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Original Article

A Method to Guide Pressure Selection for Programmable Pressure Valves after Ventriculoperitoneal Shunt Surgery

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Abstract

Introduction Programmable pressure valves with antisiphon/gravity devices are recommended for ventriculoperitoneal shunts. However, cerebrospinal fluid (CSF) overdrainage and underdrainage still frequently occur because of the lack of effective pressure regulation methods. Therefore, this study aimed to provide a method to guide valve pressure selection after ventriculoperitoneal shunt placement.

Materials and Methods A total of 31 patients whose valve pressure was lowered for the last time after ventriculoperitoneal shunt placement were enrolled in this study. Glucose solution was injected into the reservoir before and after adjustment, and the residual glucose concentration was measured 20 minutes later. Residual glucose concentrations were then compared between before and after adjustment. In vitro experiments were also conducted to simulate the flow of CSF through the shunt valve and detect the relationship between flow rate and residual glucose concentration.

Results The glucose concentration in the CSF was significantly decreased after adjusting (mean ± standard deviation, 15 ± 6.6 vs. 5.6 ± 3.1 mmol/L, respectively; $p < 0.01$).

Conclusion When the residual glucose concentration is higher than 10 mmol/L, an underdrainage shunt should be considered, and when it is lower than 10 mmol/L, an appropriate pressure should be considered, which provides a reference for lowering the shunt valve pressure.

Keywords
- programmable pressure
- hydrocephalus
- ventriculoperitoneal shunts
- cerebrospinal fluid
- underdrainage

* *Chen Fan and Hongri Zhang are equally to this work and share first authorship.*

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Introduction

Insertion of a ventriculoperitoneal shunt is a surgical method used for hydrocephalus.[1–3] A programmable pressure valve with an antisiphon/gravity device generally is recommended.[4,5] However, overdrainage and underdrainage of cerebrospinal fluid (CSF) remains a common issue.[6]

There are a few related studies on the measurement of shunt flow after ventriculoperitoneal shunt placement, and there are reports of phase-contrast magnetic resonance imaging, Doppler ultrasound, and other techniques being used to detect flow in the shunt tube.[7–9] However, because of the slow flow rate of CSF in the shunt tube, errors in this type of detection are relatively large. Therefore, the method of detecting flow cannot be used to guide pressure selection for programmable pressure valves. Thus, it is mainly used in the diagnosis of shunt tube obstruction.

Many experts now believe that implementing an initial high-pressure setting, which is gradually reduced, is the correct approach to the pressure setting of valves.[10,11] However, there is no uniform standard for determining the initial pressure and when downward adjustment is necessary. Therefore, the aim of this study was to provide a method to guide the selection of valve pressure.

Materials and Methods

Physiological Mechanism

A concentrated glucose solution (GS) is injected into the reservoir, where it is progressively diluted by the CSF flowing through the reservoir toward the peritoneal cavity. The degree of dilution of the concentrated glucose is directly proportional to the flow rate of the CSF (►**Fig. 1**).

In Vitro Experiment

The Medtronic PS Medical Delta valves (Medtronic, Minneapolis, Minnesota, United States) were used for the in vitro experiment. For configuration of artificial CSF, 1.5 mL of 5% GS was combined with physiological saline for a total volume of 100 mL. The glucose concentration of the artificial CSF was 3.5 ± 0.6 mmol/L. The diverter valve was connected vertically, the flow rate was controlled using a micropump, and the artificial CSF was passed through the diverter valve at different speeds (►**Fig. 2**). Note that 0.1 mL of 5% GS was injected into the reservoir of the shunt valve. After 20 minutes, 0.1 mL was drawn from the reservoir, and the residual glucose concentration was measured by using a blood glucose meter (OneTouch UltraVue, Johnson & Johnson, New Brunswick, New Jersey, United States) (►**Fig. 2**). The measurement results were analyzed and compared.

