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The use of abdominal binders to treat over-shunting headaches

Clinical article

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Object. Headaches are common in children with shunts. Headaches associated with over-shunting are typically intermittent and tend to occur later in the day. Lying down frequently makes the headaches better. This paper examines the efficacy of using abdominal binders to treat over-shunting headaches.

Methods. Over an 18-year period, the senior author monitored 1027 children with shunts. Office charts of 483 active patients were retrospectively reviewed to identify those children with headaches and, in particular, those children who were thought to have headaches as a result of over-shunting. Abdominal binders were frequently used to treat children with presumed over-shunting headaches, and these data were analyzed.

Results. Of the 483 patients undergoing chart review, 258 (53.4%) had headache. A clinical diagnosis of over-shunting was made in 103 patients (21.3% overall; 39.9% of patients with headache). In 14 patients, the headaches were very mild (1–2 on a 5-point scale) and infrequent (1 or 2 per month), and treatment with an abdominal binder was not thought indicated. Eighty-nine patients were treated with a binder, but 19 were excluded from this retrospective study for noncompliance, interruption of the binder trial, or lack of follow-up.

The remaining 70 pediatric patients, who were diagnosed with over-shunting headaches and were treated with abdominal binders, were the subjects of a more detailed retrospective study. Significant headache improvement was observed in 85.8% of patients. On average, the patients wore the binders for approximately 1 month, and headache relief usually persisted even after the binders were discontinued. However, the headaches eventually did recur in many of the patients more than a year later. In these patients, reuse of the abdominal binder was successful in relieving headaches in 78.9%.

Conclusions. The abdominal binder is an effective, noninvasive therapy to control over-shunting headaches in most children. This treatment should be tried before any surgery is considered. It is suggested that the abdominal binder may modulate abnormally increased intracranial pulse pressures associated with over-shunting. Interactions with the cerebrovascular bed are suspected to account for persistent headache relief after the binder is discontinued. *(http://thejns.org/doi/abs/10.3171/2012.2.PEDS11146)*

Key Words • **cerebrospinal fluid shunt** • **over-shunting headache** • **abdominal binder** • **intracranial hypotension** • **intracranial pulse pressure** • **hydrocephalus**

Headaches are common in children with shunt-treated hydrocephalus,[18,26] and some of these children may have very small ventricles. The so-called "slit-ventricle syndrome" describes this clinical condition.[12,16,22] Shunt siphoning, over-shunting, and intracranial hypotension are presumed to be the underlying causes of symptoms.[18,26] Over-shunting is reported to occur in 0.9%–34% of cases in children.[1,6,15,17] Fouyas et al.[13] described a group of 23 symptomatic shunt-treated children, most presenting with headache, who did not have obvious shunt failure. Intracranial pressure monitoring suggested the diagnosis of overdrainage in 56.5%.

Symptoms from over-shunting can occur at any age, although they are unusual in children younger than 3 years old. Perhaps younger children do not have the language skills to express their discomfort. Over-shunting symptoms can occur spontaneously in a child who has had a shunt for years, or symptoms may present soon after a shunt is placed or revised.[10,15,25]

Headache is the hallmark symptom of over-shunting

Abbreviation used in this paper: ICP = intracranial pressure.

and tends to occur as the day goes on (late morning, afternoon, or evening). This is presumably a function of shunt siphoning, which occurs when the child is upright.[26] There is frequently a postural component to the headache; lying down makes the headache better.[3,23] Other symptoms occur with much less frequency, including nausea, vomiting, lethargy, dizziness, and diplopia. Strabismus and paresis of upward gaze have been reported.[3,12,15] In fact, the clinical presentation of a child with over-shunting can be identical to that of a child with shunt failure.[16,20,24] On rare occasions, there may be an alteration of the level of consciousness.[6,12,26]

Various authors have speculated on the apparent similarities between over-shunting headache and common migraine, and an abnormality of vascular reactivity has been suggested.[7,26] Czosnyka et al.[5] reported that intracranial hypotension appears to augment the intracranial pulse pressure amplitude and that this somehow relates to an abnormality of vascular reactivity. Foltz and Blanks[11] showed that reducing ICP below the normal range by withdrawing CSF causes the intracranial pulse pressure to increase. We suggest that this observation is likely important to our understanding the pathophysiology of over-shunting symptoms.

