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ORIGINAL ARTICLE

Systematic follow-ups were not associated with reduced acute ventriculoperitoneal shunt dysfunction in infancy

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Abstract

Aim: Hydrocephalus surgery with a ventriculoperitoneal shunt is a life-saving treatment, but it has been associated with a high risk of dysfunction and complications. We investigated whether infants who received a ventriculoperitoneal shunt below 12 months of age had a reduced risk of acute shunt dysfunction if they were included in a structured follow-up programme.

Methods: A population-based, retrospective chart review was performed at Uppsala University Children's Hospital, Sweden. Patients were identified by International Classification of Diseases, Tenth Revision codes and surgical codes from 1 January 2005 to 31 December 2019. Those who received the structured follow-up programme from April 2012 were compared with historical controls.

Results: We identified 95 patients (66% male): 47 in the follow-up group and 48 controls. Their mean age was 2.6 (range 0–12) months. There was a high 44% acute shunt dysfunction rate during the first year after primary surgery: 38% in the follow-up group and 50% in the control group ($p = 0.25$). The difference was not significant.

Conclusion: The structured follow-up programme was not associated with a significant reduction in acute shunt dysfunction. Predictive models could help to identify patients at risk for shunt dysfunction and complications and improve surveillance and follow-up programmes.

KEYWORDS
hydrocephalus, prevention, shunt dysfunction, surveillance, ventriculoperitoneal shunt

1 | INTRODUCTION

Hydrocephalus in children under 1 year of age is one of the most common neurological conditions that paediatricians handle. They are a significant burden for both patients and their parents. The incidence of congenital and acquired hydrocephalus in infancy has been shown to vary by both geographical location and socioeconomic status. Incidence rates of between 80 and 316 per 100000 have been reported.[1–3] The aetiology has been shown to be heterogeneous and age dependent. Congenital abnormalities are the predominant cause in infants, including spina bifida associated hydrocephalus and acquired post haemorrhagic and post infectious hydrocephalus. The condition

Abbreviations: CI, Confidence Interval; CT, Computer Tomography; MRI, Magentic Resonance Imaging; US, Ultrasound.

has mostly been reported to be secondary to brain tumours, head trauma and central nervous system infections in older children.[1,3–7]

Left untreated, progressive hydrocephalus will lead to macrocephaly, neurocognitive decline, the loss or arrest of gross and fine motor skills, seizures and eventually death.[8,9] The standard treatment for hydrocephalus is to perform neurosurgery by inserting a ventriculoperitoneal shunt.[8] This is needed when the intraventricular pressure becomes symptomatic. Unfortunately, this treatment poses a relatively high risk of malfunction and complications. The risk of malfunction is highest within the first year after the primary surgery and studies have reported that 23%–42% of children needed their surgery to be repeated within the first year.[10–14] The aetiology of dysfunction varies. Common causes include clogging or dislocation of the proximal part of the catheter close to the ventricle and dysfunction of the distal part of the catheter. Other causes include infections, wound closure problems and mechanical valve failure.[12–15] Young age at the time of the primary surgery seems to have been the most predictive known risk factor for shunt dysfunction. Other risk factors that have been constantly reported have been prematurity, male gender, obstructive hydrocephalus and spina bifida.[10,13,15–17] Acute shunt dysfunction poses a high risk of sequelae for the patient, because the increase in intracranial pressure can damage the brain parenchyma. Therefore, early detection optimises outcomes and planned daytime surgery has been demonstrated to be superior to acute or night-time surgery, with fewer complications.[18,19]

In April 2012, Uppsala University Children's Hospital, Sweden, launched a structured follow-up programme for infants with hydrocephalus who had received their first ventriculoperitoneal shunt. The primary aim was to detect early signs of shunt dysfunction, in order to reduce complication rates. The detailed follow-up programme entailed six clinical and radiological assessments within the first postoperative year. We also gathered data on historical controls before April 2012, who had not been included in any structured follow-up programme. This enabled us to carry out a pre-post intervention study.

