Endoscopic options in children: experience with 134 procedures

Clinical article

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Object. There are frequent applications for endoscopy in neurosurgery. However, endoscopic surgery in children has peculiar characteristics and is associated with different rates of success. In this study, the authors report on their experience with 134 consecutive endoscopy procedures performed in 126 patients < 18 years of age.

Methods. Between April 1993 and October 2007, 134 endoscopic procedures were performed in 126 children. Indications for surgery included brain tumors in 48 children, cystic lesions in 24, aqueductal stenosis in 23, various malformations in 20, hemorrhage and infarction in 6, and isolated ventricles in 5 children. In this long-term follow-up study, data were analyzed with respect to clinical and radiological success rates, as well as shunt dependence both in relation to lesion origin, and to the type of endoscopic procedure performed (endoscopic third ventriculostomy [ETV], septostomy, aqueductoplasty, or cystocisternostomy). Finally, the influence of patient age on the success rate was evaluated.

Results. In 114 patients, restoration of CSF circulation was the goal of endoscopy, but in 2 patients only ventriculoscopy was performed followed by ventriculoperitoneal shunt placement. In 12 of 114 patients, tumor biopsy sampling or resection was performed simultaneously with shunt placement. In another 12 patients, only endoscopic tumor resection without CSF circulation restoration was done. The follow-up period ranged from 1 to 6 years. Thirteen tumor biopsies, 7 partial tumor resections, and 4 endoscopically complete tumor resections were performed. An intraoperative switch to microsurgery was made in 2 patients because of recurrent hemorrhage and an overly time-consuming endoscopic surgery. Cerebrospinal fluid circulation was successfully restored in 81 (72%) of 112 patients, with the use of endoscopy in the setting of tumor-related hydrocephalus providing the best results (86% success rate). However, of the various endoscopic procedures, cyst openings (cystocisternostomy, cystovenlocisternostomy, and ventriculocystocisternostomy) provided the best results—superior even to ETV—with a success rate of 77% and no complications. In contrast, endoscopic aqueductoplasty had a high failure and complication rate. Patients < 6 months old who underwent ETV, septostomy, or aqueductoplasty had poor results and became more frequently shunt dependent than older children.

Conclusions. Overall, endoscopy can be considered safe and effective in children. Based on the authors’ data, acute hydrocephalus cases such as those caused by tumors are the best candidates for endoscopic CSF flow restoration. Interestingly, cyst openings to the ventricles or cisterns were the most successful endoscopic techniques with the lowest complication rate. Aqueductoplasty should be reserved for selected cases. Finally, the success rate of endoscopic techniques remains poor in infants < 6 months of age; this was not only true of ETV, but also other techniques such as septostomy and aqueductoplasty. (DOI: 10.3171/2008.11.PEDS0887)

Key Words • arachnoid cyst • endoscopic cystovenlocisternostomy • endoscopic third ventriculostomy • endoscopic ventriculocystocisternostomy • obstructive hydrocephalus • pediatric neurosurgery

The use of endoscopy in the treatment of hydrocephalus is an old technique with its beginnings in the early 20th century when Sir Walter Dandy began treating hydrocephalus by cauterizing or endoscopic re-
Hopkins optics and high-resolution cameras, has led to a tremendous increase in the number of neuroendoscopic procedures performed since the early 1990s. Many different neuroendoscopic indications have since been described, and reports on successful endoscopic treatments for various pathological entities such as obstructive hydrocephalus of any origin,1,4–6,8,10,15,17,21–23,25,29–32,38,40,42,48,51 arachnoid cysts,12,14,19,34 and septum pellucidum cysts,14,19,34 and intra- and paraventricular tumors16,33 have been frequent. Even in rare cystic lesions18 or idiopathic normal pressure hydrocephalus,18 successful CSF circulation restoration has been described with endoscopy.

Rates of success and complications after neuroendoscopy are highly variable, however.38 Often these diverging results are said to be caused by the different prognosis between pediatric and adult patients, with a peculiar role of the patient’s age.3,15 Neuroendoscopic results are therefore examined particularly closely in children. In this study we present the results of neuroendoscopy performed in children (patients up to 18 years of age). During the past 15 years, we have performed > 1400 neuroendoscopic procedures.

Methods

Study Design

The senior author (M.R.G.) developed a universal neuroendoscopic system in cooperation with Karl Storz Company in the late 1980s and early 1990s.15 Since January 1993, this neuroendoscopic system was applied in all intracranial neuroendoscopic surgeries at the Department of Neurosurgery of Ernst Moritz Arndt University in Greifswald, Germany, until March 2003, and since February 2003 in the Department of Neurosurgery of the Nordstadtkrankenhaus in Hannover, Germany. All neuroendoscopic procedures performed with the GAAB neuroendoscopic system were analyzed, and patients have been followed up since January 1993. All patients underwent routine follow-up with a first visit at 3–6 months postoperatively, after which they were cared for by their own pediatricians. We were only consulted in cases of complications or at the parents’ request. Additionally, many of the children were followed up for clinical research purposes. The follow-up period was considered to have ended when subsequent open microsurgical tumor procedures, shunt placement, or endoscopic revisions were performed, or if the child died.

