International Journal on Magnetic Particle Imaging
Vol 6, No 2, Suppl 1, Article ID 2009074, 3 Pages

Proceedings Article

MPI based intracranial pressure (ICP) monitor for hydrocephalus patients

M. Sener[1,3,*] · B. O. Gurses[2] · O. Akbulbul[3] · T. Turhan[4] · A. Baltaci[2]

[1]Incensus Mechatronics, Izmır, Turkey
[2]Mechanical Engineering Department, Ege University, Izmir, Turkey
[3]Graduate School of Natural and Applied Science, Ege University, Izmir, Turkey
[4]Neurosurgery, Ege University, Izmir, Turkey
[*]Corresponding author, email: mert@incensus.co

Abstract

Intraventricular shunts are the conventional medical devices for the treatment of hydrocephalus. The most common and life threatening complication of the implanted devices is the probability of the blockage or the misalignment of shunts after the implantation procedure. The most common way to diagnose these complications is the application of Computed Tomography. Unfortunately, frequent exposure to x-ray radiation can have degrading effects such as memory loss, stroke-like symptoms, poor brain function and even it can lead to cancer. In this study, an elastic capsule filled with super paramagnetic iron oxide nanoparticles is used for the measurement of the intracranial pressure (ICP). The diameter of the capsule is measured by the magnetic particle imaging method (MPI). The performance of the proposed method is evaluated with a Matlab/SIMULINK model.

I Introduction

Cerebrospinal fluid (CSF) is a transparent, colorless fluid that circulates through brain ventricles, cranial and spinal subarachnoid spaces. In addition to providing hydromechanical support in the brain, it plays an important role in neural metabolic activity [1]. The production of CSF in the body is about 0.5 ml per minute [2]. Problems may occur in the circulation of this continuously produced fluid in the intracranial space. This causes local accumulation of fluid and the ICP increases. This condition is described as hydrocephalus in medical literature. Hydrocephalus can be diagnosed with Computed Tomography (CT), Magnetic Resonance Imaging (MRI) or telemetric devices. Because of malfunction of electronic devices in the intracranial space or long imaging time of MRI system, CT scan is preferred to diagnose hydrocephalus especially in the emerging situations. The criteria of the diagnosis of hydrocephalus are dilation of the frontal horns of the lateral ventricles, the third ventricle and the temporal horn periventricular lucency and the Evans' index (the ratio of maximum width of the frontal horns of the lateral ventricles and the maximal internal diameter of the skull) being greater than 0.3 [2], [3]. In this condition, excess of this fluid in the brain must be removed from the effected ventricular space. The ventriculoperitoneal (VP) shunt which draining excess of CSF from brain's ventricles to peritoneal cavity was developed [4]. However, these devices are in the class of medical devices that are most prone to cause problems during and after the placement surgery. In pediatric patients, the probability of failure is 30-40 % in 1 year and 50 % in 2 years [5]. In order to observe the increased ICP due to such complications, the patient is exposed to X-ray many times during her/his life time. In pediatric patients, giving a cumulative dose of Cerebral CT scans of about 50 mGy can triple the risk of leukemia, and about 60 mGy can triple the risk of brain cancer [6]. In this

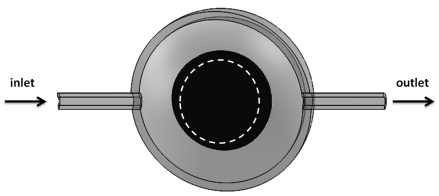

Figure 1: Magnetic capsule.

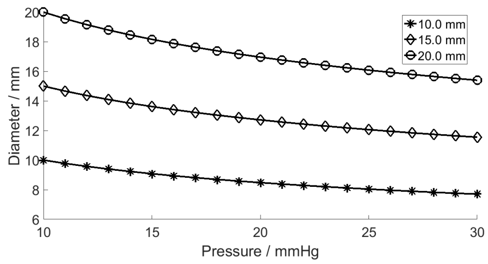

Figure 2: Diameter changes between pressure change according to initial diameter.