The primary aims of this study were to assess compliance with the follow-up programme and test the hypothesis that a structured follow-up programme would be associated with a reduced rate of acute shunt dysfunction. The secondary aims were to investigate the aetiologies and risk factors for shunt dysfunctions in the whole cohort.

Key Notes

- Hydrocephalus surgery with a ventriculoperitoneal shunt is a life-saving procedure that has been associated with a high risk of dysfunction and complications in infants.
- A detailed, structured follow-up programme was not associated with a significant reduction in acute shunt dysfunction in infants under 12 months of age when they were compared with historical controls.
- Surveillance and follow-up programmes could be improved by developing predictive models to identify patients at risk.

2 | METHODS

All children under 12 months of age who received a ventriculoperitoneal shunt at the Uppsala University Children's Hospital were included in this population-based study from 1 January 2005 to 31 December 2019. The hospital is a tertiary referral centre for paediatric neurology and paediatric neurosurgery in the mid Sweden healthcare region. It covers seven counties and approximately 350 000 of the 2.1 million inhabitants are under 18 years of age. Children were identified in the paediatric neurology ward and outpatient clinic by clinicians using International Classification of Diseases, Tenth Revision codes. These were for: hydrocephalus (G91), other diseases in the brain (G93), congenital hydrocephalus (Q03) and spina bifida (Q05). Children were also identified by the surgical code AAF00-99 in the neurosurgical operation unit. Hospital medical records were collected from the paediatric, neurosurgery, neuroradiology and ophthalmology departments and scrutinised for up to 1 year after the child's primary shunt surgery.

The structured follow-up programme was launched in April 2012, to optimise care for children under 12 months of age with hydrocephalus who received a ventriculoperitoneal shunt. Older children were not subjected to the same detailed follow-up. The detailed follow-up programme included six visits to the paediatric neurology outpatient clinic Uppsala University Children's Hospital or to their local county hospital during the first year. The visits comprised an assessment by an experienced paediatric neurologist or paediatrician, together with ophthalmological and radiological evaluations. The first visit, 2 weeks after the primary surgery, was combined with removing the sutures. These visits were performed less frequently after the first postoperative year and took place 18 and 24 months after surgery and then annually until 18 years of age. The patients were then referred to the adult neurology or neurosurgery outpatient clinic (Table 1). Before April 2012, patients visited 2 weeks after surgery to have their sutures removed, but there were no standard follow-up visits scheduled after that point. Parent education was not a part of the intervention, but both the follow-up group and control group received information about the symptoms of acute shunt dysfunction.

The children all received a ventriculoperitoneal shunt during the study period. The intervention group were those that underwent this procedure from April 2012 and received structured follow-up and the controls were those who received their shunt before April 2012 and did not (Figure 1). Acute shunt dysfunction was defined as rapidly evolving signs or symptoms of increased intracranial pressure. These included vomiting, irritability, lethargy, a bulging fontanelle, sunset phenomenon and swelling along the shunt tube. The time intervals from primary ventriculoperitoneal shunt surgery to the first postoperative episode of acute shunt dysfunction were noted in months. The rates of acute shunt dysfunction were noted for both the follow-up and control groups (Table 1).

TABLE 1 The basic ventriculoperitoneal shunt follow-up programme after primary shunting for the youngest children with an open anterior fontanelle.

Time after surgery	Clinical evaluation	Palpation of valve and tubing	Head circumference, length and weight	Ophthalmology[a]	Neuroradiology
2 weeks	✓	✓	✓	✗	US
6 weeks	✓	✓	✓	✓	US
3 months	✓	✓	✓	✗	US
5 months	✓	✓	✓	✓	US
8 months	✓	✓	✓	✗	✗
12 months	✓	✓	✓	✓	CT
18 months	✓	✓	✓	✓	✗
24 months	✓	✓	✓	✓	MRI
Annually (until 18 years)	✓	✓	✓	✓	✗

Abbreviations: CT, Computer tomography performed, with low-dose CT if possible; MRI, Magnetic resonance imaging performed; US, Ultrasound of the brain performed; ✓, Performed, ✗, Not performed.