In this study we present our experience with this neuroendoscopic system in 134 neuroendoscopic intracranial procedures performed in 126 children between April 1993 and October 2007. The indications for neuroendoscopy in relation to various underlying pathologies, as well as the associated success and complication rates are discussed. Additionally, the success and complication rates after various endoscopic procedures regardless of the underlying disease are analyzed.

Endoscopic Equipment

For all intracranial endoscopic procedures, a sophisticated and complex neuroendoscopic system is mandatory, including brilliant optics and effective instruments such as scissors, hooks, puncture needles, biopsy, grasping forceps, a bright Xenon cold light source, and a high-resolution digital video camera. An automated irrigation device was also found to be helpful. If irrigation was required, 37°C-warm lactated Ringer solution was used. A 3 or 4 Fr Fogarty balloon catheter was used to enlarge the stoma. Neuronavigational guidance was used in cases such as myelomeningocele when intracranial orientation was expected to be challenging.

Endoscopic Surgical Technique

Our surgical technique has been presented in detail elsewhere.1,2,15,16,35–38,43,44 In brief, all procedures were performed with the patient supine and in a state of general anesthesia with the head slightly anteflexed in Mayfield 3-pin fixation or fixed with bandages only in infants ≤ 2 years old. Antibiotic medications were not routinely prescribed. An ideal trajectory to the lesion through the various cysts and ventricles to the target/perforation point and—in third ventricle lesions—through the foramen of Monro was calculated based on preoperative CT and MR imaging. The surgical field was prepared and draped. A 3-cm skin incision and a 10-mm bur hole were made. After opening the dura mater, the operating sheath containing the trocar was introduced with or without navigational guidance into the lateral ventricle, and the endoscope was fixed at the endoscope holder. After removal of the trocar, the lateral ventricle was inspected with the rigid 0° diagnostic optic. A right-side approach to the third ventricle was preferred. If the foramen of Monro appeared to be very narrow, a site with the wider foramen of Monro was chosen. In ETV, the work sheath was advanced through the foramen of Monro under direct view; the mammillary bodies and the infundibular recess were identified. After switching to the 0° working optics, a blunt perforation was made at the midline halfway between the mammillary bodies and the infundibular recess with forceps or bipolar diathermia. The stoma was enlarged by inflating a Fogarty balloon catheter. If a Liliequist membrane was present, it was also perforated with the forceps. Final inspection was performed with the 0° diagnostic optics to identify the dorsum sellae as well as the tip of the basilar artery to be sure that a sufficient ventriculostomy was made. A similar perforation technique was applied to septostomies. If indicated, the accurate placement of the perforation was secured with neuronavigation. In stent placements, a standard ventricular catheter with several additional perforations was used. The catheter was enhanced through the endoscopic work sheath and inserted into the aqueduct or stoma under direct view. Regardless, removal of the guidance wire prior to stent placement is mandatory. If there was a risk of stent migration, we used a long stent connected to an Ommaya reservoir at the bur hole. Tumor biopsy sampling, resection, and hematoma evacuation were performed in a piecemeal fashion. After vigorous application of bipolar coagulation in vascularized lesions, the lesion was resected with grasping forceps and the cystic parts were evacuated with a suction syringe. In cystoventriculostomies and cystocisternostomies, neuronavigation was almost always applied. The cyst was entered either directly from the bur hole or the ventricle. Perforation of the cyst capsule and enlargement of the stoma were completed in the same fashion as an ETV. In the beginning of this patient
series and in all recurrent stenoses, stents were placed. In aqueductoplasty, the entry of the aqueduct was inspected with the aid of 0, 30, 45° (available since 2005), and 70° diagnostic optics. The diagnostic scopes were replaced by the operating scope. Aqueductoplasty was performed with the aid of a 3 Fr Fogarty balloon catheter. After inflation and restoration of the lumen, the aqueduct and fourth ventricle were inspected with a 2.5-mm steerable fiberscope to check aqueduct patency. Additionally, the flexible scope was used to perforate distal membranous obstructions that could not be visualized with the rigid scopes.

