ELSEVIER

Computer Methods and Programs in Biomedicine 69 (2002) 147–161

Computer Methods and Programs in Biomedicine

www.elsevier.com/locate/cmpb

A telemedicine support for diabetes management: the T-IDDM project

R. Bellazzi [a,*], C. Larizza [a], S. Montani [a], A. Riva [a], M. Stefanelli [a], G. d'Annunzio [b], R. Lorini [c], E.J. Gomez [d], E. Hernando [d], E. Brugues [e], J. Cermeno [e], R. Corcoy [e], A. de Leiva [e], C. Cobelli [f], G. Nucci [f], S. Del Prato [g], A. Maran [f], E. Kilkki [h], J. Tuominen [h]

[a] *Dipartimento di Informatica e Sistemistica, Università di Pavia, via Ferrata 1, I-27100 Pavia, Italy*
[b] *I.R.C.C.S. Policlinico S. Matteo, Pavia, Italy*
[c] *Fondazione Gaslini, Genova, Italy*
[d] *Universidad Politecnica de Madrid, Madrid, Spain*
[e] *Fundacion Diabem, Barcelona, Spain*
[f] *Università' di Padova, Padova, Italy*
[g] *Padova University Hospital, Padova, Italy*
[h] *Helsinki University Hospital, Helsinki, Finland*

Received 17 March 2001; received in revised form 1 July 2001; accepted 3 August 2001

Abstract

In the context of the EU funded Telematic Management of Insulin-Dependent Diabetes Mellitus (T-IDDM) project, we have designed, developed and evaluated a telemedicine system for insulin dependent diabetic patients management. The system relies on the integration of two modules, a Patient Unit (PU) and a Medical Unit (MU), able to communicate over the Internet and the Public Switched Telephone Network. Using the PU, patients are allowed to automatically download their monitoring data from the blood glucose monitoring device, and to send them to the hospital data-base; moreover, they are supported in their every day self monitoring activity. The MU provides physicians with a set of tools for data visualization, data analysis and decision support, and allows them to send messages and/or therapeutic advice to the patients. The T-IDDM service has been evaluated through the application of a formal methodology, and has been used by European patients and physicians for about 18 months. The results obtained during the project demonstration, even if obtained on a pilot study of 12 subjects, show the feasibility of the T-IDDM telemedicine service, and seem to substantiate the hypothesis that the use of the system could present an advantage in the management of insulin dependent diabetic patients, by improving communications and, potentially, clinical outcomes. © 2002 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Telemedicine; Diabetes management; Demonstration study; Clinical outcomes

---

* Corresponding author. Tel.: +39-0382-505-511; fax: +39-0382-505-373
E-mail address: ric@aim.unipv.it (R. Bellazzi).

PII: S0169-2607(02)00038-X

1. Introduction

Diabetes Mellitus is one of the major chronic diseases in industrialized countries, deriving from an insufficient secretion of insulin by pancreatic beta cells. Seven to 20% of the total number of diabetic patients are affected by type 1 diabetes (also referred to as Insulin Dependent Diabetes Mellitus). Since type 1 diabetic patients have no residual endogenous insulin secretion, they need exogenous insulin injections to regulate blood glucose metabolism, in order to prevent ketoacidosis and coma, and to reduce the risk of later life invalidating complications. It has been proven that Intensive Insulin Therapy (IIT), consisting of 3–4 injections every day, or of the use of subcutaneous insulin pumps, is the most effective way to stabilize blood glucose, and therefore to reduce or delay diabetes complications. The increase in therapy planning complexity and costs is the obvious drawback [1]. Type 1 diabetic patients have to perform a strict daily self-monitoring of Blood Glucose Level (BGL), by measuring it before every injection, and by recording it on hand written diaries, together with the amount of insulin injected, and with additional information about diet and life style. Moreover, every 2–4 months they undergo periodical control visits, during which the data coming from home monitoring are analyzed, in order to assess the metabolic control achieved by the patients. Laboratory results and historical and/or anamnestic data are considered as well, in order to update the patient's therapeutic insulin protocol. How to balance the advantages coming from IIT with its disadvantages is a matter of discussion, that involves social and ethical considerations.

The complexity of diabetes care led to the definition of the EU funded project Telematic Management of Insulin-Dependent Diabetes Mellitus (T-IDDM: HC-1047) [2]. T-IDDM was concerned with the design, implementation and testing of an intelligent telemedicine service for improving patients management according to the best current medical practice. The project was meant to accomplish the following specific aims:

- to support physicians in providing patients with an effective treatment leading to a good glycaemic control, and to achieve a careful balance between insulin therapy, diet and physical activity, thus delaying the onset and/or slowing the progression of chronic complications;
- to provide patients at home or in other non-clinical environments with an appropriate level of continuous and intensive care through telemonitoring and teleconsultation services, taking into account the needs of remote or isolated individuals that are unable to reach frequently the hospital institutions;
- to allow a cost-effective monitoring of a large number of patients, automating data collection and the management of a large set of therapeutic protocols;
- to support a continuous education of patients through teleconsultation services;
- to allow the patient to customize the insulin therapy within the bounds established by the physicians.

Thus, the overall aim of the T-IDDM project was the definition of a suitable cost-effective solution to the problem of type 1 diabetic patients monitoring, by exploiting the current advances in Information Technology.

2. State of the art of telemedicine support for diabetes

The potential usefulness of computerized systems for managing diabetic patients has been advocated since early 1980s. The interest for telemedicine application, in particular, is demonstrated by the widespread appearance in the literature and on the Internet of this kind of services. Telemedicine solutions range from simple systems, in which patients and physicians communicate by the telephone, to more complex ones, exploiting Web interfaces. In more detail, three kinds of telemedicine systems have been studied:

- telephone assistance systems: patients periodically receive phone calls from a health care provider, who gives them advice about their therapy, and/or educational information [3–5];
- visit by visit systems: following Lehmann's definition [6], visit by visit systems are devoted

to assist physicians to interpret the time series data coming from home monitoring and to update the therapeutic protocol. In the context of telemedicine applications, visit by visit systems provide patients with the possibility of downloading their monitoring data from the reflectometer to a centralized data-base, while physicians have access to all patients' data through various visualization, data analysis, and possibly decision support tools at the hospital [7–15];
- complete assistance systems: these systems integrate the visit by visit philosophy with the capability of providing day by day assistance to patients, i.e. they supply therapeutic advice to patients during every day self-management of the disease [6]. The telemedicine systems that belong to this category are obviously the more complex ones, and require the solution of non-trivial problems, in particular dealing with the kind of interface, platforms and tools that should be provided to the users. In several applications, patients were provided with ad-hoc software and hardware tools [16], smart-phones [17] or palmtops [18,19], while access to more complex software tools (i.e. Web service) was limited to physicians and care providers [19,20]. More recently, access to the Web both from hospital and patients' house has been proposed [21].

