Navigated endoscopic surgery for multiloculated hydrocephalus in children

Clinical article

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Object. Multiloculated hydrocephalus remains a challenging condition to treat in the pediatric hydrocephalic population. In a retrospective study, the authors reviewed their experience with navigated endoscopy to treat multiloculated hydrocephalus in children.

Methods. Between April 2004 and September 2008, navigated endoscopic procedures were performed in 16 children with multiloculated hydrocephalus (median age 8 months, mean age 16.1 ± 23.3 months). In all patients preoperative MR imaging was used for planning entry sites and trajectories of the endoscopic approach for cyst perforation and catheter positioning. Intraoperatively, a rigid endoscope was tracked by the navigation system. For all children the total number of operative procedures, navigated endoscopic procedures, implanted ventricular catheters, and drained compartments were recorded. In addition, postoperative complications and radiological follow-up data were analyzed.

Results. In 16 children, a total of 91 procedures were performed to treat multiloculated hydrocephalus, including 29 navigated endoscopic surgeries. Finally, 21 navigated procedures involved 1 ventricular catheter and 8 involved 2 catheters for CSF diversion via the shunt. The average number of drained compartments in a shunt was 3.6 ± 1.7 (range 2–9 compartments). In 9 patients (56%) a navigated endoscopic procedure constituted the last procedure within the follow-up period. One additional surgery was necessary in 3 patients (19%) after navigated endoscopy, and in 4 patients (25%) 2 further procedures were necessary after navigated endoscopy. Serial follow-up MR imaging demonstrated evidence of sufficient CSF diversion in all patients.

Conclusions. Navigated endoscopic surgery is a safe and effective treatment option for multiloculated hydrocephalus. The combination of the endoscopic approach and neuronavigation further refines preoperative planning and intraoperative orientation. The aim of treatment is to drain as many compartments as possible and as soon as possible, thereby establishing sufficient CSF drainage with few ventricular catheters in single shunt systems. Close clinical and radiological follow-up is mandatory because multiple revisions are likely. (DOI: 10.3171/2010.1.PEDS09359)

Key Words • loculated • compartmental • navigation • multi cystic hydrocephalus • neuroendoscopy

With an annual population incidence for shunt insertion of about 5.5 per 100,000, hydrocephalus is a common condition in pediatric neurosurgery. Because untreated hydrocephalus will lead to significant neurological morbidity and developmental delay, treatment is offered once the diagnosis is established. Primary treatment options are CSF-diversion procedures—either by shunting the CSF to a compartment outside of the cranial vault in communicating hydrocephalus or in case of noncommunicating hydrocephalus by reopening blocked CSF pathways or bypassing sites of obstruction. Along with the number of initial procedures to treat hydrocephalus, the high rate of operative revisions remains a persisting problem. Possible predictive factors for complicated hydrocephalus resulting in multiple revisions are prematurity and infancy, low weight, preceding infections, previous revisions, and distorted anatomy including multiloculated hydrocephalus.

This article contains some figures that are displayed in color online but in black and white in the print edition.

Abbreviation used in this paper: VP = ventriculoperitoneal.
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Multiloculated hydrocephalus with several noncommunicating ventricular compartments and possibly additional extraventricular cysts constitutes an especially challenging condition.1,3,6 The leading causes of a hydrocephalus are infection and significant intraventricular hemorrhage.15 Treatment options for multiloculated hydrocephalus consist of microsurgical fenestration of cysts, shunting in which multiple catheters are placed in several cystic compartments, endoscopic fenestration in which communications are established to the ventricles, or a combination of these methods.2,9,19,21,32

Endoscopy in patients with multiloculated hydrocephalus is challenging, because the orientation along normal anatomical landmarks is missed, but this disadvantage can be avoided by utilization of neuronavigation.1,4,11,12,14,30 This retrospective study presents our experience with navigated endoscopic surgery for the treatment of multiloculated hydrocephalus.

**Methods**

**Patient Population**

The database of all operative procedures from April 2004 to September 2008 was retrospectively reviewed. All children younger than 10 years of age who had undergone at least one navigated endoscopic procedure to treat multiloculated hydrocephalus within this period were selected. Patients undergoing a navigated endoscopic procedure to connect an isolated fourth ventricle were only considered for this study if the connection was achieved by penetrating a posterior cystic wall of the supratentorial dilated part of the fourth ventricle into the posterior lateral ventricle. Not considered for this series were patients who had undergone aqueductoplasty in which the fourth ventricle was connected using a transaqueductal stent.

We were able to identify 16 children who had at least one operative procedure that fulfilled the aforementioned criteria. One child had a congenital multiloculated condition. Seven children experienced intraventricular hemorrhage as a single course of cyst development. Four patients suffered a multicystic appearance of their hydrocephalus due to infection and 4 children due to both pathologies of hemorrhage and infection (Table 1). All latter patients were supra-regional referrals to our department. The mean age of all children was 16.1 ± 23.3 months (median 8 months, range 2–90 months) at the time of the first navigated endoscopic operation. Ten children (62.5%) were less than 1 year and 14 (87.5%) were less than 2 years of age. The male/female ratio was 1:1. All children presented with clinical signs of hydrocephalus or, if previously treated, with signs of shunt malfunction or infection. Radiological evidence of progressive and significant as well as repeated enlargement of the compartmented ventricular system on serial MR images also constituted a secondary indication for operative intervention.