The senior author (F.H.S.) has used the abdominal binder for many years to treat headaches attributed to over-shunting with good results. This report evaluates the effectiveness of using an abdominal binder in this clinical setting. A possible mechanism of action is discussed.

Methods

The clinical diagnosis of over-shunting typically included headaches occurring later in the day, headache improvement on lying down, and small ventricles on CT scanning. All patients underwent funduscopic examination to exclude papilledema. In addition, some patients underwent a shunt tap procedure to confirm that the shunt was working, and some underwent ICP monitoring. Occasionally, the binder was tried in patients with headaches who did not have a typical clinical picture for over-shunting.

Latex-free Dale Abdominal Binders (Dale Medical Products, Inc.) were used to treat the patients with presumed over-shunting headaches of significant severity (more than 2 on a 5-point scale) and frequency (more than 1–2 times/month). The binders are available in widths of 6, 9, and 12 in. In practice, they were sized to extend from approximately 1 in below the groin up to the bottom of the rib cage at the anterior axillary line. It was advised that the binder be placed on the patient by a parent or adult so that it could be very snug. It was recommended that this be accomplished when the patient was lying down. These binders have Velcro strips to facilitate application. The abdominal binder can be used over or under clothing. Figure 1 shows an adolescent boy in an abdominal binder.

In the early years of this retrospective study, the patients were instructed to wear an abdominal binder only when they were upright. Subsequently, the patients were asked to wear the binder 24 hours a day, taking it off only to shower or bathe. Many of the clinical records did not provide information that would allow retrospective determination of whether the binder was used around the clock. The binder was worn for approximately 1 month and was usually discontinued once the headaches were no longer present. With institutional review board approval, data were collected to determine the number of patients treated with an abdominal binder for the relief of headaches related to over-shunting between January 1, 1990, and January 31, 2009. Patients were identified through a clinical practice database as being those with shunt-treated hydrocephalus who were being monitored by the senior author (F.H.S.). Patient charts held in storage were not retrieved for data extraction.

Fig. 1. Photograph of an adolescent boy in a 12-in abdominal binder. The binder should extend over the costal margin and below the groin.

Collected data included patient sex, age at initial shunt surgery, whether the patient had headaches during follow-up, headache characteristics, whether headaches were thought by the neurosurgeon to be related to over-shunting on the basis of the clinical evaluation, whether an abdominal binder was tried, and the results of such trials.

Additional data were collected on recurrence of headaches after binder usage and the efficacy of repeat

usage of the abdominal binder. Binder efficacy was entirely subjective and was determined from chart notations of office follow-up visits, recording verbal feedback of the patients and families as to the incidence, frequency, and severity of the headaches. Patients were excluded if their medical records indicated that they were noncompliant in the use of the binder.

Data were analyzed using SPSS (version 15.0, SPSS, Inc.). Data analysis was limited to descriptive statistics as no comparison groups were identified with this study.

Results

In this study, 1027 patients were identified through the clinical practice database. Of these, 483 patient charts were available onsite and were reviewed for data extraction. Nearly all of these patients had undergone shunt treatment by the senior author, using a medium-pressure Pudenz valve (Integra LifeSciences) and an open-ended peritoneal catheter. Of these 483 patients, 258 (53.4%) were found to have had headaches based on information in their medical charts. One hundred three patients were thought to have over-shunting (21.3% overall; 39.9% of patients with headaches); however, only 89 patients (18.4% overall; 34.5% of patients with headaches) were treated using an abdominal binder. Fourteen patients with very mild and infrequent headaches were not treated. In practice, this represented patients with headaches of 1 or 2 severity on a 5-point scale and 1 or 2 episodes/month. Of the 89 patients treated with an abdominal binder for presumed over-shunting headaches, 9 were lost to follow-up, 7 were excluded for noncompliance, and 3 were admitted to the hospital before efficacy of the binder could be determined. The remaining 70 patients were the subjects of more detailed study.