The use of these tools has generally led to positive results: some clinical trials have demonstrated a significant reduction of HbA1c in the group adopting the telemedicine system [4,9,10,14,15], and also when this outcome was not obtained, other positive indicators were found, such as an amelioration of social functioning, of self-efficacy, and of communication with the physician (see for example [3,11]).

Within the T-IDDM project, we have worked at the implementation of a complete assistance system. Physicians have been provided with a Web interface for accessing a wide range of tools over the Internet or over the hospital Intranet. An ad-hoc software, running on a PC and allowing communication of data and messages with the hospital, has been implemented for patients' use. Additional details of the T-IDDM architecture are described in the following section.

3. General architecture

The T-IDDM service implementation relies on the cooperation of two modules, a Medical Unit (MU) and a Patient Unit (PU), connected through a telecommunication system (Internet or the Public Switched Telephone Network (PSTN)). The MU assists the physician in the definition of the basal insulin regimen through a periodic evaluation of patient's data, while the PU helps the patients in their self-monitoring activity, by suggesting insulin dose adjustments, when needed; moreover, it supports data collection, either manually or automatically from a the Blood Glucose measurement instrument, i.e. the reflectometer, and data delivery to the clinic.

The MU therefore integrates a visit by visit assistance for the physician with the possibility of providing *telecare* to patients, via the telecommunication link between hospital and patients' house. On the other hand, the PU gives day by day support to the patients, allowing for *teleconsultation*. The connection between the PU and the MU is driven by the patient, who, in absence of particularly urgent situations, sends the monitoring data to the MU periodically, e.g. every 7–10 days. The two units usually work asynchronously, since it is not exactly a priori known when data communications will take place. This means that the PU must have a sufficient degree of autonomy to properly handle the different patient management situations.

Fig. 1 shows the T-IDDM architecture.

The development and implementation of the T-IDDM service followed the following steps:

- user needs analysis: in this phase, we identified the data to be represented in the T-IDDM data-base, and designed the data-base structure; moreover, we analyzed the functionality needed by physicians, in order to define the MU data analysis and decision support tools. Finally we worked on the interface requirements [22];
- functional specifications: the analysis of user needs, both from the patients and from the physicians point of view, was translated in the PU and MU functional specifications [23];

- implementation of the service: two different implementations, an Internet, exploiting Internet as telecommunication system, and an Intranet based demonstrator, relying on PSTN for direct connection to the server at the hospital were realized [24,25].

In the following sections, we will provide a detailed description of MU and PU functionality. The approaches for implementation are quite different mainly because the MU is used by professionals at the hospital, while the PU is intended to be used in non controlled scenarios (patient home, office, etc.) with a commonly available platform, as it is a PC. The different approaches do not affect the communication process because PU and MU dialogue and interchange relevant information through common communication procedures.

The general architecture of the T-IDDM system (Fig. 2) shows how the application layer is independent from the communication level.

3.1. MU functionality

The MU is a Web-based application supported by a distributed environment, in which the following servers transparently cooperate, to provide the physician with all the required functionality:

- a data-base server (Oracle™ RDBMS);
- a Temporal Abstraction server (written in C);
- a Data Analysis server (written in Common Lisp);
- a Decision Support System (written in Common Lisp);
- a Web server (written in Common Lisp);

The core of the system is represented by the Web server, called LispWeb [26]. Applications built using LispWeb have full control over the transactions that take place between the server and the Web browser, and can at the same time make calls to powerful functions to generate HTML pages. Moreover, LispWeb makes it extremely easy to integrate legacy applications written in Common Lisp, and to make them accessible on the Web. The use of the LispWeb server allows the Web-based application to exploit the full power of a high-level programming language, as well as any number of external services through an extension of the HTTP protocol, called STSP. For example, communications with the PU rely on this protocol.

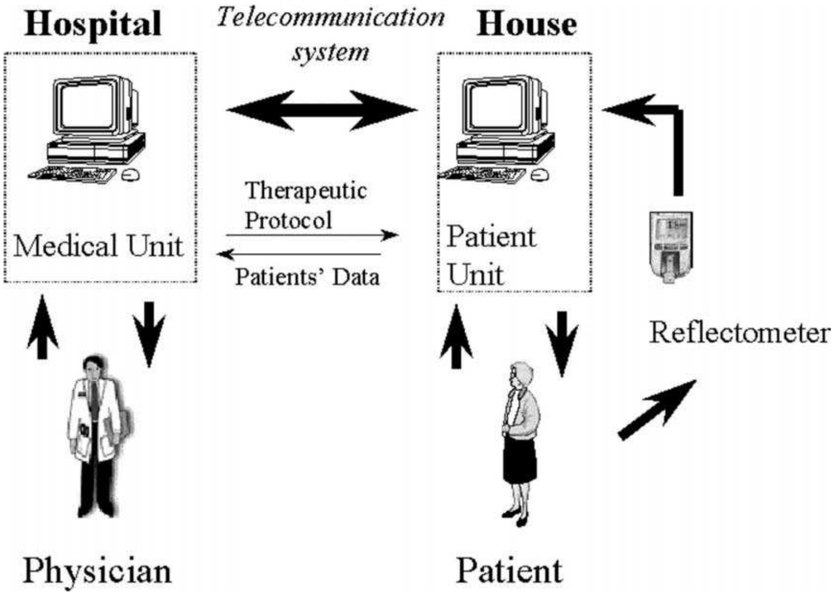


Fig. 1. The T-IDDM project architecture.

