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Perioperative risk factors for short-term shunt revisions in adult hydrocephalus patients

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Abstract

OBJECTIVES - The aim of this study was to prospectively study perioperative variables associated with revision after shunt surgery for adult hydrocephalus.

METHODS - Two protocols were designed to prospectively study perioperative risk factors during shunt insertion. During 10 years (1995-2004), 450 adult (age > 16 years) patients with first-time shunt implantations were studied. Patients who had been treated with endoscopic third ventriculostomy were excluded from the study. All shunts were designated as meeting one of two endpoints: 1) shunt failure requiring revision within 6 months, or 2) no shunt failure within 6 months. Shunt revision within 6 months postoperatively was considered to be related to the shunting procedure.

RESULTS - Eighty-five shunt revisions were performed within 6 months after insertion. During the study period the revision rate declined from 21.1 % to 9.1 %. Revision rates were the same for ventriculoperitoneal (n = 411) and ventriculoatrial (n = 39) shunts. The predictive values of variables related to the patient, operating room, surgical technique and shunt system were analysed to determine shunt outcome.

CONCLUSIONS - Right frontal placement of the ventricular catheter was associated with the lowest rate of revisions. Adjustable valves were associated with a lower risk for shunt revision. Shunt revision rates did not differ between ventriculoperitoneal and ventriculoatrial shunts.

Key words: *Hydrocephalus · Shunt · Revision · Adult · Shunt failure · Perioperative*

Word count: 2493

Introduction

In Sweden, the annual incidence of surgery for hydrocephalus is 3.4 per 100,000 adults.[1] Shunting of the cerebrospinal fluid from the ventricular system to the peritoneum or the right atrium is the primary treatment for 80% of the hydrocephalic adults with communicating hydrocephalus and might also be secondary treatment for those patients with non-communicating hydrocephalus who do not improve after endoscopic third ventriculostomy (ETV).[2] Post-operative complications include infection, obstruction, subdural fluid collection, seizures, overdrainage headache and shunt underdrainage.[3]

The incidence of morbidity related to shunt management is of great importance when determining the risk-to-benefit ratio in the treatment of hydrocephalus.[3] Shunt malfunction can be broadly divided into mechanical shunt failure and shunt infection.[4] Studies have shown an overall 1-year shunt failure rate of 30-40% [5-8] and shunt failures most commonly occur within 6 months post-operatively.[4] Infection occurs in 3-15% [4, 8-14] of the patients after shunt surgery, while an infection rate of 0.3% has been achieved after modifying the operative practice.[15] The mortality rate related to shunt surgery varies from 2 to 9%.[16-17]

Various factors related to CSF shunt malfunction have been analysed. These include prematurity and age of the patient,[12-14, 18] aetiology of the hydrocephalus,[14] shunt type,[12, 19-20] surgeon's operating experience,[8-10, 12, 15, 21] number of revisions,[14] position of ventricular catheter tip,[22] distal placement of the catheter,[23] handling of shunt equipment,[4, 24] shaving of the scalp [8, 25] and duration of the operation.[12]

The aim of this study was to prospectively evaluate perioperative risk factors for revision after shunt implantation in adult hydrocephalus patients.

Material and Methods

In January 1995, a prospective, observational cohort study of all shunt operations (primary insertions and revisions) was initiated at the Department of Neurosurgery, Sahlgrenska University Hospital in Gothenburg, Sweden. Two protocols were designed to record perioperative data during shunt insertion (insertion protocol) and shunt revision (revision protocol), respectively. The protocols were filled in during surgery by the scrub nurse and, in case of missing or unclear data, were completed by the surgeon directly after surgery. Between January 1995 and December 2004, 586 consecutive patients underwent a total of 932 CSF-shunt operations. In this study, we included all patients older than 16 years, who had undergone primary shunt implantation or subsequent revision within 6 months after primary surgery (figure 1). Patients who had undergone endoscopic third ventriculostomy were excluded. Of the 450 patients meeting inclusion criteria, 85 patients were revised within 6 months after surgery. In case of death, the date and cause were obtained from the National Board of Health and Welfare.