[a]Performed by an ophthalmologist to evaluate the optic disc and signs of papillary oedema.

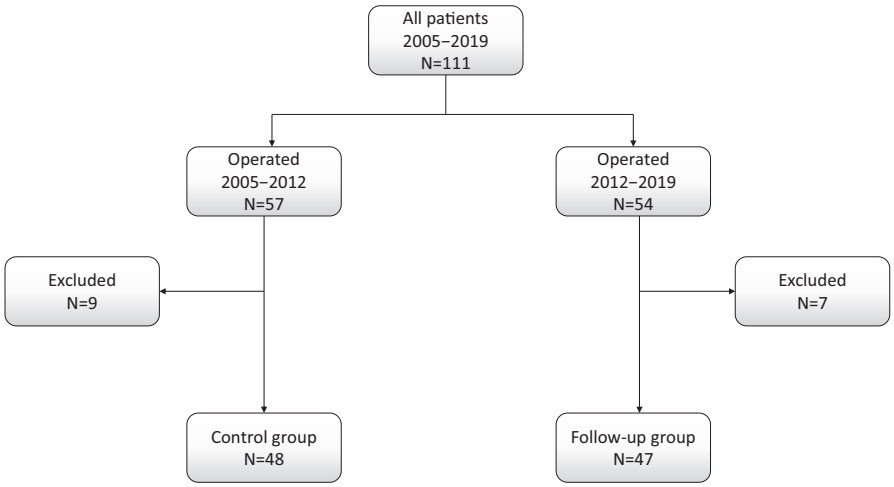

FIGURE 1 Flow chart of patient data and the patients who were finally included in the control and follow-up group. A total of 16 children were excluded.

3 | STATISTICS

Pearson's Chi-squared test and the Student's *t*-test were used to analyse differences between the follow-up and control groups, including the rates of shunt revisions within 12 months of the primary shunt surgery. Multiple logistic regression analysis was used to detect the risk factors for these revisions. We calculated 95% confidence intervals (CI). All the statistical tests were two-tailed and the level of significance was set at $p < 0.05$. The statistical analysis was performed with SPSS, version 28 (IBM Corp, New York, USA).

4 | RESULTS

4.1 | Clinical findings and patient characteristics

The records showed that 111 children received their first ventriculoperitoneal shunt before 12 months of age from 1 January 2005 to 31 December 2019. We excluded 16 children. One child was born severely ill and treated in the neonatal intensive care unit for more than 12 months. Five children were lost to follow-up and three had insufficient data in their medical records. Seven children died within a year of their primary surgery from causes that were not related to complications with their ventriculoperitoneal shunts. These included brain tumours and severe malformation syndromes. Therefore, 95 children (66% male) were included in the study. The follow-up group consisted of 47 infants (70% males) and the control group of 48 infants (63% males) (Figure 1).

The three most common causes of hydrocephalus in the whole cohort were spina bifida (26%), intraventricular haemorrhage (31%) and obstructive hydrocephalus (27%). No significant differences were found between the two groups regarding the following parameters: sex, gestational age and age at primary surgery. Table 2 demonstrates their basic patient characteristics. The most frequently inserted ventriculoperitoneal shunt (94%) was the Codman Medos Hakim (Integra LifeSciences, Princeton, New Jersey, USA). This was followed by the Codman Accu-Flo, abdominal catheter with resistance (5%) (Integra LifeSciences) and the Miethke proGAV 2.0 (Christoph Miethke GmbH & Co KG, Potsdam, Germany), which accounted for just 1%.

