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Telemedicine: Insulin pump controlled via the Global System for Mobile Communications (GSM)

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Abstract

In the future, the delivery of drugs using telemetric techniques will become more and more important. In the present investigations an experimental insulin pump has been developed which is remote-controlled via a computer program and the Global System for Mobile Communications (GSM). The commands for pump control are transferred in encrypted form via the Short Message Service (SMS). The pump can be programmed in advance for a time period of 24 h. An integrated sensor gives exact information about the number of steps executed by the stepping motor which is controlling the drug release. Model experiments show that there is almost no delay between sending the control SMS and execution of the commands by the pump.

Keywords: Telemedicine; Telepharmacy; Insulin; Drug delivery systems; Infusion pumps

1. Introduction

The concept of telemedicine is to compensate the spatial distance between patient and physician using telecommunication devices. In particular patients suffering from chronic diseases such as diabetes mellitus have been in the focus of new developments in this field. Regarding the therapy of diabetes, a modem has been used to transfer results of measurements of capillary blood glucose concentration to their health care provider. The telemedical care can lead to better glycemic control (Montori et al., 2004) and helps to reduce costs in diabetes therapy (Chase et al., 2003). Therefore, the transmitted data can be used to improve the quality of the patient's treatment and health status. Telemedicine can also be integrated in diabetes education. Telemedicine technology proved to be successful and lead to equally effective results as education in person (Izquierdo et al., 2003).

Another way of telemanagement is the remote control of a drug delivery device such as an insulin pump using a telecommunication system. Our research group has been concerned with the development of small sized insulin delivery systems for several years (Gröning and Walz, 1995; Drengenberg, 2000). Current insulin pumps often suffer from mechanical problems such as pistons stuck in the reservoir. This is due to the fact that in such pumps the stepping motor is the only element providing the required energy for the piston movement (Austenat, 1999). Pump manufacturers often supply the patients with two identical models of their pumps to compensate technical failures. The developed insulin pump uses the stepping motor only as the controlling element while the mechanical energy is provided by a spring integrated into the pump.

2. Materials and methods

2.1. Materials

Insulin for external pumps (H-Tronin 100 for H-Tron Hoechst) was obtained from Hoechst, Frankfurt/M., Germany.

2.2. Description of the insulin pump

In the present investigation a new technique has been developed to control insulin pumps via the Global System for Mobile Communications (GSM). Control commands are transferred in encrypted form via the network provider's Short Message Service Center (SMSC) (Fig. 1). The commands are sent from a

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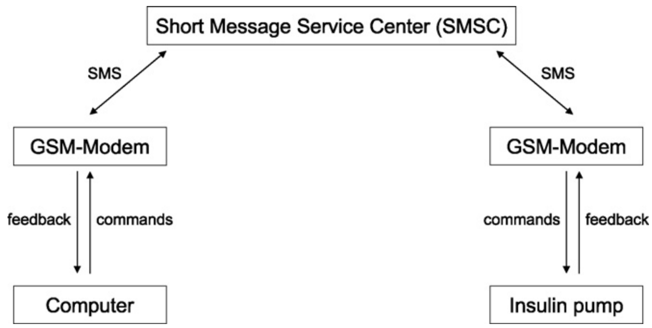

Fig. 1. Functional principle of the computer-based insulin pump control via GSM.

computer which is connected to a GSM-modem. The patient's pump is equipped with a similar GSM-modem. After receiving the command information encrypted in the Short Message (SMS), the modem transmits these signals to a stepping motor which controls the insulin release of the pump. An integrated infrared sensor measures the gear's rotation and thereby the exact number of steps executed by the stepping motor. This information is sent back using a SMS to the computer. The programmed and the obtained insulin release can be controlled.

