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Evaluation of Titanium Mesh Electrode using for Transcutaneous Intrabody Communication by Tissue-Electrode Impedance

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***Abstract*— We developed a new transcutaneous communication system (TCS) that uses the human body as a conductive medium for monitoring and controlling an artificial heart and other implanted artificial organs in the body. The TCS is able to transmit data between everywhere on the surface of the body and everywhere inside the body, however poor contact between tissue and the electrode influences on communication performance. Thus in this study, we have developed a titanium mesh electrode for the internal transmission electrode. The titanium mesh electrode has advantages of histocompatibility and mechanical stable contact to the tissue by infiltration of the tissue into the titanium mesh like as an extracellular matrix. There titanium mesh electrodes were implanted separately into the dorsal region of the rats under the skin and the electrical performance of the titanium mesh electrode was evaluated by means of measuring the electrode-tissue boundary resistance. In vivo experimental results showed that the titanium mesh electrode had stable mechanical contact to tissue and lower electrode –tissue boundary resistance. In conclusion, the titanium mesh electrode showed excellent histocompatibility it realized stable contact to tissue as anchor, and it had superior electrical property. Thus the titanium mesh electrode is suitable for an internal electrode of the TCS to monitor artificial organs implanted into the body.**

I. INTRODUCTION

A transcutaneous communication system (TCS) is one of the key technologies for monitoring and controlling an artificial heart and other artificial organs which are implanted inside the body. The TCS needs to be stable bi-directional communication through the skin without interference from other patients' devices.

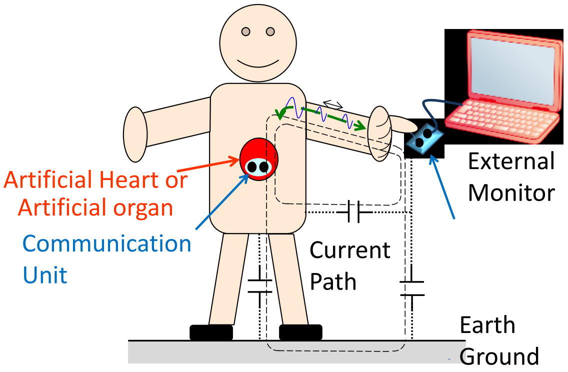

Figure 1 TCS using the human body as a transmission channel for monitoring an artificial heart and other implantable artificial organs

We have developed a new TCS using the body as a conductive medium (figure 1) [1-2]. The TCS has advantages of stable data transmission with tether-free, easy regulation of the telecommunication area around a patient and no interference with those devices in other patients.

Performance of the TCS was evaluated by a communication test in an animal experiment using a waking goat [3]. Three internal communication units were fixed on the pericardium, on the internal wall of the chest cavity, in the abdominal cavity near the left kidney. Three external units were placed on the neck, ear lobe, and horn, respectively. The TCS was able to transmit data concurrently for 4 weeks under full-duplex communication at a transmission ratio of 115 kbps between the external units and the internal units except the unit on the left cavity. While the electrodes on the pericardium and in the abdominal cavity had excellent contact to tissue, the electrode on the internal wall of chest cavity had poor contact with tissue, and poor contact between the tissue and the electrode caused communication fault. Electrical properties between the electrode and tissue or skin influences on communication performance of the transcutaneous communication using human body as conductive medium, and further study is required to improve the contact condition between tissue and the electrode.

A transmission electrode of an external unit is required low impedance between the electrode and the skin in order to reduce electrical loss and then to improve data transmission performance [4]. A transmission electrode of an internal unit is also required low electrode impedance between the electrode and the tissue for improvement of transmission performance. In addition, the transmission electrode of the

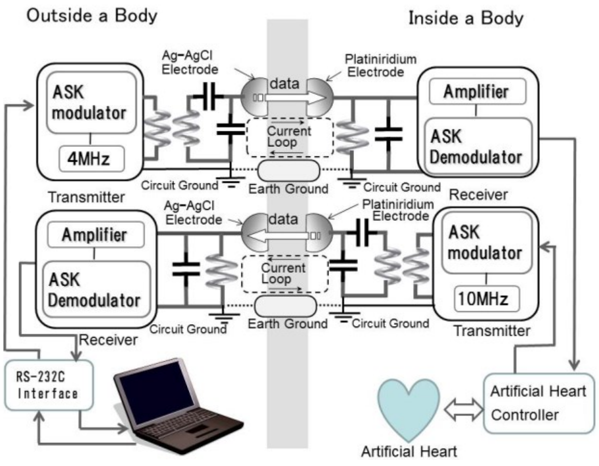

Figure 2 Configuration of the transcutaneous communication system

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internal communication unit is required biocompatibility and long-term electrically and mechanically stable contact to the tissue.