4.2 | Programme compliance and rates of acute shunt dysfunction

Compliance with the follow-up programme was good, with 68% of the patients completing four or more visits. The rates of acute shunt dysfunctions during the first year after primary surgery were high. Surgery for acute shunt dysfunction was performed on 44% of all patients. There was a slight difference in the frequency of acute shunt dysfunction, with fewer in the follow-up group (38%) than the control group (50%) ($p = 0.25$). No acute shunt dysfunctions were diagnosed during the planned follow-up visits and they were no more common in patients who made fewer control visits (Figure 2).

We found that 28 patients visited Uppsala for their follow-up visits and 14 patients had their outpatient visits at both Uppsala and their local county hospital. The remaining five patients only had their outpatient visits at their local county hospital. A planned shunt revision was performed in nine children and seven were in the follow-up group. All procedures, except a single shunt revision, were performed to manage over drainage problems, which did not cause acute shunt dysfunctions. Eight children received an anti-siphon device or the ventriculoperitoneal shunt system was changed from shunt tubing with distal pressure to the Codman Medos Hakim shunt system, which has a conventional valve. One child in the follow-up group underwent planned surgery when the computed tomography scan at their 12-month check-up revealed a dislocated ventricular catheter.

TABLE 2 Comparisons of basic patient characteristics between the follow-up and control groups.

Variable	Follow-up group ($n = 47$) *n* (%)	Control group ($n = 48$) *n* (%)	*p*-value
Sex			0.43
Female	14 (30)	18 (37)	
Male	33 (70)	30 (63)	
Gestational age			0.95
Term ≥37 weeks	33 (70)	34 (71)	
Preterm <37 weeks	14 (30)	14 (29)	
Age primary surgery[a]	2.3	2.8	0.44
Major causes of hydrocephalus			
Spina bifida	13 (28)	12 (25)	0.77
Intraventricular haemorrhage	14 (30)	15 (31)	0.88
Obstructive hydrocephalus[b]	15 (32)	11 (23)	0.33

Note: Pearson's Chi-squared test or the Student's *t*-test were used to test for statistical significance.

[a]Months.

[b]Aqueduct stenosis, expansive cysts.

4.3 | Time intervals to acute shunt dysfunctions

The time intervals from the primary ventriculoperitoneal shunt surgery to the first episode of acute shunt dysfunction were analysed for all 95 patients. There was a clear tendency for early postoperative shunt dysfunction, with 54% occurring within 2 months and 79% within 5 months (Figure 3). There was no difference between the follow-up and control groups in this regard.

4.4 | Aetiologies of shunt dysfunction

Proximal shunt dysfunction occurred in 38% of patients who underwent surgery for acute shunt dysfunction. Other aetiologies were wound closure problems (10%), shunt infections (7%) and inadequate shunting (7%). There were no significant differences between the follow-up and control groups in this regard (Table 3).

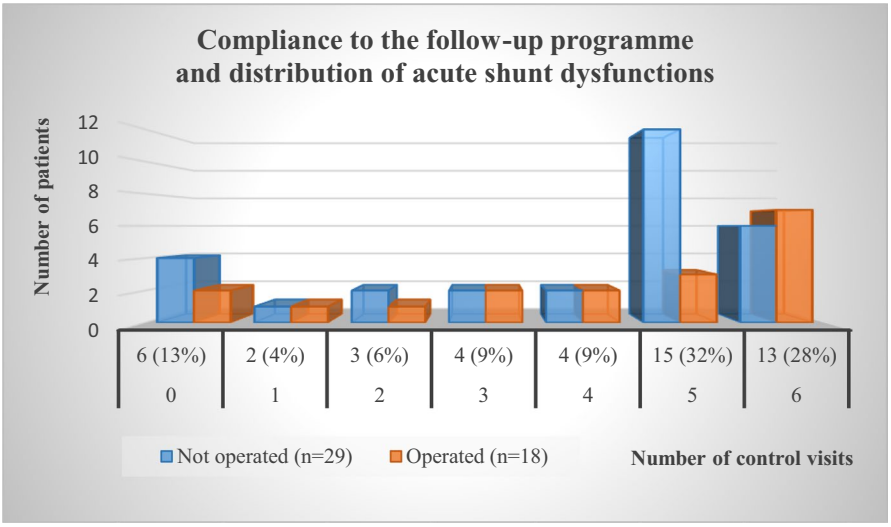

FIGURE 2 Distribution of patients with acute shunt dysfunctions that required surgery in relation to the number of performed control visits during the follow-up programme. Acute shunt dysfunctions did not seem to be more prevalent in patients with fewer control visits.