### Results

We performed 134 operations in 126 patients. In 114 patients restoration of CSF circulation was the goal, but in 2 patients with intracerebral hematomas only a ventriculoscopy was performed followed by ventriculoperitoneal shunt placement. In 12 of the 114 patients, a tumor biopsy or resection was performed simultaneously with the shunt placement. In another 12 patients, only an endoscopic tumor procedure without CSF circulation restoration was done. The mean follow-up period was 1 year, with a range of up to 6 years. There was a 72% success rate for CSF circulation restoration (in 81 of 112 patients) with the endoscopic technique providing the best results in tumor-related hydrocephalus (86% success rate; Table 1 and Fig. 1). In children < 14 years of age, the success rate reached 71% (66 of 93). In infants < 2 years of age, there was a 56% success rate (15 of 27 patients) for restoration of CSF circulation; this declined to 43% (6 of 14) in infants in their first 6 months of life. Twenty-six percent of all patients (29 of 112 patients) with the endoscopic technique providing the best results in tumor-related hydrocephalus (86% success rate; Table 1 and Fig. 1). In children < 14 years of age, the success rate reached 71% (66 of 93). In infants < 2 years of age, there was a 56% success rate (15 of 27 patients) for restoration of CSF circulation; this declined to 43% (6 of 14) in infants in their first 6 months of life. Twenty-six percent of all patients (29 of 112 patients) with the endoscopic technique providing the best results in tumor-related hydrocephalus (86% success rate; Table 1 and Fig. 1). In children < 14 years of age, the success rate reached 71% (66 of 93). In infants < 2 years of age, there was a 56% success rate (15 of 27 patients) for restoration of CSF circulation; this declined to 43% (6 of 14) in infants in their first 6 months of life.

**TABLE 1: Causes of hydrocephalus in relation to the success of CSF restoration**

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>No. of Patients</th>
<th>No. w/ Clinical Improvement</th>
<th>No. w/ Radiological Benefit</th>
<th>No. w/ Shunt Dependence</th>
</tr>
</thead>
<tbody>
<tr>
<td>tumor</td>
<td>36</td>
<td>31 (86%)</td>
<td>27 (75%)</td>
<td>4 (11%)</td>
</tr>
<tr>
<td>w/o subsequently resected posterior fossa tumor</td>
<td>25</td>
<td>20 (80%)</td>
<td>18 (72%)</td>
<td>4 (16%)</td>
</tr>
<tr>
<td>arachnoidal, intra- or paraventricular cyst</td>
<td>24</td>
<td>19 (79%)</td>
<td>15 (63%)</td>
<td>5 (21%)</td>
</tr>
<tr>
<td>aqueduct stenosis</td>
<td>23</td>
<td>16 (69%)*</td>
<td>12 (52%)</td>
<td>7 (31%)</td>
</tr>
<tr>
<td>brain malformation</td>
<td>20</td>
<td>8 (40%)</td>
<td>2 (10%)</td>
<td>12 (60%)†</td>
</tr>
<tr>
<td>hemorrhage &amp; infarction</td>
<td>4</td>
<td>3 (75%)</td>
<td>3 (75%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>isolated ventricle</td>
<td>5</td>
<td>4 (80%)</td>
<td>3 (60%)</td>
<td>1 (20%)</td>
</tr>
<tr>
<td>total</td>
<td>112</td>
<td>81 (72%)</td>
<td>62 (55%)</td>
<td>29 (26%)</td>
</tr>
</tbody>
</table>

* Three of these were revised endoscopically.
† Nine new shunts were placed.

Altogether, 19 symptomatic complications occurred in 134 operations. There were transient complications after 17 procedures (13%), including 6 CSF fistulas, 4 cases of meningitis, and 3 epidural hematomas, as well as 1 case of diabetes insipidus with hormonal changes, 1 case of psychosyndrome, 1 trochlear nerve palsy, and 1 case of transient hemiparesis. There were permanent complications in 2 patients (1.5%), including 1 oculomotor nerve palsy and 1 patient with permanent diabetes insipidus and pubertas praecox. Additionally, clinically silent complications included 6 intraoperative intraventricular hemorrhages, 2 switches to microsurgery for time-consuming tumor resection, 1 aqueduct and 1 fornix lesion.

**Success Rate and Underlying Pathological Entity**

**Intraventricular and Paraventricular Tumors.** In the 48 patients (32 boys and 16 girls) with intra- and paraventricular tumors (17 astrocytomas; 9 medulloblastomas; 4 craniopharyngiomas; 3 ependymomas; 2 pituitary adenomas, primitive neuroectocermal tumors, neurinomas, subependymomas each; 1 germinoma, glioblastoma multiforme, neuroblastoma, plexus papilloma, ganglioglioma each; and 2 cases of gliosis), preoperative symptoms included cephalgia (60%), vomiting and nausea (52%), and ataxia (31%), among others. Thirty-two ETVs, 5 stent placements (2 aqueduct stents, 2 long stents through foramen of Monro and aqueduct, and 1 stent through the foramen of Monro only), and 3 septostomies were performed for hydrocephalus. In 4 patients, 2 procedures for CSF restoration were combined (ETV and aqueduct stenting in 2, and septostomy and long stent placement in 2). Thirteen tumor biopsies, 7