All patients received antibiotics and 98.6 % of the patients were shaved by electric clipper pre-operatively. 84 % of the patients received Cefuroxim (1500 mg, iv) as a single-dose at the start of the operation while other generics were chosen depending on the resistance pattern from the CSF culture. In cases of penicillin allergy a single dose Klindamycin (600 mg, iv) was used. No patients received antibacterial shunt material, such as Bactiseal™. Gloves were generally changed after tunnelation and in the case of skin contact during surgery.

Patients with ventriculostomy preoperatively were considered as shunt candidates if the CSF Albumin was lower than 1 g/l and there was a normal CSF cell count. In case of infection three negative CSF cultures were required preoperatively to consider the patient for shunt insertion.

The placement of the shunt and valve was chosen by the surgeon. Different valves were available during the study due to hospital policy unrelated to the study. The ventricular catheter length was chosen to reach immediately anterior to the foramen of Monroe and the ventricular catheter length of 10-11 cm was intended to be placed into the cella media of the ventricular system via the occipital route. The variables included in the perioperative protocols are presented in table 1.

All shunts were designated as meeting one of two endpoints: 1) shunt failure requiring revision within 6 months, or 2) no shunt failure within 6 months. Shunt revision within 6 month postoperatively was considered to be related to the shunting procedure. When shunt obstruction was suspected it was verified by shuntography, showing obstruction of injected radionuclide [26] or lumbar infusion test, showing a higher R_{out} than expected from the valve [27]. A shunt infection was diagnosed depending on the clinical picture, elevated CSF cell count, and the presence of a positive CSF culture. Overdrainage was defined as the presence of headache combined with radiological findings (CT/MRI) of collapsed ventricles while underdrainage was defined as the presence of hydrocephalus symptoms combined with testing of the shunt (26, 27).

The aetiologies of the hydrocephalus among the studied patients were obtained from the hydrocephalus database at the Hydrocephalus Research Unit, Institute of Clinical Neuroscience, Sahlgrenska Academy, Göteborg University, Sweden.

Statistics

For discrete data, the Fisher exact probability test was used to analyse dichotomous nominal variables and regular Chi-square test was used to analyse non-dichotomous nominal variables. Mantel-Haenszel's chi square test was used for ordinal variables. Continuous variables were analysed using the Mann-Whitney U test.

Mantel Haenszel chi-square test for trend in contingency table was used to compare the annual shunt revision rates.

For survival analyses, Kaplan-Meier estimates were calculated and formally tested with the log-rank test. Multivariate analyses were performed using stepwise Cox proportional hazard regression; only those variables that affected survival time in univariate tests ($p < 0.1$) were included as possible predictors. All tests were two-tailed and conducted at a 5 % significance level.

Figure 1. Flow chart for patients and procedures included in the study.
N = number of procedures, n = number of patients, ETV = endoscopic third ventriculostomy.

Table 1. Perioperative insertion and revision protocols (revised). (Online Appendix)

Insertion Protocol	
Age	date of birth
Gender	female / male
Operator	attending / resident
Operating room used prior to the operation	yes / no
Total number of persons present in operating room	n
Procedure performed	ventriculo-peritoneal / ventriculo-atrial shunt
Ventricle catheter length	cm
Catheter location	frontal / occipital, right / left
Valve manufacturer	Delta / Strata / Sophy / Sigma / Codman
Opening pressure	cm H ₂ O
Peritoneal catheter length	cm
Superficial wounds	yes / no

Eczema or pimple	yes / no
Tracheostomy	yes / no
Preoperative ventricular drain	yes / no
Accessory incision(s)	n
Glove change	n
Length of operation	minutes
Revision Protocol	
Priority	acute / elective
Indication for revision	mechanical (proximal to the valve) / mechanical (distal to the valve) / infection / overdrainage / subdural haematoma / other
Type of revision procedure	Total shunt system removal / total shunt system replacement / conversion from VP- to VA-shunt / conversion from VA- to VP-shunt / valve replacement / distal procedure / proximal procedure / other