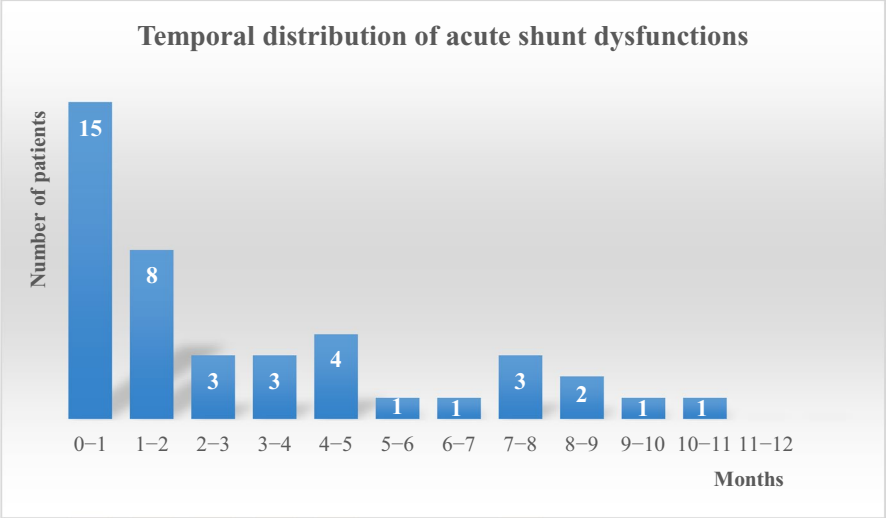

FIGURE 3 Distribution of acute shunt dysfunctions related to the time that elapsed after the primary surgery. Numbers relate to the whole patient cohort.

TABLE 3 Causes of acute shunt dysfunction.

Cause of shunt dysfunction	Whole cohort *n* = 42/95 (44%) *n* (%)	Follow-up group *n* = 18/47 (38%) *n* (%)	Control group *n* = 24/48 (50%) *n* (%)	*p* value
Proximal shunt dysfunction	16/42 (38)	7/18 (39)	9/24 (38)	0.93
Wound closure problems	4/42 (10)	3/18 (17)	1/24 (4)	0.30
Shunt infection	3/42 (7)	0/18 (0)	3/24 (13)	0.25
Inadequate shunting	3/42 (7)	1/18 (6)	2/24 (8)	1.00
Distal shunt dysfunction	2/42 (5)	0/18 (0)	2/24 (8)	0.50
Shunt malfunction	1/42 (2)	1/18 (6)	0/24 (0)	0.43
Not specified	13/42 (31)	6/18 (33)	7/24 (29)	0.78

4.5 | Risk factors for shunt dysfunction

Various risk factors for shunt dysfunction were analysed for the whole cohort. Low age at primary surgery was almost significant for a ventriculoperitoneal shunt dysfunction ($p = 0.06$). Details regarding the different risk factors are demonstrated in Table 4.

TABLE 4 Risk factors for a ventriculoperitoneal shunt dysfunction, using multiple logistic regression analysis.

Variable	*p*-value	Odds ratio	95% CI
Age at primary shunting (0–12 months)	0.06	0.83	0.69–1.00
Obstructive hydrocephalus	0.27	0.54	0.18–1.61
Spina bifida	0.80	0.87	0.27–2.77
Prematurity	0.90	0.93	0.33–2.63
Haemorrhage	0.75	1.21	0.37–3.93

Abbreviation: 95% CI, 95% confidence interval.