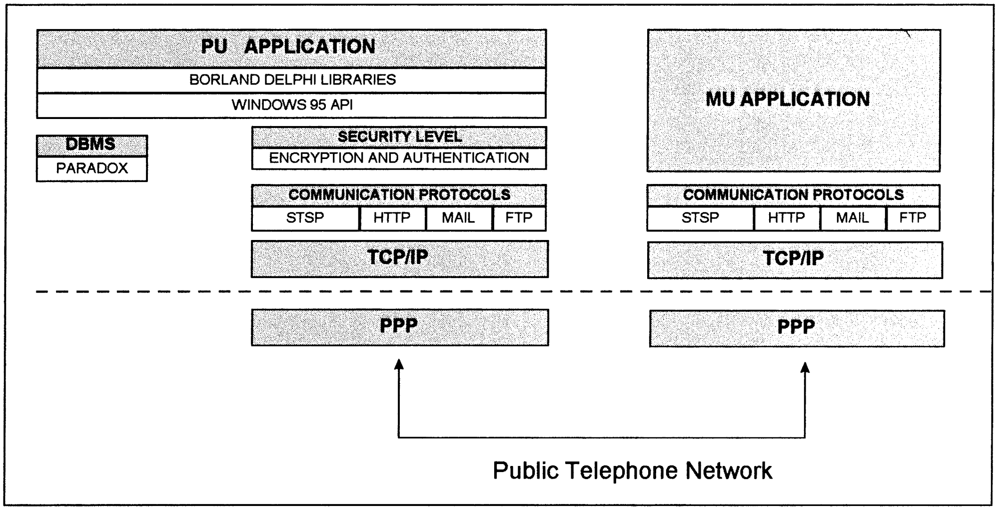


Fig. 2. The general T-IDDM system architecture.

Through LispWeb, the four servers embedded in the MU architecture can perform complex forms of negotiations, thus providing the physician with the required assistance.

The Decision Support System, in particular, implements the Rule-Based Reasoning (RBR) methodology [27]. In type 1 diabetes care, the therapy revision process typically consists of four consecutive tasks; within the T-IDDM RBR system, each task is mapped into a specific set of rules, fired through a forward chaining mechanism. In detail, the reasoning paradigm proceeds as follows:

1. data analysis: to interpret the effects of a therapy, we provide a probabilistic description of the *typical day* of the patient, by calculating the BGL modal day. The BGL modal day is a well-known indicator of the patient's answer to the therapy she/he is following. Our approach enables the handling of missing data (see [28]), after a discretization and aggregation of BGL values performed on the basis of Temporal Abstraction concepts [29]. From an implementation viewpoint, we resort to the cooperation of the Temporal Abstraction server and of the Data Analysis server;
2. problem identification: the results of modal day trigger the identification of hyperglycaemia or hypoglycaemia in the different periods of the day;
3. suggestion selection: for each detected problem, a set of suggestions on how to modify the current insulin therapy are proposed and the most effective ones are selected by resorting to the concept of insulin *competence*. The most competent insulin, i.e. the one that has the stronger effect on the moment of the day in which the problem has been found, is identified by relying on the pharmacokinetics of the different insulin types [30];
4. therapy revision: the RBR system adjusts the current insulin therapy, in accordance with the selected suggestions, and shows it through the Web interface. It typically proposes small adjustments to the current insulin protocol, and to the overall daily insulin requirement. As a matter of fact, it is meant to be general enough to be safely applicable to any patient in a variety of different situations.

The RBR generality sometimes leads to an advice which is not well tailored for the situation at hand, especially when dealing with a poorly controlled patient. These observations, confirmed in the verification study (see Section 4.1), led to the development of an upgraded version of the decision support functionality, that integrates RBR with the Case Based Reasoning (CBR) methodology [31]. CBR is a reasoning paradigm that consists of retrieving past situations similar to the current one, and of presenting them to the user, to help the solution of the current problem. Within this Multi Modal Reasoning methodology, past cases retrieval is used to specialize the rules behavior in the problem identification and in the therapy revision steps, by setting proper rule parameters to specific values, selected on the basis of the situation at hand. This extension of the decision support functionality has been preliminary tested within T-IDDM by resorting to simulation studies and has provided encouraging results. For additional information about the Multi Modal Reasoning system and its further evolutions, see for example [29]. Other details about the overall MU architecture, in particular about the data analysis functionality, have been presented elsewhere [32].

3.2. PU functionality

The goal of the Patient Unit application is to help diabetic patients in their self-monitoring activity, by allowing manual and automatic data collection and transmission of monitoring data and messages from patients to doctors. By using the PU, patients can also consult treatment modifications and messages from doctors. The PU has a local data-base that allows patients to work autonomously without the need of a permanent connection to the MU.

The PU application is envisaged to be used mainly at home, but it could also be installed in a hospital environment or in a primary care center. For this reason the application data-base can manage data from several patients and performs a user access control when it is started to assure data privacy.

The PU application comprises five different scenarios:

- patient logbook
- treatment consultation
- electronic messages
- communications
- administration of the application.

The 'patient logbook' functionality allows patients to consult, visualize and fill in their monitoring data. The following sub-scenarios are included:

- 'Glycaemia', allows to visualize and enter blood glucose self-monitoring data, both manually or downloading them directly from the glucose meter.
- 'Diet', allows to visualize and enter information about modifications in the prescribed diet.
- 'Insulin', allows to visualize and enter information about modifications in the insulin therapy.
- 'Ketonuria & Glycosuria', allows to visualize and enter information about ketonuria and glycosuria self-monitoring data.
- 'Personal Data' allows the access to 'Patient Personal Data', like birthday, sex and weight.
- 'Graphical representation' allows the user to plot the blood glucose monitoring data.

In the 'treatment consultation' scenario, patients can consult their current diet and insulin plans prescribed by the physician. This information is updated automatically whenever the patient connects the PU to the MU if a change in the therapy has been decided at the hospital. The 'electronic messages' scenario has a functionality similar to a commercial e-mail client and allows the patients to read the messages coming from physicians and to write messages to be sent to the hospital. The 'communications' scenario allows users to start the communication process whenever they want, and to set up the communication parameters (PPP server telephone number and MU socket). The 'administration' scenario allows the management of multiple patient users and to select the language of the PU user interface.