In this study, we investigated a titanium mesh electrode for the internal transmission electrode of the internal unit. The titanium mesh has an advantage of histocompatibility, and it is used for an artificial extracellular matrix in tissue engineering [5]. The purpose of this study is to demonstrate electrical performance of the titanium mesh electrode by measurement of tissue-electrode boundary resistance.

II. MATERIAL AND METHOD

A. Configuration of the Transcutaneous Intrabody Communication System

The TCS mainly consists of an external unit and an internal unit, and each unit of the TCS consists of a data transmitter and a data receiver [1-3] (Figure 2). The data transmitter has an oscillator (carrier frequencies:4 and 10 MHz), an amplitude shift keying(ASK) modulator, an L-C series-parallel resonant interface circuit[2], and an electrode. The data receiver consists of an L-C tuned circuit, an ASK demodulator and an electrode, and resonant frequency of the L-C tuned circuit is tuned into the each carrier frequency in order to receive data current effectively. The TCS transmits data under full duplex communication with a transmission ratio of 115 kbps. While a prototype model of the TCS employs Ag-AgCl electrodes in the external unit, and platiniridium electrodes in the internal unit, further study was required to achieve stable data communication [3].

B. External and Internal Electrode

An electrode of the TCS internal unit is required to be low electrode impedance between the electrode and the tissue, biocompatibility, and long-term electrically and mechanically stable contact to tissue.

An irregularly layered and sintered titanium fibers is known for its good histocompatibility [6]. The titanium mesh which is made of titanium fibers with a diameter of 50μm resulting in a mesh with 86% volumetric porosity is used for not only a percutaneous device [7] but also an artificial extracellular matrix [5, 8] for bone regeneration.

In this study, we devise a titanium mesh electrode for the internal unit (Figure3). Sintered titanium fiber mesh (Hi-Lex Co., Titanium Web Cell-House, Hyogo, Japan) with a volumetric porosity of 87% and a fiber diameter of 50μm is used as an electrode material. The average pore size of the titanium mesh is 200μm. The titanium mesh electrode is disk shaped, with a diameter of 5 mm, a thickness of 1.5 mm.

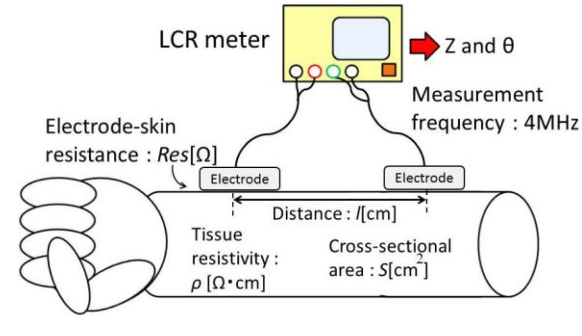


Figure 5 Measurement method of electrode-skin resistance

Figure 3 Titanium mesh electrode for the TCS internal unit

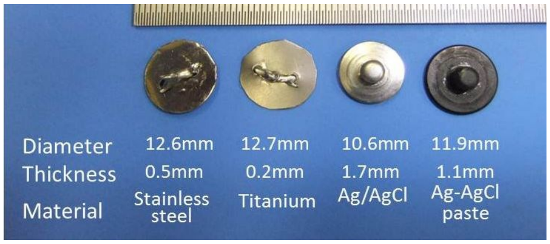


Figure 4 Examined electrodes for the external unit

Also we examined 4 kinds of electrodes for the external unit wearing on the skin: an Ag-AgCl electrode (Lifemed Co., S-30A, Tokyo, Japan), an Ag-AgCl past electrode (Nihon Koden, Bitroad-Bs,Tokyo,Japan),a stainless steel electrode, a titanium electrode shown in figure 4.