**Imaging and Planning**

In all patients preoperative 1.5-T MR imaging (Phillips) was performed to evaluate the intracranial anatomy. Thin-cut MR images were obtained with T2-weighted sequences (TE and TR 2500–5000 and 86–120 msec, respectively) and in 3D fast field echo sequences (TR and TE 11.60 and 5.3 msec, respectively). The MR imaging data set was transferred via network connection to the planning station of the navigation platform (iPlan 2.6, BrainLab). The MR imaging data set was used for preoperative planning of entry points and trajectories. Usually 1 or 2 entry points and trajectories were defined. Preferential consideration was given to standard frontal, parietal, or temporal entry points. The trajectories were planned to connect as many isolated compartments as possible. The length of the planned trajectories and their position within the multiloculated ventricular system were used to calculate the sites of the additional proximal perforations for the ventricular catheters. The planned image data set was transferred to the navigation system in the operation theater. We used the navigation platform BrainLab VectorVision2 system (Figs. 1 and 2).

**Surgery**

All children received perioperative prophylactic antibiotic treatment, usually with flucloxacillin (50 mg/kg) for 24 hours. The head was immobilized either on a vacuum mattress and further secured with tape to the operative table or in a pediatric headrest system (DORO, pro med instruments GmbH). The reference frame for the navigation system was securely attached to the operating table, and registration was performed prior to preparation and draping by surface matching using a SoftTouch tool (BrainLab). After firmly attaching a reference tool to the proximal end of the endoscope, a reference matrix facilitates one’s ability to define the length and diameter of the endoscopic unit (Minop, Aesculap AG) (Fig. 2).

The previously planned entry points were identified with the help of the navigation system and a bur hole was

**Fig. 1.** Screenshot of the neuronavigation platform 3D reconstruction [A], inline views [B and C], and pre- and postoperative sagittal MR images [D], showing the virtually planned trajectory to connect an isolated fourth ventricle to the left lateral ventricle by opening a thin supratentorially displaced membrane.
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placed, accordingly. Navigated guidance of the endoscope was used to enter the CSF cavities along the planned trajectory and throughout the procedure to identify respective targets for cyst fenestration or position of catheters within the multiloculated ventricular system (Fig. 2). Primarily, fenestrations were performed. One or two ventricular catheters with additional proximal perforations along their course were placed via the fenestrations, thereby facilitating drainage of several ventricular compartments with one catheter. The additional perforations in the ventricular catheter were placed according to the estimated position of the catheter segment within the CSF compartments and simply cut into the proximal part of the catheter with a small bone rongeur. Thereafter, the ventricular catheter was connected via a bur hole reservoir and subcutaneous tubes to a valve with a gravitational unit (Pae-diGAV 9/24 or 9/29 cm H\textsubscript{2}O, Christoph Miethke GmbH und Co. KG) in the series of the first 11 children. Later on, an adjustable valve (proGAV, Christoph Miethke GmbH und Co. KG) was used. The initial setting for the adjustable unit of the valve was chosen according to age, any previously implanted valve settings, and the size of the ventricular system but was in the range of 8–10 cm H\textsubscript{2}O for the horizontal position. The chosen resistance of the gravitational unit (vertical position) of the proGAV valve was 20 cm H\textsubscript{2}O.\textsuperscript{27} In all patients peritoneal diversion of the CSF was used. In cases in which 2 ventricular catheters were placed the catheters were connected via a Y-shaped connector proximal to the single implanted valve. The ventricular and distal catheters were commercially available as regular silicon catheters (Christoph Miethke GmbH und Co. KG) or antibiotic impregnated catheters with rifampicin and clindamycin (Bactiseal, Codman).

\textbf{Data and Follow-Up}

For each patient, the age at the first operation and the time point of possible further operative revisions were collected. The number of drained compartments of the multiloculated ventricular system was counted for every navigated endoscopic procedure. Postoperative complications were recorded.

After discharge from the hospital, all children were followed up clinically with regular outpatient appointments and serial MR imaging. The first MR imaging session was usually done within 3 months to assess catheter position and configuration of the ventricular system. Subsequent MR imaging evaluations were scheduled every 3–6 months.

\textbf{Results}

\textbf{Patients and Operative Procedures}

Ninety-one procedures were performed in 16 children during the observation period. The average number of procedures per child was 5.7 ± 2.8 (range 1–11 procedures, median 5.5 procedures). Among these 91 procedures were a total of 29 navigated endoscopic procedures. Half of the population (50%) required a single navigated endoscopic intervention and 4 (25%), 3 (18.8%), and 1 (6.3%) required 2, 3, or 4 interventions, respectively.

