A Micro Shunt Valve with Anti-siphon Effect

Sang Wook Lee*, Hyeun Joong Yoon and Sang Sik Yang****

Abstract - This paper presents the fabrication and testing of a two-way pressure regulation micro shunt valve with an anti-siphon effect that can be implanted in hydrocephalus patients. This micro shunt valve consists of a silicone rubber membrane and a valve seat for the opening pressure control as well as the anti-siphon behavior. The two-way pressure regulation and the anti-siphon effect of the micro shunt valve are verified experimentally for various sizes of membranes and valve seats.

Keywords: anti-siphon, hydrocephalus, micro shunt valve

1. Introduction

Hydrocephalus is a neurological disease resulting in an abnormal increment in intracranial pressure that occurs when there is an unusual accumulation of cerebrospinal fluid (CSF) in the ventricles and/or subarachnoid space of the brain [1]. The abnormal accumulation of CSF is attributed to an overproduction of CSF, an obstruction of the drainage of CSF, or a failure of the structures of the brain to reabsorb the fluid [2]. A CSF shunt system drains cerebrospinal fluid from the brain to the abdominal cavity.

The conventional CSF shunt system consists of a passive shunt valve opened by intracranial pressure and a catheter to drain the CSF. However, the conventional CSF shunt system is relatively expensive and the shunt valve occupies extensive space. It is difficult to manage the problem of over-drainage and under-drainage. Moreover, there is the drawback of abrupt undesirable forward drainage for the negative pressure, which is referred to as siphon effect. Kim et al. fabricated an electromagnetic micro pump that can shunt CSF to regulate the intracranial pressure [3]. However, it is very complicated to implement a closed-loop control system that monitors the intracranial pressure and adjusts the flow rate of the implanted micro pump. A recent attempt has been performed to fabricate a small and simple valve for the CSF shunt system by micromachining technology [4]. However, the micro valve for the CSF shunt system does not meet certain requirements such as the opening pressure and the anti-siphon effect. In this paper, an implantable micro shunt valve is proposed. The micro shunt valve has a valve seat and a silicon rubber membrane. Adjusting the dimensions of these two structures can control the two-way opening pressures and the anti-siphon effect.

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2. Micro shunt valve design

The structure of the micro shunt valve is shown in Fig. 1. The upper substrate has a silicone rubber membrane and the lower substrate consists of an inlet with a valve seat and an outlet connected through a micro channel. Silicone rubber is a biocompatible and nontoxic material [5]. In addition, its flexibility is suitable for membrane use where a large displacement is needed [6, 7]. The silicone rubber membrane extended by the valve seat has a built-in tensile stress. The dimensions of the membrane and the valve seat determine the opening pressure of the micro shunt valve.

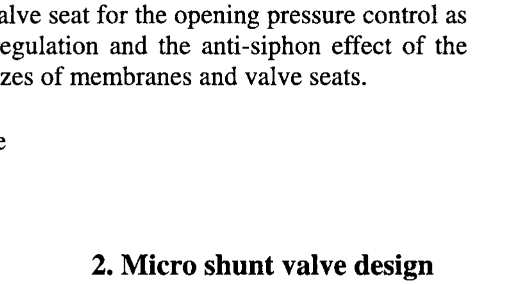


Fig. 1 The structure of the micro shunt valve

Fig. 2 illustrates the working principle of the micro shunt valve. Fig. 2 (a) explains that the micro shunt valve is closed when the inlet pressure is less than the valve opening pressure corresponding to the built-in tensile stress in the membrane. On the contrary, Fig. 2 (b) shows that the micro shunt valve opens when the inlet pressure exceeds the tensile stress in the membrane.

When abrupt negative pressure is loaded on the outlet of the micro shunt valve, net flow increases and over-drainage occurs [2]. This presents a very dangerous situation for hydrocephalus patient to be in. To prevent the over-drainage, an anti-siphon device is needed in addition to the micro shunt valve. The principle of anti-siphon effect is shown in Fig. 3. In case a negative outlet pressure is applied, the silicone rubber membrane is pushed up by the positive inlet pressure and pulled down by the negative outlet pressure. If the negative outlet pressure is large enough, the micro shunt valve is closed and the fluid flow stops.

