Noninvasive Brain Pathology Monitoring Using Admittance Measurement: A Preliminary Study

P. Yambangyang[(1)], *C. Neatpisarnvanit*[(2)]
[(1)]*Biomedical Engineering Programme, Faculty of Engineering, Mahidol University, Salaya Campus*
[(2)]*Department of Electrical Engineering, Faculty of Engineering,* Mahidol University, Salaya Campus

ABSTRACT - Intraventricular catheter is a device, which is used to measure the intracranial pressure (ICP) in brain pathology. However, the use of this device is invasive, and there is a risk of infection [1]. This paper presents a preliminary study investigating the possibility of using the admittance (the inverse of impedance) measurement technique to monitor the ICP or brain pathology. The main aim of this research is to study how volume variation of fluids (brain's fluids) in a rigid model (the skull) affects the electrical admittance picked up by surface electrodes. The model representing the human's brain consists of three layers of constant resistivity materials. These materials are designed to represent gray matter, soft tissue, and cerebrospinal fluid (CSF) in the brain [2]. Skins and bony structures around the skull are intentionally omitted in this study to simplify the rigid model construction. The resistivity of these layers is 300, 500 and 65 Ω•cm, respectively. Based on experimental results, we observe that the admittance of these three layers vary proportionally with the increasing volume, i.e. pressure, in the rigid model. Furthermore, the measured admittance also depends on frequency and magnitude of the electrical current flowing through the rigid model. The results suggest that it may be possible to monitor the changing pressure in the brain by measuring bioelectrical admittance via electrodes placed on the skull.

KEY WORDS – Admittance measurement, Intracranial pressure, Noninvasive monitoring.

บทคัดย่อ - Intraventricular catheter เป็นเครื่องมือที่ใช้ในการตรวจวัดความดันในสมอง (ICP) ของผู้ป่วยที่มีสภาวะเป็นโรคทางสมอง อย่างไรก็ตามวิธีนี้เป็นการวัดแบบลุกล้ำในร่างกาย ซึ่งจะเสี่ยงต่อการติดเชื้อ บทความนี้นำเสนอการทดลองเบื้องต้นในการหาความเป็นได้ของการใช้การวัด Admittance ในการเฝ้าติดตามค่าความดันในสมองของผู้ป่วย หรือสภาวะความเป็นโรคของสมอง จุดประสงค์หลักของงานวิจัยนี้ เพื่อที่จะศึกษาผลกระทบของการเปลี่ยนแปลงของปริมาตรของ ของเหลวที่อยู่ในแบบจำลองที่มีปริมาตรจำกัด ต่อค่า Admittance อย่างไร โดยการใช้อิเล็กโทรดติดที่ผิวหนัง แบบจำลองนี้จะเป็นตัวแทนของสมองคน ซึ่งจะประกอบด้วยชั้นของวัสดุที่มีสัมประสิทธิ์ความต้านทานทางไฟฟ้าจำนวน 3 ค่า ซึ่งชั้นวัสดุเหล่านั้นจะเป็นตัวแทนของ gray matter, soft tissue และ CSF ของสมอง เพื่อให้เกิดความง่ายต่อการสร้างแบบจำลอง เราได้ละเลยค่าความต้านทานของ ผิวหนังและกะโหลกศีรษะ ค่าสัมประสิทธิ์ความต้านทานไฟฟ้าทั้ง 3 ค่า คือ 300 500 และ 65 โอห์ม.เซนติเมตร จากการทดลองเราพบว่าค่า Admittance ของแบบจำลองมีการเปลี่ยนแปลงเป็นสัดส่วนกับการเพิ่มขึ้นของปริมาตรของสารละลายในแบบจำลอง นอกจากนี้ค่าของ Admittance ยังขึ้นอยู่กับค่าของความถี่ และขนาดกระแสที่ไหลผ่านแบบจำลอง จากผลการทดลองแนะได้ว่า มีความเป็นไปได้ที่จะติดตามการเปลี่ยนแปลงของความดันในสมองโดยใช้วิธี Admittance ผ่านทางอิเ็กโทรดที่ติดที่ผิวหนัง

คำสำคัญ – การวัดความนำทางไฟฟ้า, ความดันในสมอง, การเฝ้าระวังแบบไม่ลุกล้ำ.