3.2.1. The PU user interface

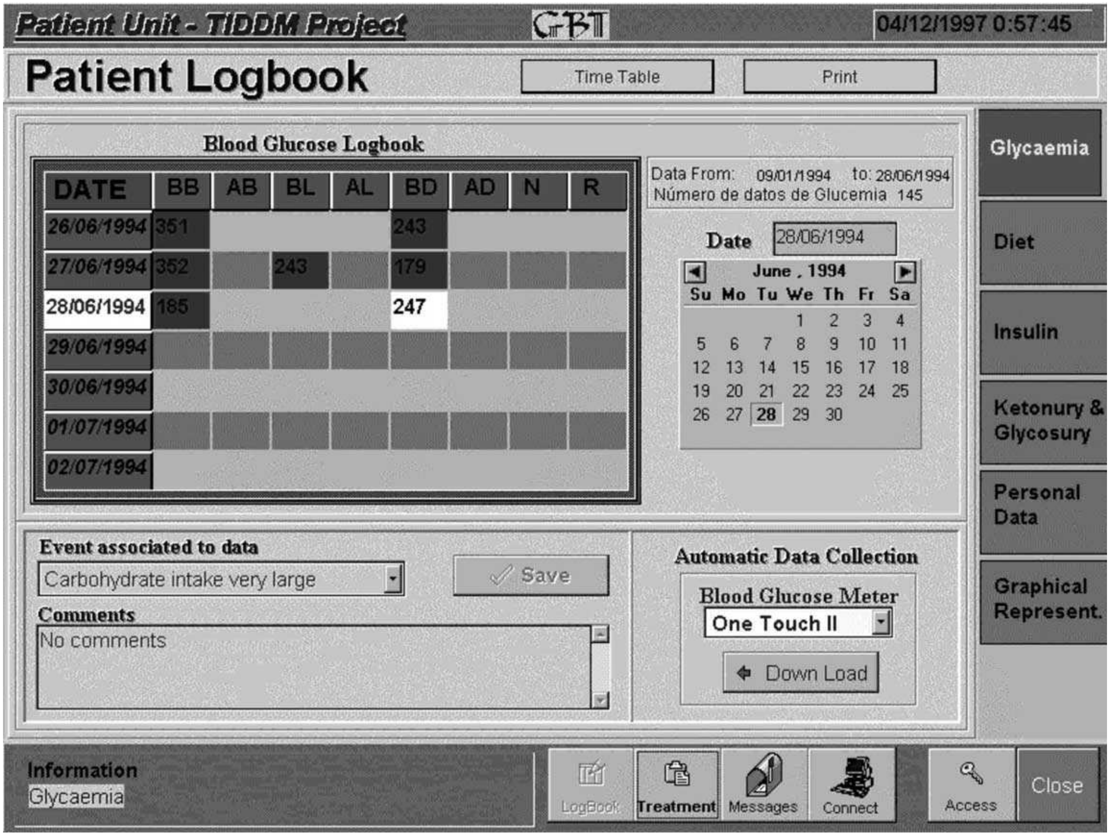
One of the most effective ways of making computer-based systems more intelligible to users is through analogy, i.e. ease of use and learning is improved through similarities between system features and other similar mechanisms or processes more familiar to users. So, the way to proceed when developing a graphical user interface is to identify a real world analogy and, later on, to create an interface 'metaphor' having similar characteristics. A metaphor is a mapping relation between aspects of the conceptual model and objects of the real world. By using graphical metaphors the system can show a coherent view, allowing users to easily associate the real world object with the graphical metaphor and to implicitly transfer their knowledge to the interaction with the interface.

To implement the PU we selected a patient's logbook to manage the monitoring data. The logbook has been implemented using a 'notebook' metaphor because patients are already used to this kind of object to manage their blood glucose measurements. In addition, the PU interface extends the logbook metaphor to all types of monitoring data, as for example, ketonuria, glycosuria, diet and insulin modifications. The graphical notebook presents tabs to allow the user to select different options. This metaphor simulates the pages in a notebook and assigns one page to each different scenario. Users can move through pages by clicking the tabs with the mouse (see Fig. 3) and proceed in time from week to week by using a calendar where individual days can be selected. The logbook presents a whole week in the same screen and data can be filled in boxes devoted to a date and to a moment of the day: BB, Before Breakfast; AB, After Breakfast; BL, Before Lunch; AL, After Lunch; BD, Before Dinner; AD, After Dinner; N, Night; R, Random. Patients can select different 'tabs' on the right margin of the logbook assigned to different variables and information.

Visualization tools are also implemented for helping patients in making decisions about therapy adjustments.

3.2.2. Software and hardware architecture

The T-IDDM Patient Unit runs in a Windows PC provided with a secondary serial port RS232



Blood Glucose Logbook

DATE	BB	AB	BL	AL	BD	AD	N	R
26/06/1994	351				243			
27/06/1994	352		243		179			
28/06/1994	185				247			
29/06/1994								
30/06/1994								
01/07/1994								
02/07/1994								

Data From: 09/01/1994 to: 28/06/1994
Número de datos de Glucemia 145

Date 28/06/1994

Event associated to data: Carbohydrate intake very large

Comments: No comments

Blood Glucose Meter: One Touch II

Information: Glycaemia

Fig. 3. Data downloading to the T-IDDM PU.

for communications with Lifescan glucose meters (OneTouch II and Profile) and an Ethernet card or a modem to establish TCP/IP communications with the T-IDDM MU.

The PU development tool was 'Borland Delphi 1.0'. This commercial product allows the graphical definition of Graphical User Interfaces (GUIs) under Microsoft Windows and use Object Pascal as programming language. The PU application runs under the Microsoft Windows 95 operating system. The data-base has been implemented with the 'Database Desktop version 5.1' tool included in Delphi. The chosen data-base type is Paradox 5.0 and the data-base management is done by using local SQL. The printing management of reports from the PU application has been implemented with the 'ReportSmith version 2.5' tool, also included in Borland Delphi.

4. Evaluation

The overall evaluation of the T-IDDM service was split in two phases: (1) a verification phase; and (2) a demonstration phase. The goal of verification was to preliminary test T-IDDM functionality, so as to possibly re-implement a sub-part of the service, if needed, before demonstration.

4.1. Verification

The key objective of T-IDDM verification phase was that of testing each component of the prototype to ensure usability and agreement with user needs and functional specifications. In particular, we aimed at verifying the PU–MU interconnection through the telecommunication system, and the reliability of the automatic therapy advisor. In order to fulfill these objectives, we have gone through a three-step process.

4.1.1. Technical verification

First, a technical verification on advice generation was performed, by relying on a diabetic patient simulator [33], and on a simple software able to connect the simulator to the MU prototype. The time horizon for weekly data collection was 3 BGL measures/day and the T-IDDM decision support system was allowed to suggest a new protocol each week. To obtain the typical operative conditions of the T-IDDM prototype, the simulated samples were corrupted with a 10% error. The performance of the reasoner was considered good in each of the proposed cases since it proved to be able to bring the BGL profile to the normality range within 6 weeks from the establishment of control by the MU (see Fig. 4). These results were seen as a prerequisite to begin the clinical evaluation of the prototype. In fact, when dealing with real subjects, the prototype has to face with additional uncertainty as the day by day patient variability, the presence of missing BGL measures and occasional changes in insulin regimen and meal intake.

In parallel we also considered the capabilities of data downloading from the reflectometer to the PU prototype. Finally, the MU-PU interconnection was verified by showing that the proposed system was able to reliably handle data collection and transmission.