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![Graph of the percentages of clinical and radiological improvement and shunt dependence after all procedures according to patient age groups.](image-url)
partial tumor resections, and 4 endoscopically complete tumor resections were undertaken. A combined procedure for treatment of CSF circulation problems and tumor diagnosis or resection was performed in 12 cases. The mean surgical time was 71 minutes (range 25–258 minutes). In 3 cases, intraventricular hemorrhage was a serious problem that was controllable with vigorous irrigation. However, further tumor resection was too time consuming, and an intraoperative switch to microsurgery was required in 2 cases. A histological diagnosis was obtained in all tumor procedure cases. Postoperative complications consisted of 1 case of transient diabetes insipidus, 4 CSF fistulas, 1 case of meningitis, and 1 transient psychosyndrome. There were no permanent complications in this group. Two patients had already undergone ventriculoperitoneal shunt placement prior to their presentation in our department, and in these cases only a tumor resection or biopsy was performed; 4 additional patients became shunt-dependent after ETV (11%).

Hydrocephalus-associated symptoms were successfully treated endoscopically in 31 of 36 patients (86% success rate; Table 1). On MR imaging or ultrasonography follow-up, a decrease in ventricular enlargement was noted in 27 cases (75% success rate). In 11 cases, open microsurgical tumor resection followed within 14 days of endoscopic surgery. The mean follow-up period for all patients with tumor was 13 months (range 2 weeks–62 months). Within the follow-up period, 9 patients (19% of all patients in the tumor group and 25% of all those with CSF circulation problems) died of tumor progression.

Arachnoidal, Intraventricular, and Paraventricular Cysts. The arachnoidal, intraventricular, and parenchymal cyst group included 14 arachnoid cysts, 2 multiloculated cysts, 2 choroid plexus cysts, 3 pineal cysts, 2 septum pellucidum cysts, and 1 colloid cyst in 12 boys and 12 girls. Arachnoid cysts were located in the temporal/middle fossa in 10, the suprasellar in 3, and the posterior fossa in 1. Preoperative symptoms included cephalgia (56%), vomiting and nausea (30%), increased head circumference (15%), and various others. Twenty-seven procedures were performed in 24 patients: 7 cystoventriculostomies including 2 stent placements, 12 cystocisternostomies including 2 stent placements, 2 ventriculocystocisternostomies, 6 septostomies, and 3 ETVs (Fig. 2). Two pineal cysts and the colloid cyst were aspirated and the capsule was widely resected. A combination of various endoscopic procedures was performed in 6 cases (ETV and septostomy in 3, cystoventriculostomy and cystocisternostomy in 1, septostomy and cyst wall resection in 1, septostomy and cystoventriculostomy in 1). The mean surgical time was 76 minutes (range 35–135 minutes). There were 2 cases of meningitis and 1 CSF fistula. There was no permanent morbidity in this group. In 1 multiloculated cyst case, 3 revisions had to be performed because of infection. This patient and 4 others became shunt dependent (21%). Nineteen patients (79%) remained shunt free and their symptoms were successfully treated endoscopically (Table 1). Radiologically, a reduction in ventricular enlargement or cyst size was found in 15 (63%) of 24 patients. The mean follow-up period was 13 months (range 1–55 months).

Aqueductal Stenosis. Twenty-six procedures in 23 patients (17 boys and 6 girls) were performed for aqueductal stenosis. Clinically, the patients suffered from cephalgia (46%), nausea and vomiting (39%), psychosyndrome (31%), and increased head circumference (31%), among other symptoms. Twenty-one ETVs and 7 aqueductoplasties were performed, including 1 stent placement. In 5 patients, ETV and aqueductoplasty were performed simultaneously. Three ETVs were done as repeated ETVs for stoma closure. In another 3, ventriculoscopies were done to verify that the ETV remained open. The mean surgical time was 62 minutes.

Fig. 2. Images obtained in a 17-year-old boy with a large choroid plexus cyst. a and e: Coronal and sagittal T2-weighted MR images showing a large intraventricular cyst in the left lateral ventricle. b–d, f and g: Endoscopic views. Intraoperative view of the cyst with direct contact with the choroids plexus in the posterior part of the left lateral ventricle (b), cyst puncture with a needle and fluid aspiration (c), and piecemeal resection of the cyst wall (d). Such a large portion of the cyst wall is resected that an open ventriculocystostomy results (g). h: Sagittal T2-weighted MR image obtained 3 months after surgery. There are no signs of recurrence.
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(range 30–120 minutes). Six patients had undergone shunt placement prior to their initial visit at our department, and all required shunt explantation for dysfunction. In 2, a new shunt was not required because of a functional ETV. Four of these patients and 3 new patients, including 1 who underwent revision surgery, required shunts. There was 1 case of permanent oculomotor nerve palsy, 1 of transient trochlear nerve palsy, 1 of permanent diabetes insipidus, 2 postoperative epidural hematomas, and 1 clinically silent intraoperative hemorrhage. Sixteen of 23 patients benefited from the endoscopic procedure clinically (69% success rate, Table 1). Seven patients (31%) became or remained shunt dependent. A decrease in ventricular enlargement was found on imaging in 12 patients (52%). The mean follow-up period was 15 months (range 1–54 months).