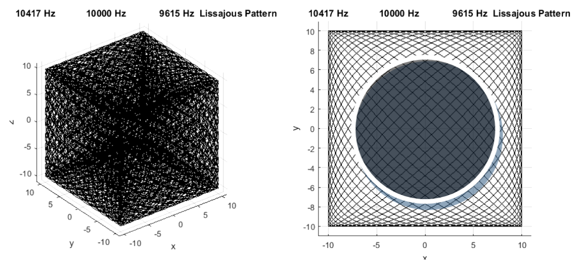

Figure 3: Lissajous curve and magnetic capsule which has a diameter of 15mm are represented in the 20x20 mm FOV.

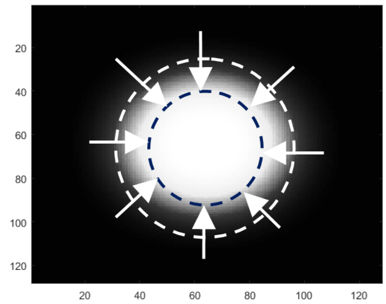

Figure 4: Diameter change of MPI images from 10mmHg to 20mmHg for 15mm diameter.

study, an MPI based pressure measurement method is proposed for the monitoring of ICP. MPI is a tracer based imaging modality and particle concentration inside the workspace can be quantified with electromagnetic fields [7]. MPI system has advantages like high scanning rate, high sensitivity, no tissue background, and lack of ionizing radiation. With these advantages, MPI is a good candidate for hydrocephalus patients who have to be exposed to x-rays frequently during their life time [8] [9]. Pressure changes in the intracranial space can be observed with a capsule in a chamber that can be attached to the shunt with the help of MPI without ionizing radiation. In the proposed methods, a capsule filled with a predefined amount of magnetic nanoparticle is placed inside chamber. The pressure rise in the intracranial space induces a volume change in the capsule. This volume change has a strong effect on the concentration of magnetic nanoparticles which can be monitored by the magnetic particle imaging system [10].

II Material and methods

A constrained body is connected to the intraventricular shunt. The magnetic capsule contains a silicon capsule with a precise amount of SPION. It has one inlet and one outlet to transfer CSF to the distal end of the shunt. When the fluid flows inside to the constrained body, the diameter of the capsule changes according to the pressure of the fluid.

Pressure change affect the diameter of gas capsule which contains SPIONs. Silicone based magnetic capsule which made of RTV silicone will mixed with SPIONs. After the mixture will shaped to the spherical form and it is mounted to reservoir of the VP shunt. The volume change of the capsule, which contains a certain amount of air, changes the concentration. When the pressure increase, volume of the gas bubble decrease. This pressure and volume relation can be defined by polytropic process. In this process, there is no heat transfer occurs across the boundary.

$$PV^n = P_2 V_2^n = \text{constant} \tag{1}$$

In the Equation (1), P represents pressure, V volume and n is a polytropic index (1.4 for air) [11]. ICP magnitudes in healthy humans are in the range of 7-15 mmHg [12]. In hydrocephalus patients, a pressure above 15 mmHg can be considered as mild increase, above 20 mmHg is abnormal and above 25 mmHg needs to be start medical treatment [13]. The volume change in the capsule due the pressure rise can be calculated by the Equation (1). Calculations and simulations of pressure changes and visualization of the concentration are set up in the MATLAB/Simulink.

Field of View (FOV) of workspace is selected 20x20 mm, as a Lissajous curve. Lissajous curve density which means maximum distance between two points is 267μm. For 10 kHz excitation field, repetition time is 31.2 ms.

The response of SPIONs is modelled with a Gaussian function and the blur of a particles' response is defined with Full-Width-Half-Maximum [14].