Overall, the entire group of 483 patients first underwent shunt treatment at a mean age of 1.11 years. The 258 children with headaches initially underwent shunt treatment at a mean age of 1.44 years. The initial group of 103 children with presumed over-shunting headaches first underwent shunt treatment at a mean age of 0.98 years, and the 70 patients with over-shunting headaches who underwent detailed study underwent initial shunt treatment at a mean age of 1.21 years. On the other hand, patients without headaches underwent shunt treatment at a mean age of 0.76 years, and comparing these data with those of patients with headache barely reaches statistical significance ($p < 0.05$).

Of the 70 patients treated with an abdominal binder for presumed over-shunting headaches, the headaches started at a mean age of 9.5 years. In 14 children, the headaches tended to occur late in the day. Generally, there was a note in the chart that lying down helped the headache. The frequency of headaches was reported in 39 patients: 4 patients had several headaches daily, 17 had 1 headache daily, 9 had headaches every other day, 1 had 2 headaches per week, 6 had 1 per week, and 2 had a headache every other week.

The average age at the time of the first trial of an abdominal binder was 11.5 years. The children were kept in a binder for a mean of 4.7 weeks. Of the 70 patients treated with an abdominal binder, the headaches greatly improved or went away in 60 patients (85.7%). The binder was probably effective in 1 additional patient (1.4%) and ineffective in 9 patients (12.9%). These results are summarized in Fig. 2.

Although some patients reported improvement in their headache only hours after the application of an abdominal binder, most patients experienced improvement in the frequency and severity of the headache within several days. It sometimes required a week or more for the headaches to go away entirely.

Of the 61 patients who had a favorable or probably favorable response to using the abdominal binder, 36 started having headaches again, usually after a year or so (mean interval 1.54 years). In 1 patient, headache recurred 14.1 years after discontinuing the binder. The binder was tried a second time in 29 patients, of whom 26 had had a successful first trial of using the binder and 3 did not. Ten of these 29 patients were subsequently lost to follow-up, leaving 19 patients with known efficacy on second binder usage. Reuse of the abdominal binder was effective in 15 (78.9% of those patients with follow-up information). Moreover, it is likely that some of the 10 patients lost to follow-up also had favorable responses to reusing the binder, discontinuing its use on their own, and not keeping follow-up appointments because the headaches went away. These results are summarized in Figs. 3 and 4.

Shunt taps were performed as part of the clinical assessment in 17 patients. According to the notations in the medical records, the shunt appeared to be "normal" or "working" in 9 patients. In 6 patients, the notes described low pressure or spontaneous flow with low pressure. In 1

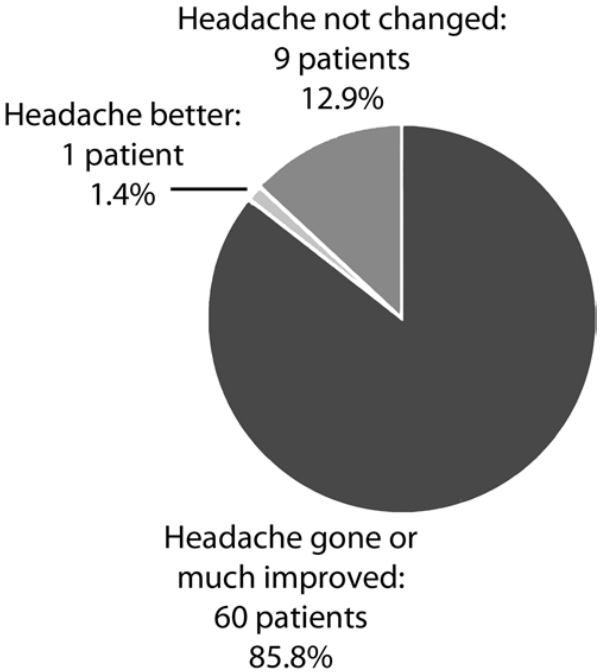

Fig. 2. Pie chart showing the effect of abdominal binders in patients with over-shunting headache (n = 70).

