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

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► Table 1 is published online only at http://jnnp.bmj.com/content/vol80/issue11

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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. Over 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 end points: (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: 85 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.

In Sweden, the annual incidence of surgery for hydrocephalus is 3.4 per 100 000 adults.[1] Shunting of the CSF 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.[2] Postoperative 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 postoperatively.[4] Infection occurs in 3–15%[4 8–14] of 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, Gothenburg, Sweden. Two protocols were designed to record peroperative data during shunt insertion (insertion protocol) and shunt revision (revision protocol), respectively. The protocols were completed 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 (fig 1). Patients who had undergone endoscopic third ventriculostomy were excluded. Of the 450 patients meeting the inclusion criteria, 85 patients were revised within 6 months after surgery. In the 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 preoperatively. Eighty-four per cent of the patients received cefuroxim (1500 mg intravenously) 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 of klindamycin (600 mg intravenously) 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 level 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.

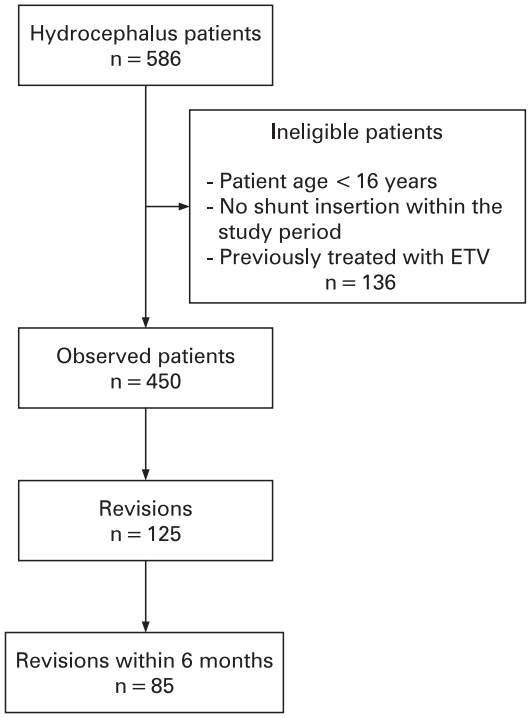

Figure 1 Flowchart for patients and procedures included in the study. ETV, endoscopic third ventriculostomy.

Placement of the shunt and valve was chosen by the surgeon. Different valves were available during the study according to hospital policy, unrelated to the study. The ventricular catheter length was chosen to reach immediately anterior to the foramen of Monroe and a 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 (available online).

All shunts were designated as meeting one of two end points: (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, or 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 the regular χ^2 test was used to analyse non-dichotomous nominal variables. Mantel–Haenszel's χ^2 test was used for ordinal variables. Continuous variables were analysed using the Mann–Whitney U test.

Mantel–Haenszel χ^2 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.

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 2 shows the different perioperative variables related to shunt revision within 6 months. Shunt survival analysis for different variables is presented in table 3.

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 4); 42.4% of the revisions were due to proximal or distal mechanical failure (underdrainage).

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 multivariate analysis that this variable was dependent on the catheter location and was not a significant risk factor in 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. Accessory incision(s) was not a significant risk factor but one accessory incision was associated with the lowest rate of revision. The number of glove changes was unrelated to shunt revision.