C. Measurement Method of Electrode-Tissue Resistance

We measured the electrode-tissue impedance and the electrode-skin impedance using a commercially available LCR meter (Hioki, 3531Z, Nagano, Japan). Principle of the electrode-skin impedance measurement is shown in figure 5[9]. Two electrodes are placed on the arm separating each other by distance *l*. Relationship between the measured electrode-electrode resistance *R* and separation of two electrode *l* is as a following equation,

$$\mathrm{R} = \frac{\rho}{\mathrm{S}} l + \mathrm{Res} \qquad (1)$$

where ρ is resistivity of the tissue, *S* cross-sectional area of the arm and *Res* represents the electrode-skin resistance.

As we measure the electrode- electrode resistance *R* under changing the distance *l*, we can obtain the tissue resistivity ρ and electrode-skin resistance *Res* using the cross-sectional area of arm *S*.

The electrode-tissue resistance *Ret* is obtained by means of the same principle as measurement of the electrode-skin resistance (figure 6). Three titanium mesh electrodes are implanted separately into dorsal region of the rat under the skin. We measure 3 combinations of electrode-electrode resistances *R*, and we can obtain the tissue resistivity ρ and the electrode-tissue resistance *Ret* using the mean cross-sectional area of the rat's body *Sb*.

All procedures in this study were approved by Tokai University Institutional Review Board for Human Research and by Tokai University Institutional Review Board for Animal Care and Use, and they were performed according to the guideline for human research and that for animal experiments of Tokai University.

III. RESULT

A. Measurement results of external electrodes

Figure 7 shows measurement results of relationship between the two electrodes' distance *l* and the resistance *R*. Measurement frequency of the LCR meter was 4 MHz, and we calculated the resistance *R* from measured values of impedance and phase angle. The subject was a health male of 24 years old, and his mean cross-sectional area of the arm was 23.9 cm^2. From gradients of each graph, the tissue resistivity ρ was obtained as 142Ω・cm ～178Ω・cm (table.1), and the value of the measured tissue resistivity ρ is approximate to the reported tissue resistivity value[10].

Values of the electrode-skin resistance *Res* derived from y-intercept of each graph in figure 7 were also shown in table 1. The stainless steel electrode has the lowest value of the electrode-skin resistance and the electrode-skin resistance of the Ag-AgCl paste electrode has the highest value.

B. Measurement results of titanium mesh electrode

Two male rats (300g and 305g, 15 age in weeks) were anesthetized with isoflurane and pentobarbital(40 mg/kg). Three titanium mesh electrodes were implanted under the skin separately into the dorsal region of each rat with distances of *l1*=25 mm and *l2*=40 mm (no_1), and with distances of *l1*=30 mm and *l2*=40 mm (no_2). Average cross-sectional areas of the rats were *Sb*=19.3 cm^2 and 17.3 cm^2 respectively.

The rat's tissue infiltrated into the titanium mesh electrode 30 minutes after implantation, and it showed tight mechanical connection between the electrode and the tissue.

Figure8 shows in vivo measurement results of electrode-tissue resistance *Ret.* Measurement frequency of the LCR meter was 4 MHz, and we calculated the resistance *R* from measured values of impedance and phase angle. We obtained the same relation between the electrode distance *l* and the resistance *R* as figure 7. The tissue resistivity ρ was obtained as 150Ω・cm and 140Ω・cm, and the electrode-tissue resistance *Ret* was obtained as 117Ω and 104 Ω respectively.

IV. DISCUSSION

Intrabody communication using the human body as a transmission medium has been investigated in order to achieve personal area networks for communication between wearable information devices and sensors[11,12], and biomedical applications were also studied[13,14]. We have developed a new TCS using the body as a conductive medium for monitoring and controlling an implantable artificial heart. Using a waking goat, we showed that the intrabody communication can transmit data bi-directionally between everywhere on the surface of the body and everywhere inside the body without any adverse effect on the heart [3, 15].