An experimental insulin pump has been constructed for this investigation (Fig. 2). It consists of an insulin reservoir which can be emptied by a piston. The volume of the reservoir is 300 μl. An infusion set is attached to the front end of the insulin reservoir (Disetronic Set 10, Disetronic, Burgdorf, Switzerland). The piston is connected to a piston rod. The end of the syringe is closed by a stopper with a bore-hole of 3.1 mm in diameter for the piston rod. A steel spring has been installed between the piston connector and the stopper. When the reservoir is filled, the spring is compressed and stores the mechanical energy which is required to release the insulin. Outside the syringe a

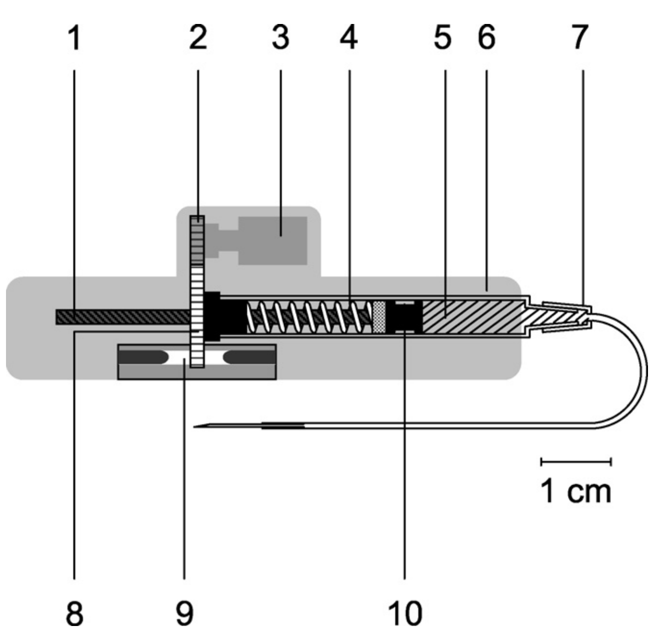

Fig. 2. Schematic diagram of the spring-powered insulin pump: (1) piston rod; (2) gear; (3) stepping motor; (4) spring; (5) insulin reservoir; (6) acryl glass frame; (7) infusion set; (8) gear; (9) infrared detector; (10) piston.

gear (diameter 16.0 mm) is connected to the piston rod. The thread lead prevents the piston rod from moving without additional energy. This additional energy is provided by a stepping motor (No. 740.39.12/480487, Conrad Electronic, Hirschau, Germany) which is installed parallel to the reservoir. A second gear is attached to the motor (diameter 9.0 mm). Rotation of the gears moves the piston forward and thereby releases insulin from the reservoir.

The motor is connected to a circuit board (102.0 mm × 53.0 mm) with a stepping motor controller (L 297/L 298, RS-Components, Mörfelden, Germany). The GSM-modem (A2-3 "Alarm", Falcom, Langewiesen, Germany) is equipped with special software, which controls four digital in and outputs. One of the outputs is connected to the stepping motor controller chip. Energy for both the board and the modem is provided by a power supply (12 V, 300 mA). The infrared detector consists of two elements, the infrared transmitter (OP165D, Conrad Electronic) and the receiver (OP505D, Conrad Electronic). The gear connected to the piston rod is situated in the 14.0 mm space between both elements. The gear has bore-holes in an angle of 60°. This allows counting of the gear's rotation in steps of 60°. The detector's signals are transferred to a binary counter. Eight impulses of the infrared detector correspond to 44 motor steps and the release of 1 I.U. of insulin from the reservoir. Every eighth signal causes a signal from the counter. It is transferred to a digital input of the GSM-modem. Upon receiving a signal on this input the modem sends a SMS to a programmed number containing the information that 1 I.U. of insulin has been released.

2.3. Release experiments

The release rates used in the experiments are based on a basal rate scheme as used for patients changing their therapy to continuous subcutaneous insulin infusion (Disetronic Medical Systems GmbH, 1998). The amount of insulin released is determined by continuous weighing (Tschöpe et al., 1987). Measurements are transferred in regular intervals to a personal computer using a serial cable connection. A GW-Basic computer program has been developed to record the data in a file on the disc drive and in addition as a printout.

3. Results

The computer program used in these investigations is written in Visual Basic (Visual Basic Professional 4.0, Microsoft Corp., Seattle, USA). The program window "Pump Settings" (Fig. 3) allows input of insulin release rates for a maximum of 24 h in an interval of 60 min. In addition, the number of motor steps required for the release of 1 I.U., the planned time period for the release and the pump's phone number must be given to the computer. A plausibility check is made by the software for each time interval. The software calculates the motor steps necessary for the programmed release. An encrypted SMS containing the step interval is sent every 60 min to the pump. In the window "Pump Control" (Fig. 4) the cumulated amount of programmed insulin release and the real amount of insulin released as reported