Results

A total of 411 ventriculoperitoneal (VP) and 39 ventriculoatrial (VA) shunt insertions were performed. Of these 450 patients, 85 underwent shunt revision within 6 months after shunt insertion. Revision rates within 6 months after shunt insertion were equivalent for VA and VP shunts. Table 2a shows the different perioperative variables related to shunt revision within 6 months. Shunt survival analysis for different variables is presented in table 2b. Mortality rates were 2 % (n=9) within 4 weeks and 5.3 % (n=24) within six months postoperatively (table 3). The mortality rate for patients with idiopathic (normal pressure) hydrocephalus was 2,4 % within 6 months. Revision rate tended to declined towards the end of the study period from 21,2 % to 9,1 % (p=0,165).

The shunt infection rate was 5.6 %. A shunt infection was reported as the indication for shunt revision in 28.2 % of shunt revisions performed within 6 months (table 3). 42.4 % of the revisions were due to proximal or distal mechanical failure (underdrainage).

Table 2a. Perioperative variables correlated to shunt revision within 6 months.

Variable	Primary procedures	Revision within 6 months	No revision within 6 months	Hazard Ratio (confidence interval)	P-value
Number of patients	450	85 (18.9%)	365		
Age	n = 450	n = 85	n = 365	0.99 (0.98-1.00)	3) 0.121
Mean (SD)	56.9 (± 18.0)	53.44 (± 18.35)	56.86 (± 17.98)		
Gender	n = 450				1) 0.926
Female	245 (54.4%)	47 (19.2%)	196		
Male	205 (45.6%)	38 (18.5%)	167		
Shunt type	n = 450				1) 0.608
VP-shunt	411 (91.3%)	76 (18.5%)	335		
VA-shunt	39 (8.7%)	9 (23.1%)	30		
Valve brand/ manufacturer	n = 449			1.216 (1.05-1.41)	2) 0.078
PS Medical Delta Shunt (non-adjustable)	208 (46.3%)	47 (22.6%)	161		1) 0.086
PS Medical Strata Shunt (adjustable)	125 (27.8%)	13 (10.4%)	112		1) 0.005*
Sophysa adjustable shunt Sophy SU-8	95 (21.2%)	21 (22.1%)	74		1) 0.453
Codman-Medos Programmable Hakim Valve	15 (3.3%)	3 (20.0%)	12		1) 1.000
Orbis Sigma	6 (1.3%)	1 (16.7%)	5		1) 1.000
Valve type	n = 449			1.86 (1.18-2.93)	1) 0.007*
Adjustable valves	235 (52.3%)	37 (15.7%)	198		
Non-adjustable	214 (47.6%)	48 (22.4%)	166		
Ventricular catheter placement	n = 442			0.81 (0.68-0.96)	2) < 0.001*
Right occipital	166 (37.6%)	44 (26.5%)	122		1) 0.003
Left occipital	15 (3.4%)	7 (46.7%)	8		1) 0.024
Right frontal	242 (54.8%)	28 (11.6%)	214		1) < 0.001
Left frontal	19 (4.3%)	5 (26.3%)	14		1) 0.568
Ventricular catheter length (cm)	n = 436	n = 82	n = 354	1.13 (1.04-1.23)	1) 0.004*
Mean (SD)	8.11 (2.10)	8.82 (± 2.14)	7.94 (± 2.05)		
Valve pressure (cm H₂O)	n = 439	n = 83	n = 356	1.05 (1.01-1.09)	3) 0.063
Mean (SD)	9.10 (4.77)	10.15 (± 5.10)	8.86 (± 4.66)		
Peritoneal catheter length (cm)	n = 386	n = 69	n = 317	1.01 (0.99-1.04)	3) 0.113
Mean (SD)	24.23 (6.73)	24.05 (± 6.82)	25.10 (± 6.28)		
Pre-operative ventriculostomy	n = 449				1) 0.805
Yes	104 (23.4%)	21 (20.2%)	83		
No	345 (76.6%)	64 (18.6%)	281		
Tracheostomy	n = 368				1) 0.399
Yes	21 (5.7%)	6 (28.6%)	15		
No	347 (94.3%)	65 (18.7%)	282		
Superficial wounds	n = 373				1) 0.282
Yes	73 (19.6%)	17 (23.3%)	51		
No	300 (80.3%)	51 (17.0%)	249		
Eczema/pimples	n = 371				1) 0.830
Yes	53 (14.3%)	9 (17.0%)	44		
No	318 (85.7%)	62 (19.5%)	256		
Accessory incision(s)	n = 373				4) 0.065
None	118 (31.6%)	27 (22.9%)	91		
One	230 (61.7%)	31 (13.5%)	199		
Two or more	25 (6.7%)	4 (16.0%)	21		
Operating room used prior to the operation	n = 366				1) 0.379
Yes	171 (46.7%)	28 (16.4%)	143		
No	192 (53.3%)	40 (20.8%)	155		
Number of persons in the operating room	n = 371	n = 304	n = 67	1.07 (0.97-1.18)	3) 0.321
Mean (SD)	6.10 (1.86)	6.34 (± 2.05)	6.05 (± 1.81)		
Glove changes	n = 368				4) 0.310
None	10 (2.7%)	2 (20.0%)	8		
One or two	282 (76.6%)	46 (16.3%)	236		
Three or more	76 (20.7%)	17 (22.4%)	59		
Length of the operation (minutes)	n = 365	n = 300	n = 65	1.00 (1.00-1.01)	3) 0.102
Mean (SD)	56.71 (27.65)	55.54 (± 26.05)	62.14 (± 33.79)		
Experience of the operator	n = 450				1) 1.000
Attending	386 (85.8%)	73 (18.9%)	313		
Resident	64 (14.2%)	12 (18.8%)	52		