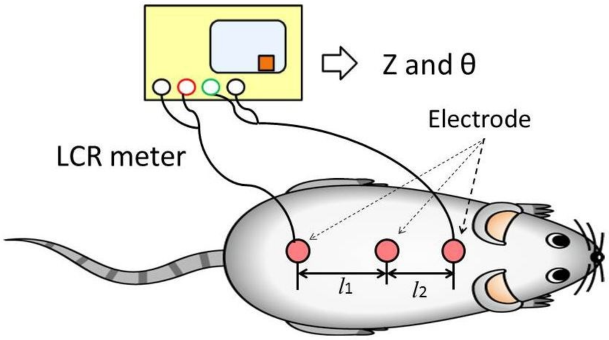


Figure 6 Measurement method of electrode-tissue resistance

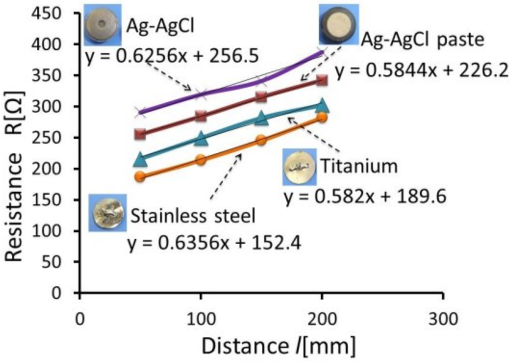
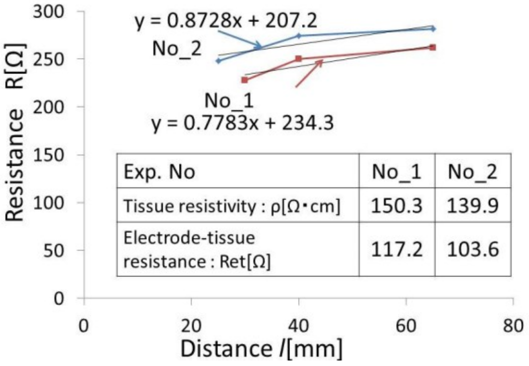


Figure 7 Measurement results of electrode – electrode resistance

Table 1 Tissue resistivity of arm and electrode-skin resistance

Electrode	Stainless steel	Titanium	Ag-AgCl	Ag-AgCl paste
Body tissue resistivity : ρ[Ω・cm]	157.9	145.8	177.9	142.2
Electrode-skin resistance : Res[Ω]	76.2	94.8	128.2	113.1



Exp. No	No_1	No_2
Tissue resistivity : ρ[Ω・cm]	150.3	139.9
Electrode-tissue resistance : Ret[Ω]	117.2	103.6

Figure 8 measurement results of electrode-tissue resistance

However the *in vivo* experimental results showed that contact condition between the electrode and tissue or skin influences communication performance [3] .

A transmission electrode is required low electrode-skin or tissue impedance in order to reduce electrical loss and to improve data transmission performance [4]. Furthermore, a transmission electrode of an internal unit is required to be biocompatibility and long-term electrical and mechanical stability of the electrode-tissue contact condition.

In this study, we devise a titanium mesh electrode for the internal unit (Figure3). Sintered titanium fiber mesh with a volumetric porosity of 87% and a fiber diameter of 50μm was showed good histocompatibility [5] and excellent sessile to the tissue, and it has been used for an extracelluer max to regenerate bone.

We have already developed a conventional measurement method to measure electrode-tissue or skin boundary impedance [9], and in this study we evaluated the titanium mesh electrode by means of measuring the electrode-tissue resistance. Wegmueller et.al already reported measurements of the electrode's resistance to select an optimum electrode for intrabody communication [13], but they did not take account of the electrode-skin boundary resistance. L.Rubin measured a titanium mesh electrode resistance in vivo [16], however value of resistance that they reported was the sum of the tissue resistance and the electrode-tissue boundary resistance. Thus there has been no report to measure the tissue resistance and the electrode-tissue resistance separately.

From the results of this study, the stainless steel electrode has lower electrode-skin resistance than electrode-tissue resistance of the titanium mesh electrode. However conductance per unit area of the electrode-tissue of the titanium mesh electrode (0.04 $1/\Omega\cdot\text{cm}^2$) is bigger than that of the stainless electrode (0.01 $1/\Omega\cdot\text{cm}^2$). In addition, the titanium mesh electrode has porous structure and the structure was suitable for invasion of cell into the electrode. Thus it achieves mechanically stable anchor between the electrode and the tissue.

Further study is needed to evaluate long-term electrical characteristics of the titanium mesh electrode in vivo comparing with other metallic electrodes. Also mechanical performance of the titanium mesh electrode should be evaluated in tissue of a chest cavity of a goat. But from results of this study, titanium mesh electrode is promising to be a suitable internal electrode for the internal communication unit of intrabody communication.

V . CONCLUSION

In this study, we devise a titanium mesh electrode for the internal unit. The titanium mesh electrode showed excellent histocompatibility and it realized stable contact to tissue as an anchor, and it had superior electrical property.

While long-term evaluation by an animal experiment is required, the titanium mesh electrode is suitable for the internal electrode of the TCS internal communication unit.

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