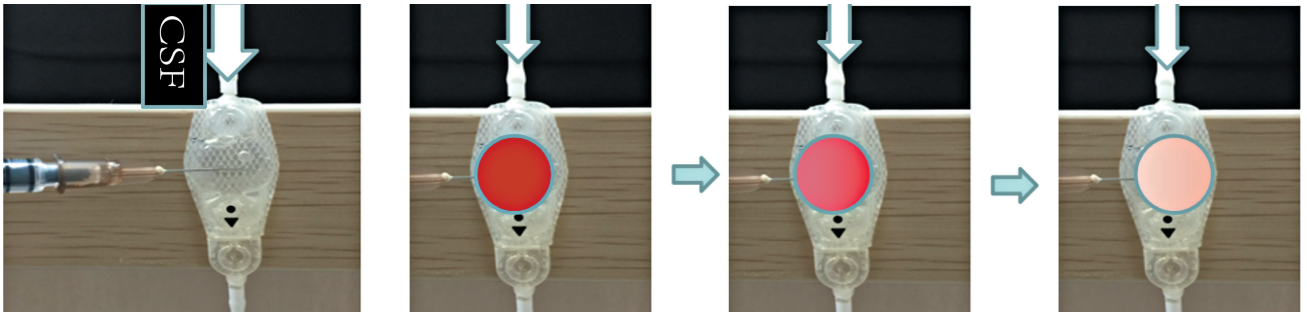

Fig. 1 A high concentration of glucose is injected into the reservoir (the intensity of the red color indicates the glucose concentration within the reservoir). The glucose in the reservoir continuously flows with the cerebrospinal fluid into the abdominal cavity, where it becomes progressively diluted. The degree of dilution is proportional to the flow rate of the cerebrospinal fluid.

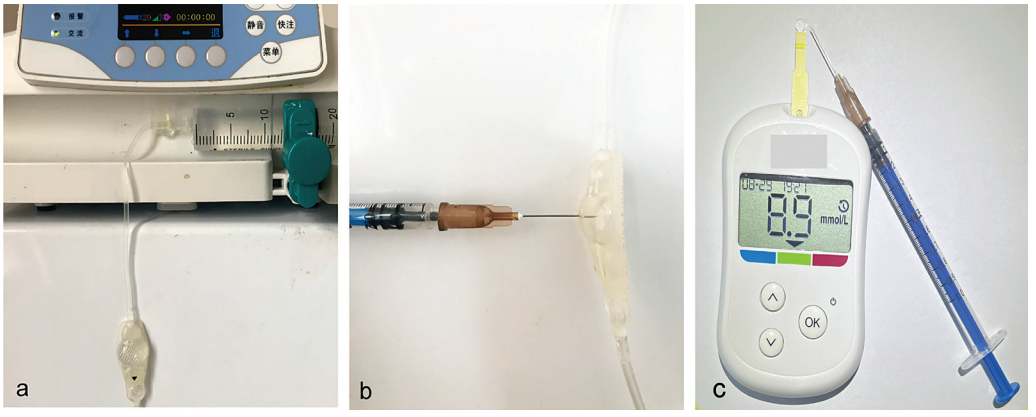

Fig. 2 Schematic diagram of the in vitro experiment. (A) Introduction of the simulated cerebrospinal fluid shunt to set different flow rates. (B) Puncture site of the reservoir. (C) Glucose concentration was measured by using a blood glucose meter.