* = significant p-value, 1) = Fisher exact test, 2) = Chi square test, 3) = Mann-Whitney test, 4) = Mantel-Haenszel test

Table 2b. Shunt survival analysis for the different variables at the time of shunt insertion.

Variable	Number of patients	P-value
Age	450	2) 0.127
Gender	448	1) 0.661
Shunt type (VP/VA)	450	1) 0.233
Valve brand/ manufacturer	449	1) 0.030*
Valve type (programmable/non-programmable)	449	1) 0.007*
Ventricular catheter placement	442	1) < 0.001*
Ventricular catheter length (cm)	436	2) 0.004*
Valve pressure (cm H ₂ O)	439	2) 0.010*
Peritoneal catheter length (cm)	386	2) 0.379
Pre-operative ventriculostomy	449	1) 0.126
Tracheostomy	368	1) 0.344
Superficial wounds	373	1) 0.221
Accessory incision(s)	373	1) 0.274
Operating room used prior to the operation	366	2) 0.441
Number of persons in the operating room	371	1) 0.199
Glove changes	368	1) 0.134
Length of the operation (minutes)	365	2) 0.572
Experience of the operator	450	1) 0.602

* = significant p-value, 1) = log-rank test, 2) = Cox regression test

Table 3. Revision referral, indication and procedure in the patient sample (n=85).

Variable	Number of revisions	Percentage
Priority		
acute	43	50.6
elective	39	45.9
n/a	3	3.5
Indication for revision		
infection	24	28.2
mechanical (proximal to the valve)	18	21.2
mechanical (distal to the valve)	18	21.2
hygroma	4	4.7
overdrainage	2	2.4
other revision	18	21.2
n/a	1	1.2
Type of revision procedure		
total shunt system removal	32	37.6
proximal procedure	16	18.8
distal procedure	15	17.6
valve replacement	11	12.9
total shunt system replacement	2	2.4
conversion from VP- to VA-shunt	2	2.4
conversion from VA- to VP-shunt	1	1.2
other procedure	6	7.1

Surgical variables

Ventricular catheter location was a significant risk factor for shunt revision. Right frontal placement of the ventricular catheter was associated with a significantly decreased risk (11.6 %; $p < 0.001$) for shunt revision within 6 months while right occipital (26.5 %; $p = 0.003$) and left occipital (46.7 %; $p = 0.024$) placements were associated with an increased risk. Figure 2

shows survival curves by shunt placement. Shorter ventricular catheters were associated with a lower revision rate, although it was shown with multi-variate analysis that this variable was dependent on the catheter location and not a significant risk factor itself. The peritoneal catheter length was not associated with an increased risk for shunt revision.