5 | DISCUSSION

Hydrocephalus surgery is a life-saving procedure among very young children, but it has been linked to a high risk of complications. This was a retrospective single centre, population-based, pre-post intervention study. It found that 44% infants who received their first ventriculoperitoneal shunt when they were under 12 months of age needed repeat surgery for acute shunt dysfunction within 12 months of their primary surgery. Other studies have similarly reported that 30%–40% of all children who received a ventriculoperitoneal shunt at a young age needed repeat surgery within the first postoperative year.[10–13,20]

Our main aims were to investigate compliance with an ambitious follow-up programme and to determine whether early detection could minimise the frequency of acute shunt dysfunctions and the need for acute surgery. Compliance with the follow-up programme was good. There was a slight difference in the frequency of acute shunt dysfunctions, with fewer in the follow-up group than the historic controls (38% vs. 50%). However, it was not statistically significant ($p = 0.25$).

Most of the shunt dysfunctions developed shortly after the child's primary surgery, with 54% and 79% occurring within 2 and 5 months, respectively. This important finding was in line with previous studies.[10,12,13] However, the follow-up programme was not associated with a reduced frequency of acute shunt dysfunctions, despite the fact that it comprised four postoperative controls within 5 months of the primary surgery. One possible explanation could be that shunt

dysfunctions developed rapidly, within hours to days. This would mean that the follow-up programme was too crude to be regarded as a screening method. To effectively identify threatening shunt dysfunctions would probably require more frequent postoperative controls and medical resources. It would also increase patient and parental burdens, by expecting them to attend multiple healthcare appointments. Thoroughly informing parents about the high risk of shunt dysfunction, within a short time of the primary surgery, is of utmost importance. They should also be provided with rigorous information about possible signs and symptoms of acute shunt dysfunction.

Whether the follow-up programme could have had any other positive consequences was not investigated. It would be important to examine possible differences in the amount and severity of sequelae between the follow-up and control groups following their acute shunt dysfunctions. Another potential detectable parameter in the follow-up programme could be shunt over drainage and the development of a small head circumference. Indeed, six cases of over drainage that needed planned shunt revision were detected in the follow-up group. Whether we had a lower frequency of subjects with a small head circumference in the follow-up group than the control group will be further analysed. These data will be presented in another paper. Other possible advantages of a structured follow-up programme are giving parents better and repeated information. This might have a positive impact on their overall health and quality of life. After all, studies have reported that paediatric chronic illnesses affect the entire family, not just the child.[21,22]

Efforts to reduce high complication rates are very appropriate. They have the potential to reduce morbidity and decrease the substantial financial burden that shunt surgery places on the paediatric healthcare system.[23] Whether the reduced rate of acute shunt dysfunction we observed in our study would reach statistical significance in a larger study is unclear. A prospective multicentre or national study that investigates this might be of benefit. A larger prospective study could also investigate lead times from symptom debut to a confirmed clinical and radiological shunt dysfunction. This could shed new light on the actual resources needed to identify threatening shunt dysfunctions at an early stage. Also, machine learning has recently been used to predict the risk of shunt failure and develop predictive models to anticipate shunt complications in children.[24,25] Further development of such models could help to better identify patients at risk. The importance of routine following up patients with shunted hydrocephalus has been debated.[26,27] Future research should focus on how to improve surveillance and follow-up programmes, while integrating cost analyses and parental collaboration.