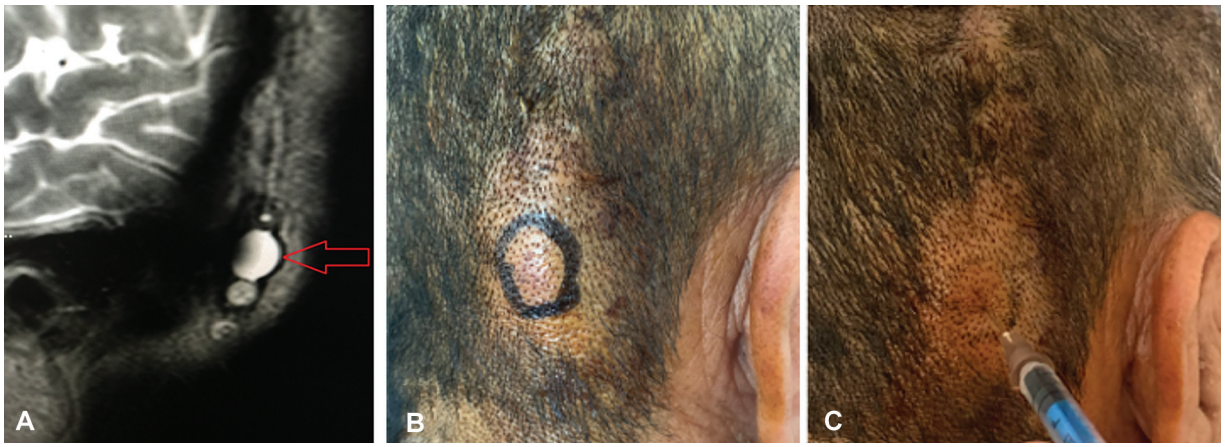

Fig. 3 Schematic diagram of the in vivo experiment. (**A**) The red arrow in the magnetic resonance image marks the location of the reservoir. (**B**) Puncture site mark in patients in the obstruction group. (**C**) Glucose solution was injected into the reservoir.