III Results and discussion

Diameter changes due to the pressure rise are presented in the Figure 2. When the pressure is increased in the intracranial space, the diameter of the magnetic capsule will decrease and the concentration of SPION will increase. This increase in the concentration will brighten the reconstructed image. For example, magnetic capsule with 15 mm diameter will be shrinked by 2.28 mm in diameter when the pressure increased from 10mmHg to 20mmHg. This shrink can be measured with ~9px resolution. Resolution can be increased with smaller FOV and higher density of Lissajous curve but this density increment will increase repetition time. In addition to capsule's surface tension and strength of material have to be taken in account in the future works. Magnetic capsule where mounted inside the reservoir of the VP shunt provides possibility to detect obstruction of the shunt which occur in the distal tip and valve malfunction. On the other hand proximal tip occlusions cannot be observed.

IV Conclusions

The changes in the ICP can affect magnetic capsule's diameter. MPI based ICP monitor can be used for hydrocephalus patients without ionizing radiation. With this advantage, patients who need to be checked frequently after the implantation of intraventricular shunt can avoid the exposure to cumulative X-rays.

Acknowledgments

This work was supported by The Scientific And Technological Research Council of Turkey (Project Number 118E769)

References

[1] M. Puntis, U. Reddy, and N. Hirsch, "Cerebrospinal fluid and its physiology," Anaesth. Intensive Care Med., vol. 17, no. 12, pp. 611–612, 2016.

[2] A. K. Toma, "Hydrocephalus," Surg. (United Kingdom), vol. 33, no. 8, pp. 384–389, 2015.

[3] P. M. Capone, J. A. Bertelson, and B. Ajtai, "Neuroimaging of Normal Pressure Hydrocephalus and Hydrocephalus," Neurol. Clin., vol. 38, no. 1, pp. 171–183, 2020.

[4] J. S. Robertson, M. I. Maraqa, and B. Jennett, "Ventriculoperitoneal Shunting for Hydrocephalus," Br. Med. J., vol. 2, no. 5861, pp. 289–292, 1973.

[5] B. W. Hanak, R. H. Bonow, C. A. Harris, and S. R. Browd, "Cerebrospinal Fluid Shunting Complications in Children," Pediatr. Neurosurg., vol. 52, no. 6, pp. 381–400, 2017.

[6] M. S. Pearce et al., "Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: A retrospective cohort study," Lancet, vol. 380, no. 9840, pp. 499–505, 2012.

[7] B. Gleich and J. Weizenecker, "Tomographic imaging using the nonlinear response of magnetic particles," Nature, vol. 435, no. 7046, pp. 1214–1217, 2005.

[8] N. Panagiotopoulos et al., "Magnetic particle imaging: Current developments and future directions," Int. J. Nanomedicine, vol. 10, pp. 3097–3114, 2015.

[9] M. Gräser et al., "Human-sized Magnetic Particle Imaging for Brain Applications," Nat. Commun., no. 2019, 2018.

[10] T. Knopp, N. Gdaniec, and M. Möddel, "Magnetic particle imaging: From proof of principle to preclinical applications," Phys. Med. Biol., vol. 62, no. 14, pp. R124–R178, 2017.

[11] X. Li, Y. Wei, and Y. He, "Simulation on polytropic process of air springs," Eng. Comput. (Swansea, Wales), vol. 33, no. 7, pp. 1957–1968, 2016.

[12] M. J. Albeck, S. E. Borgesen, F. Gjerris, J. F. Schmidt, and P. S. Sorensen, "Intracranial pressure and cerebrospinal fluid outflow conductance in healthy subjects," J. Neurosurg., vol. 74, no. 4, pp. 597–600, 1991.

[13] M. Czosnyka and J. D. Pickard, "Monitoring and interpretation of intracranial pressure," J. Neurol. Neurosurg. Psychiatry, vol. 75, no. 6, pp. 813–821, 2004.

[14] S. N. B. A. Webb, Introduction to Medical Imaging Physics, Engineering and Clinical Applications. 2011.

10.18416/ijmpi.2020.2009074