Brain Malformations. Hydrocephalus was associated with brain malformations including Aicardie Syndrome, Dandy Walker malformation, Chiari malformation, dysgenesis of the foramen of Monro, and myelomeningocele in 20 patients (9 boys and 11 girls). Clinically, the patients suffered from severe mental retardation (65%), cephalgia (40%), increased head circumference (35%), nausea and vomiting (30%), and various other maladies. In this very heterogeneous group, 16 ETVs, 3 septostomies, 3 aqueductoplasties including 1 stenting, 1 stoma of the foramen of Monro, 1 cystoventriculostomy, and 2 ventriculoscopies were performed in 21 total operations. The mean surgical time was 50 minutes (range 20–80 minutes). Five patients had previously undergone shunt placement (25%), and 2 of these presented with shunt malfunctions. In 3 patients with shunts, the endoscopic procedure was performed because of persisting symptoms despite radiological and clinical evidence of good shunt function. Complications consisted of 1 clinically silent aqueduct lesion, 1 fornix lesion, and 1 intraventricular hemorrhage. One CSF fistula, 1 case of meningitis, 1 transient hemiparesis, and 1 epidural hematoma occurred. The endoscopic procedure in this heterogeneous group was successful in 8 (40%) of 20 patients. Radiologically, ventricle size decreased in only 2 patients (10%), despite the vivid flow void signal on MR imaging in another 5 patients. Nine patients required shunts and 3 patients had received shunts prior to endoscopy, totalling 12 shunt-dependent patients (60% of the group of children with malformations). The mean follow-up period was 6 months with a maximum of 23 months after the endoscopic procedure; 2 children died during the follow-up period.

Intracerebral Hemorrhage and Brain Infarction. In 6 children (1 boy and 5 girls) with hydrocephalus due to intracerebral hemorrhage (in 5) or brain infarction (in 1), 3 ETVs were performed (1 for cerebellar infarction, 1 for cerebellar hemorrhage, and 1 for blockage of the foramen of Monro and aqueduct caused by a blood clot). In 2 cases (in 1 simultaneously with ETV), intraventricular blood was removed. In the other 2 cases, only a ventriculoscopy and subsequent shunt placement were performed. Preoperatively, all children presented with decreased consciousness. The mean surgical time was 73 minutes (range 50–95 minutes). Intraoperatively, a recurrent hemorrhage occurred in 1 patient with intraventricular hemorrhage. No other complications were noted. The clinical and radiological success rate was 75% (3 of 4 patients, Table 1) and was 100% if ETVs were considered only. The mean follow-up in this group was only 1 month.

Isolated Ventricle. In 5 patients (3 boys and 2 girls) with isolated ventricles, an isolated fourth ventricle was present in 3, an isolated temporal horn in 1, and an isolated lateral ventricle in 1. Because most cases of isolated fourth ventricle remain clinically silent, treatment decisions were based on progressive clinical symptoms or radiological signs. The main presenting symptoms were mental retardation in 3 patients (60%) and increased head circumference in 2 (40%). Three aqueductoplasties with stenting, ETV, septostomy, and cystoventriculostomy in 1 patient each were performed. The mean surgical time was 68 minutes (range 30–100 minutes). A patient with an isolated fourth ventricle required subsequent shunt placement. The endoscopic technique was successful clinically in 4 patients (80%), and radiologically in 3 (60%). The follow-up period ranged from 6 months to 6 years.

Success Rate and Type of Endoscopic Procedure

Endoscopic Third Ventriculostomy. Seventy-six ETVs were performed in 73 patients. The procedure was combined with septostomy in 5, aqueductoplasty in 9 (including 3 stents), foraminotomy in 1, blood clot removal in 1, tumor removal in 11, and cystostomies of any kind in 4. The mean surgical time was 60 minutes (range 30–258 minutes). The clinical ETV success rate was 70% with respect to the number of patients, and 67% with respect to number of procedures (Table 2). A decrease in ventricle size was seen in 56% of patients and after 54% of procedures. Twenty-six percent of the patients became shunt dependent. Clinically relevant complications occurred in 16%, with permanent complications in 3% (1 patient with diabetes insipidus and pubertas praecox, and 1 with oculomotor nerve palsy). Although there was no significant difference between children < 14 years and < 2 years of age compared to the whole group, infants in their first 6 months of life more frequently required shunts (Fig. 3).