Adjustable valves were associated with a significantly decreased risk for shunt revision within 6 months (15.7 %, $p=0.007$). Twenty-one surgeons performed the shunt insertions. Of the total 450 shunt insertions, 323 were performed by two of the investigators. Shunt revision rates did not differ between qualified neurosurgeons and neurosurgery residents. The number of shunt insertions performed by the surgeons varied from 1 to 176, but the number of operations per surgeon was unrelated to shunt revision. Length of operation did not differ between revised and non-revised patients. ($p=0.102$). Accessory incision(s) was not a significant risk factor, ($p=0.065$); however, one accessory incision was associated with the lowest rate of revision. The number of glove changes was unrelated to shunt revision.

Figure 2. Kaplan-Meier shunt survival curve showing the time to shunt revision related to shunt placement (Log-Rank test, $p < 0.005$). 1 = Right occipital, 2 = Left occipital, 3 = Right frontal, 4 = Left frontal. (Log-rank test, $p < 0.005$).

The valve pressure was not a significant risk factor for undergoing shunt revision. Neither the use of the operating room within 4 hours prior to shunt insertion nor the number of persons present in the operating room at the time of shunt insertion was associated with increased risk for shunt revision.

Patient variables

Age and gender were not significant risk factors for shunt revision. Patients with eczema, pimples or superficial wounds at the time of shunt surgery were not at increased risk for revision, nor were those with tracheostomy or pre-operative ventricular drain.

The aetiologies of the hydrocephalus in the patient sample are presented in table 4. Aetiology was not associated with risk for shunt revision within six months. Mortality rates were 2 % ($n = 9$) within 4 weeks and 5.3 % ($n = 24$) within six months postoperatively (table 4). The mortality rate for patients with idiopathic (normal pressure) hydrocephalus was 2.4 % within 6 months. Causes of death within 6 months postoperatively are described in table 5.

Table 4. Aetiology of hydrocephalus among the patients studied ($n=450$) and the correlation to shunt revision within 6 months (Chi-square test, $p=0.520$).

Aetiology of hydrocephalus	Number of patients	Revision within 6 months	No revision within 6 months	Mortality
Idiopathic	125 (27.8%)	18	107	3 (2.4%)
Infection	19 (4.2%)	3	16	0
Subarachnoidal haemorrhage	113 (25.1%)	29	84	9 (8.0%)
Other cerebrovascular disease	24 (5.3%)	4	20	1 (4.2%)
Trauma	47 (10.4%)	7	40	2 (4.3%)
Tumour	65 (14.4%)	12	53	8 (12.3%)
Other aetiology	56 (12.4%)	11	45	1 (1.8%)
n/a	1 (0.2%)	0	1	0

Table 5. Mortality and cause of death within 6 months postoperatively. Causality refers to death directly related to the shunt procedure.

Gender	Age	Cause of hydrocephalus	Cause of death	Weeks of survival after shunt surgery	Causality Yes (Y) / No (N) / Uncertain (U)
F	77	Subdural hematoma	Stroke	18	N
F	77	Normal pressure hydrocephalus	Stroke/Pneumonia	16	N
F	76	Subarachnoidal hemorrhage	Myocardial infarction	2	N
F	71	Normal pressure hydrocephalus	Hemorrhagic stroke	21	N
F	71	Tumour	Multiple cerebral metastasis	5	N
M	69	Tumour	Malignant glioma	12	N
F	69	Subarachnoidal hemorrhage	Ischemic stroke	5	N

