Child's Nerv Syst (1987) 3:30–34

Child's Nervous System CNS

Dynamic changes of cerebrospinal fluid shunt flow in patient's daily life

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Abstract. The shunt flow rate will be greatly influenced by the changing posture of the patient. A newly designed method of assessing shunt flow rate by isotope clearance is described and the results of phantom experiments and clinical data are presented. This method makes it possible to assess shunt flow rates in a variety of postures, such as recumbent, or head raised or as posture changes from recumbent to sitting and eventually to upright. As patients changed from the recumbent to the sitting position, shunt flow rates ceased in some cases. In cases with low flow rates in the recumbent position, shunt flow rate increased with any elevation of the upper half of the body. In many cases, flow rates increased as the patient's position changed from recumbent to sitting and then to the upright position. The results suggest that shunt flow rates vary substantially as postures alter in a patient's daily life.

Key words: Hydrocephalus – Cerebrospinal fluid flow – Shunt flow rate.

Shunt device placement diverting cerebrospinal fluid (CSF) is a reasonably effective treatment of choice for hydrocephalus and is now widely used. However, a number of complications are known, such as overdrainage, obstruction and intermittent flow. One of the goals to be achieved in treating hydrocephalic patients by shunting is to obtain the optimal CSF flow rate through the shunting system (shunt flow rate), although an adequate shunt flow rate must differ from time to time and CSF dynamics and shunt flow rate are likely to be greatly influenced by changing posture. It is helpful, therefore, to provide a reliable way of measuring shunt flow rate in vivo. The purpose of this communication is to describe a newly designed method of assessing shunt flow rate by radioactive tracer clearance method. The authors present the results of phantom experiments and clinical data.

Phantom experiments: materials and methods

Cadmium telluride is a material developed as a room temperature semi-conductor and is highly efficient in detecting gamma rays. Using this material, a computerized single probe system especially made for shunt flow rate assessment has been assembled. The size of cadmium telluride detector (Radiation Monitoring Devices) is 16 mm in diameter and 2 mm thick, and it's weight is 17 g (Fig. 1). The block diagram (Fig. 2) shows the entire system used in this study.

Shunt flow rates have been studied in Pudenz type shunts which consisted of a 16-mm standard type medium-pressure reservoir, Pudenz ventricular catheter and Pudenz low-pressure peritoneal catheter with an inner diameter of 1.3 mm. The whole assembly is the shunt system most commonly used in our institution. The cadmium telluride detector was placed over the reservoir and various flow rates were provided by adjusting an infusion pump. In the experiments, in which flow rates were 0.017, 0.023, 0.047, 0.069, 0.122, 0.170, 0.211, 0.306, 0.340, 0.476, 0.680, 0.701, 0.953, 1.225, 1.770, 2.384, 3.062, 4.768 ml/min, approximately 0.01 ml of ^{99m}Tc (labeled technicium pertechnetate), 100 μCi, was

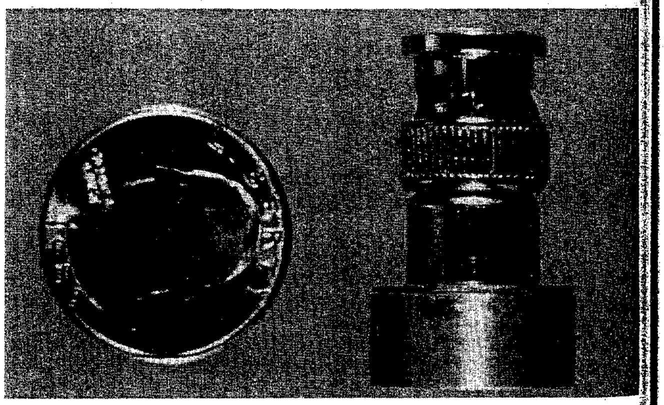

Fig. 1. Cadmium telluride detector (Radiation Monitoring Devices, A-100 series)