1. Introduction

Brain pathology, e.g. edema, hematoma, and hydrocephalua, usually involves the accumulation of fluid in brain. The skull is a rigid volume containing brain's tissues and fluids. In general, the skull has a volume of about 1650 ml, which consists of 150 ml of blood volume, 150 ml of CSF, and other fluids [1]. When the fluid's volume inside the brain is increased, the building up of pressure called ICP inside the brain is inevitable. In general, the ICP will be compensated by the decreasing of the CSF volume. However, this compensation is limited at a certain range of ICP levels. When the ICP level increases beyond the safe limit, a dangerous situation, i.e. the cerebral ischemia, will be a consequence [3].

Conventional method for ICP monitoring required surgical procedures, which are accompanied by an increased risk of infection. A non-invasive technique could make it possible to monitor ICP more easily and repeatedly in patients with a variety of neurosurgical conditions, thus aiding clinical management and reducing the mortality and morbidity related to neurological disease.

In the past, ICP monitoring was performed by invasive methods, such as intraventricular device. The catheter is surgically inserted into the brain. The transducer built-in at the tip of the catheter converts the pressure into an electrical signal [1]. The drawbacks of this method are that it requires surgery, and there is a risk of infection. For these reasons, non-invasive method becomes necessary.

Transcranial doppler ultrasonic is a noninvasive technique, which can measure the cerebral blood flow (CBF). However, the doppler velocities may be altered by several factors, including the angle of insonation of the artery, the diameter of the vessel and other variables that influence the CBF. Moreover, this technique is expensive [1].

Bioelectrical impedance measurement is quick, portable and inexpensive. Impedance is inversely proportional to the volume of the conductor through which a current passes [3]. Bioelectrical impedance is widely used to investigate volume change in various parts of human body.

The hypothesis of this paper is built upon the following ideas. The relationship between pressure and impedance (or, inversely, the admittance) is indirect. The changed volume in the brain generates pressure. The result of these changing also causes changing of tissue's impedance [5]. The pressure may be related to these properties. The brain's impedance variation can be measured by applying a 1-2.5 mA, at 50 Hz, alternating current through the brain via two electrodes, whereas another pair of electrodes records the measured voltage. In normal operation, only 15% of the applied current can penetrate through the skull [3]. The skull not only attenuates the amount of the applied current, but also reduces the signal from an expected impedance change in the brain. The hypothesis of this study is that a changed volume in brain will affect the electrical impedance. This variation can be measured by impedance or admittance technique.

The proposed study is to investigate the effects of fluid's volume variation in a rigid model on electrical admittance. This study is expected to be a preliminary study for the design of brain pathology monitoring systems using admittance measurement, in the near future.

2. Method

2.1 Experimental Setup

The measurement system is shown in Fig. 1. The system consists of constant resistivity model, signal conditioning circuitry, and measuring equipment. The model is fabricated using three layers of constant resistivity materials. The resistivity values of these layers are 300, 500, and 65 Ω•cm representing gray matter, soft tissue and CSF inside the brain, respectively [2].