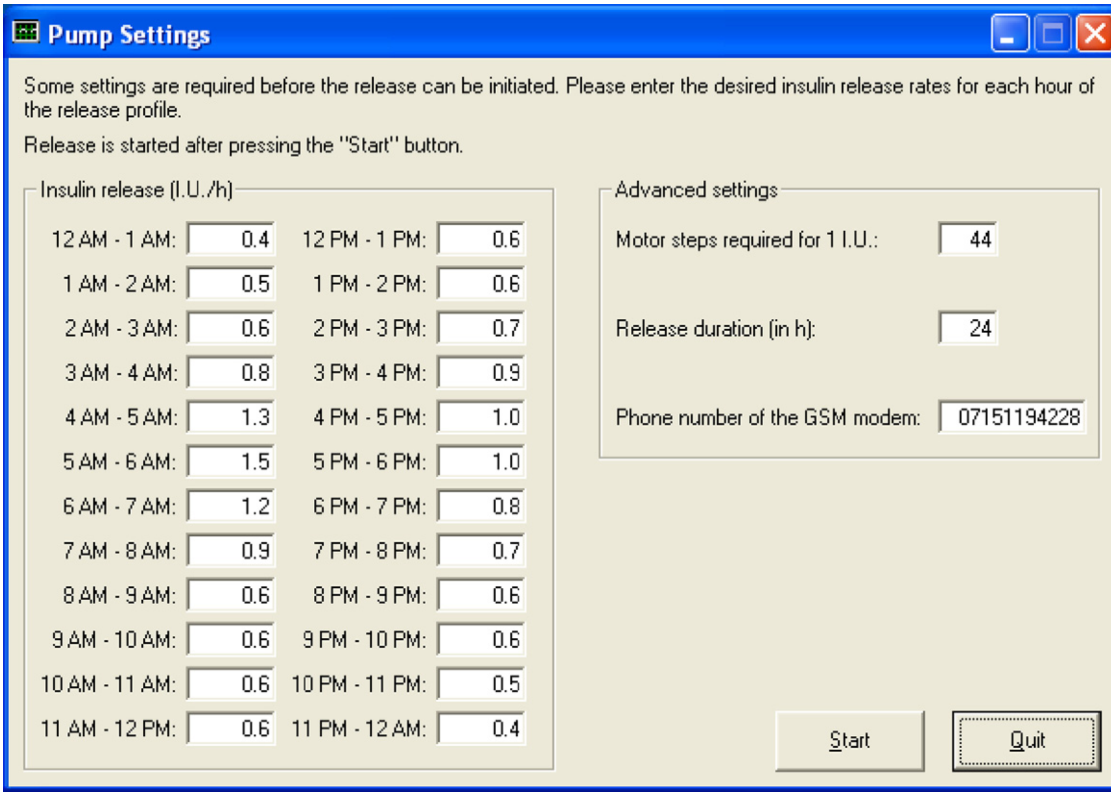

Fig. 3. Program window “Pump Settings”.