4.1.2. Clinical verification

The general goal of clinical verification was that of testing data collection by the PU, data transfer between PU and MU, and data storing in the MU on a large time scale (11 months), to see if positive clinical findings could be identified on real subjects. Three well compliant pediatric patients were enrolled at the Policlinico S. Matteo Hospital in Pavia. Although the number of patients was small, we obtained encouraging results. Briefly, after the enrollment of the patients in using the T-IDDM prototype the results were: (i) 9% reduction in patients mean BGL (from 146.3 to 133.9 mg/dl); (ii) 11% reduction in median BGL (from 158 to 141.3 mg/dl); (iii) 9% reduction in HbA1c (from 7.77 to 7.1%).

4.1.3. Pilot clinical validation

Finally, a pilot clinical validation was started on 12 patients, enrolled in the four medical verifications centers of the project. The aim of this phase was that of testing the MU therapeutic advice generation on real patient data, and of comparing it with the diabetologist advice. The RBR system always motivated its suggestions on

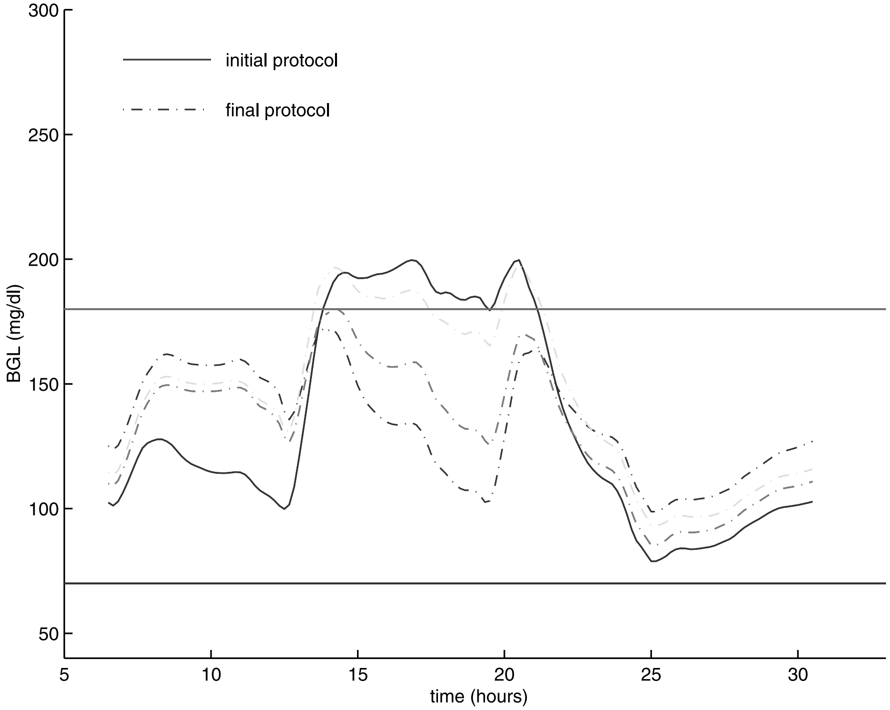


Fig. 4. Simulation of a pediatric patient (25 kg) with an error in insulin therapy. The RBR system succeeds in adjusting the metabolic behavior (BGL between 70 and 180 mg/dl) after two intermediate adjustments.

a base consistent with that of the diabetologists. Briefly, the MU advice influenced the insulin daily requirement with a maximal increase of 16%, a maximal decrease of 13% and a mean absolute variation of 5.5%. The systems strategy seemed quite flexible and capable of taking into account complex control rules. In conclusion the clinicians involved agreed that the prototype, albeit too prudent in certain occasions, seemed to work well.

4.2. Demonstration

The T-IDDM project demonstration took place in four European validation sites: (1) Policlinico S. Matteo, Pavia, Italy; (2) Hospital San Pau, Barcelona, Spain; (3) University Hospital, Padova, Italy; (4) University Hospital, Helsinki, Finland. Two different philosophies of the T-IDDM architecture were tested: an Intranet based and an Internet based service. The Intranet option (see Fig. 5) required to be locally managed by the health care provider, with modem access from the

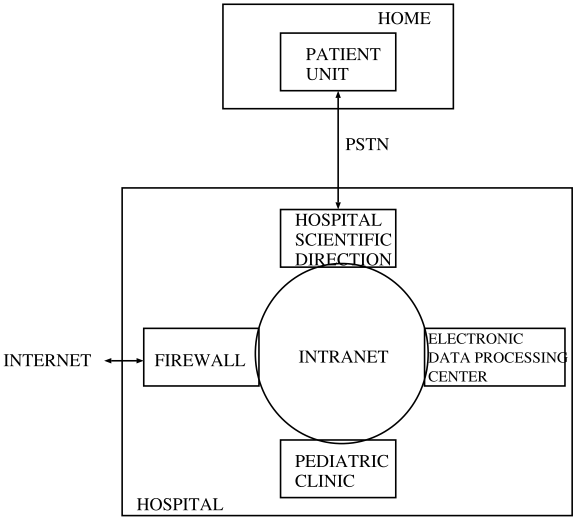


Fig. 5. Intranet-based architecture of the T-IDDM project.

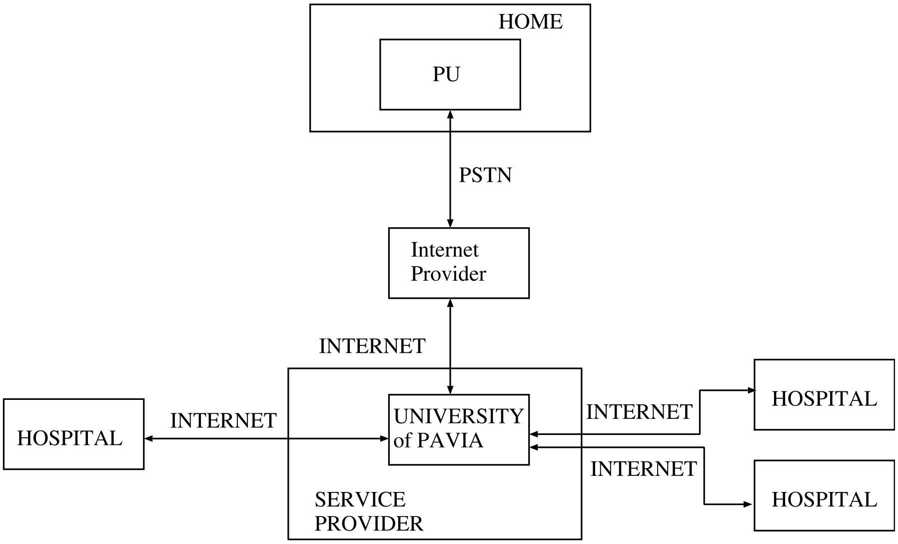


Fig. 6. Internet-based architecture of the T-IDDM project.