Endoscopic Septostomy. Thirteen endoscopic perforations of the septum pellucidum were undertaken in 12 patients. The procedure was combined with ETV in 5, aqueductoplasty in 1, long stent implantation in 2, tumor biopsy/resection in 3, and cystoventriculostomy in 1. The mean surgical time was 78 minutes (range 48–105 minutes). Septostomy was clinically successful and achieved a decrease in ventricle size in 50% of patients and after 46% of procedures (Table 2); 33% of patients became shunt dependent. Clinically relevant complications occurred in 15% of patients but were not permanent. We found that the clinical and radiological success rate of the procedure declined with younger patient age, reaching a 100% failure rate in 2 infants < 6 months of age (Fig. 4).

Endoscopic Aqueductoplasty. Fourteen endoscopic aqueductoplasties, including 5 stent implantations, were performed in 14 children. This procedure was combined with ETV in 9 cases, and with septostomy, aqueductoplasty, and tumor resection in 1 case each. The mean surgical time was 71 minutes (range 35–120 minutes). The
clinical success rate was 57% and radiological success rate was 43% (Table 2). However, reclosure of the aqueduct occurred in 3 patients, requiring repeated operations and subsequent ETV (21%). Forty-three percent (6 of 14) of the patients became shunt dependent. Clinically relevant complications occurred in 7 (50%) of 14 patients and permanent complications in 2 (1 had diabetes insipidus with pubertas praecox, and 1 had permanent oculomotor palsy). Although there was no significant difference between the outcomes in children < 14 years of age (54% clinical and 39% radiological success rate), and children < 2 years of age (50% clinical and 25% radiological success rate) in comparison with the whole group, both included infants < 6 months of age who required shunts (Fig. 4).

**Endoscopic Cyst Procedures**

Cystocisternostomy, Cystoventriculostomy, and Ventriculocistocisternostomy. Twenty-two patients received a total of 23 procedures for cyst openings. There were 13 cystocisternostomies including 1 revision, 8 cystoventriculostomies, and 2 ventriculocystocisternostomies. Cystoventriculostomy and cystocisternostomy as well as cystoventriculostomy and septostomy were combined in 1 case each. The mean surgical time was 77 minutes (range 35–120 minutes). Clinical success rate reached 74% with respect to procedures, and 77% with respect to patients. Radiologically, the cyst size decreased in 48% and 50%, respectively. Only 14% of the patients became shunt dependent. In this group, no clinically relevant complications were observed. There was no significant difference in children < 14 years of age (71% clinical and 45% radiological success rate), and < 2 years of age (60% clinical and 40% radiological success rate). Of the 2 infants, 1 with an arachnoid cyst benefited clinically and radiologically, the second infant did not improve but died before shunt placement (50% success rate, Fig. 4).

![Fig. 3. Graph of the percentage of clinical and radiological improvement and shunt dependence after ETV according to patient age group.](image1)

![Fig. 4. Graph of the percentage of clinical and radiological improvement and shunt dependence after endoscopic CSF circulation restoration procedures (septostomy, aqueductoplasty, and cyst openings) after exclusion of ETV according to patient age groups.](image2)

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**TABLE 2: Cerebrospinal fluid circulation restoration procedures and success rates calculated according to the numbers of patients and numbers of procedures**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>No. of Pts/No. of Procs</th>
<th>Clinical Improvement</th>
<th>Radiological Benefit</th>
<th>Recurrences</th>
<th>Shunt Dependence</th>
<th>Transient Complications</th>
<th>Permanent Complications</th>
<th>Total Clinical Complications</th>
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<tbody>
<tr>
<td>ETV</td>
<td>73/76</td>
<td>70% (51/73)</td>
<td>56% (41/73)</td>
<td>4% (3/73)</td>
<td>26% (19/73)</td>
<td>0%</td>
<td>0%</td>
<td>16% (12/76)</td>
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<tr>
<td>w/o subsequently resected</td>
<td>62/65</td>
<td>65% (40/62)</td>
<td>52% (32/62)</td>
<td>5% (3/62)</td>
<td>31% (19/62)</td>
<td>0%</td>
<td>0%</td>
<td>16% (12/76)</td>
</tr>
<tr>
<td>posterior fossa tumors</td>
<td></td>
<td>62% (40/65)</td>
<td>49% (32/65)</td>
<td>29% (19/65)</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>septostomy</td>
<td>12/13</td>
<td>50% (6/12)</td>
<td>50% (6/12)</td>
<td>8% (1/12)</td>
<td>33% (4/12)</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>aqueductoplasty</td>
<td>14/14</td>
<td>46% (6/13)</td>
<td>46% (6/13)</td>
<td>31% (4/13)</td>
<td>15% (2/13)</td>
<td>15% (2/13)</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>cyst procedures</td>
<td>22/23</td>
<td>77% (17/22)</td>
<td>50% (11/22)</td>
<td>5% (1/22)</td>
<td>14% (3/22)</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>foraminotomy</td>
<td>2/2</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>long stent</td>
<td>2/2</td>
<td>100%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>all stent implantations</td>
<td>12/12</td>
<td>83% (10/12)</td>
<td>67% (8/12)</td>
<td>0%</td>
<td>17% (2/12)</td>
<td>8% (1/12)</td>
<td>8% (1/12)</td>
<td>17% (2/12)</td>
</tr>
<tr>
<td>total</td>
<td>125/130</td>
<td>69% (86/125)</td>
<td>53% (66/125)</td>
<td>6% (8/125)</td>
<td>26% (32/125)</td>
<td>13% (17/130)</td>
<td>3% (4/130)</td>
<td>16% (21/130)</td>
</tr>
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<td></td>
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<td>66% (86/130)</td>
<td>51% (66/130)</td>
<td>25% (32/130)</td>
<td>0%</td>
<td>0%</td>
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* Procs = procedures; Pts = patients.
† All were switched to ETV.
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Foraminotomy of Monro. There were only 2 isolated foraminotomies including 1 stent implantation with surgical times of 40 and 50 minutes. Both patients showed clinical improvement after the foramen was opened, and there were no complications. No radiological differences were noted, and no shunts were placed.