The size of the micro shunt valve is 7.8 mm × 5.8 mm × 0.8 mm and the height of the valve seat is 190 ± 20 µm. The width and the height of the micro channel are 300 µm and 20 µm, respectively. The size of the outlet is 1200 µm × 1200 µm. The membrane and the inlet are both square. To compare the effects of the sizes of the membrane and the inlet, two kinds of dimensions for each are investigated. Table 1 shows the four different types of valve dimensions found in this paper.

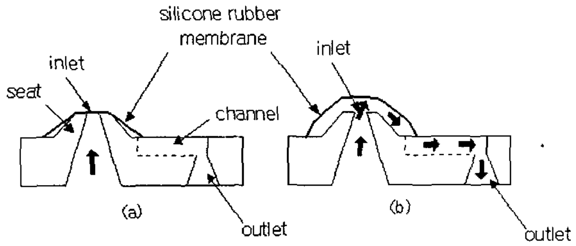


Fig. 2 The working principle of the micro shunt valve

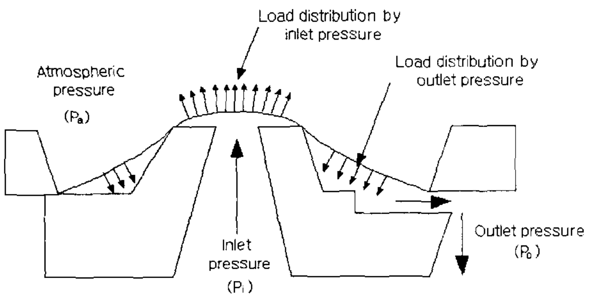


Fig. 3 Principle of the anti-siphon mechanism

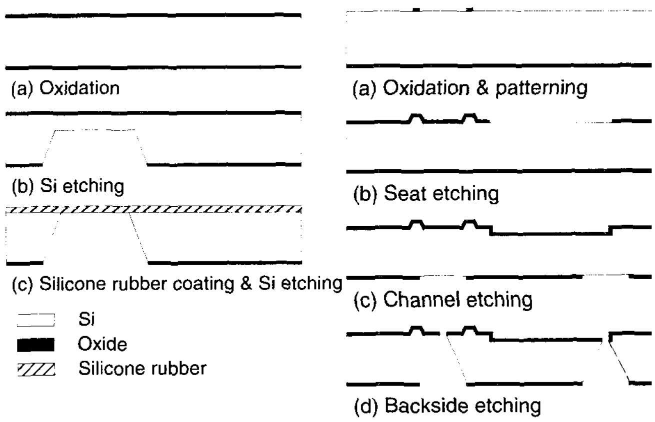
Table 1 The four types with different sizes

Type	Membrane (µm)	Inlet (µm)
1	3600	800
2	3600	1200
3	4200	800
4	4200	1200

3. Fabrication

Fig. 4 (a) shows the fabrication process of the silicone rubber membrane. A silicon dioxide layer for an etch mask is grown on a 525 µm-thick 4 inch n-type (100) silicon wafer. To construct the cavity, the silicon dioxide is patterned and the backside of the wafer is etched by 400 µm with TMAH (Tetraethyl ammonium hydroxide) etchant. On the front side of the wafer, a silicone rubber (ShinEtsu KE44G, Japan) is spin-coated at 1500~2000 rpm. After silicone rubber coating on the front side, the backside is etched again with TMAH etchant to remove any remaining silicon in the cavity.

Fig. 4 (b) is the fabrication process of the valve seat on the lower substrate. A silicon dioxide layer for an etch mask is grown on a 525 µm-thick 4 inch n-type (100) silicon wafer. To construct the valve seat, silicon dioxide is patterned and the front side of the wafer is etched at about 190 µm with TMAH etchant. After the valve seat is formed, the 20 µm-deep channel is fabricated using TMAH etchant. In order to construct the inlet and the outlet, the silicon dioxide layer is patterned and the backside is etched. The temperature of TMAH is maintained at 90℃ to keep the etch rate at 1 µm/min in (100) direction [8]. Fig. 5 shows the photograph of the fabricated micro shunt valve on a finger.