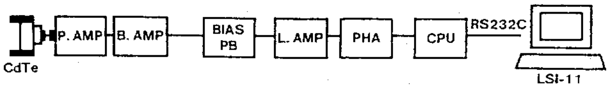

Fig. 2. Block diagram of the system. RMD (Radiation Monitoring Devices) PSP-1 system (*CdTe:* cadmium telluride detector; *P.AMP:* preamplifier module; *B.AMP:* buffer amplifier supply module; *BIAS PB:* bias and preamplifier supply module); *LSI-11:* microcomputer (Digital Equipment Corporation)

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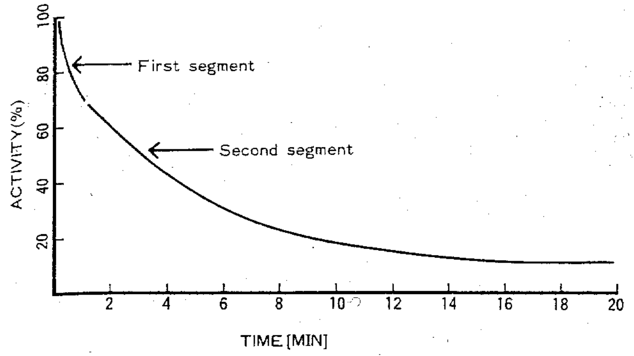

Fig. 3. The radioactivity clearance curve recorded immediately after the tracer injection. The clearance curve has two components; the first segment indicates very rapid clearance and the second segment shows slow clearance curve after the radioactivity has diminished to below 70% of the initial counts

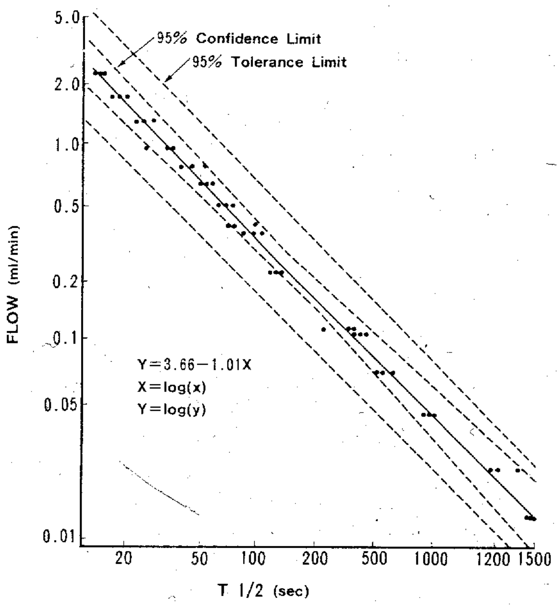

Fig. 4. Correlation of shunt flow rates (F) from 0.017 ml/min to 2.384 ml/min and clearance half-time (t½) of the second segment in phantom experiments

injected into the reservoir through a 27-gauge needle. These injections were made in the middle of the reservoir in vertical fashion. Recording of the radioactivity at 3-s intervals in the reservoir by cadmium telluride detector was started immediately following the injection of the tracer. The time-activity curve was recorded and a radioactivity clearance half-time was determined from the curve. These examinations were repeated three times for each flow rate.

Phantom experiments: results

The radioactivity clearance curve which was recorded immediately after the injection is shown in Fig. 3. The radioactivity clearance curve consisted of two components, i.e., the first segment indicated very rapid clearance of between 100% and 70% of radioactivity and the second segment represented the slow clearance curve after the radioactivity was below 70% of the initial counts. In this study, only the second segment component was used for estimation of shunt flow rates. When the shunt flow rates were 3.062 ml/min and 4.768 ml/min, there was no correlation between radioactivity clearance half-time and shunt flow rates, as the tracer rapidly disappeared from the reservoir. The radioactivity clearance half-time (t ½) of the second segment and the corresponding shunt flow rates (F ml/min) from 0.017 ml/min to 2.384 ml/min are shown in Fig. 4. The relationship between F and t ½ of the second segment is expressed as:

$$\log F = 3.66 - 1.01 \log t\tfrac{1}{2} \qquad (1)$$

The period prior to the appearance of the first segment is quite short [14]. The tracer may be mixed by the complex stream lines in the reservoir within a few minutes, and the second segment of the clearance curve then appears [14]. In clinical practice, it usually takes a few minutes after the injection of the tracer before recording of radioactivity can start because approximately 1 min is required for preparation, applying the detector and fixing it to the scalp. Therefore, the recording of the first segment may be easily missed; then only the second segment can be checked as a single exponential clearance curve. If shunt flow rates exceed 2,500 ml/min, these shunt flow rates are simply expressed as "2,500 ml/min plus".

Table 1. The etiology of hydrocephalus in the 60 patients

Ruptured intracranial aneurysm	22 cases
Unknown etiology	11 cases
Obstructive hydrocephalus caused by neoplasm	8 cases
Intraventricular hemorrhage	7 cases
Aqueduct stenosis	6 cases
Meningitis	2 cases
Spinal cord tumor	2 cases
Porencephaly	2 cases

Clinical materials and method

Sixty hydrocephalic patients were studied under a variety of clinical conditions. Ages of the patients were from 2 to 86 years; 25 were male and 35 were female. The etiology of hydrocephalus in this series is given in Table 1. All patients were shunted using a Pudenz 16-mm standard reservoir connected to a Pudenz ventricular catheter and Pudenz low-pressure peritoneal catheter. Of these patients 58 received ventriculoperitoneal shunts and 2 patients received cyst-peritoneal shunts. Patients with antisiphon devices were excluded from this study.

These patients were requested to remain in the supine position at least 1 h prior to the study. After skin preparation over the reservoir, some 100 μCi of sterile ^{99m}Tc pertechnetate in 0.01 ml of isotonic saline was injected into the middle portion of the reservoir in vertical fashion using a 27-gauge needle. Care was taken to avoid air bubbles in both syringe and needle. Following the introduction of the tracer into the reservoir, the cadmium telluride detector was snugly placed over the reservoir (Figs. 5, 6). As the radioactivity decreased to approximately 70% of the initial

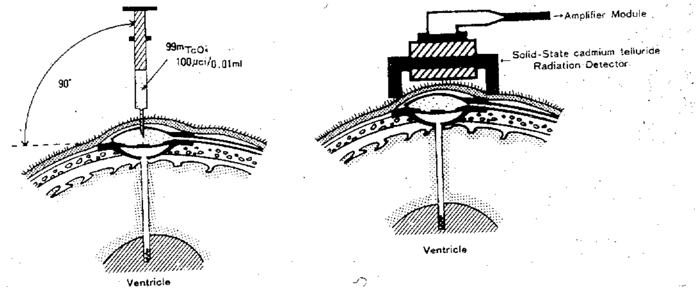

Fig. 5. After skin preparation over the reservoir, some 100 μCi of sterile $^{99m}TcO_4^-$ in 0.01 ml of isotonic saline was injected into the middle portion of the reservoir in vertical fashion using a 27-gauge needle. The cadmium telluride detector was snugly placed over the reservoir