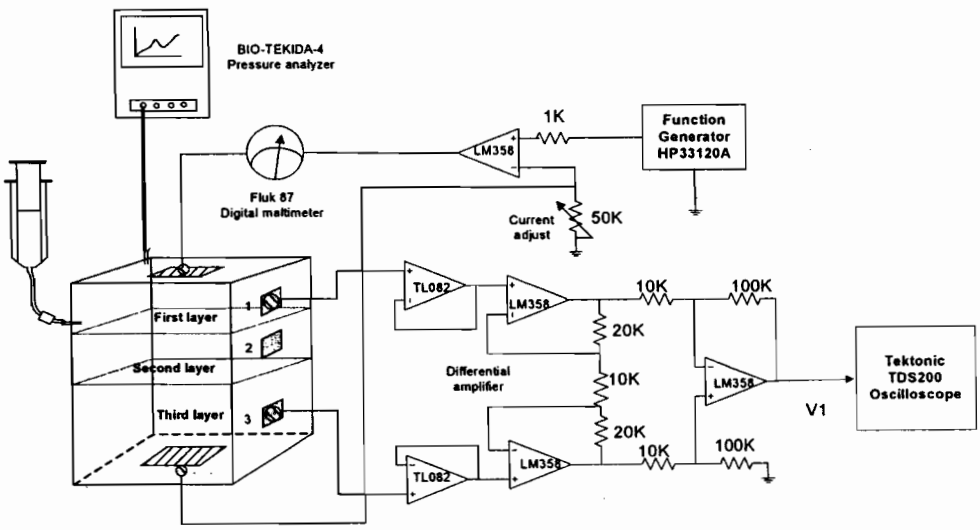


Figure 1. Experimental setup

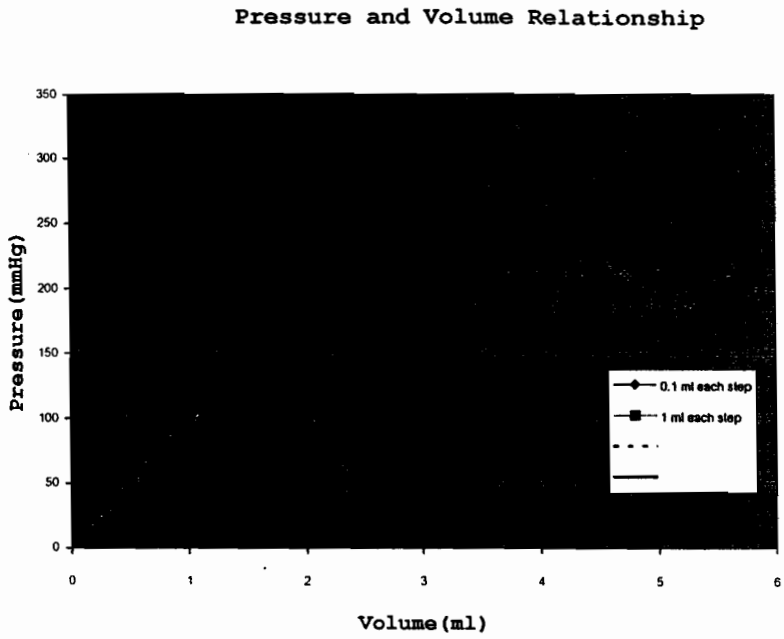


Figure 2. Measured pressure and volume relationship performed at 0.1 ml and 1 ml steps.

The constant conductivity materials were prepared from saline solution with known conductivity. The saline was prepared from sodium chloride and deionization water. There are three saline layers. The conductivity of these layers were measured at 15.2×10^{-3}, 2×10^{-3} and 3.33×10^{-3} S/cm respectively. The concentration of saline is 0.0276 molar at 680 ml, 0.034 molar at 920 ml, 0.159 molar at 628 ml corresponding to gray matter, soft tissue and CSF layers. Conductivity meter (Inolap cond level 2, Model Tetracon 326) was employed to confirm measured conductivity values of each saline solution. Five grams of agar powder was added into those saline solutions. The saline with agar powder prepared in the previous processes was cooked to form the layers (second and third layers). This technique has been used by *Supan el at* for the measurement of swine myocadial [7].

2.2 Experimental procedure

There are two experiments in this study. The first experiment was to determine the relationship between volume and pressure in the rigid chamber. Measurement was performed on constant conductivity layers. The saline was injected into the model by a syringe pump to represent the increasing pressure, while the pressure was observed. There are two experimental sessions. First, we varied the saline injections from 0 ml to 1 ml at 0.1 ml stepwise. Second, we varied the saline injections from 0 ml to 5 ml at 1 ml stepwise. Pressure analyzer was used to record the changing pressure levels in both sessions.

In the second experiment, measurement was performed to establish the relationship between injected saline's volume (i.e. chamber's pressure) and admittance, picked up by the surface electrodes, in the rigid chamber. The measurement was performed by applying different alternating current values of 1 mA, 2 mA, 5mA, and 10 mA at various frequencies 1 kHz, 10 kHz, 50 kHz, and 100 kHz. The amplitude of signal measured by the oscilloscope was limited at 1 Vp-p. The saline solution used in this experiment is the same saline solution as in the first experiment. The solution was injected into the chamber from 0 ml to 5 ml at 1 ml stepwise. The oscilloscope was used to measure the voltage, which is detected by an instrumentation amplifier.

3. Experimental Results

Figure 2 illustrates that volume and pressure relationship in the rigid model is proportional. This result also indicates that the change in fluid volume of 0.1ml will cause change in pressure of 12 mmHg.

Table 1 summarizes admittance magnitude of the rigid model (the ratio of constant effective current flowing through the rigid model and measured effective voltage picked up by the electrodes) at different frequencies (1kHz, 10 kHz, 50 kHz, and 100 kHz) and different current levels (1 mA, 2 mA, 5 mA, and 10 mA). Figure 3 shows the magnitude of the admittance measured 1 kHz. By comparing all admittance values in Table 1, this 1 kHz frequency gives the best relationship between the admittance and the chamber's volume (i.e. pressure), especially at 1 mA constant current level.