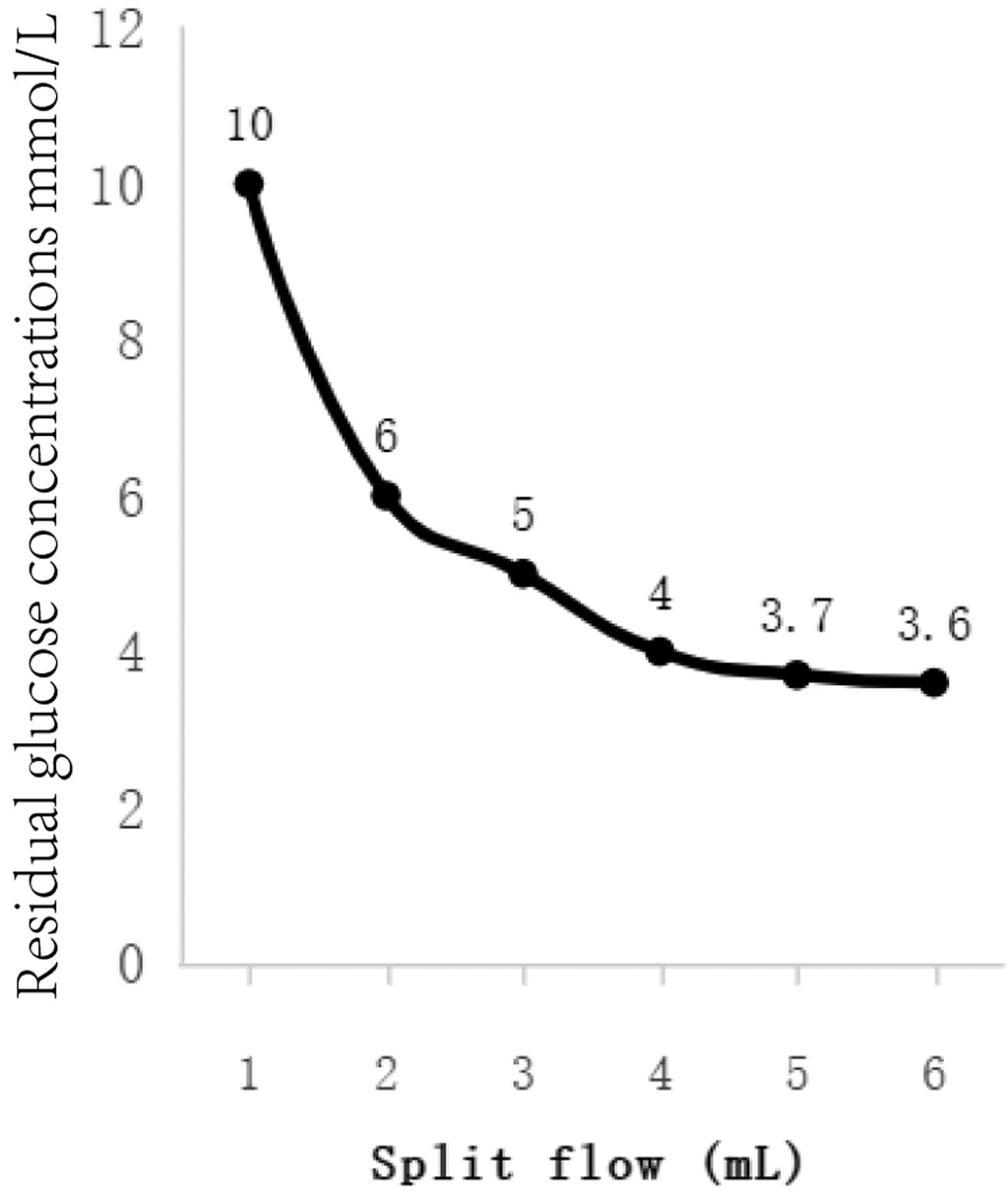

Fig. 4 Schematic diagram of in vitro experimental results. The residual glucose concentration decreases with an increasing saline flow rate.

Second, we chose a flow rate of 3 mL/h as an underdrainage group and 6 mL/h as a control group. For each group, we performed nine experiments and compared the test results.

In Vivo Experiment

Patient Enrolment and Ethical Approval

Thirty-one patients whose valve pressure was lowered for the last time after ventriculoperitoneal shunt insertion were included in the study (14 women and 17 men; mean age, 46.5 ± 6.5 years; age range, 27–69 years). The study was conducted in accordance with the Helsinki Declaration. Informed consent was obtained from all participants.

All patients had received a ventriculoperitoneal shunt 7 to 90 days earlier, the wound healed well, and the valve bounced normally after external pressure. All patients underwent shunting using an adult programmable pressure antisiphon device (PS Medical Strata II, Medtronic). Patients with diabetes were excluded.

Before reducing the valve pressure, 12 cases were set at a performance level of 2.0, 16 cases at 1.5, and 3 cases at 1.0. Sixteen patients were conscious, nine were hazy, and six were comatose. Before adjustment, head computed tomography (CT) showed slightly small ventricles in 8 cases, normal ventricles in 10 cases, and enlarged ventricles in 13 cases.

Detection of Residual Glucose Concentration

The residual concentration of glucose was measured 1 day before and 3 days after the valve pressure was lowered. The measurements were carried out under a state of fasting for 8 hours. To reduce the influence of body position on the measurement, the participants laid flat