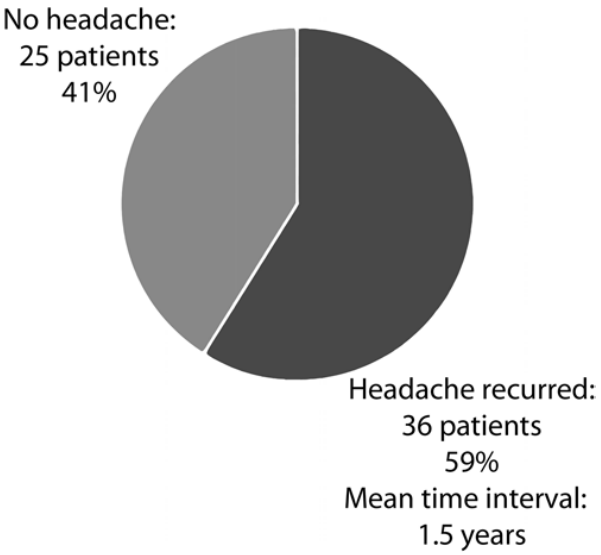

Fig. 3. Pie chart showing recurrence of headache in original responders to use of abdominal binder (n = 61).

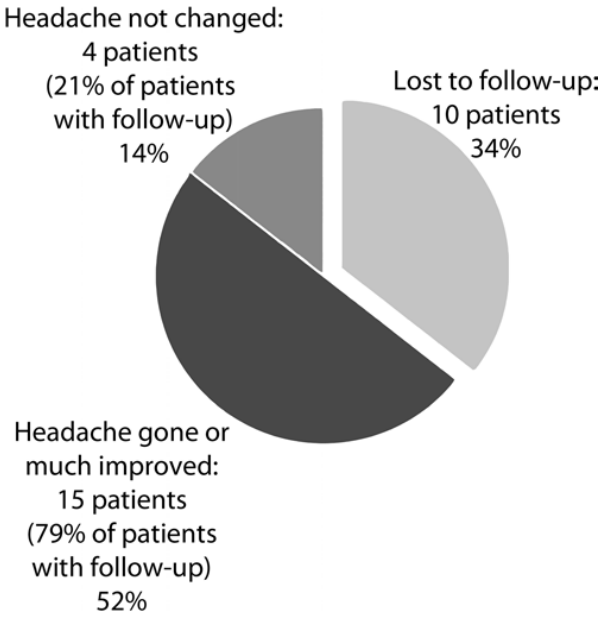

Fig. 4. Pie chart showing results of a repeat trial of the abdominal binder for recurrent or continued headache (n = 29). Of these patients, 26 had originally responded to abdominal binder treatment and 3 had not.

patient, very little fluid could be aspirated. Overall, these comments indicate that spontaneous flow of CSF was present in 16 of the 17 patients who underwent a shunt tap.

Eight patients underwent ICP monitoring as part of the headache workup, and the ICP data were believed to show normal or low ICP in all patients. On the other hand, 15 patients underwent 18 procedures to monitor ICP after a trial of wearing an abdominal binder. In 3 of these 15 patients, the monitoring was done shortly after the binder trial because of persistent headache, and the ICP was interpreted to be low or normal. The others were studied because of the recurrence of headache despite a good original response to wearing the abdominal binder.

Lack of Symptom Subjectivity and Observer Bias

It can be argued that the data of this retrospective study are of limited worth because objective measures of outcome, such as headache scales, were not always reported in the medical records. To address this problem of symptom subjectivity and observer bias, an attempt was made to reevaluate the office charts to identify those patients with over-shunting headaches who had complete relief of their headaches with the use of an abdominal binder. Unfortunately, a comprehensive re-review was not entirely possible because of a hardware failure of the neurosurgery primary server. Although practice data were retrieved from tape backups, the research drive was lost, and usable data could not be salvaged. A not-so-current offsite backup of this research project provided a partial patient list. Accordingly, only 58 of the 89 patients with presumed over-shunting headaches and binders could be identified for this repeat chart review.

This abbreviated list identified 47 of the 70 patients with over-shunting headaches who were treated with an abdominal binder and were subjected to retrospective study. These results are summarized in Table 1. In summary, 27 patients (57.4% of the 47 patients treated with a binder; 69.2% of the 39 patients who had a favorable response to a binder) had complete relief of their headaches. It is suggested that these results are objective and free of observer bias. The results from the remaining 30.8% of binder responders may include inaccuracies due to the lack of objective outcome measures and observer bias. In other words, most patients (69.2%) who had a favorable response to using an abdominal binder experienced complete relief of headache.