4. Discussion

Based on the proposed hypothesis, it was assumed that the fluid's volume variation effects pressure and, consequentially, the admittance of a rigid model. The first experiment attempted to find the correlation between volume

and pressure. The obtained results from the first experiment show that the relationship between volume and pressure is proportional and linear. The results also indicate that an increase in fluid volume of 0.1ml causes an increase in pressure of 12 mmHg. These finding imply that the small variation of volume can induce a considerable amount of pressure in the rigid model. Compliance parameters of constant conductivity materials are also important factors in this experiment. However, the compliance parameter used in these experiments is dictated by the compliance of the agar. This means that the three layer materials' compliance parameters are fixed to the agar's compliance value.

The second experiment was to investigate the effect of fluid's volume variation of a rigid model on electrical admittance. The results show that the admittance would increase, if the volume of fluid or injected saline were increased. The admittance varies proportionally with the volume of injected saline. The measurement of the acquired admittance was performed to determine the effect of changing volume on layers' admittance while adding the constant concentration saline (to simulate increasing CSF) in the rigid model. To search for a suitable relationship between volume in the rigid model and the admittance, the measurement was performed with various the frequency and current levels.

The results indicate that the measured admittance not only depends on the frequency, but also the current used in the measurement. Moreover, the admittance also depends on ion concentration and fluid's volume [6]. These findings lead to a conclusion. The admittance in the rigid model varies proportionally with the increasing volume, when the concentration of the saline solution is constant. In general, a human body maintains electrolyte concentration at the equilibrium level (such as sodium and potassium pump). This fact is also true in the case of hematoma, edema and hydrocephalus where the accumulation of CSF in the brain exists.

5. Conclusions

Based on experimental results, we observe that the admittance of these three layers vary proportionally with the increasing volume, i.e. pressure, in the rigid model. The increasing volume (i.e. pressure) can be measured indirectly via the admittance by using the four-electrode method. Furthermore, the measured admittance also depends on frequency and magnitude of the electrical current flowing through the rigid model. The experimental results suggest that it may be possible to monitor the changing pressure in the brain by measuring bioelectrical admittance via electrodes placed on the skull. The ability to conduct electrical current in any fluid depends on concentration and the amount of ions in the fluid itself. These factors influence the admittance of the rigid model. There exists some forms of brain diseases involving the accumulation of fluid in the brain, e.g. edema, hematoma, and hydrocephalua. In these cases, we believe that the proposed approach may be applied to detect or monitor these brain diseases.

References

[1] Zeev Feldman and Raj K. Narayan, *Head Injury, Third Edition,* "Intracranial Pressure Monitoring: Techniques and Pitfalls," pp. 247-272.

[2] Vries P. M. J. M de, Meijer J. H., Vlaanderen K., Visser V., Oe P. L, De P. L, Donker A. J. M and Schneider. H., "Measurement of Transcellular Fluid Shift During Haemodialysis," *Medical & Biological Engineering & Computing*, 1989, vol. 27, pp. 152-158.

[3] Barbara E. Lingwood, Kimble R. Dunster, Paul B. Colditz, Leigh C. Ward, "Noninvasive Measurement of Cerebral Bio-impedance for Detection of Cerebral Edema in the Neonatal Piglet," *Brain Research*, 2002, vol. 945, pp. 97-105.

[4] Lee E. Baker, "Application of the Impedance Technique to the Respiratory System," *IEEE Engineering in Medicine and Biology Magazine*, March 1968, pp. 50-52.

[5] Schoeller D. A., Kushner R. F., "Determination of Body Fluids by the Impedance Technique," *IEEE Engineering in Medicine and Biology Magazine*, March 1989, pp. 19-21.

[6] Max E. Valentinuzzl, Julio C. Spinlli, "Intracardiac Measurements with the Impedance Technique," *IEEE Engineering in Medicine and Biology Magazine*, March 1989, pp. 27-34.

[7] Jang-Zern Tsai, James A. Will, Scott Hubbard-Van Stelle, Hong Cao, Supan Tungjitkusolmum, Young Bin Choy, Dieter Haemmerich, Vicken R. Vorporian, John G. Webster, "In Vivo Measurement of Swine Myocardial Resistivity," *IEEE Trans. on Biomed. Eng.*, 2002, vol. 49, pp. 472-482.