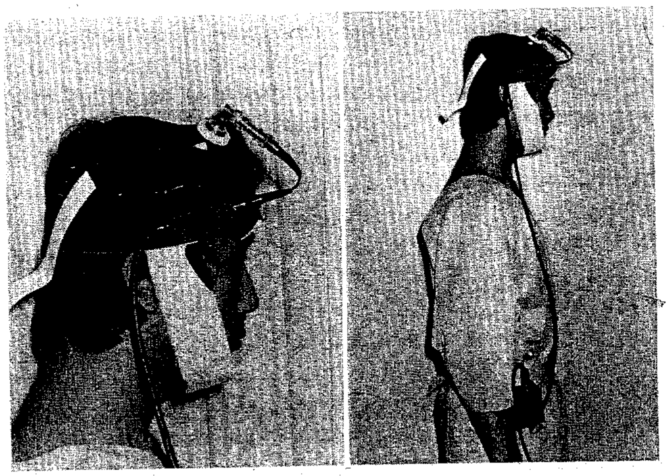

Fig. 6. The cadmium telluride detector was placed snugly over the reservoir

count, measurements were started. The shunt flow rates were computed from Eq. (1). Measurements were made under the following conditions: (1) 10 min measurement in recumbent position; (2) measurement carried out as the head was raised 5° at 2-min intervals, when the shunt flow rate in the recumbent position was less than 0.01 ml/min; (3) or, posture changed from recumbent to sitting and eventually to upright.

Clinical results

The shunt flow rates varied from nearly zero to 0.85 ml/min in the recumbent position. The shunt flow rate changes are summarized in Fig. 7 as the head was raised 5° every 2 min in 15 patients whose shunt flow rates did not exceed 0.01 ml/min in the recumbent position. In 5 patients shunt flow rates increased as the heads were raised 5°, in 2 patients at 15° and in 1 patient at 20°; in 3 patients the shunt flow rates increased as the head was raised 25°, while in 1 patient the shunt flow rate increased at 30°. The observed increase of shunt flow rate after raising the head was impressive. In 3 patients, however, shunt flow rates did not change with any degree of head raising. It was confirmed by operation that the peritoneal tubing in these patients was obliterated. The study in a 56-year-old male is illustrated in Fig. 8; the shunt flow rate showed an abrupt increase to 1.39 ml/min when the head was elevated to 25° from the recumbent position. The studies in which the patient's posture were changed from recumbent to sitting and then to the upright position demonstrated shunt flow rate alterations with an abrupt increase following the posture change, as is indicated in Fig. 9. However, in 4 patients the shunt flow rates decreased when the posture changed from recumbent to sitting. The shunt flow rate changes in a 15-year-old boy are shown in Fig. 10. The shunt flow rate of 0.36 ml/min in the recumbent position became nearly zero in the sitting position but was restored to 0.38 ml/min in the upright position.

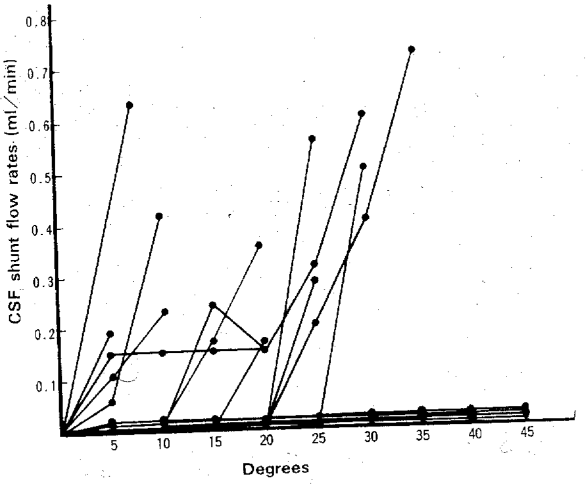

Fig. 7. Summary of changes in shunt flow rate as the head was raised 5° every 2 min in the patient whose shunt flow rates were below 0.01 ml/min in the recumbent position. An impressive increase of the shunt flow rate was observed at a certain degree of head raising, for each patient