Discussion

Our data suggest that approximately 86% of patients with headache attributed to over-shunting will experience

TABLE 1: Re-review of patients with headaches who were treated with an abdominal binder to identify patients with complete relief of headaches*

Effect of Abdominal Binder	No. of Patients (%)	
	Results of Re-Review	Original Review
total no. of patients	47	70
substantial improvement	38 (80.9)	60 (85.7)
HA gone	27 (57.4)	
HA gone w/ qualifications†	4 (8.5)	
HA much improved	7 (14.9)	
HA slightly improved	1 (2.1)	1 (1.4)
no effect on HA	8 (17.0)	9 (12.9)

* HA = headache.

† Two patients had rare headaches (< 1/month) that were not severe, 2 patients experienced headache recurrence after discontinued use of the binder, and 1 patient was also taking migraine medication.

improvement in the headache with an abdominal binder. This study has several limitations. First, the data collected are retrospective and subjective. In the office records reviewed for this retrospective study, the severity and frequency of the headaches were not always quantified. The clinician frequently wrote what the patient and/or the family said regarding severity and frequency of headaches. However, headache scales were not consistently documented. Nonetheless, 60 of the 70 patients treated with abdominal binders had dramatic improvement in their headache. Statistical analysis of headache scale data would have been desirable, but such data were not consistently available. Therefore, these data cannot show the precise efficacy of the abdominal binder. On the other hand, a re-review of the charts of 47 of the 70 patients with over-shunting and binders indicated that nearly 70% of patients who responded favorably to using an abdominal binder had complete relief of headache.

Second, it is unlikely that all of the patients with presumed over-shunting had headaches as a direct result of intracranial hypotension. Some patients who were fitted with the binder did not have a typical clinical picture of over-shunting. Nonetheless, despite these limitations, this noninvasive therapeutic measure appears to have amazing efficacy in many patients with presumed over-shunting headaches. Moreover, there appears to be a lasting effect, and headache relief may persist more than a year. Reusing the binder is effective in the majority of cases.

Intracranial pulse pressures increase with the level of ICP.[5,11,27] This is a feature of physiology. In hydrocephalus, this pulse pressure–ICP relationship is exaggerated, and the intracranial pulse pressure is abnormally increased.[8,9,21] Using CSF withdrawals, Foltz and Blanks[11] showed that reducing pressures below the physiological baseline will result in marked augmentation of the intracranial pulse pressure, not unlike the pulse pressure increase that is seen at high pressures.

Normally, the pressure pulsations of the arteries at the base of the brain displace the CSF of the basal cisterns down the clivus into the spine with each cardiac systole. This can be appreciated on gated CSF studies with MRI technique.[14,29] Studying patients undergoing myelography, Martins and colleagues[22] showed that breathing 5% CO_2 causes the spinal sac to enlarge. On the other hand, hyperventilation causes the brain volume to decrease, and the spinal sac gets smaller as CSF moves back into the head. The spinal epidural veins are in free communication with the large veins of the chest and abdomen, and these epidural veins likely enlarge or constrict to accommodate CSF movement into and out of the spine during systole and diastole, respectively.[22] In other words, the spinal epidural veins may serve as a shock absorber, since epidural blood can be displaced during systole into the great veins of the chest and abdomen with each bolus of CSF displaced from the head into the spine. In diastole, CSF flow changes direction and moves out of the spine back toward the Circle of Willis. This is a physiological process.[14,29]

However, with over-shunting, the volume of CSF is reduced, not only in the ventricles, but also in the cisterns at the base of the brain. It is suggested that the reduced volume of CSF in the basal cisterns cannot effectively transmit the arterial pressure pulsations into the spine where reciprocal pulsatile changes in epidural venous blood can dampen these arterial pulsations.[14] The intracranial pulse pressures become augmented, and the patient may experience adverse symptoms (headache) or signs (cranial nerve VI palsy).[2,12]

It is suggested that an abdominal binder possibly functions to compress the pelvic veins, which are in free communication with the epidural venous plexus. It is hypothesized that the abdominal binder distends the epidural venous plexus so that it can function better as a shock absorber; more venous blood can be transiently displaced out of the spine with each systole. The result is a reduction in intracranial pulsations and improvement in signs and symptoms.[4,22]

Years ago, the senior author originally attempted to examine the efficacy of using an abdominal binder for the treatment of over-shunting headaches in a prospective study that was designed to show that the headaches recur when the binder is removed. The plan was to then reapply the binder to see if the headaches respond a second time. However, in nearly all of the patients who showed a favorable response to the binder, the headaches did not recur when the binder was discontinued. Recurrence after many months was not uncommon. The proposed mechanism of action must account for the observed lasting effect of the binder, and this issue is considered below.