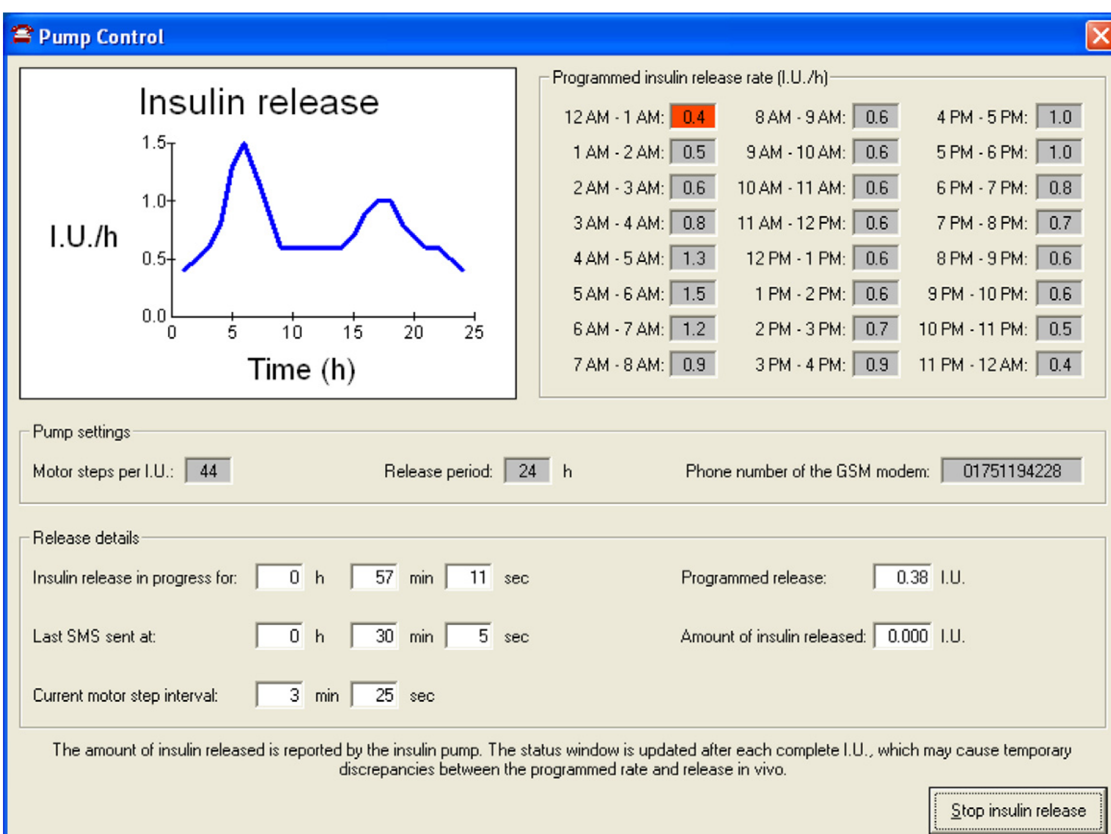

Fig. 4. Program window “Pump Control”.

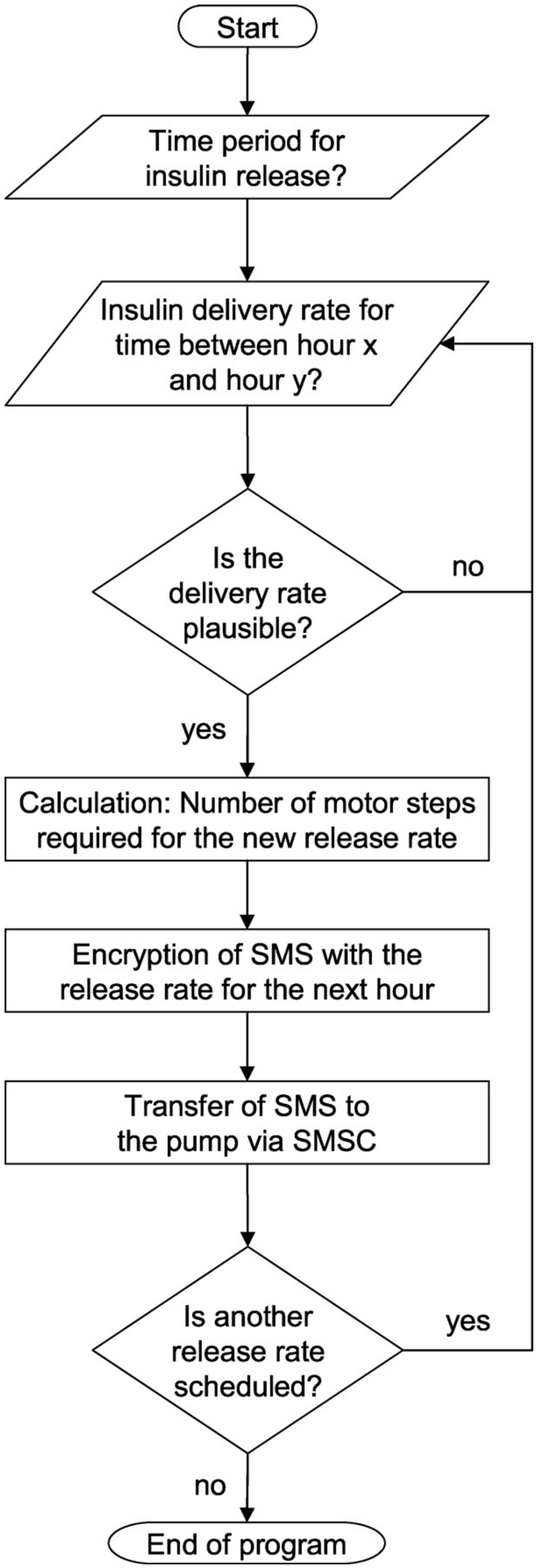

Fig. 5. Flow chart of the steps and actions executed by the Visual Basic program.