Stent Implantation. An implantation of a ventricular stent consisting of a standard ventricular catheter was performed in 12 procedures (in 5 tumors, 4 arachnoid cysts, 1 malformation, 1 aqueductal stenosis, and 1 isolated ventricle). Stents were placed through the aqueduct in 5 cases, in 2 cystocisternostomies, in 2 cystoventriculostomies, the foramen of Monro in 1 case, and the foramen of Monro and the aqueduct (using a long stent) in 2 cases. The mean surgical time was 69 minutes (range 35–105 minutes). The clinical success rate was 83%, and radiologically hydrocephalus decreased in 67%. Shunts were placed in 17%. There was 1 permanent oculomotor nerve palsy and 1 CSF fistula (rate of all complications 17% and permanent complications 8%). No children < 3 years old were in this group.

Discussion

Endoscopic third ventriculostomy has generally been accepted as the treatment of choice in patients with noncommunicating hydrocephalus because the procedure is simple, fast, and safe, and in selected cases it can be performed repeatedly with satisfactory results.38,45 Intracranial neuroendoscopy offers more treatment options than just restoration of the CSF circulation in obstructive hydrocephalus by ETV, however. In the present study we present a detailed analysis of the endoscopic intracranial procedures we performed in children between 1993 and 2007.

In 134 operations, 24 endoscopic tumor biopsies or resections and 112 procedures for CSF flow restoration were performed. Among the tumor cases, 2 procedures were switched to microsurgery because of recurrent bleeding and an overly time-consuming surgery. Aside from this, reliable endoscopic tumor biopsy or resection was performed in 92% of patients. The general clinical success rate to restore CSF circulation was 72% and the radiological success rate was 55%. Of 29 surgical complications, 10 (8%) remained clinically silent, 17 (13%) were transient, and 2 (1.5%) were permanent. These data are in agreement with a number of published results.1,3,6,10,17,21–23,38 In particular, the difference between the clinical and radiological success rate is well known and has been discussed previously.38 Although the small number of patients did not permit multivariate analysis of outcome to be performed, some peculiar findings of our study require careful interpretation and special consideration.

With respect to the underlying pathological entity, there was a particularly high success rate of 86% in restoration of CSF circulation in tumor cases. A success rate of ~70% was noted with other good indications for surgery such as arachnoid cysts, aqueductal stenosis, or isolated ventricles. The success rate in restoring CSF circulation in patients with tumors was superior to the success rate of any single endoscopic procedure such as ETV, septostomy, aqueductoplasty, cyst opening, and even stent placement. Thus, although no definitive conclusions can be drawn, tumor-related problems with CSF circulation appear to be particularly well-suited to endoscopic CSF restoration, regardless of the technique used. The reasons for these favorable results remain speculative, but are most likely influenced by the rather acute onset of hydrocephalus-related symptoms. There is probably also less of a tendency for membrane formation as is sometimes observed in arachnoid cysts or inflammatory cases. Lastly, a major portion of the patients with tumors underwent subsequent open tumor removal (11 patients [31%]) or received treatment for CSF circulation problems caused by nonresectable tumors that progressed and caused clinical deterioration and death (9 patients [25%]). Therefore, the CSF circulation problem in these cases would not last as long as in other benign indications. Taking all of these reasons into account, the acute onset of symptoms and the rather short period of postoperative follow-up because of subsequent surgery or disease progression and death might be major causes of the high success rate with endoscopy in tumor-related hydrocephalus.