The most common causes of shunt revisions were proximal shunt dysfunction (38%), inadequate wound healing (10%) and shunt infections (7%). Similar findings have been reported by other studies.[13,15,20,28] The overall frequency of shunt infections in relation to all patients receiving a ventriculoperitoneal shunt was only 3% in our study. This was less than a previous retrospective study performed in Uppsala on children under 15 years of age who had just received surgery. That study found an overall infection rate of 8% and this rose to 10% for infants.[29]

Studies on preventable shunt dysfunction have been lacking. In 2016, the term preventable shunt revision rate was proposed by Venable et al. as a specific, meaningful, measurable and possibly modifiable quality metric for paediatric shunt surgery.[30] The authors argued that 33% of the revision surgery that was carried out was due to potentially preventable causes. A preventable cause was defined as an inaccurate proximal or distal catheter placement, an infection or inadequately assembled shunt apparatus. It was difficult to compare our results with this study, because we did not know the exact cause of the proximal shunt dysfunctions. However, 17% of the shunt failures in our study were caused by shunt infections or wound closure problems. Another 38% were proximal shunt dysfunctions and it was likely that inaccurate proximal or inadequately assembled shunt apparatus caused a part of these. Therefore, it seems likely that we had comparable results to Venable et al.[23]

Our study supported other studies when it came to the most prominent risk factor for shunt dysfunction, which was young age at the time of primary shunting.[13,31] We were not able to find any other risk factors, although prematurity, male gender, obstructive hydrocephalus and spina bifida also have been reported.[10,16,17] Although our study comprised a relatively large cohort of 97 infants, it might have been too small to identify potential risk factors.

6 | STRENGTHS AND LIMITATIONS

One of the strengths of this population-based study was that it included a relatively large number of patients who were under 12 months of age when they received primary shunt surgery for hydrocephalus. Paediatric neurosurgery in the mid Sweden healthcare region is only performed at Uppsala University Hospital and we believe that all the patients who received this were included in this study. The number of excluded patients and missing data were low. A thorough review of all hospital medical records was performed. The general limitations of this study were related to the retrospective design, as varying amounts of information were found in the medical records. We could not exclude a type 2 error as a result of the sample size. In addition, we could not completely exclude reporting bias, because of the greater scrutiny inherent in being part of the programme. However, it is likely that this would have resulted in more complications.

One possible explanation for the lack of effect in our study could have been poor compliance with the follow-up programme. However, this was relatively good, so it seems unlikely that non-adherence was behind the lack of change in the complication rates. It is also reasonable to believe that compliance was even higher, because it was difficult to retrieve all the data from the medical records at the local county hospitals. Moreover, acute shunt dysfunctions did not seem to predominate in patients with fewer control visits. Thus, non-compliance did not seem to hide a potential benefit of the programme. Another possible limitation of the study was that some of the clinical and neuroradiology assessments were performed at different hospitals. Both Uppsala University Children's Hospital and

the local county hospitals were involved in the follow-up. However, experienced paediatric neurologists and paediatricians performed all the clinical assessments, and neuroradiology results were routinely sent to Uppsala University Children's Hospital for central review. The basic patient characteristics were also comparable between the groups. Factors, such as sex, gestational age, the underlying cause of the hydrocephalus and the child's age at primary surgery, did not differ between the follow-up and control groups.

7 | CONCLUSION

Using a ventriculoperitoneal shunt to perform hydrocephalus surgery on infants was associated with a high risk of dysfunction and complications. A structured follow-up programme, with frequent clinical assessments and radiological controls, was not associated with a significant reduction in acute shunt dysfunction in infants under 12 months of age. Developing predictive models to better identify patients at risk for shunt dysfunction and complications might help to improve future surveillance and follow-up programmes.

AUTHOR CONTRIBUTIONS

Gunnar Liminga: Conceptualization; writing – original draft; writing – review and editing; methodology; investigation. **Benjamin Ahlbäck:** Investigation; methodology. **Sami Abu Hamdeh:** Conceptualization; writing – review and editing. **Pelle Nilsson:** Conceptualization; writing – review and editing. **Christoffer Ehrstedt:** Writing – original draft; funding acquisition; investigation; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Original data are available from the corresponding author upon reasonable request.

ETHICS

The study was approved by the Swedish Ethical Review Authority (registration no. 2019/00163).

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