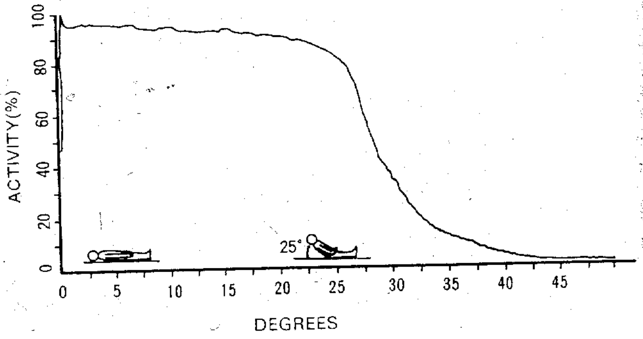

Fig. 8. Measurement of radioactivity as the head was raised 5° at 2-min intervals, in a 56-year-old male whose shunt flow rate showed an abrupt increase to 1.39 ml/min when the head was elevated to 25° from the recumbent position

Discussion

In hydrocephalic patients with implanted shunts, several problems have been noted as a consequence of low intra-

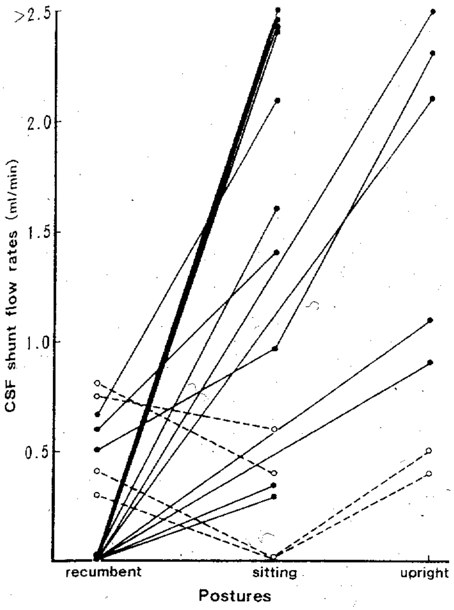

Fig. 9. Relationship between postural changes and shunt flow rates. The shunt flow rates showed an abrupt increase following postural changes. In four patients, however, the shunt flow rates decreased in the sitting position

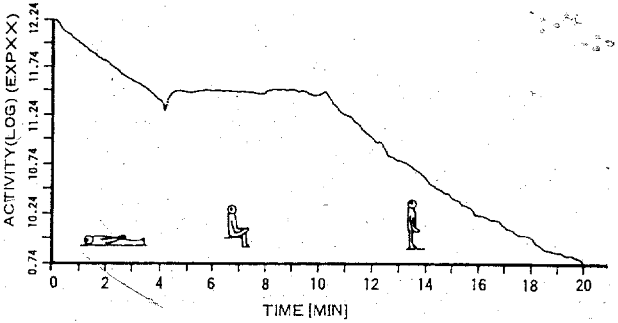

Fig. 10. The changes of shunt flow rate seen in a 15-year-old boy. The flow rate of 0.36 ml/min in the recumbent position became nearly zero in the sitting position but the rate was restored to 0.38 ml/min in the upright position

cranial pressure secondary to overdrainage [12] through shunts. In an infant craniosynostosis [13], occlusion or stenosis of the aqueduct [8], and subdural hematoma have been well documented [1]. This report is the first on shunt flow rate changes *during* continual alterations in the patient's posture. Previous reports only compared the shunt flow rates in the recumbent position with those after changing to the sitting and then upright position [3, 4, 11]. A number of classical methods of measuring shunt flow rate using thermosensitive devices [5, 18] or ultrasound have been reported [7]. All of these studies revealed only shunt patency but not CSF flow, which is much needed in clinical practice. The radioactive clearance method requires the puncturing of a reservoir, entailing the risk of infection and damaging the reservoir. In spite of these disadvantages, quantification of shunt flow rate by radioactive tracer methods [3, 4, 11, 14, 17] remains an attractive method. Methods in which shunt flow rate were quantitatively assessed in both recumbent and upright positions have been described in the literature [3, 4, 11] and these authors reported that shunt flow rates increased when the posture was changed from the recumbent to the upright position. Their results are in good agreement with ours. However, their methods could not be used routinely, owing to the bulky collimator. The detector used in our study is small so that it is possible to assess shunt flow rate in a variety of postures. The detector is so light that it can be snugly attached over the reservoir for a certain period of time without causing patient discomfort. The radiation exposure to a patient from 100 μCi is relatively low, i.e., 1.2 mrads to the total body and 10 mrads to the colon. Although the results should always be considered with the clinical findings and other parameters, this method may be useful in the management of hydrocephalic patients.

