Study on opening pressure of hydrocephalus shunt under siphon

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Abstract. The opening pressure of the hydrocephalus shunt with the siphon device was studied and analyzed in this paper. The influence of fluid velocity and siphon height on the opening pressure of hydrocephalus shunt is analyzed. According to the national medical industry standards, the hydrocephalus shunt must be opened by the liquid column detection method. In this paper, computational fluid dynamics was used to simulate the liquid column pressure, and the interaction analysis of the two factors of flow rate and siphon height was carried out. Finally, the influence of flow velocity and siphon height on the opening pressure of hydrocephalus shunt was obtained in this paper, and the relevant formula of the influence of these two factors on the opening pressure was obtained.

1. Introduction
The hydrocephalus shunt is a medical device that contains a one-way device that can drain excess cerebrospinal fluid in the skull to other parts of the body (such as the abdominal cavity) to reduce intracranial pressure [1-2]. The key component of the hydrocephalus shunt is the shunt valve, which can be automatically opened or closed according to the intracranial pressure to balance the intracranial pressure of the patient. At present, there are many types of diverter valves, such as diverter valves equipped with anti-siphon devices. To detect the influence of anti-siphon devices on opening pressure and closing pressure, this article mainly focuses on anti-siphon devices for further research.

During the pressure quality test of the hydrocephalus shunt, the detection device fully simulates the real human hydrocephalus flow. According to the national pharmaceutical industry standard, the inner diameter of the connecting pipe of the hydrocephalus shunt test piece is 1mm, and the pump flow rate is 5-60ml/h, the height of the siphon level is 300mm. Due to the small inner diameter of the pipeline and the low flow rate of the pump, it belongs to the category of microfluidics [3-4], so this article uses microfluidics technology for research and analysis.

This paper uses computer-aided design technology to draw the siphon device model, uses computational fluid dynamics to solve the flow field flow of the model, and studies whether the siphoning effect has an effect on the opening pressure of the hydrocephalus shunt and the degree of influence.

2. Test device for anti-siphon device
According to the national pharmaceutical industry standards, when testing the pressure quality of hydrocephalus with an anti-siphon device, an anti-siphon test device is required [5-6]. The test device of the anti-siphon device is shown in Figure 1.
During the pressure quality test of the anti-siphon hydrocephalus shunt, a certain flow rate is output by the peristaltic pump and flows to the hydrocephalus shunt test piece after the liquid column detection and pressure sensor. A siphon test pipe is connected below the test piece. The end of the siphon pipe is immersed in the constant temperature water to form a siphon structure, and the height of the siphon pipe is ensured to be 300mm. The test device is used to detect the opening and closing pressure of the anti-siphon hydrocephalus shunt. When the pump provides pressure, the liquid level of the liquid column rises. When the system pressure reaches the opening pressure of the hydrocephalus shunt, the liquid column the moment when the liquid level changes from rising to falling are the opening pressure of the diverter; when the system pressure drops and the system pressure is less than the opening pressure of the diverter, the valve of the diverter is closed and the liquid level of the liquid column changes from falling to rising. The liquid column pressure is the closing pressure of the splitter [7-9].

3. Pressure loss analysis

3.1. Build a model
In the siphon pipeline, the main factors that affect the pressure are the liquid flow rate, the siphon height, and other factors. The basin model is established for the siphon device and imported into the finite element software for meshing. The siphon pipe model and mesh division are shown in Figure 2.
3.2 Parameter setting

Import the meshed model into the CFD software, and set the parameters according to the test environment of the specimen. In order to simulate the real working environment of the hydrocephalus shunt with siphon function, according to the national pharmaceutical industry standard, the fluid medium used is pure water, the water temperature is maintained at 37℃, the fluid velocity range is maintained at 0.001-0.005m/s, and the siphon height difference is maintained in 130-170mm.

The boundary conditions and parameter settings of the simulation model are as follows: the inlet selects the flow-pressure inlet; the outlet is the pressure outlet, and the relative pressure is negative pressure; the wall is selected as a non-slip wall; the liquid column is set as the monitoring surface, and the liquid column is drawn Monitoring curve of pressure change [10].

3.3 Orthogonal test analysis

3.3.1. Multi-factor orthogonal analysis. The fluid flow rate and the pressure difference caused by the siphoning effect are the main factors that affect the results of the pressure quality detection of the hydrocephalus shunt. A multi-factor orthogonal experiment is designed, and the factor level coding is shown in Table 1.

| Level | Flow rate A (m/s) | Siphon height difference B (mm) |
|-------|------------------|-------------------------------|
| -1    | 0.001            | 130                           |
| 0     | 0.003            | 150                           |
| 1     | 0.005            | 170                           |

Use computational fluid dynamics software to simulate and analyze the designed orthogonal experiment. Set the liquid column surface as the monitoring surface to monitor the pressure changes. The monitoring curve is shown in Figure 3. When the flow rate is 0.003m/s and the negative pressure generated by the siphon is -500Pa, the monitoring curve is shown in Figure 3(a), at this time the opening pressure of the hydrocephalus shunt is 225Pa; when the flow rate is 0.003m/s, there is no siphon effect to produce negative pressure, that is, when the pressure difference reaches 1500Pa, the monitoring curve is shown in Figure 3(b), at this time the opening pressure of the hydrocephalus shunt is 2500Pa. The difference between the two is the difference in liquid column pressure in Table 2.
The maximum value of the liquid column pressure is the opening pressure of the splitter, the fluid flow rate and the siphon pressure difference are independent variables, and the liquid column pressure is the opening pressure of the splitter as the evaluation index. The simulation experiment results obtained are shown in Table 2.