When ICP has been monitored in patients with supposed over-shunting, the following 3 patterns have been observed in our institution (personal observation, senior author): 1) intracranial hypotension, 2) intracranial hypotension with intermittent plateau waves of very high ICP, and 3) intracranial hypertension. In our institution, those with consistently high ICP (Pattern 3) are thought to have shunt malfunction, and their shunts are revised. Most of the remaining patients tend to have Pattern 1 (intracranial hypotension), and these patients are treated with a binder. If the binder fails to control symptoms, an antisiphon device can be added to the shunt.[7,15,16,18,19,28] If this surgery is not successful, a cranial morcellation procedure as described by Epstein et al.[10] can be considered, if the symptoms are severe enough to warrant major surgery. This procedure is also done in patients with plateau waves superimposed on low ICP (Pattern 2). It is suggested that patients with this ICP pattern likely have an unstable cerebrovascular bed in which plateau waves are triggered from pathological augmentation of the intracranial pulse pressure. Moreover, many have suggested a vascular component contributing to the pathophysiology of this disease. Migraine medications are occasionally helpful in the control of symptoms.[24]

One possibility to explain the lasting efficacy of an abdominal binder to ameliorate symptoms long after the discontinuation of the binder is that the abdominal binder tends to correct the abnormally increased intracranial pulse pressure. This pulse pressure reduction soothes a hyperreactive cerebrovascular bed, and this serves to reset the threshold of vascular hyperactivity to a more normal level; even though pulse pressure augmentation likely recurs when the binder is removed, the cerebrovascular

hyperactivity does not recur—at least for a while. Clearly, this needs further study.

Conclusions

This study shows that headaches resulting from over-shunting will respond to the use of an abdominal binder 86% of the time, and that headache relief usually persists even after the binder is discontinued. Headaches can recur many months later, and reusing the abdominal binder is effective in the majority of cases. This nonsurgical management of over-shunting headaches can be an invaluable therapeutic tool in a pediatric neurosurgical practice. It is suggested that the mechanism of action of the abdominal binder involves the indirect modulation of intracranial pulse pressure abnormalities. This hypothesis requires further study.

Disclosure

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Author contributions to the study and manuscript preparation include the following. Conception and design: Sklar, Nagy. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Sklar. Statistical analysis: Robertson. Administrative/technical/material support: Sklar, Robertson. Study supervision: Sklar.