Fox et al. [9] pointed out that the flow rate (F) of fluid through a tube is given as the following formula of Poiseulle's law [9]:

$$F=\Delta P\,(\pi/8)\,(1/n)\,(r^4/L)\,. \qquad (2)$$

In this model ΔP is the differential pressure, n is viscosity of fluid (for water, $n=1$), r is the tube radius (the radius of Pudenz peritoneal catheter is constant with an inner diameter of 1.3 mm), and L represents the length of the tube. The effect of the tube length is in a linear inverse relationship; the longer the tube, the slower the flow rate. ΔP is calculated from the next formula [9, 16]:

$$\Delta P=IVP+HP-(PP+CP) \qquad (3)$$

In this formula, IVP stands for intraventricular pressure; PP is intraperitoneal pressure; CP represents the closing pressure of the reservoir; and HP is the hydrostatic pressure. The major disadvantage of using the Eqs. (2) and (3) for estimation of shunt flow rates in the clinical situation is the fact that exact measurements of the ventricular and intraperitoneal pressures are not available. The fluctuation of the pressures, for various reasons, makes it difficult to use these formulae in estimating shunt flow rates. The normal intraventricular pressure in the upright position is subatmospheric [2]. The ventriculoperitoneal shunt decreases intraventricular pressure [10, 15, 20] significantly. The intraperitoneal pressure also varies with posture or the location of the peritoneal catheter tip. The intraperitoneal pressure ranges from 0 to 750 mmH$_2$O in the supine position [19]. The hydrostatic pressure increases in the upright position and the shunt flow rate increases when sitting, standing and with the head in the raised position. In spite of substantial CSF flow through the shunt system in the recumbent position, in two patients shunt flow rates were nearly zero in the sitting position but eventually restored to reasonable rates in the upright position. Possibly kinking of the tubing brought the flow to a halt [6], and/or in this particular situation the intraperitoneal pressure plus closing pressure were in excess of the intraventricular pressure. The variability of these factors is so complicated that the shunt flow rate cannot be simply computed from Eqs. (2) and (3).

In this clinical series, the shunt flow rates varied from nearly zero to 0.85 ml/min in the recumbent position, but these shunt flow rates do not necessarily correlate with clinical features. None of the patients had complications, such as subdural hematoma, subdural fluid collection, craniosynostosis and orthostatic headache even though shunt flow rates increased in the head raising, sitting and standing positions. Three patients showed no clinical improvement when shunt flow rates did not change with any degree of head raising. Shunt revisions were carried out for peritoneal tube obstructions and these patients did quite well afterwards.

In conclusion, the shunt flow rate is greatly influenced by postural changes which take place normally in daily life: an increase, decrease and temporary halt of the flow may occur. In the management of hydrocephalic bedridden patients with implanted shunts, postural change is important: the head should be raised and the sitting position occasionally adapted. Finally, a low shunt flow rate below 0.01 ml/min when the head is raised or in the sitting or upright positions is a sensitive indicator of shunt malfunction or obstruction. In spite of the increase in shunt flow rate observed after raising the head, extremely low shunt rates in the recumbent position (less than 0.01 ml/min) may suggest intermittent shunt flow obstruction.

Acknowledgements. This material was presented in part in the Pediatric Section of the American Association of Neurological Surgeons (Houston, Texas, 4–6 December 1985), at the 14th Annual Meeting of the Japanese Society of Pediatric Neurosurgery (Kouchi, 26–28 March 1986), and at the 14th Annual Meeting of the International Society for Pediatric Neurosurgery (Madrid, 30 September to 3 October 1986). This work was supported by a Tokai medical research grant.