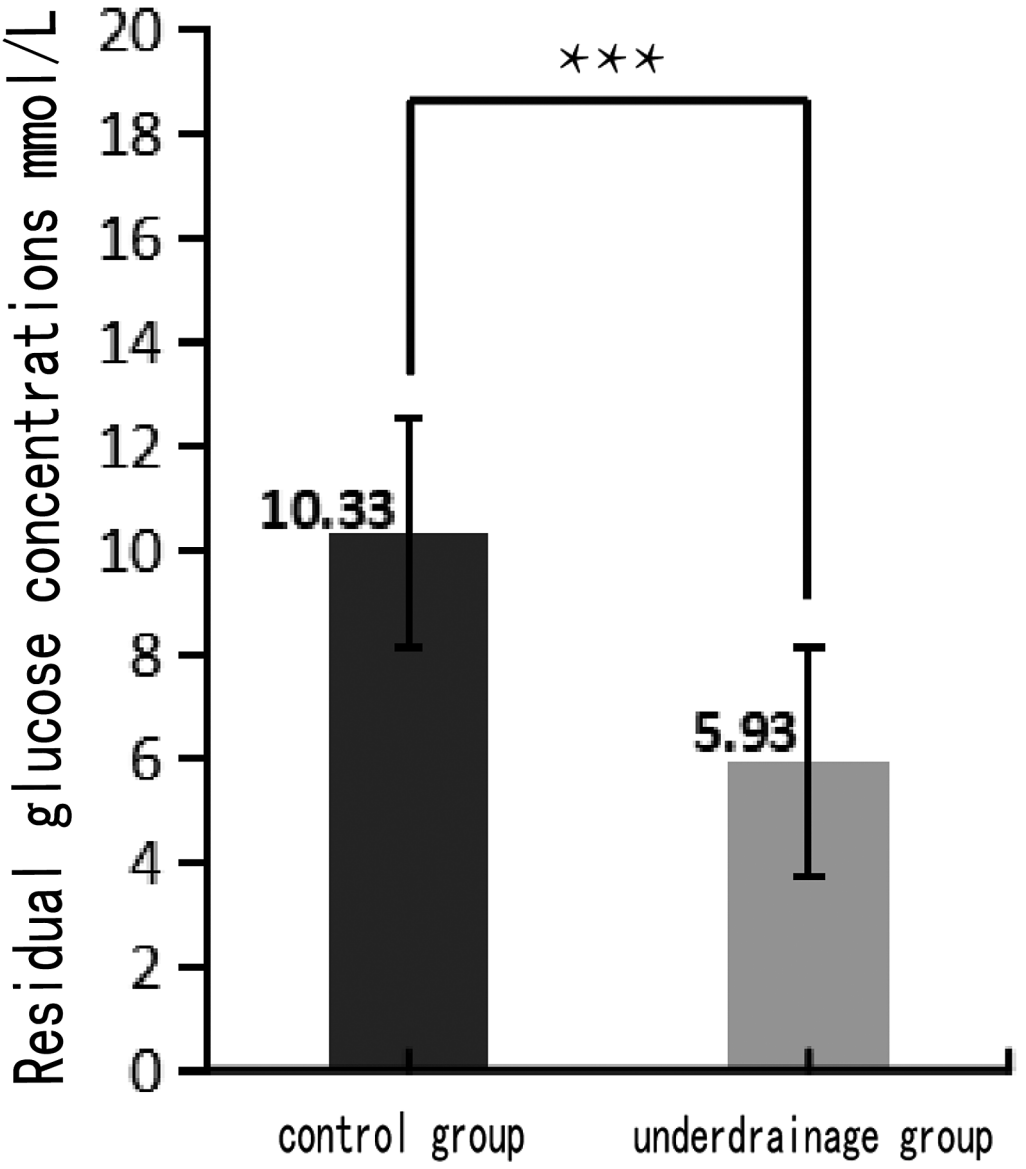

Fig. 5 Schematic diagram of in vitro experimental results ($n = 9$). Bar graph of the residual glucose concentration for the artificial cerebrospinal fluid flow rates of 3 and 6 mL/h ($p < 0.001$).

for an hour before the test and then changed to a sitting position. After valve positioning and skin disinfection, 0.1 mL of 5% GS was injected into the reservoir of the shunt valve. After 20 minutes, 0.1 mL was drawn from the reservoir and the residual glucose concentration was measured (►**Fig. 3**).

Statistical Analysis

SPSS version 27.0 software (IBM Corp., Armonk, New York, United States) was used for statistical analysis. The measurement data conformed to a normal distribution and are described as the mean ± standard deviation. The groups were compared using a paired *t*-test and *p*-values < 0.05 were considered to indicate a statistically significant difference.

Results

In Vitro Experiment

The results showed that the residual glucose concentration decreased with an increasing velocity of physiological saline (►**Fig. 4**). The GS concentration in the control group (6.5 ± 1.1) was significantly lower ($p = 0.001$) than that in the underdrainage group (9.7 ± 0.8; shown in ►**Fig. 5**).

In Vivo Experiment

Statistical analysis revealed no significant differences in fasting blood sugar after adjustment. The residual concentrations of CSF before and after adjustment were 15 ± 6.6 and 5.6 ± 3.1 mmol/L, respectively. The residual glucose concentration was significantly decreased after adjustment ($p < 0.01$) (►**Fig. 6**).

After adjustment, a performance level of 1.5, 1.0, and 0.5 were set in 12, 16, and 3 cases, respectively. Head CT scans showed that after adjustment, the ventricles of 13 patients were smaller than those before adjustment, and the ventricles of 18 patients had no obvious changes. Ten patients had an improved state of consciousness, 15 had improved cognitive scores, 5 had decreased muscle tone, 3 had decreased blood pressure, and 2 had decreased seizure frequency. In all the cases, there were no ventricles in the slit state.