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

Table 2 Perioperative variables correlated to shunt revision within 6 months

Variable	Primary procedures	Revision within 6 months	No revision within 6 months	Hazard ratio (CI)	p Value
No of patients	450	85 (18.9)	365		
Age	n = 450	n = 85	n = 365	0.99 (0.98–1.00)	§0.121
Mean (SD)	56.9 (18.0)	53.44 (18.35)	56.86 (17.98)		
Gender (n (%))	n = 450				†0.926
Women	245 (54.4)	47 (19.2)	196		
Men	205 (45.6)	38 (18.5)	167		
Shunt type (n (%))	n = 450				†0.608
VP shunt	411 (91.3)	76 (18.5)	335		
VA shunt	39 (8.7)	9 (23.1)	30		
Valve brand/manufacturer (n (%))	n = 449			1.216 (1.05–1.41)	‡0.078
PS Medical Delta Shunt (non-adjustable)	208 (46.3)	47 (22.6)	161		†0.086
PS Medical Strata Shunt (adjustable)	125 (27.8)	13 (10.4)	112		†0.005*
Sophysa adjustable shunt Sophy SU-8	95 (21.2)	21 (22.1)	74		†0.453
Codman–Medos Programmable Hakim Valve	15 (3.3)	3 (20.0)	12		†1.000
Orbis Sigma	6 (1.3)	1 (16.7)	5		†1.000
Valve type (n (%))	n = 449			1.86 (1.18–2.93)	†0.007*
Adjustable valves	235 (52.3)	37 (15.7)	198		
Non-adjustable	214 (47.6)	48 (22.4)	166		
Ventricular catheter placement (n (%))	n = 442			0.81 (0.68–0.96)	‡<0.001*
Right occipital	166 (37.6)	44 (26.5)	122		†0.003
Left occipital	15 (3.4)	7 (46.7)	8		†0.024
Right frontal	242 (54.8)	28 (11.6)	214		†<0.001
Left frontal	19 (4.3)	5 (26.3)	14		†0.568
Ventricular catheter length (cm)	n = 436	n = 82	n = 354	1.13 (1.04–1.23)	†0.004*
Mean (SD)	8.11 (2.10)	8.82 (2.14)	7.94 (2.05)		
Valve pressure (cm H_2O)	n = 439	n = 83	n = 356	1.05 (1.01–1.09)	§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)	§0.113
Mean (SD)	24.23 (6.73)	24.05 (6.82)	25.10 (6.28)		
Preoperative ventriculostomy (n (%))	n = 449				†0.805
Yes	104 (23.4)	21 (20.2)	83		
No	345 (76.6)	64 (18.6)	281		
Tracheostomy (n (%))	n = 368				†0.399
Yes	21 (5.7)	6 (28.6)	15		
No	347 (94.3)	65 (18.7)	282		
Superficial wounds (n (%))	n = 373				†0.282
Yes	73 (19.6)	17 (23.3)	51		
No	300 (80.3)	51 (17.0)	249		
Eczema/pimples (n (%))	n = 371				†0.830
Yes	53 (14.3)	9 (17.0)	44		
No	318 (85.7)	62 (19.5)	256		
Accessory incision(s) (n (%))	n = 373				¶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 (%))	n = 366				†0.379
Yes	171 (46.7)	28 (16.4)	143		
No	192 (53.3)	40 (20.8)	155		
No of persons in the operating room	n = 371	n = 304	n = 67	1.07 (0.97–1.18)	§0.321
Mean (SD)	6.10 (1.86)	6.34 (2.05)	6.05 (1.81)		
Glove changes (n (%))	n = 368				¶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 (min)	n = 365	n = 300	n = 65	1.00 (1.00–1.01)	§0.102
Mean (SD)	56.71 (27.65)	55.54 (26.05)	62.14 (33.79)		
Experience of the operator (n (%))	n = 450				†1.000
Attending	386 (85.8)	73 (18.9)	313		
Resident	64 (14.2)	12 (18.8)	52		

*Significant p value: †Fisher's exact test; ‡χ^2 test; §Mann–Whitney test; ¶Mantel-Haenszel test.
VA, ventriculoatrial; VP, ventriculoperitoneal.

Table 3 Shunt survival analysis for the different variables at the time of shunt insertion

Variable	No of patients	p Value
Age	450	‡0.127
Gender	448	†0.661
Shunt type (VP/VA)	450	†0.233
Valve brand/manufacturer	449	†0.030*
Valve type (programmable/non-programmable)	449	†0.007*
Ventricular catheter placement	442	†<0.001*
Ventricular catheter length (cm)	436	‡0.004*
Valve pressure (cm H_2O)	439	‡0.010*
Peritoneal catheter length (cm)	386	‡0.379
Preoperative ventriculostomy	449	†0.126
Tracheostomy	368	†0.344
Superficial wounds	373	†0.221
Accessory incision(s)	373	†0.274
Operating room used prior to the operation	366	‡0.441
No of persons in the operating room	371	†0.199
Glove changes	368	†0.134
Length of the operation (min)	365	‡0.572
Experience of the operator	450	†0.602

*Significant p value: †log rank test; ‡Cox regression test.
VA, ventriculoatrial; VP, ventriculoperitoneal.

The aetiologies of the hydrocephalus in the patient sample are presented in table 5. Aetiology was not associated with risk for shunt revision within 6 months. Mortality rates were 2% (n = 9) within 4 weeks and 5.3% (n = 24) within 6 months postoperatively (table 5). 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 6.

DISCUSSION

The 6 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.

Table 4 Revision referral, indication and procedure in the patient sample (n = 85)

Variable	No (%) of revisions
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)

VA, ventriculoatrial; VP, ventriculoperitoneal.