Table 1
Features of the patients enrolled for the T-IDDM Intranet service demonstration in Pavia

Patient	Sex	Age (years)	Profession	Experience with PC	Weight (kg)	Diabetes duration (years)	Complications
PAV1	M	11	Student	Poor	26	5	None
PAV2	M	15	Student	Good	59	5	None
PAV3	M	17	Student	Good	54	3	None
PAV4	F	17	Student	Poor	70	5	None
PAV5	F	15	Student	Good	53	4	None
PAV6	M	8	Student	Poor	29	2	None

patients' houses. This solution was adopted at the Policlinico S. Matteo Hospital in Pavia. The MU and PU communicated through a PSTN using a PPP connection supported by a server situated at the hospital Intranet. The MU Web-server was located on a Sun Sparc at the Hospital Scientific Direction, while the data-base run on a HP-9000 in the EDP of the Policlinico S. Matteo hospital.

The Internet-based service (see Fig. 6) kept the server and the data-base managed by an external service provider, and enabled authorized patients and physicians to connect to the system using Internet (Barcelona, Padova and Helsinki tested this second option). The Internet solution thus required no management of servers and of technical stuff at the hospital site, but had to solve more problems related to the security of data collected at the central site and to the interface with existing legacy systems [34].

The Intranet service evaluation started in June 1998, and involved six pediatric patients; the Internet service evaluation started in January 1999, and involved 13 adult patients.

4.2.1. Intranet service results

The main features of the six pediatric patients enrolled at the Pavia site are described in Table 1. Tables 2 and 3 show the results of the Intranet service demonstration at the Pavia site.

In an average of 415 follow-up days, 901 BGL measurements/patient were collected. Patient/physician communication was increased, since 56

Table 2
Results of the T-IDDM Intranet service demonstration in Pavia

Number of follow up days	415 [144 517]
Number of connections to the MU	35 [7 59]
Number of BGL sent	901 [157 1525]
Number of therapy changes	8 [1 12]
Number of messages sent by physicians	56 [14 88]
Number of messages sent by patients	35 [7 57]

The outcomes are reported as averages and ranges.

messages were sent from physicians and 35 messages from patients (as an average) by exploiting the T-IDDM telecommunication link. Moreover, in comparison to clinical practice at the Pavia center, the number of therapy revisions was nearly doubled (one every month).

HbA1c, the most important indicator of hyperglycaemia, showed an average decrease of 1.23% (statistically not significant). On the contrary, there was a significant reduction of insulin requirement (0.095%, Wilcoxon's test for paired data, $P < 0.03$) (see Table 3).

4.2.2. Internet service results

The main features of the patients enrolled for the Internet service demonstration are listed in Table 4. Tables 5 and 6 show the results of the Internet service demonstration at Helsinki, Padova and Barcelona. In an average of 206 follow-up days, 467 BGL measurements/patient were collected. Patient/physician communication was increased, since there were 23 messages sent from physicians and four from patients (as an average) by exploiting the T-IDDM telecommunication link. Moreover, like with the Intranet ser-

Table 3
Impact of the usage of the T-IDDM system on Pavia patients' metabolic control

Patient	HbA1c entry (%)	HbA1c end study (%)	Insulin entry (U/kg per day)	Insulin end study (U/kg per day)
PAV1	7.9	7.6	1.04	0.96
PAV2	8.3	7.8	1.16	1.01
PAV3	5.3	6.4	0.39	0.31
PAV4	9.2	9.2	0.71	0.62
PAV5	13.3	6.6	1.23	1.13
PAV6	6.5	5.5	0.42	0.35

Table 4
Features of the patients enrolled for the T-IDDM Internet service demonstration (in Helsinki, Padova and Barcelona)

Patient	Sex	Age (years)	Profession	Experience with PC	Weight (kg)	Diabetes duration (years)	Complications
HEL1	M	55	Project manager	A lot	84.5	42	Retinopathy Neuropathy
HEL2	M	34	Coordinator	A lot	83.5	2	None
HEL3	F	35	Transport expert	A lot	70	15	None
HEL4	F	35	Social worker	Medium	55	16	Retinopathy
HEL5	M	14	Student	A lot	50	9	None
HEL6	F	51	Sales woman	Medium	56	35	Retinopathy Nephropathy
PAD1	F	34	Employee	A lot	53	5	None
BAR1	M	31	Music player	A lot	71.5	12	None
BAR2	M	31	PC technician	A lot	71.8	11	None
BAR3	F	38	Physician	Medium	66.5	6	None
BAR4	M	31	Physician	Medium	77.5	4	None

Table 5
Results of the T-IDDM Internet service demonstration (in Helsinki, Padova and Barcelona)

Number of follow up days	206 [49 302]
Number of connections to the MU	21 [2 43]
Number of BGL sent	467 [30 856]
Number of therapy changes	4 [0 9]
Number of messages sent by physicians	23 [1 59]
Number of messages sent by patients	4 [0 24]

The outcomes are reported as averages and ranges.

vice implementation, it was possible to increase the number of therapy changes (4 vs. 3 in normal clinical practice, as an average). Of note, the Pavia patients, probably due to their pediatric age, exploited more often the system functionality. It is somewhat difficult to derive a general conclusion from the Internet service demonstration, because the patient population was not homogeneous, both in terms of clinical characterization as well as from the system usage point of view: some of them entered the demonstration very late, and used T-IDDM only for a couple of months. Interestingly, the use of the T-IDDM service led to a closer contact between patient and physician: this is a positive result, even if not significantly reflected by the metabolic parameters modifications.

4.2.3. Usability results

Concerning usage and usability, the MU was generally well accepted, and was considered reliable and helpful by physicians, who accessed its functionality at least once a week. A positive judgment was expressed both on the data visualization and on the data analysis tools; the electronic patient record was often exploited and updated. The RBR tool was queried during many working sessions, and was generally found reliable and in accordance with the physician's opinion.

Dealing with the PU, questionnaires on technical issues and on performances reported positive judgments. The usability verification presented more heterogeneous results: while the PU was recognized by all patients to be easy to use and relatively efficient, the help provided by the system was considered acceptable only by three patients. Moreover, a negative opinion was provided by one patient on the user interface. These results suggest that a better compliance could be obtained by designing a PU that is tailored on the individual user's needs, and by customizing it according to different patient categories.