F	68	Subarachnoidal hemorrhage	Subarachnoid hemorrhage	12	U
F	67	Normal pressure hydrocephalus	Ischemic stroke	9	N
F	63	Subarachnoidal hemorrhage	Post subarachnoid hemorrhage	16	N
F	58	Tumour	Disseminated malignant disease	22	N
F	63	Subarachnoidal hemorrhage	Meningitis/Ventriculitis	2	Y
F	64	Subarachnoidal hemorrhage	Pneumonia	0,5	U
F	61	Subarachnoidal hemorrhage	Pneumonia	6	N
F	51	Tumour	Posterior fossa tumour with haemorrhage	3	N
F	57	Subarachnoidal hemorrhage	Subarachnoid haemorrhage	6	N
F	48	Tumour	Disseminated malignant disease	1	N
M	54	Subarachnoidal hemorrhage	Subarachnoid haemorrhage	4	U
F	47	Tumour	Malignant lymphoma	2	N
M	44	Tumour	Malignant glioma	11	N
M	45	Trauma	Pneumonia	18	N
F	30	Tumour	Multiple cerebral metastasis	4	N
F	26	Congenital	Cerebral infarction	3	N
F	46	Trauma	Trauma	20	N
♀:♂=20:4	mean			mean 19.2	
	58.2				

Discussion

A tendency of decline in revision rate was observed during the study period. One possible reason for this improved surgical outcome may be simply that when a shunt surgery protocol is applied greater attention is paid to details of the surgical procedure.[15]

The six-month shunt revision rate observed in the present study (18.9 %) is in agreement with previous studies.[19-20, 23] Our infection rate (5.6 %) was also comparable with previous studies,[9, 12, 15, 20, 28-30] although the time from shunt insertion to revision differed among the studies.

Surgical variables

Interestingly, we found that the location of the ventricular catheter was correlated to increased risk of developing a shunt complication. Tuli et al. reported a significantly decreased hazard ratio in occipital versus frontal ventricular catheter placement, although the study was made on paediatric patients.[22] The lower risk for complication or revision might in theory be primarily explained by a shorter catheter, with less risk of a suboptimal insertion angle. An 11 or 10 cm ventricular catheter was used in occipital shunt placements. Moreover, it is also possible that the biomechanical stress on the shunt valve differs in frontal and occipital placement of the ventricular catheter. Our findings support placement of ventricular catheters anterior to the foramen of Monroe in the right lateral ventricle. However, the long term risk for shunt revisions was not addressed in this study, and it might differ between occipital and frontal placement of the ventricular catheter.

Left-sided placement of the ventricular catheter was almost never the first hand choice. The increased risk with left ventricular catheter placement could be explained by the fact that these patients were high risk in that they had undergone several previous procedures and were more apt to develop shunt malfunction. The study showed that shorter ventricular catheters were associated with a significantly lower revision rate, but the clinical importance of this difference is limited.

Adjustable valves were associated with the lowest risk for shunt revision in the present study. However, in addition to the multivariate analysis, a univariate analysis shows that the adjustable valves were significantly (43.4 %; $p < 0.001$) more often inserted in the right frontal position. 105 (43.4 %) of the right frontal shunts were adjustable compared with 23 (13.9 %) of right occipital shunts. Previous studies have not shown any advantage to the use of adjustable valves,[31-32] although one retrospective study has shown that adjustable valves are associated with a decreased risk of shunt revision.[33] The lower revision rate with adjustable shunts may owe to the fact that the surgeon, instead of revising the shunt immediately, may try to reprogram the shunt and thereby simply postpone an inevitable shunt

revision. If this was the case we would have been expecting a higher proportion of adjustable valves being revised within 12 months when comparing with 6 months. However, we found that the 12 month revision rate for adjustable valves (48 of 110 revisions) was almost the same as the 6 month revision rate for adjustable valves (37 of 85 revisions). Among shunts revised within 12-months there were a lower proportion of adjustable valves (43.6 %) compared to non-adjustable valves (56.3 %).