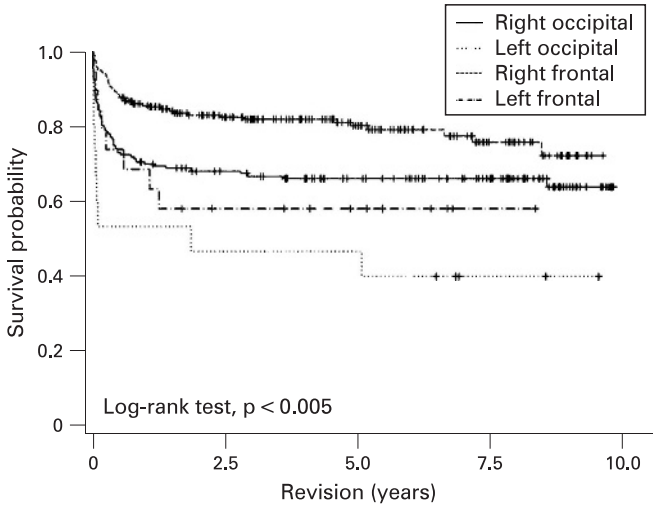

Figure 2 Kaplan–Meyer shunt survival curve showing the time to shunt revision related to shunt placement (log rank test, p<0.005). 1 = right occipital; 2 = left occipital; 3 = right frontal; 4 = left frontal (log rank test, p<0.005).

Surgical variables

Interestingly, we found that the location of the ventricular catheter was correlated with 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 conducted in paediatric patients.[22] 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.

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 showed that the adjustable valves were significantly (43.4%; p<0.001) more often inserted in the right frontal position. A total of 105 (43.4%) of the right frontal shunts were adjustable compared

Table 5 Aetiology of hydrocephalus among the patients studied (n = 450) and the correlation to shunt revision within 6 months (χ^2 test, p = 0.520)

Aetiology of hydrocephalus	No (%) of patients	Revision within 6 months	No revision within 6 months	Mortality (n (%))
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 6 Mortality and cause of death within 6 months postoperatively

Gender	Age (y)	Cause of hydrocephalus	Cause of death	Weeks of survival after shunt surgery	Causality (yes (Y)/no (N)/ uncertain (U)
F	77	Subdural haematoma	Stroke	18	N
F	77	Normal pressure hydrocephalus	Stroke/pneumonia	16	N
F	76	Subarachnoidal haemorrhage	Myocardial infarction	2	N
F	71	Normal pressure hydrocephalus	Haemorrhagic stroke	21	N
F	71	Tumour	Multiple cerebral metastasis	5	N
M	69	Tumour	Malignant glioma	12	N
F	69	Subarachnoidal haemorrhage	Ischaemic stroke	5	N
F	68	Subarachnoidal haemorrhage	Subarachnoid haemorrhage	12	U
F	67	Normal pressure hydrocephalus	Ischaemic stroke	9	N
F	63	Subarachnoidal haemorrhage	Post subarachnoid haemorrhage	16	N
F	58	Tumour	Disseminated malignant disease	22	N
F	63	Subarachnoidal haemorrhage	Meningitis/ventriculitis	2	Y
F	64	Subarachnoidal haemorrhage	Pneumonia	0,5	U
F	61	Subarachnoidal haemorrhage	Pneumonia	6	N
F	51	Tumour	Posterior fossa tumour with haemorrhage	3	N
F	57	Subarachnoidal haemorrhage	Subarachnoid haemorrhage	6	N
F	48	Tumour	Disseminated malignant disease	1	N
M	54	Subarachnoidal haemorrhage	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
	Mean 58.2			Mean 19.2	

Causality refers to death directly related to the shunt procedure.

with 23 (13.9%) of the right occipital shunts. Previous studies have not shown any advantage with 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 be due to the fact that the surgeon, instead of revising the shunt immediately, may try to reprogramme the shunt and thereby simply postpone an inevitable shunt revision. If this were the case we would have expected a higher proportion of adjustable valves to be revised within 12 months compared 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 was a lower proportion of adjustable valves (43.6%) compared with non-adjustable valves (56.3%).

Our data suggest that there is no difference in the risk of revision between experienced and inexperienced surgeons. Similar results have been reported by Shurtleff and colleagues[10] whereas Borgbjerg and colleagues[12] and George and colleagues[9] found this variable to be important. It may be argued that in an ideal training situation, the risk of 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 on 323 (46.3%) of the patients. However, the revision rate of these patients did not differ from that of patients operated on by 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 but in this study an increased number of glove changes was 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 of shunt revision.

Eczema, pimples or superficial wounds were not associated with an increased risk of 6 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 because of 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 preoperative ventricular drainage to be a risk factor for shunt revision. These findings were surprising but might be due 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 neurosur-

gical 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.

Because of 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 the risk for shunt revisions.

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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