Fig. 7 summarizes all the patients' answers to the questionnaires on the PU usability issues.

5. Conclusions

In the context of the EU funded T-IDDM project, we have designed, developed and evaluated a telemedicine system for type 1 diabetic patients management. The system relies on the integration of two modules, a PU and a MU, able

Table 6
Impact of the usage of the T-IDDM system on Helsinki, Padova and Barcelona patients' metabolic control

Patient	HbA1c entry (%)	HbA1c end study (%)	Insulin entry (U/kg per day)	Insulin end study (U/kg per day)
HEL1	8	7.4	0.62	0.574
HEL2	5.8	7.2	0.35	0.337
HEL3	9.9	9.7	0.45	0.493
HEL4	7.7	8.6	0.55	0.689
HEL5	7.8	8.2	1.37	1.442
HEL6	8.2	9.2	0.49	0.49
PAD1	8.4	8.6	0.5	0.54
BAR1	6.8	6	0.9	0.86
BAR2	8.1	7	0.71	0.88
BAR3	7.3	8.3	0.74	0.74
BAR4	7.1	7.1	0.55	0.54

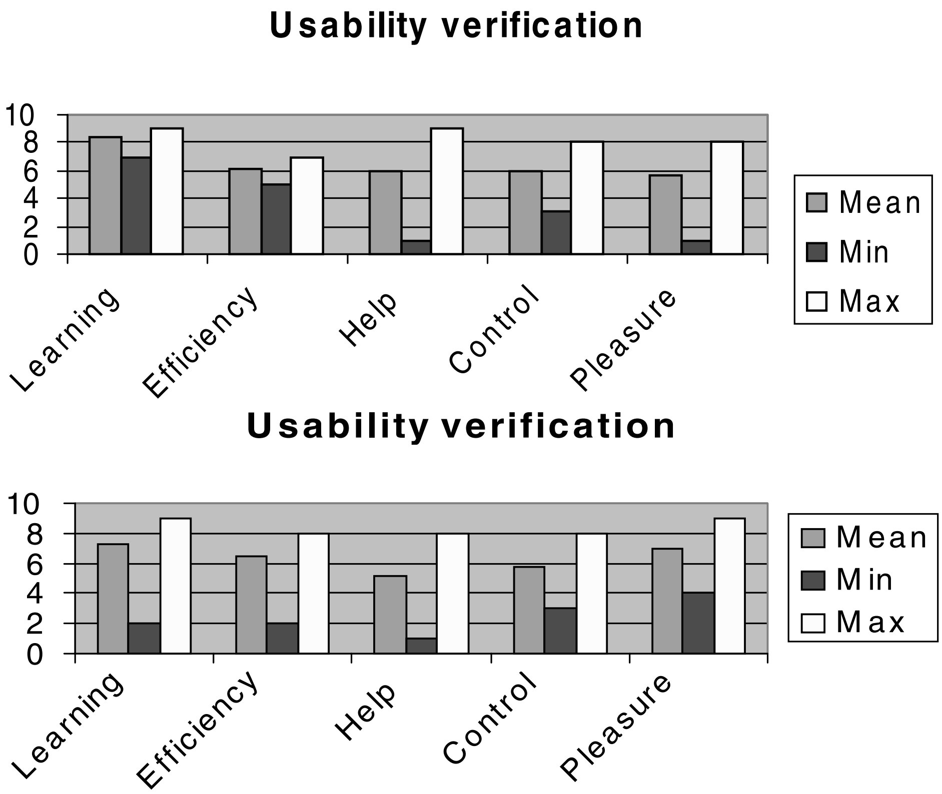


Fig. 7. All patients' answers to the questionnaires on PU usability issues; the upper part of the figure summarizes the answers provided by the Pavia patients, while the lower summarizes the answers provided by the patients taking part to the Internet service verification.

to communicate over the Internet or by making a direct connection to the hospital. Patients are allowed to automatically download their monitoring data from the reflectometer, and to send them to the hospital data-base; moreover, they are supported in their every day self monitoring activity. Physicians are provided with a set of tools for data visualization, data analysis and decision support, and can send messages and/or therapeutic advice to the patients. The T-IDDM service has been evaluated through the application of a formal methodology, and has been used by European patients and physicians for about 18 months. The outcomes obtained during the project demonstration, albeit obtained on a small number of subjects, show the feasibility of the T-IDDM telemedicine service, and seem to substantiate the hypothesis that the use of the system could present an advantage in the management of type 1 diabetic patients. In particular, it could permit to perform a tighter control of the patients' metabolic situation, in a cost-effective way, without requiring additional visits and personal contacts between patients and physicians [35]. We speculate that this is likely the reason why the HbA1c and the insulin requirement were reduced in some of the subjects participating to the evaluation.

Nevertheless, we are aware that ours is essentially a feasibility study, due to the small number of patients involved, and to the absence of a control group; obviously a clinical trial is needed to confirm our hypotheses, and this will be one of our goals in the future. As a matter of fact, some of the authors are currently working at a new multi-access telemedicine service [36], that will extend the T-IDDM functionality, by making it accessible through different media (e.g. Web interface, Web TV, Computer Telephony Integration, palmtops, mobile phones) and tailorable on the basis of the single user needs. In this way, we hope to overcome some of the difficulties encountered during the T-IDDM demonstration, especially linked to usability issues. Then, we plan to confirm and enforce the encouraging clinical results obtained within T-IDDM through a randomized trial performed over a homogeneous population. Finally, the impact on the hospital organization will also be addressed, with the purpose of understanding the changes in patients/physicians relationships and in the physicians workflow.

Acknowledgements

This paper is part of the EU TAP project T-IDDM HC 1047.

References

[1] The Diabetes Control and Complication Trial Research Group, The effect of intensive treatment of diabetes on the development and progression of long-term complications in insulin-dependent diabetes mellitus, N. Engl. J. Med. 329 (1993) 977–986.

[2] R. Bellazzi, C. Cobelli, E.J. Gomez, M. Stefanelli, The T-IDDM project: Telematic management of Insulin Dependent Diabetes Mellitus, in: M. Bracale, F. Denoth (Eds.), Proc. Health Telematics 95, Ischia, Italy, 1995, pp. 271–276.

[3] J.D. Piette, M. Weinberger, S.J. McPhee, The effect of automated calls with telephone nurse follow-up on patient-centered outcomes of diabetes care: a randomized, controlled trial, Med. Care 38 (2) (2000) 218–230.

