Feasibility of a remote monitoring system for patients with an implantable left ventricular assist device using Personal Handy-Phone System telecommunication technology

Abstract We have been developing a remote monitoring system for patients with implanted artificial hearts. The remote monitoring system consists of two digital data links: an electromagnetic transcutaneous digital-data transmission (TDT) system between an artificial heart controller inside the body and a mobile computer outside the body, and a public high-speed data transmission service using PHS (Personal Handy-Phone System) between the mobile computer and a host computer in a hospital. The TDT system mainly consists of an ASK (Amplitude Shift Keying) circuit with carrier electromagnetic wave frequencies of 4MHz and 10MHz and corresponding demodulation circuit, thin loop coil antennas for transmission and receiving, and a one-chip microcomputer for the alarm system for indicating misalignment of antennas outside the transmittable range to ensure error-free data transmission. In our remote monitoring system, motor current and motor rotational angle data from the implanted controller are framed together by a control code for data error checking and correcting at the receiving site, and the data are sent through the PHS connected to the mobile computer. GPS (Global Positioning System) positioning data are also sent to the host computer with control codes. The host computer calculates pump outflow and arterial pressure and displays the data in real-time waveforms. The host computer also displays the patient’s position on the map and the condition of the batteries. The results of this study showed that the driving condition of the artificial heart and the subject’s position could be remotely monitored on the host computer. It could be concluded that this monitoring system is useful for remote monitoring of patients with an implanted artificial heart.

Key words Artificial heart · VAD · Monitoring · Telecommunication

Introduction

Clinical application of a pulsatile electric implantable left ventricular assist device (LVAD) to support patients with end-stage cardiac disease until a donor heart is available for transplantation has become standard procedure. More than 50% of patients using an implantable LVAD can be discharged to wait at home for transplantation in the United States and Europe. On the other hand, it has been reported that half of the discharged patients have to be rehospitalized due to medical reasons or device-related problems. For patients’ safety, a remote-monitoring system using mobile telecommunication technology is needed for a doctor in a hospital to monitor the condition of an LVAD-implanted patient who is outside the hospital.

We have been developing the remote monitoring system applied mobile telecommunication technology for patients wearing the implantable LVAD. We have already reported the bidirectional telecommunication system between a mobile computer that the patient brings and a host computer in the hospital to transmit LVAD motor position and motor current data using PHS (Personal Handy-Phone System) and to transmit the patient’s position using the Global Positioning System (GPS). PHS is Japan’s original cellular phone system, which serves the world’s fastest mobile communications. The PHS service provides a comfortable mobile computing environment whereby subscribers can use PDAs (Personal Digital Assistants) and notebook PCs (Personal Computers) by connecting them to the PHS network. We have also developed a transcutaneous bidirectional high-speed data transmission system between an LVAD controller and the mobile computer. We have also investigated a method of estimating a patient’s instantaneous blood pressure from LVAD motor current and motor rotational angle using neural networks.
The object of this study is to demonstrate the feasibility of the LVAD remote monitoring system that synthesizes the transcutaneous digital data transmission (TDT) system between the controller inside the body and outside the body, telecommunication applied for PHS between the patient and the hospital, and estimation of blood pressure using neural networks on the host computer in the hospital.

**Methods**

**Outline of remote monitoring system**

The remote monitoring system consists of the LVAD controller implanted in the body, the mobile computer with a PHS terminal, a GPS receiver, cell stations for PHS service, ISDN (Integrated Services Digital Network) telephone line network, and the host computer in the hospital (Fig. 1). The transcutaneous digital data transmission system is responsible for bidirectional communication between the implanted controller and the mobile computer (IBM, ThinkPad 235, USA). The PHS serves as a means of bidirectional communication between the mobile computer carried by the patient and the hospital by digital communication link according to PIAFS (PHS Internet Access Forum Standard). The host computer system consists mainly of a personal computer connected to the NTT ISDN network through a terminal adapter (NEC, Aterm ITX70, and Japan). After establishment of two communication links, the host computer can remotely control the LVAD via the PHS service by transmission requests for motor current and motor rotational angle data, by drive-mode change requests (fixed-rate drive or full-fill full-empty drive), and by drive-rate change requests during fixed-rate driving.

The host computer instantaneously displays motor rotational angle and motor current waveforms on the monitor screen, and it also computes actual driving rate, instantaneous pump outflow, and mean aortic pressures using neural networks that have input data of the motor rotational angle and motor current data.

**Transcutaneous digital-data transmission system**

Figure 2 shows a block diagram of the TDT system and other electronics inside the body. The TDT system mainly consists of an ASK (Amplitude Shift Keying) circuit with carrier electromagnetic wave frequencies of 4MHz and 10MHz and corresponding demodulation circuit, thin loop