References

1. Arriada N, Sotelo J: Continuous-flow shunt for treatment of hydrocephalus due to lesions of the posterior fossa. **J Neurosurg 101:**762–766, 2004
2. Blanks JP, McPherson D, Foltz EL: Acute negative intracranial pressure effects on the auditory evoked response in rabbits. **Neurosurgery 17:**877–882, 1985
3. Bode H, Strassburg HM: [Craniocerebral dysproportion—a contribution to the significance of extracerebral fluid collections in infancy.] **Klin Padiatr 199:**399–402, 1987 (Ger)
4. Citerio G, Vascotto E, Villa F, Celotti S, Pesenti A: Induced abdominal compartment syndrome increases intracranial pressure in neurotrauma patients: a prospective study. **Crit Care Med 29:**1466–1471, 2001
5. Czosnyka M, Czosnyka Z, Momjian S, Pickard JD: Cerebrospinal fluid dynamics. **Physiol Meas 25:**R51–R76, 2004
6. Di Rocco C: Is the slit ventricle syndrome always a slit ventricle syndrome? **Childs Nerv Syst 10:**49–58, 1994
7. Di Rocco C, Massimi L, Tamburrini G: Shunts vs endoscopic third ventriculostomy in infants: are there different types and/or rates of complications? A review. **Childs Nerv Syst 22:**1573–1589, 2006
8. Ekstedt J: CSF hydrodynamic studies in man. 1. Method of constant pressure CSF infusion. **J Neurol Neurosurg Psychiatry 40:**105–119, 1977
9. Ekstedt J: CSF hydrodynamic studies in man. 2. Normal hydrodynamic variables related to CSF pressure and flow. **J Neurol Neurosurg Psychiatry 41:**345–353, 1978
10. Epstein F, Lapras C, Wisoff JH: 'Slit-ventricle syndrome': etiology and treatment. **Pediatr Neurosci 14:**5–10, 1988
11. Foltz EL, Blanks JP: Symptomatic low intracranial pressure in shunted hydrocephalus. **J Neurosurg 68:**401–408, 1988
12. Foltz EL, Lederhaus S: Ventricular CSF pulse pressure amplitude: an index of intracranial compliance, in Marguth F, Brock M, Kazmer E, et al (eds): **Advances in Neurosurgery, ed 4.** Berlin: Springer-Verlag, Vol 7, 1979, pp 295–304
13. Fouyas IP, Casey ATH, Thompson D, Harkness WF, Hayward RD: Use of intracranial pressure monitoring in the management of childhood hydrocephalus and shunt-related problems. **Neurosurgery 38:**726–732, 1996
14. Greitz D: Cerebrospinal fluid circulation and associated intracranial dynamics. A radiologic investigation using MR imaging and radionuclide cisternography. **Acta Radiol Suppl 386:**1–23, 1993
15. Hanlo PW, Cinalli G, Vandertop WP, Faber JA, Bøgeskov L, Børgesen SE, et al: Treatment of hydrocephalus determined by the European Orbis Sigma Valve II survey: a multicenter prospective 5-year shunt survival study in children and adults in whom a flow-regulating shunt was used. **J Neurosurg 99:** 52–57, 2003
16. Hyde-Rowan MD, Rekate HL, Nulsen FE: Reexpansion of previously collapsed ventricles: the slit ventricle syndrome. **J Neurosurg 56:**536–539, 1982
17. Kestle JR, Walker ML: A multicenter prospective cohort of the Strata valve for the management of hydrocephalus in pediatric patients. **J Neurosurg 102 (2 Suppl):**141–145, 2005
18. Kondageski C, Thompson D, Reynolds M, Hayward RD: Experience with the Strata valve in the management of shunt overdrainage. **J Neurosurg 106 (2 Suppl):**95–102, 2007
19. Kremer P, Aschoff A, Kunze S: Risks of using siphon-reducing devices. **Childs Nerv Syst 10:**231–235, 1994
20. Kuurne T, Servo A, Porras M: Subdural effusions re-appearing after shunts in patients with non-tumoural stenosis of the aqueduct. **Acta Neurochir (Wien) 67:**127–134, 1983
21. Linder M, Nichols J, Sklar FH: Effect of myelomeningocele closure on the intracranial pulse pressure. **Childs Brain 11:** 176–182, 1984
22. Martins AN, Wiley JK, Myers PW: Dynamics of cerebral fluid and the spinal dura mater. **J Neurol Neurosurg Psychiatry 35:**468–473, 1972
23. Mea E, Savoiardo M, Chiapparini L, Casucci G, Bonavita V, Bussone G, et al: Headache and spontaneous low cerebrospinal fluid pressure syndrome. **Neurol Sci 28 (Suppl 2):**S232–S234, 2007
24. Nowak TP, James HE: Migraine headaches in hydrocephalic children: a diagnostic dilemma. **Childs Nerv Syst 5:**310–314, 1989
25. Oi S, Matsumoto S: Infantile hydrocephalus and the slit ventricle syndrome in early infancy. **Childs Nerv Syst 3:**145–150, 1987
26. Rekate HL: Shunt-related headaches: the slit ventricle syndromes. **Childs Nerv Syst 24:**423–430, 2008
27. Sklar FH, Elashvili I: The pressure-volume function of brain elasticity. Physiological considerations and clinical applications. **J Neurosurg 47:**670–679, 1977
28. Tokoro K, Chiba Y: Optimum position for an anti-siphon device in a cerebrospinal fluid shunt system. **Neurosurgery 29:**519–525, 1991
29. Zhu DC, Xenos M, Linninger AA, Penn RD: Dynamics of lateral ventricle and cerebrospinal fluid in normal and hydrocephalic brains. **J Magn Reson Imaging 24:**756–770, 2006

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