(a) silicon rubber membrane (b) valve seat

Fig. 4 Fabrication process of the micro shunt valve

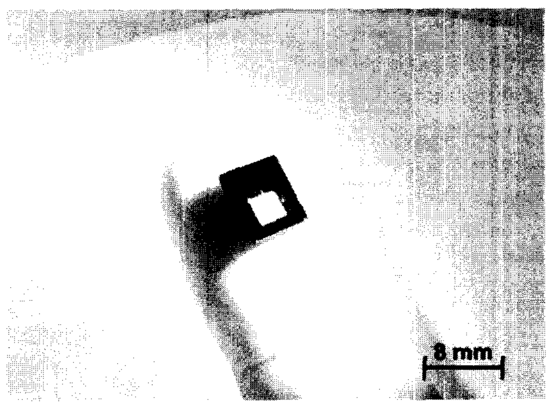


Fig. 5 The photograph of the fabricated valve

4. Results

To obtain the flow characteristics of the micro shunt valve, forward and backward flow tests were performed. The measurement setup for the flow tests is shown in Fig. 6. The forward flow characteristic test is performed when a positive inlet pressure, P_i is applied on the micro shunt valve and the outlet pressure, P_o is zero. On the contrary, the backward flow characteristic test is performed when a positive outlet pressure is applied on the micro shunt valve and the inlet pressure is zero.

Fig. 7 shows the forward flow characteristics for the four types of valve dimensions. When the sizes of the inlet and the membrane are 0.8 mm and 3.6 mm, respectively, the micro shunt valve achieves maximum flow rate. The opening pressure ranges from 25 mmH_2O to 75 mmH_2O. The flow rate increases as the applied pressure increases. This Fig. also illustrates that the slope of the curve depends on the membrane size. As the membrane size becomes smaller, the slope becomes stiffer. Fig. 8 indicates the backward flow characteristics for the four types of valve dimensions. The primary opening pressure is 50 mmH_2O for all cases except when the inlet size and the membrane size are 0.8 mm and 3.6 mm, respectively. The maximum flow rate occurs when the inlet and membrane sizes are 0.8 mm and 3.6 mm, respectively. Consequently, both the primary opening pressure and the flow rate can be adjusted by the sizes of the inlet and the membrane of the micro shunt valve.

To observe the anti-siphon effect, the flow rate is measured while a positive pressure is applied to the inlet and a negative pressure is applied to the outlet. Fig. 9 shows the experimental results of the anti-siphon effect test performed on the micro shunt valves. As the negative outlet pressure increases, the pressure difference increases and the forward fluid flow increases. However, the fluid flow decreases abruptly when negative outlet pressure exceeds the critical pressure. Fig. 9 also illustrates that the critical pressure increases as the