Our data suggest that there is no difference in the risk for revision between experienced and inexperienced surgeons. Similar results have been reported by Shurtleff et al.,[10] whereas Borgbjerg et al.[12] and George et al.[9] found this variable to be important. It may be argued that in an ideal training situation, the risk for complications should not be heightened if the operation is performed by junior doctors under the guidance of senior neurological surgeons. One limitation with this study is that two of the investigators operated 323 (46.3 %) of the patients. However, the revision rate of these patients did not differ from that of the patients operated by the other surgeons.

One accessory incision was necessary during frontal shunt placement. However, the number of accessory incisions was not a significant risk factor for shunt revision.

More than two glove changes could indicate that the surgical procedure did not run smoothly, however in this study an increased number of glove changes were not associated with a higher risk of revisions.

Shunt complications were not found to be associated with use of the operating room prior to operation or to the number of persons in the operating room. This suggests that adequate maintenance routines were upheld between and during the operations.

Patient variables

Age, gender and aetiology of the hydrocephalus were not associated with the risk for shunt revision.

Eczema, pimples or superficial wounds were not associated with an increased risk of six-month shunt failure. *Staphylococcus epidermidis* and *Staphylococcus aureus* (present in the skin flora) have been reported to be the most common aetiologies of shunt infection.[9, 11] *Propionibacterium acne* has also been studied in association with shunt infection.[11] It has been argued that some such patients are prone to develop shunt infection; however, we found no association between shunt failures and skin manifestations.

Patients with a tracheostomy generally have undergone intensive care due to severe systemic illness and their skin infection is localised close to the shunt on the neck. However, we did not find an increased risk for shunt revision in this group; nor did we find pre-operative ventricular drainage to be a risk factor for shunt revision. These findings were surprising, but might owe to good operating room standards and pre- and postoperative care, reducing revision risk for these otherwise normally high risk patients.

An important reason for the initial success of ventricular shunts[34] in the treatment of hydrocephalus was the contemporaneous improvement in perioperative care of the neurosurgical patients. Advances in anaesthesiology, antibiotic therapy, aseptic procedures, surgical technique, operating room standards and postoperative care have tremendously reduced mortality rates in the neurosurgical field. In hydrocephalus surgery, this reduction in fatal complications has meant that indications for surgical intervention have broadened to include adults with normal pressure hydrocephalus.[35] Although perioperative mortality has successively declined to almost zero, the complication rate of shunt surgery has remained high. A complication rate of 50 % after 5 years has been described.[12, 36] A large proportion of the complications is related to under- or over-function of the shunt.

Due to the high complication rate in shunt surgery, many studies have focused on improving the shunts by developing material[37-38] and valve mechanisms.[39-41] Furthermore,

endoscopic neurosurgery has been developed[42] as an alternative to shunting that avoids many of its side effects. However, there have been few prospective studies focusing on the perioperative variables of shunt surgery.

Obviously, this is an observational study that explores shunt failure and the variables are not analysed in a controlled way. Many variables are dependant on hospital policy or the decisions of individual surgeons. Randomised controlled studies are needed to better evaluate surgical options and their impact on risk for shunt revisions.

Our study indicates that the standards of perioperative care today reduce the revision rate for presumed high risk patients and that the risk for revision does not differ between individual surgeons using the same surgical method. Further reductions in revision rates are probably best accomplished through technical and material developments of shunts.

Conclusions

In this prospective study of 450 adult patients who underwent shunt surgery we found an increased risk of short term shunt revision in non-adjustable valves and after occipital placement of the ventricular catheter. Shunt revision rates did not differ between VP and VA shunts. These findings should encourage further studies on perioperative variables with a randomised controlled design.

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Hydrocephalus patients

n = 586

Ineligible patients

- Patient age < 16 years
- No shunt insertion within the study period
- Previously treated with ETV

n = 136

Observed patients

n = 450

Revisions

n = 125

Revisions within 6 months

n = 85