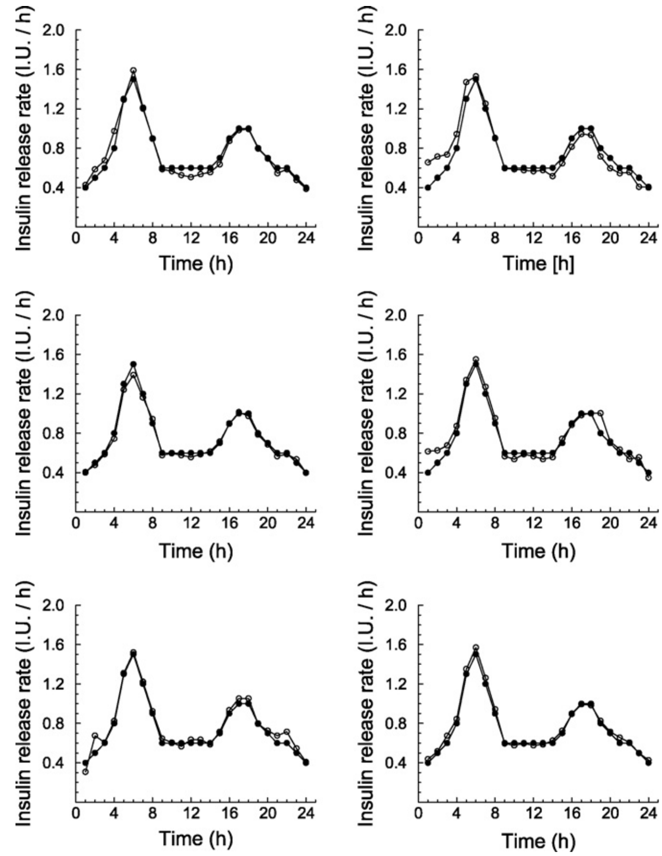

Fig. 6. Remote-controlled insulin release from the experimental insulin pump ($n = 6$: (●), programmed release rate; (○), obtained release rate).

by the pump are displayed. Fig. 5 shows a flow chart of the steps and actions executed by the program.

The release rates are programmed in the Visual Basic program as shown in Fig. 3 and the insulin release is started. Results of the release tests are displayed in Fig. 6. In a time span of 60 min a maximum discrepancy in programmed and obtained release of 2.6 mg/0.26 I.U. can be observed. After cumulating the results of 24 h the discrepancy between the programmed and observed release is 6.9 mg/0.69 I.U. which corresponds to 3.8% of the total amount. The pump releases the insulin according to the programmed profile. Increasing as well as decreasing insulin release rates can be accomplished. Nearly no time delay between the scheduled change of release and the pump's reaction due to the SMS transfer can be observed.

4. Discussion

In the present investigations a new experimental remote-controlled insulin pump has been developed. Today, commercially available insulin pumps are complex technical devices. The handling of the pumps can be a problem, especially for very young or elderly people who have difficulties with programming and using the pump. Therefore, the possibility of external programming and monitoring of insulin pumps may be important to improve the quality of continuous subcutaneous insulin infusion (CSII). A basic release profile can be programmed by a health care provider, e.g. in a diabetes center, and then be transmitted to the pump. The feedback mechanism informs the health care provider about discrepancies in programmed and obtained release of insulin.

The use of SMS as the means of communication between computer and delivery device allows immediate transfer of commands to the pump. The concept of the mechanical energy required for the piston movement coming from the spring and not from the stepping motor only decreases the risk of hyperglycaemia due to a lack of insulin infusion. Security issues will have to be considered in the further development of the pump. An integrated backup mechanism will be necessary to compensate in areas of low GSM network coverage or in cases of network failure. In addition to the plausibility check in the computer software security measures must include a flow-regulating mechanism.

In the future a combination with a continuous glucose monitoring system might be possible. These systems could transfer the data of the measurements to the responsible medical personnel using the pump's GSM-modem. After checking the data the health care provider could change the release profile and send the optimized scheme back to the patient.

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