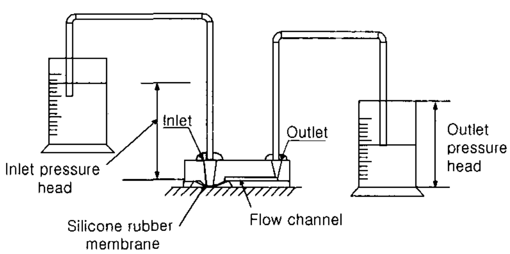


Fig. 6 Measurement setup for the micro shunt valve

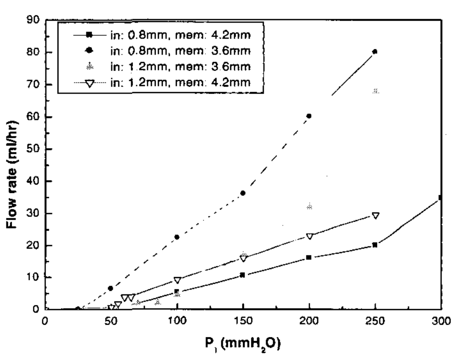


Fig. 7 The forward flow characteristics of the valves

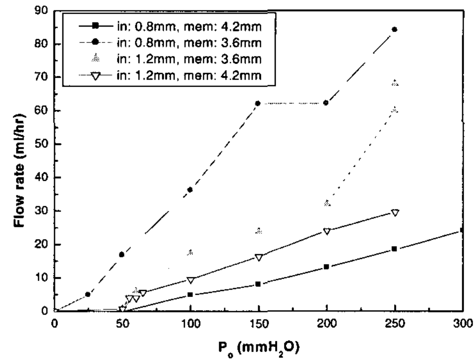
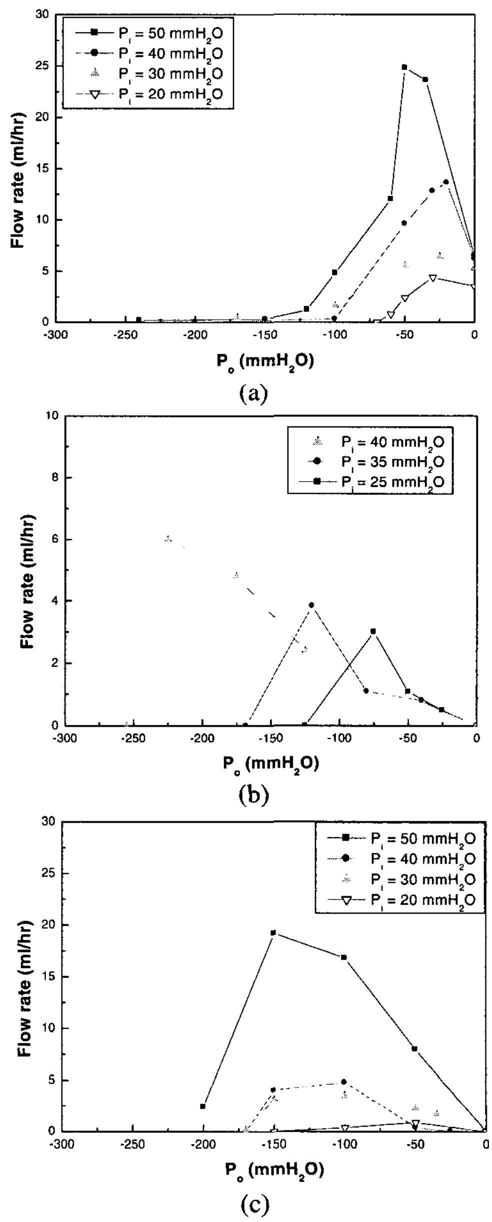
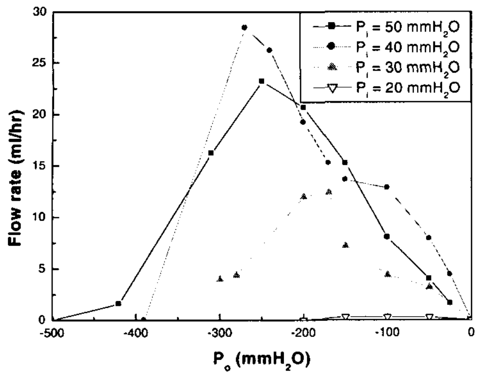


Fig. 8 Backward flow characteristics of the valves

membrane size and/or the inlet size increases. These results confirm that the anti-siphon effect can be controlled by adjusting the valve dimension.





(d)

(a) inlet: 0.8 mm, membrane: 3.6 mm
(b) inlet: 0.8 mm, membrane: 4.2 mm
(c) inlet: 1.2 mm, membrane: 3.6 mm
(d) inlet: 1.2 mm, membrane: 4.2 mm

Fig. 9. Anti-siphon flow characteristic of the valves

5. Conclusion

In this paper, a micro shunt valve for the CSF shunt was fabricated. The micro shunt valve for the CSF shunt consists of a silicone rubber membrane and a valve seat. The valve was miniaturized by micromachining technology. As shown in flow characteristic test results, the micro shunt valve has a primary opening pressure determined by the built-in tensile stress in the membrane. In addition, the anti-siphon effect was confirmed when a large negative pressure was applied to the outlet. This result illustrates that the fabricated valve is a feasible solution for the CSF shunt two-way pressure regulation micro shunt valve.

Acknowledgements

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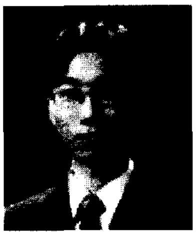

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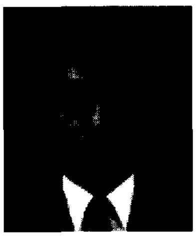

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