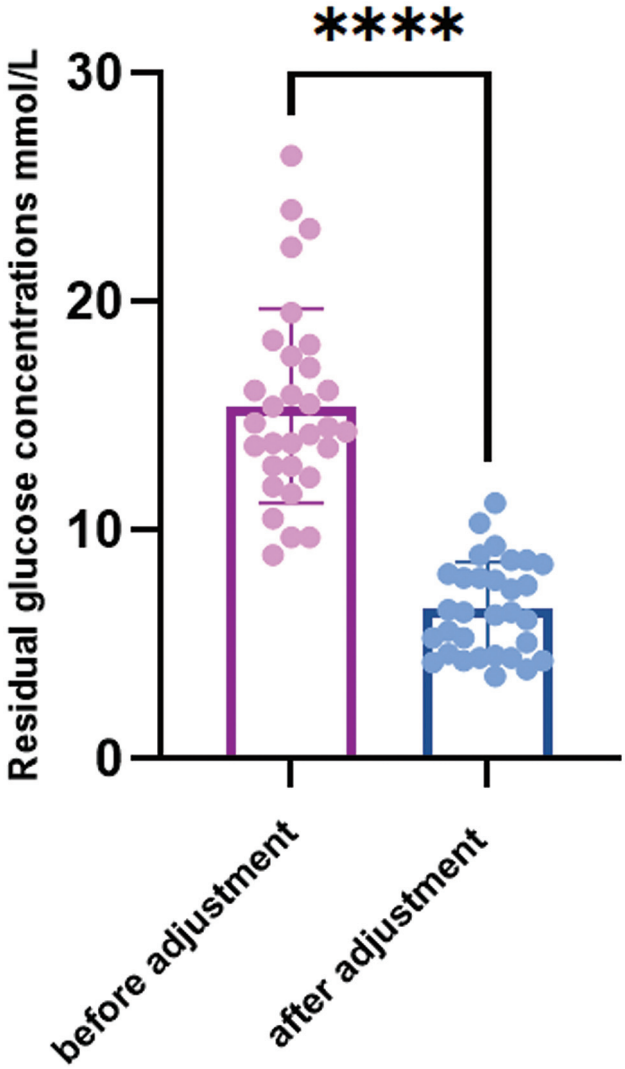

Fig. 6 Schematic diagram of residual glucose concentration measurement results. Histogram of the residual glucose concentration before and after adjustment ($p < 0.001$).

Discussion

Because of over- and underdrainage, a considerable number of patients had inappropriate shunt pressure after shunting and could not achieve optimal shunt flow.[12] We hypothesize the main reasons for this are as follows: (1) intracranial pressure (ICP) varies greatly among patients before surgery. High-, medium-, or even low-pressure hydrocephalus may occur. It is difficult to accurately assess the ICP before surgery. (2) Determining the optimal shunt pressure based solely on clinical manifestations is difficult as clinical and postoperative manifestations vary greatly among individuals. (3) The pressure of the shunt pump could not be completely adjusted based on the size of the ventricles as the imaging data showed varying results. Although the ventricles of most patients became smaller after surgery, some still had large or normal ventricles.

According to idiopathic normal pressure hydrocephalus practice guidelines reported by the American Academy of Neurology, ICP and the patient's clinical manifestations should be evaluated before shunt surgery and a higher valve pressure should be initially set, which can be gradually lowered after surgery.[13,14] The method used in this study was similar to those guidelines, with the pressure adjusted to a higher level and then gradually decreased thereafter. Before lowering the pressure, we injected GS into the reservoir and detected residual glucose concentrations (which is inversely proportional to the CSF flow). Residual glucose concentrations were measured by a trained neurosurgeon blinded to the clinical condition of the patient.