References

1. Becker DP, Nulsen FE (1968) Control of hydrocephalus by valve regulated venous shunt: avoidance of complications in prolonged shunt maintenance. J Neurosurg 28:215–226
2. Bradly KC (1970) Cerebrospinal fluid pressure. J Neurol Neurosurg Psychiatry 33:387–397
3. Brendel AJ, Wynchank S, Castel JP, Barat JL, Leccia F, Ducassou D (1983) Cerebrospinal shunt flow in adults: radionuclide quantitation with emphasis on patient position. Radiology 149:815–818
4. Chervu S, Chervu LR, Vallabhajosyula B, Milstein DM, Shapiro KM, Shulman K, Blaufox MD (1984) Quantitative evaluation of cerebrospinal fluid shunt flow. J Nucl Med 25:91–95
5. Chiba Y, Yuda K (1980) Thermosensitive determination of CSF shunt patency with a pair of small disc thermistors. J Neurosurg 52:700–704
6. Chiba Y, Ishiwata Y, Suzuki N, Muramoto M, Kunimi Y (1985) Thermosensitive determination of obstructed sites in ventriculoperitoneal shunts. J Neurosurg 62:363–366
7. Flitter MA, Buchheit WA, Murtagh F, Lapayowker MS (1975) Ultrasound determination of cerebrospinal fluid shunt patency. J Neurosurg 42:728–730
8. Foltz EL, Shurtleff DB (1966) Conversion of communicating hydrocephalus to stenosis or occlusion of the aqueduct during ventricular shunt. J Neurosurg 24:520–529
9. Fox JL, McCullough DC, Green RC (1972) Cerebrospinal fluid shunts: an experimental comparison of flow rates and pressure values in various commercial systems. J Neurosurg 37:700–705
10. Fox JL, McCullough DC, Green RC (1973) Effect of cerebrospinal fluid shunts on intracranial pressure and on cerebrospinal fluid dynamics. J Neurol Neurosurg Psychiatry 36:302–312
11. Harbert J, Haddad D, McCullough D (1974) Quantitation of cerebrospinal fluid shunt flow. Radiology 112:379–387
12. Jackson IJ, Snodgrass SR (1955) Peritoneal shunts in the treatment of hydrocephalus and increased intracranial pressure: a 4-year survey of 62 patients. J Neurosurg 12:216–222
13. Kloss JL (1968) Craniosynostosis secondary to ventriculoatrial shunt. Am J Dis Child 116:315–317
14. Maeda T, Mori H, Hisada K, Kadoya S (1977) Evaluation of cerebrospinal fluid flow through a Pudenz 12 mm or standard Rickham reservoir: phantom experiments. Invest Radiol 12:555–559
15. McCullough DC, Fox JL (1974) Negative intracranial pressure hydrocephalus in adults with shunts and its relationship to the production of subdural hematoma. J Neurosurg 40:372–375
16. Portnoy HD (1982) Treatment of hydrocephalus. Pediatric neurosurgery of the developing nervous system. Grune & Stratton, New York
17. Sato O, Ohya M, Tsugane R, Ikei K, Suzuki Y (1982) Quantitative measurement of cerebrospinal fluid shunt flow. Monogr Neural Sci 8:34–38
18. Stein SC, Shucart WA (1979) Noninvasive test of CSF function. Surg Forum 30:442–443
19. Yamada H, Tajima M, Nagaya M (1975) Effect of respiratory movement on cerebrospinal fluid dynamics in hydrocephalic infants with shunts. J Neurosurg 42:194–200
20. Yamada S, Ducker TB, Perot PL (1975) Dynamic changes of cerebrospinal fluid in upright and recumbent shunted experimental animals. Child's Brain 1:187–192