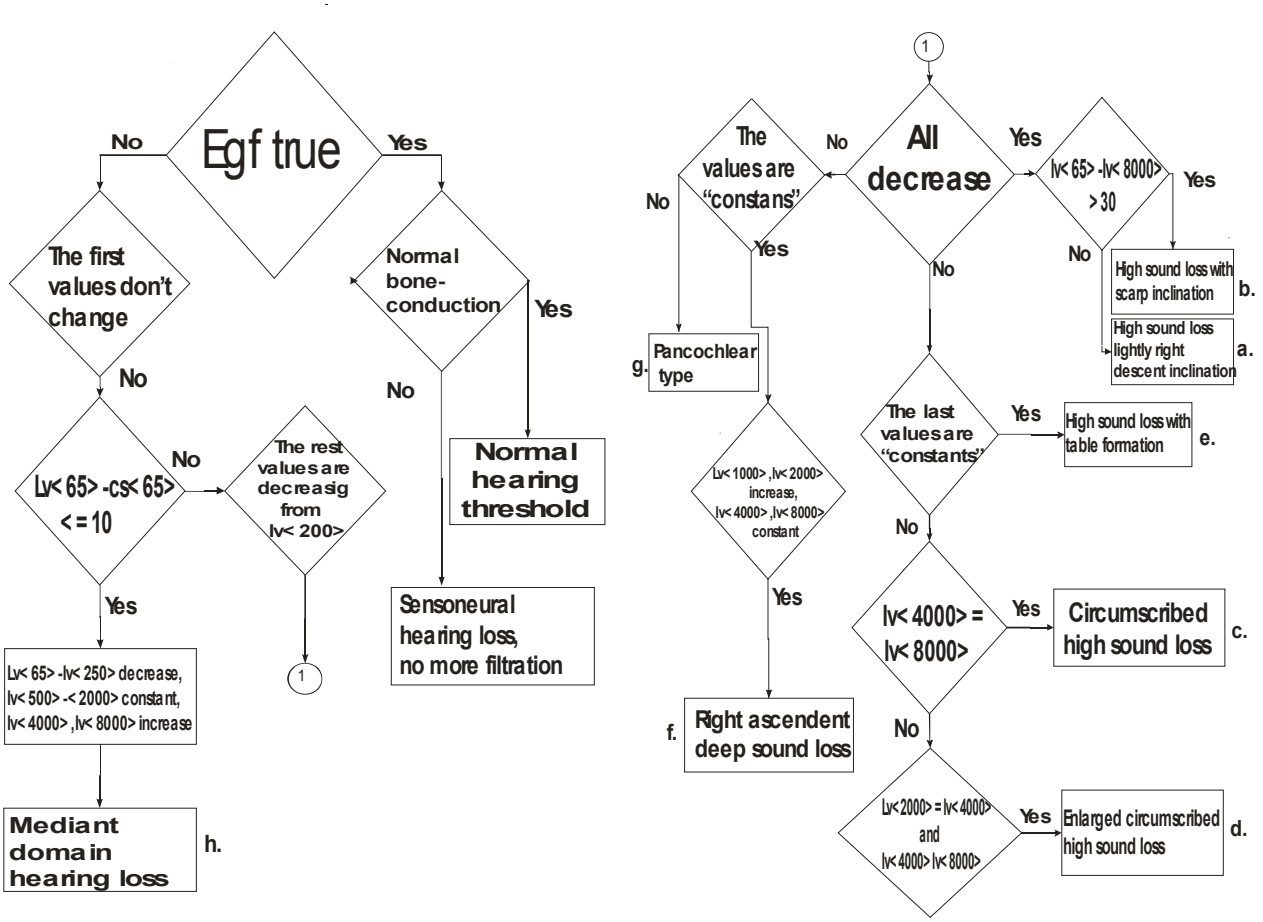

Fig.7. Decision tree of diagnosing pure tone audiometry. Egf is a boolean variable analyzing if the difference between the air conduction and the bone conduction values is quasi constant.