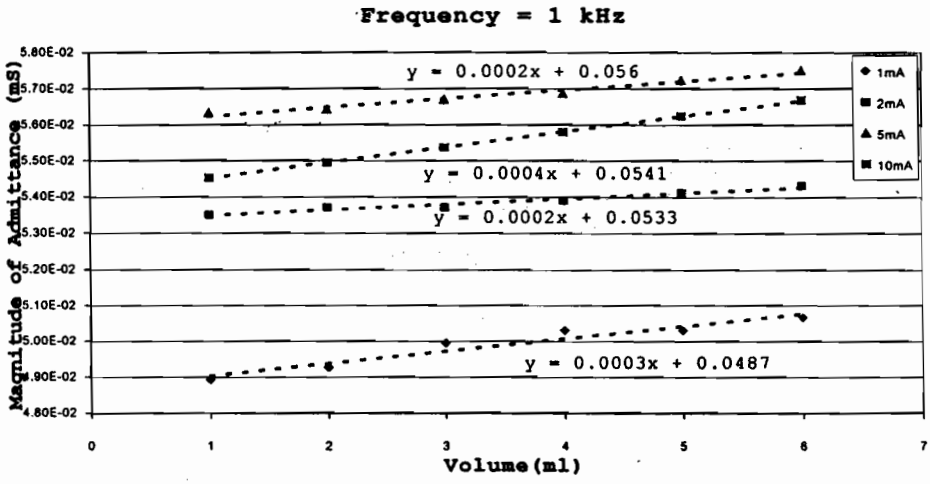


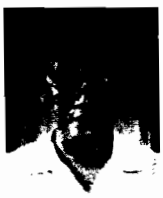
Figure 3. Relationship between admittance and volume at 1 KHz

Table 1 The experimental results performed at various frequency and current values

	Admittance (mS) at 1 kHz				*Admittance (mS) at 10 kHz*			
Volume (ml)	1mA	2mA	5mA	10mA	1mA	2mA	5mA	10mA
0	4.89E-02	5.35E-02	5.63E-02	5.45E-02	3.97E-02	4.79E-02	5.56E-02	5.76E-02
1	4.93E-02	5.37E-02	5.64E-02	5.49E-02	3.95E-02	4.81E-02	5.58E-02	5.76E-02
2	5.00E-02	5.37E-02	5.67E-02	5.54E-02	3.92E-02	4.88E-02	5.59E-02	5.76E-02
3	5.03E-02	5.39E-02	5.69E-02	5.58E-02	3.95E-02	4.89E-02	5.60E-02	5.81E-02
4	5.03E-02	5.41E-02	5.72E-02	5.62E-02	3.99E-02	4.91E-02	5.61E-02	5.81E-02
5	5.07E-02	5.43E-02	5.75E-02	5.67E-02	4.01E-02	4.94E-02	5.62E-02	5.81E-02

	Admittance (mS) at 50 kHz				*Admittance (mS) at 100 kHz*			
Volume (ml)	1mA	2mA	5mA	10mA	1mA	2mA	5mA	10mA
0	1.52E-02	2.71E-02	4.48E-02	5.29E-02	7.50E-03	1.13E-02	2.86E-02	3.70E-02
1	1.53E-02	2.72E-02	4.50E-02	5.33E-02	7.50E-03	1.13E-02	2.88E-02	3.72E-02
2	1.53E-02	2.73E-02	4.53E-02	5.49E-02	7.53E-03	1.13E-02	2.88E-02	3.74E-02
3	1.54E-02	2.74E-02	4.53E-02	5.62E-02	7.55E-03	1.14E-02	2.90E-02	3.88E-02
4	1.54E-02	2.74E-02	4.54E-02	5.67E-02	7.57E-03	1.14E-02	2.90E-02	3.88E-02
5	1.55E-02	2.76E-02	4.56E-02	5.67E-02	7.61E-03	1.15E-02	2.90E-02	3.90E-02

P.Yambangyang was born in Samutsakhon province, in 1973. He received the B.S.Tech.Edu. (Electrical Engineering) degree from King Moungkut's of Technologly North Bangkok (KMITNB) in 1998. He is currently an M.Eng (Biomedical Engineering) student in the Biomedical Engineering Program, Facultly of Engineering, Mahidol University and also works on the Biomedical Instrument Department, faculty of medicine, Siriraj Hospital. His research interests include finite-element modeling, bioelectrical impedance measurement and bioelectrical instrumentation.



Chatchai Neatpisarnvanit recieved the B.Eng. degree in electrical engineering from Chulalongkorn University, Bangkok, Thailand, in 1991, and the MS and Ph.D. degrees in electrical engineering from University of Pittsburgh, Pittsburgh, PA, in 1995 and 2000, respectively. He joined Mahidol University, Nakorn-Prathom, Thailand, in September 2000, where he is currently an instructor in the department of electrical engineering. His research interests include biomedical signal processing, system identification, and nonlinear system theory.