In this study, we relied on the dilution of glucose as a measure of shunt flow. Glucose is an endogenous molecule (naturally present in CSF and blood) with no toxic effects, even at locally high concentrations. This eliminates risks associated with exogenous markers. Glucose can be measured easily, with high sensitivity and at low cost, using standard clinical tools. Our in vitro experiments confirmed

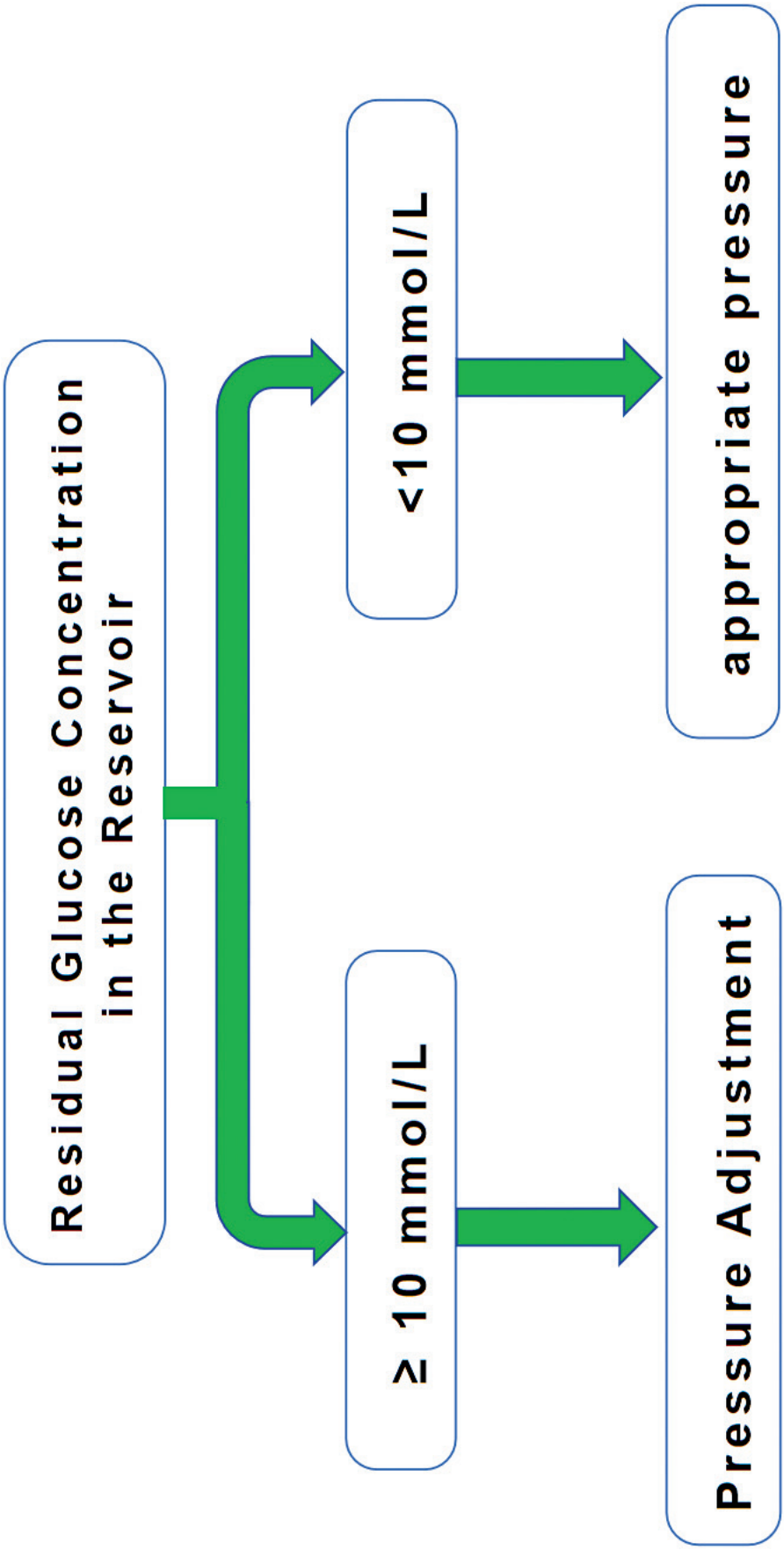

Fig. 7 A clinical decision-making flowchart based on residual glucose levels. While the residual glucose level is greater than or equal to 10 mmol/L, an adjustment of the shunt pump pressure is required. When the level drops below 10 mmol/L, the pressure is deemed appropriate.

that it can be detected using glucose meters without interference from CSF components. A 5% GS is readily available in clinical settings. A solution of 5% GS was injected into the valve reservoir. The slower the flow rate in the reservoir, the more conducive it is to material exchange (glucose is evenly distributed in the reservoir) and the smaller the detection error, so it is suitable for the inspection of shunt flow in this research.