Table 2. Orthogonal simulation experiment results.

| Experiment number | Flow rate (m/s) | Siphon height difference (mm) | Liquid column pressure difference (Pa) |
|-------------------|----------------|-----------------------------|--------------------------------------|
| 1                 | 0.003          | 150                         | 2265.0                               |
| 2                 | 0.001          | 150                         | 1428.0                               |
| 3                 | 0.001          | 170                         | 1140.0                               |
| 4                 | 0.003          | 130                         | 2447.3                               |
| 5                 | 0.001          | 130                         | 1597.5                               |
| 6                 | 0.003          | 170                         | 1991.0                               |
| 7                 | 0.005          | 170                         | 2005.0                               |
| 8                 | 0.005          | 130                         | 2460.0                               |
| 9                 | 0.005          | 150                         | 2279.0                               |

Analyze the data in Table 2 through Design-Expert software, and get formula (1)

\[ Y = -437.38 + 8.37 \times 10^5 A + 26.45B + 15.63AB - 1.04 \times 10^8 A^2 - 0.13B^2 \]  

(1)

In formula (1), \( Y \) is the column pressure, Pa; \( A \) stands for fluid velocity, m/s; \( B \) is the siphon height difference, mm.

Perform variance analysis on the results in Table 2, and the analysis results are shown in Table 3.

Table 3. Results of analysis of variance.

| Source     | Sum of Squares | df | Mean square | p-value   |
|------------|----------------|----|-------------|-----------|
| Model      | 1771905        | 5  | 354381      | < 0.0001**|
| \( A \)    | 1108110        | 1  | 1108110     | < 0.0001**|
| \( B \)    | 312268.9       | 1  | 312268.9    | < 0.0001**|
| \( AB \)   | 1.5625         | 1  | 1.5625      | 0.8200    |
| \( A^2 \)  | 346417.1       | 1  | 346417.1    | < 0.0001**|
| \( B^2 \)  | 5107.236       | 1  | 5107.236    | 0.0008**  |
| Residual   | 76.12194       | 3  | 25.37398    |           |
| Cor Total  | 1771981        | 8  |             |           |

"***" means this item is extremely significant (P<0.01); "**" means this item is significant (P<0.05).
It can be seen from Table 3 that the P-value of the regression model is much less than 0.01, indicating that the regression model is extremely significant. From the P-value of the fluid flow rate and the siphon pressure difference, it can be seen that these two factors have extremely significant effects on the pressure loss, but the P-value of the interaction is greater than 0.05, indicating that the interaction coupling has no obvious effect on the liquid column pressure. Through the above analysis, the optimized fitting formula (2) is shown below.

\[ Y = -437.38 + 8.37 \times 10^5 A + 26.45B - 1.04 \times 10^8 A^2 - 0.13B^2 \] (2)

In formula (2), \( Y \) is the column pressure, Pa; \( A \) stands for fluid velocity, m/s; \( B \) is the siphon height difference, mm.

3.3.2. Single-factor analysis. The influence of liquid flow rate and pressure difference produced by siphon is shown in Figure 4. Figure 4(a) shows the influence of liquid flow rate on liquid column pressure. It can be seen from the figure that when the siphon pressure difference is controlled at 1500Pa, when the flow rate is in the range of 0.001-0.003 m/s, the liquid column pressure shows a rapid increase trend; when the flow rate is in the range of 0.003-0.005, the liquid column pressure shows a slow decrease trend. Figure 4(b) shows the influence of the pressure difference caused by the siphon action on the liquid column pressure. When the flow rate is controlled at 0.003 m/s, as the siphon pressure difference increases, the liquid column pressure slowly decreases.

![Figure 4. Single-factor analysis chart](image)

4. Conclusion

The opening pressure of the hydrocephalus shunt with the siphon device was studied and analyzed in this paper. The simulation analysis of fluid velocity and siphon pressure difference shows that both fluid velocity and siphon effect have significant effects on the opening pressure of hydrocephalus shunt. When the siphon pressure difference remains unchanged, as the fluid flow rate increases, the liquid column pressure difference shows a rapid increase first and then slowly decreases; when the fluid flow rate maintains a certain value, as the siphon height increases, the liquid column pressure difference shows a decreasing trend.

Under the influence of the two factors of flow velocity and siphon height, the formula of opening pressure of hydrocephalus shunt is obtained by research and analysis:

\[ Y = -437.38 + 8.37 \times 10^5 A + 2.64B - 1.04 \times 10^8 A^2 - 1.26 \times 10^{-3} B^2 \]

In the formula, \( Y \) is the column pressure, Pa; \( A \) stands for fluid velocity, m/s; \( B \) is the siphon height difference, mm.
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