Automatic Detection of Unintended Indwelling Needle Dislodgement

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Abstract

Introduction: Accidental needle dislodgement during blood purification therapy has become a global problem, occasionally causing fatalities. In this study, we developed a system for automatically detecting indwelling needle dislodgement.

Method: Our system uses electrostatic capacitive coupling that is electrically connected to the dialysis circuit and to the patient's body; hence, it does not require the direct contact of electrodes with blood. Indwelling needle dislodgement was detected according to changes in the impedance between electrodes, and the connection of this system to the hospital LAN allowed the remote monitoring of needle status using network computers.

Results and Discussion: Upon needle dislodgement to one side, the blood pump was immediately stopped, a visual alarm was displayed on the web system, and an audio alarm sounded. In addition, a significant difference between normal and needle dislodgement states was identified using *t* tests. In conclusion, our system may improve the safety of blood purification therapy.

Keywords: Blood purification, Unintended indwelling needle dislodgement, Internet of things

1. Introduction

Because dialysis requires a high blood flow of approximately 200 ml/min, any unintended indwelling needle dislodgement is accompanied by rapid blood loss (Fig.1). In Japan and the United States, unintended needle dislodgement has become more common because of population aging, which results in a greater number of patients experiencing chronic renal failure^(1,2). The number of indwelling needle dislodgements is also increasing in dementia patients^(3,4), despite various safety measures⁽³⁾. Blood purification machines do not have systems for detecting indwelling needle dislodgements, and although disposable, retrofitted blood-leakage sensors are available^(5, 6). These sensors function by sounding an alarm when detecting indwelling needle dislodgement. In addition, by connecting to the dialysis machine, the blood pump can be stopped. However, these sensors cannot remotely identify the patient with needle dislodgement. A study has reported patient discomfort on mounting the sensor⁽⁷⁾. Furthermore, their use is not widespread because of increased costs. Hence, countermeasures using sensors that can be repeatedly used are required. In addition, it is important to notify which patient has taken out an indwelling needle. However, such a system has not been developed so far.

The purpose of this study was to develop a system with internet of things that uses electrodes that do not require blood contact to automatically detect indwelling

needle dislodgement.

Fig. 1. Schematic of the hemodialysis circuit⁽⁸⁾

2. Methods

2.1 Needle dislodgement detection unit and monitoring system

Fig. 2. Block diagram of the needle dislodgement detection system

The block diagram of a needle dislodgement detection unit is shown in Fig. 2. Needle dislodgement detection electrodes were connected to a function generator (2.5 V_{pp}, 10 kHz, sine wave, 33521A; Agilent Technology) with an electrical resistance of 200 k Ω , both ends of which were connected to a transformer (MG-12: TAMURA Corporation), which was connected to an instrumentation amplifier (INA128: Texas Instruments) with V_{in}⁺ and V_{in}⁻ terminals. The voltage drop due to the electrical resistance of the instrumentation amplifier was amplified and then rectified and smoothed, which was then input into the analog pin of a microcomputer (Arduino). Needle dislodgment was detected by changes in the impedance between the electrodes, and the monitoring system was connected to the hospital LAN (including wireless LAN) via the microcomputer to enable the remote monitoring of the needle status (Fig 3, 4.)

The schematic of detection electrodes attached to a

dialysis circuit is shown in Fig. 5. These electrodes (Fig. 5) were in the form of a clip, which were sandwiched onto the arterial (blood collection) and venous (blood return) sides of the dialysis circuit. Thus, no direct contact of the electrodes with blood was required, and these could be repeatedly used.

Fig. 3. Client screen of the needle dislodgement detection system

Fig. 4. Client screen of the needle dislodgement detection system

Fig. 5. Schematic of sensor attachment to the dialysis circuit

2.2 Principle of the detection electrode

Fig. 6. Electrical equivalent circuit

The dialysis circuit comprised an electrical insulator (PVC) with very high electric resistance ($M \Omega$ order). Because electric capacity is dependent on blood circulation, the introduction of air into the circuit following needle dislodgement will decrease this electric capacity, reflecting the low dielectric constant of air (approximately one) relative to that of blood (approximately 80).

As shown in Fig. 5, detection electrodes were attached to the arterial (blood collection) and venous (blood return) sides of the blood circuit at two positions. Hence, the electrodes were connected to the patient via an electrical insulator, such as the blood circuit or the dialysis indwelling needle. Accordingly, an electrical equivalent circuit (Fig. 6) was formed between the two detection electrodes. In this circuit, R was a very large impedance component because of the human body and blood circuit, and C was the capacitance component because of electrostatic capacitance between the electrodes. Because these were connected in parallel, less current flowed into the impedance component; thus, the capacitance component dominated the current value.

Capacitive reactance was expressed using the following equation:

$$X_c = \frac{1}{j\omega C} = -j \frac{1}{\omega C} \quad [\Omega] \quad (1)$$

According to this equation, as the electrostatic capacity C decreases, capacitive reactance also increases

along with a concomitant increase in electrical impedance between the electrodes. The corresponding voltage drop at the load resistance, which is connected in series with the electrode, results in a decreased detection signal output. Thus, by monitoring the detection signal output, this system detects unintended needle dislodgement.

2.3 Experimental method

(a) Needle dislodgement detection and blood pump stop tests

A beaker was filled with physiological saline, which represented the human body. A needle was immersed between the blood collection and blood return sides. A blood pump was used to circulate the saline. The state in which the needle was immersed in both sides was defined as the normal state, whereas that in which one side of the needle was disconnected was defined as the needle dislodgement state (N.D.). Upon needle dislodgement, the blood pump was stopped, and we confirmed whether the web system alert was being properly displayed.

(b) Comparison of the detected signal outputs

Differences between normal and needle dislodgement voltages of the detection circuit were determined using t tests according to the procedure of the experimental part (b) outlined in Fig. 7.

Fig. 7. Procedure for the experimental part (b)

3. Results and Discussion

3.1 Needle dislodgement detection and blood pump stop tests

Fig. 8. Snapshot of the experimental part (a)

Upon needle dislodgement on one side, the blood pump was immediately stopped, a visual alarm was displayed on the web system, and an audio alarm was sounded.

3.2 Comparison of the detected signal outputs

Fig. 9. Sampling frequencies of voltage fluctuation ratios at normal and dislodgement voltages

t tests revealed that voltage fluctuation ratios significantly differed between the normal (0.982 ± 0.011) and N.D. (0.895 ± 0.016) states ($p < 0.01$).

Experiments 3.1 and 3.2 revealed that needle dislodgement immediately sounded the alarm, which allowed the blood pump to be stopped.

Thus, this system may contribute to improve the safety of blood purification therapy.

4. Conclusions

In this study, we developed a system that enables the automatic detection of unintended indwelling needle dislodgement. The present data demonstrate that needle dislodgement was detected with sufficient accuracy under our experimental conditions. Thus, our system can be used

to enhance the safety of blood purification therapy. However, further studies are necessary to determine whether similar accuracy and safety of the circuit can be achieved under clinical conditions. In addition, it was thought that it is necessary for medical staff to evaluate the interface, thereby improving its usefulness.

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