We used the Medtronic PS Medical Delta valve in this study, which contains a reservoir with a volume of 0.5 mL and allows for extracorporeal puncture.[15] The CSF contains GS, and the normal range is within 3.6 to 4.5 mmol/L. After injecting 0.1 mL of glucose into the reservoir, the glucose concentration was 43.2 mol/l, which was much higher than that in the CSF, and there was no obvious reflux to the ventricle. Therefore, in the initial stage of detection, the interference by CSF glucose is small, but when the residual concentration is close to the concentration of CSF glucose, the degree of interference is greater; thus, to reduce its impact on this research, we chose the time interval of injecting and withdrawing as 20 minutes so that the residual concentration was in an appropriate range to reduce the experimental error. However, there may be more desirable substitutes, such as certain drugs and electrolytes. Also, a more appropriate time interval needs to be further determined.

The dilution process of GS is affected by many factors. To reduce the errors in this study, all detection operations were performed by the same neurosurgeon. The puncture point was at the center of the reservoir, and the injection and aspiration speeds were consistent; none of the participants experienced puncture-related complications.

The optimal volume of CSF that should be shunt has not been determined, However, the volume of CSF secretion in healthy individuals is 21 to 24 mL/h,[16,17] and when the drainage volume of CSF is less than 3 mL/h in the tap test of hydrocephalus, the symptoms cannot improve significantly unless the drainage volume is increased.[18] Therefore, underdrainage is suspected when the shunt flow rate is less than 3 mL/h (72 mL/d), and the pressure of valve should be decreased. In our study, the results of the in vitro study showed that when the residual glucose concentration was greater than 10 mmol/L, the CSF flow rate in the reservoir was less than 3 mL/h. Similarly, we concluded that underdrainage occurred when the residual glucose concentration was higher than 10 mmol/L.

The vivo results showed two patients with the residual glucose concentration lower than 10 mmol/L before adjustment and 3 patients above 10 mmol/L after adjustment. Detection errors or individual differences may be the reason. Therefore, we believe that when the detection value is around 10 mmol/L, more decisions should be made by clinical performance.

In terms of the limitations of this study, we found glucose to be present in the CSF, which affected the results of the residual GS; therefore, more ideal substances to replace GS require further research. Second, the volume of the reservoir is too small, which is not conducive to the full dissolution of glucose, and it is also difficult to ensure the consistency of the puncture site. At the same time, when using other devices for this test the results may significantly differ with our research due to the different reservoir volumes. Finally, this was a single-center study with only a few cases. A larger multicenter study should be performed in the future to further confirm its safety and accuracy.

Conclusion

This method provides a reference for neurosurgeons to adjust the shunt valve pressure. When the residual glucose concentration is higher than 10 mmol/L, an undershunting shunt should be considered, and when it is lower than 10 mmol/L, an appropriate pressure should be considered (the flowchart is shown in ►**Fig. 7**).

Authors' Contributions

H.Z. contributed to conceptualization, formal analysis, project administration, writing – original draft, and funding acquisition. C.F. was responsible for writing – original draft, visualization, validation, and methodology. H.B. contributed to software, validation, and data curation. X.H. provided project administration, supervision, and resources. J.P. contributed to writing – review and editing, validation, investigation, and software.

Data Availability Statement

All data generated or analyzed during this study are included in this article. Further enquiries can be directed to the corresponding author.

Ethical Approval

All procedures performed in studies involving human participants were approved by and conducted in accordance with the ethical standards of the Ethics Committee of First Affiliated Hospital of Henan University of Science and Technology (Luoyang, Henan, China) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Approval day: March 2, 2022. Approval number: 2022-03-BOXX.

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Conflict of Interest

None declared.

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