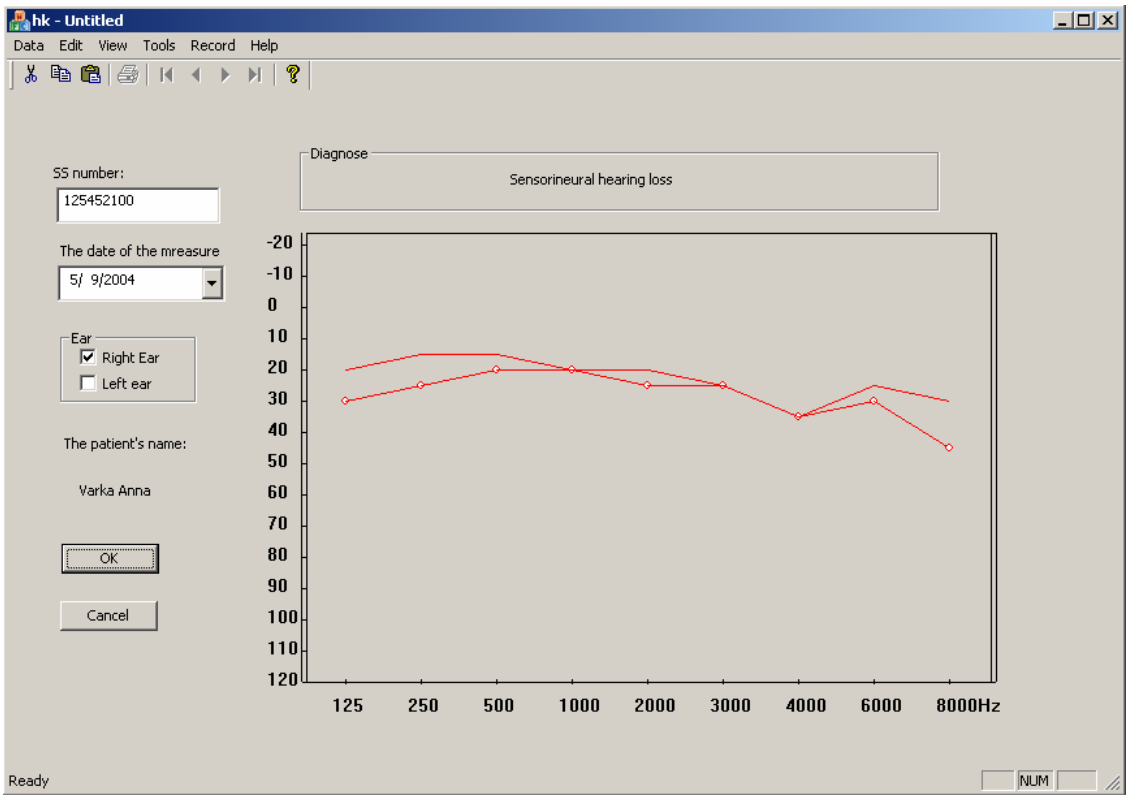

Fig.8. Diagnosing result in case of pure tone audiometry.

Finding the waves in the BERA diagram, and the application of the rules can be well algorithmized. Diagnostic software with human expert validation can be well used in detecting hearing loss. There is another advantage of computer signal processing, i.e. hearing can be characterized with physiologic parameters (eg. I-V interpeak latency). These parameters can be compared to other physiologic parameters of the patient (eg. blood sugar parameters), so the relation between different diseases (hearing loss – diabetes mellitus) can be examined.

However, the implementation of BERA is not finished yet, because we didn't finish testing the efficiency of this method.

5. CONCLUSIONS

The main advantage of the described information system is its simplicity and its user-friendly interface. The system is easy to handle and the implemented decision trees gives real help for doctors and nurses.

The database, which contains more than 5000 measurements of 110 children at the stage of the writing this article, is continuously updated with new measurements values.