[4] D.M. Thompson, S.E. Kozak, S. Sheps, Insulin adjustment by a diabetes nurse educator improves glucose control in insulin-requiring diabetic patients: a randomized trial, CMAJ 161 (8) (1999) 959–962.

[5] W.L. Whitlock, et al., Telemedicine improved diabetic management, Mil. Med. 165 (8) (2000) 579–584.

[6] E.D. Lehmann, Application of computers in clinical diabetes care, Diab. Nutr. Metab. 10 (1997) 45–59.

[7] E. Biermann, W. Dietrich, E. Standl, Telecare of diabetic patients with intensified insulin therapy, In: A. Hasman, B. Blobel, J. Dudeck, R. Engelbrecht, G. Gell, H.U. Prokosch (Eds.), Proc. MIE 2000, IOS Press, pp. 327–332.

[8] K.K. Ahring, J.P. Ahring, C. Joyce, N.R. Farid, Telephone modem access improves diabetes control in those with insulin-requiring diabetes, Diabetes Care 15 (8) (1992) 971–975.

[9] A.M. Albisser, R.I. Harris, S. Sakkal, D. Parson, S.C. En Chao, Diabetes intervention in the information age, Med. Inform. 21 (4) (1996) 297–316.

[10] A. Billiard, et al., Telematic transmission of computerized blood glucose profiles for IDDM patients, Diabetes Care 14 (2) (1991) 130–134.

[11] D.G. Marrero, et al., Clinical evaluation of computer-assisted self-monitoring of blood glucose system, Diabetes Care 12 (5) (1989) 345–350.

[12] D.G. Marrero, et al., Using telecommunication technology to manage children with diabetes: the Computer-Linked Outpatient Clinic (CLOC) Study, Diabetes Educ. 21 (4) (1995) 313–319.

[13] N.J. Morrish, D.L. Cohen, B. Hicks, H. Keen, A controlled study of the effect of computer-aided analysis of home blood glucose monitoring on blood glucose control, Diab. Med. 6 (1989) 591–594.

[14] A.M. Rosenfalck, I. Bendtson, The Diva System, a computerized diary used in young type I diabetic patients, Diab. Metab. 19 (1993) 25–29.

[15] E.K. Shultz, A. Bauman, M. Hayward, R. Holzman, Improved care of patients with diabetes through telecommunications, Ann. N.Y. Acad. Sci. 670 (1992) 141–145.

[16] E.J. Gomez, F. Del Pozo, M.T. Arredondo, M. Sanz, E. Hernando, M. Pastor, The use of hand-held devices and pocket computers in diabetes self-care: the DIACRONO experience, MEDICON 92, Italy, 1992-7958-001-9, pp. 915–918.

[17] M. Edmonds, et al., Using the Vista 350 telephone to communicate the results of home monitoring of diabetes mellitus to a central database and to provide feedback, Int. J. Med. Inf. 52 (2–3) (1998) 117–125.

[18] B. Liesenfeld, R. Renner, M. Neese, A. Zimmermann, K.D. Hepp, Telemedical care for children and adolescents with Diabetes Mellitus type 1, Diab. Nutr. Metab. 11 (1998) 63.

[19] E.J. Gomez, F. Del Pozo, M.E. Hernando, Telemedicine for Diabetes Care: the DIABTel approach towards Diabetes Telecare, Med. Inf. 21 (4) (1996) 283–296.

[20] E.J. Gomez, F. Del Pozo, M.T. Arredondo, M. Sanz, E. Hernando, A Telemedicine Distributed Decision-Support System for Diabetes Management, 14th Annual International Conference of the IEEE Engineering in Medicine and Biology Soc., Paris, 1992-CH3207-8, pp. 1238–1239.

[21] http://diabnet.vdirect.com/

[22] The T-IDDM Consortium, User Needs: T-IDDM deliverable 1, http://aim.unipv.it/projects/tiddm/ftp.html.

[23] C. Ambroso et al., T-IDDM functional specification definition: final report, T-IDDM deliverable 2.1, http://aim.unipv.it/projects/tiddm/ftp.html.

[24] E. Hernando, E. Gomez, Patient Unit final report: T-IDDM deliverable 3.2, http://aim.unipv.it/projects/tiddm/ftp.html.

[25] R. Bellazzi et al., Medical Workstation Final Report: T-IDDM deliverable 4.2, http://aim.unipv.it/projects/tiddm/ftp.html.

[26] A. Riva, M. Ramoni, LispWeb: a specialized HTTP server for distributed AI applications, Comput. Networks ISDN Syst. 28 (711) (1996) 953–961.

[27] S. Montani, R. Bellazzi, C. Larizza, A. Riva, G. d'Annunzio, S. Fiocchi, R. Lorini, M. Stefanelli, Protocol-based reasoning in diabetic patient management, Int. J. Med. Inf. 53 (1999) 61–77.

[28] M. Ramoni, P. Sebastiani, The use of exogenous knowledge to learn Bayesian Networks for incomplete databases, in: X. Liu, P. Cohen, M. Berthold (Eds.), Advances in Intelligent Data Analysis, Springer Verlag, Berlin, 1997, pp. 537–548.

[29] S. Montani, R. Bellazzi, L. Portinale, M. Stefanelli, A multi-modal reasoning methodology for managing IDDM patients, Int. J. Med. Inf. 58-59 (2000) 243–256.

[30] R. Hovorka, S. Svacina, E.R. Carson, C.D. Williams, P.H. Sönksen, A consultation system for insulin therapy, Comput. Methods Progr. Biomed. 32 (1996) 303–310.

[31] J.L. Kolodner, Case-Based Reasoning, Morgan Kaufmann, 1993.

[32] R. Bellazzi, C. Larizza, A. Riva, Temporal abstractions for interpreting chronic patients monitoring data Intelligent Data Analysis, Int. J. 2 (1998) 97–122.

[33] C. Cobelli, G. Nucci, S. Del Prato, A physiological simulation model in type I Diabetes, Diab. Nutr. Metab. 11 (1998) 78.

[34] S. Montani et al., Demonstration Phase and Demonstration of the Extensions Final Report, T-IDDM deliverable 6.2 and 11.1, http://aim.unipv.it/projects/tiddm/ftp.html.

[35] S. Pellegrini et al., Final Exploitation plan, T-IDDM deliverable 7.3, http://aim.unipv.it/projects/tiddm/ftp.html.

[36] R. Bellazzi, et al., Multi-access services for diabetes mellitus management: the M2DM project, Diab. Nutr. Metab. 13 (4) (2000) 249.