The cyst procedures (cystocisternostomy, cystoventriculostomy, and ventriculocystocisternostomy) yielded the best results with respect to success rate, shunt dependence, and complications. These results support the well-known high success rate observed with endoscopic procedures in cysts.7,9,12,14,19,20,26–28,34,35,39,46,47,50 Although again no definite conclusions can be drawn, possible reasons for these good results may reside in the superior intraoperative view that allows a very good orientation, in the preformed space within the cystic enlargement to maneuver without risk, in the frequent application of neuronavigation to more complex cases, and in the underlying causes of cyst formation. Because a slit valve mechanism has been discussed as an underlying cause of arachnoid growth,35,41 no progression is expected after the cyst is opened. Nevertheless, it remains somewhat surprising that these results are superior to those achieved with ETV. Based on our findings, endoscopic cyst procedures achieve excellent results.

The aqueductoplasty results require attention. We advocated this treatment option in the late 1990s and into the 2000s.35 At the time, we favored aqueductoplasty in any membranous aqueductal stenosis because aqueductoplasty offers true restoration of the natural CSF circulation. However, within the first 2–3 years of follow-up we found that the recurrence rate was very high, and we became increasingly reluctant to perform aqueductoplasty. As we have shown in the present study, aqueductoplasty provides the least favorable results of all investigated endoscopy techniques with respect to recurrence rate, shunt dependence, and complications. Although these data do not closely correspond to our results in adults, a very high recurrence rate has even been observed in that population. Thus, from our perspective, aqueductoplasty is the endoscopic technique of second choice; if applicable, a standard ETV is preferable. Aqueductoplasty should be reserved for selected cases such as isolated fourth ventricles in cases in which injury to the periaqueductal gray matter can be avoided. Soft silicone catheter stents without wire guidance should be used exclusively.

Ventricular catheters were implanted as stents in 5
aqueductoplasties, 4 cyst procedures, 1 foraminotomy of Monro, and 2 long-stent placements through the foramen of Monro and the aqueduct. Although this was a very heterogenous group, a high success rate was observed. Stent implantation can preserve CSF circulation and avoid reocclusion of the perforation, particularly in cases suspicious for a nonvirulent infectious or inflammatory background. Based on these results and the results in the adult population, we routinely apply stents in all isolated fourth ventricle cases and in most recurrent cases to avoid reocclusion once vivid ventriculitis is excluded from the diagnosis.

It has been well described that ETV has a higher failure rate in children than adults, particularly in infants < 6 months old. This was also observed in the present study (Fig. 4). Surprisingly, even worse results were found in endoscopic septostomy and endoscopic aqueductoplasty. Although these findings must be analyzed carefully because of the very small number of infants and the lack of multivariate analysis, it is obvious that not only ETV, but also other endoscopic restoration procedures are less successful in infants ≤ 6 months of age than in older patients. The reasons for the worse outcome in infants remain speculative. In view of the data we present in this study, a local reason in the area of the ETV such as membrane reformation at the Liliquist membrane can be excluded. Also, the poor results achieved with endoscopic septostomy do not support a general insufficient CSF resorption. Thus, as described by Wagner and Koch membranous recollection of stomas in young infants may play a significant role in septostomy and aqueductoplasty procedures also. Regardless, the few cases we have presented here forbid a definite conclusion, but the indications for neuroendoscopy should nevertheless be carefully evaluated in young infants, even when a septostomy or aqueductoplasty is planned rather than ETV.

In all, the neuroendoscopic techniques described provide good results in various indications such as tumors, cysts, aqueductal stenosis, and isolated ventricles. Although we have presented data drawn from a very heterogenous patient group, some peculiar characteristics have been found and preliminary conclusions can be drawn. In tumor-related cases, the restoration of CSF circulation provided the most favorable results. Of the various perforation techniques, cyst-opening procedures—such as cystocisternostomy, cystoventriculostomy, and ventriculocystocisternostomy—were the most successful, and had very low complication rates. Endoscopic aqueductoplasty should be preserved for use in selected cases because of the high recurrence and failure rate and the number of complications. If stoma reocclusion is expected, stent implantation may improve the chance of patency. Finally, care must be taken in the selection of infants ≤ 6 months old for endoscopic restoration of CSF circulation because a disappointingly high failure rate has been found.

Conclusions

Neuroendoscopic techniques provide very good results for a number of indications in children; tumor-related CSF circulation problems seem to be particularly well suited to neuroendoscopy. Cyst opening techniques such as cystocisternostomy, cystoventriculostomy, and ventriculocystocisternostomy provide the most favorable results with respect to success and complication rate. Endoscopic aqueductoplasty should be reserved for selected rare cases because of high rates of recurrence, shunt dependence, and complications. When reocclusion is feared, stenting might improve the success rate and minimize failures. Finally, it should be noted that not only ETV, but also other CSF restoration techniques such as septostomy and aqueductoplasty have a very high failure rate in infants < 6 months old.

Disclosure

Michael R. Gaab, M.D., Ph.D., and Henry W. S. Schroeder, M.D., Ph.D., are consultants to Karl Storz Company.

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