Testing showed an efficiency of 100 % in case of diagnosing.

The system represents only the first step of the research, looking for the possible direct relation between diabetes mellitus and hearing loss in children and it is unique in Hungary. In the future, the identification and the modeling as a multivariable system of the mentioned diseases will be investigated based on the implemented database.

Though the software was written specially for the Heim Pál Hospital, and was dedicated for the mentioned research topic, it can also be installed on other systems very easily.

The prediction of the mentioned diseases is also a very important feature of the implemented software.

Current limitation of the software is that it cannot use on-line network connection yet. Therefore the database is updated off-line. However, for the research of the direct relation between diabetes mellitus and hearing loss, it fits the requirements, because lots of security conditions guard the program from accepting wrong measurement values.

6. ACKNOWLEDGMENTS

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REFERENCES

[1] Ypsomed Selfcare Solutions, Switzerland, www.ypsomed.com.

[2] B.N., Bergman, Y.Z., Ider, C.R., Bowden, C., Cobelli, - "Quantitive estimation of insulin sensitivity", *American Journal of Physiology*, 236, **667-677**, 1979.

[3] B., Candas, J., Radziuk, - "An adaptive controller of glycemia based on a physiological model of insulin-dependent glucose removal", *Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 13 (5), **2285-2286**, 1991.

[4] M.E., Fischer, K.L., Teo, - "Optimal Insulin Infusion Resulting from a Mathematical Model of Blood Glucose Dynamics", *IEEE Transactions on Biomedical Engineering*, 36 (3), **479-486**, 1989.

[5] Cs., Juhász, B., Asztalos, - "AdASDiM: An Adaptive Control Approach to Diabetic Management", *Innovation et Technologie en Biologie et Medicine*, 17 (1), 1996.

[6] A., Sano, - "Adaptive and optimal schemes for control of blood glucose levels", *Biomedical Measurements, Informatics and Control*, 1 (1), **16–22**, 1986.

[7] Z., Benyó, B., Paláncz, Cs., Juhász, P., Várady, - "Design of Glucose Control via Symbolic Computation", *Proceedings of the 20th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 20 (6), **3116-3119**, 1998.

[8] B., Benyó, Z., Benyó, B,. Paláncz, L., Kovács, and L., Szilágyi, - "A Fully Symbolic Design and Modelling of Nonlinear Glucose Control with Control System Professional Suite (CSPS) of Mathematica", *Proceedings of the World Congress on Medical Physics and Biomedical Engineering*, Sydney, Australia, **#2813**, 2003.

[9] J., Sturis, K.S., Polonsky, E., Mosekilde, E., van Cauter, - "Computer model for mechanisms underlying ultradian oscillations of insulin and glucose", *American Journal of Physiology*, 260, **439-445**, 1991.

[10] E.D., Lehmann, T., Deutsch, - "Compartmental models for glycaemic prediction and decision-support in clinical diabetes care: promise and reality", *Elsevier, Computer Methods and Programs in Biomedicine*, 56, **193-204**, 1998.

[11] I.M., Tolic, E., Mosekilde, J., Sturis, - "Modeling the Insulin-Glucose Feedback System: The Signification of Pulsatile Insulin Selection", *Journal of Theoretical Biology*, 207 (3), **361-375**, 2000.

[12] T., Halmos, Gy., Jermendy, - Diabetes Mellitus – "Theory and Practice" (in Hungarian), Medicina Ltd, Budapest, Hungary, 2002.

[13] L., Blaniczky, - "Our child has diabetes" (in Hungarian), Therapia Ed, Hungary, 2002.

[14] A., Fonyó, - "Medical Physiology Manual" (in Hungarian), Medicina Ltd., Hungary, 2002.

[15] E., Hochenburger, - "Manual of Practical Audiology" (in Hungarian), Kossuth Ed, Hungary, 2003.

[16] J., Pytel, - "Audiology" (in hungarian), Victoria Ltd, Pécs, Hungary, 1996.