In 9 patients (56.3%) a navigated endoscopic procedure represented the final surgical procedure within the follow-up period. In 3 patients (18.8%) 1 further procedure was necessary, and in 4 patients (25%) 2 further operations were necessary after navigated endoscopy. The reasons for additional operations were revision of one of the ventricular catheters (3 patients), insertion of an additional catheter without navigation (3 patients), changing of the valve (2 patients), wound infection (2 patients), and need for an endoscopic aqueductoplasty (1 patient). The time course of all procedures in every patient performed at our institution is given in Fig. 3.

The number of compartments of the multiloculated ventricular system drained with either 1 or 2 catheters ranged from 2 compartments (9 patients) to 9 compartments (1 patient). The mean number of drained CSF compart-
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![Graph showing number of drained compartments](image)

**Fig. 4.** Number of drained compartments of the multiloculated ventricular system by 1 shunt after navigated endoscopic placement of 1 or 2 ventricular catheters.

The anatomical description of the drained compartments for every patient and the respective procedure is presented in Table 1. In 21 navigated endoscopic procedures, drainage via one ventricular catheter was established; in 8 procedures 2 ventricular catheters connected via a Y-connector were used. No patient required more than 2 ventricular catheters.

To further characterize the value of navigated endoscopic surgery, the time course of all procedures in all patients was analyzed. For 5 patients (31.3%) a navigated endoscopic procedure constituted the first operative procedure at our institution. Of the remaining 13 patients, 7 (43.8%) had at least 1 operative procedure with the intention of temporary control of the condition—for example, insertion or changing of an external ventricular drain. In 6 patients (37.5%), we attempted permanent CSF diversion by regular VP shunt surgery in which 1 or 2 ventricular catheters were placed without navigated endoscopy. Because these patients underwent a navigated endoscopic surgery at a later time, the established CSF diversion by regular VP shunt was insufficient. The CSF diversion established by navigated endoscopic surgery was successful in 3 of these patients who required no further correction of the shunt. In the remaining 3 patients only an elective upgrade of the implanted valve was necessary. In the latter group a mean number of 6.7 ± 1.5 surgeries per child was required. In comparison with the remaining patients in whom navigated endoscopic surgery was used as first-...

### TABLE 1: Summary of procedures performed in 16 patients with multiloculated hydrocephalus*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (mos)</th>
<th>Etiology</th>
<th>No. of Procedures</th>
<th>No. of Navigated Endoscopic Procedures</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
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<tr>
<td>1</td>
<td>8, F</td>
<td>hemorrhage</td>
<td>5</td>
<td>4</td>
<td>3 (1); LV &amp; C/C</td>
<td>3 (1); LV &amp; C/C</td>
<td>2 (1); LV &amp; C</td>
<td>4 (1); LV &amp; T/LV/T</td>
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<tr>
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<td>14, M</td>
<td>hemorrhage</td>
<td>3</td>
<td>2</td>
<td>2 (1); LV &amp; 4V</td>
<td>3 (1); LV &amp; C/4V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>13, M</td>
<td>infection</td>
<td>4</td>
<td>1</td>
<td>5 (1); LV &amp; C/C/C/T</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>9, F</td>
<td>hemorrhage &amp; infection</td>
<td>11</td>
<td>3</td>
<td>2 (1); LV &amp; LV</td>
<td>2 (1); LV &amp; 3V</td>
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<td>7, F</td>
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<td>2</td>
<td>1</td>
<td>2 (1); LV &amp; 4V</td>
<td></td>
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<tr>
<td>6</td>
<td>3, F</td>
<td>infection</td>
<td>8</td>
<td>2</td>
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<td>10</td>
<td>3</td>
<td>3 (1); LV &amp; T/4V</td>
<td>5 (1); LV &amp; T/T/C/4V</td>
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<tr>
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<td>7</td>
<td>3</td>
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<td>1</td>
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<tr>
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<td>14, F</td>
<td>hemorrhage</td>
<td>1</td>
<td>1</td>
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<td>1</td>
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<tr>
<td>12</td>
<td>8, M</td>
<td>infection</td>
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<td>2</td>
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<tr>
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<td>90, M</td>
<td>CM</td>
<td>6</td>
<td>1</td>
<td>5 (2); LV &amp; C/C; LV &amp; C</td>
<td></td>
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<td>5</td>
<td>2</td>
<td>4 (2); LV &amp; LV/C/T</td>
<td>3 (2); LV &amp; LV; T</td>
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</tr>
</tbody>
</table>

* C = isolated cyst; CM = congenital multiloculated condition; LV = lateral ventricle; T = isolated temporal horn; 3V = isolated third ventricle; 4V = isolated fourth ventricle.
line treatment for permanent CSF diversion, a smaller number of surgeries per child was necessary (mean 5.1 ± 3.3; p = 0.09, Mann-Whitney U-test).

Complications

The total number of complications observed after the 29 navigated endoscopic procedures was 11 (37.9%), whereas no complications occurred after 18 procedures (62.1%). Infection of the shunt system occurred after 4 navigated endoscopic procedures (13.8%). In these cases we performed explantation of the shunt, temporary external drainage, and navigated endoscopic reimplantation of the shunt system following adequate antibiotic treatment. In 3 procedures (10.3%) obstruction of the endoscopically placed ventricular catheter was observed, necessitating further endoscopic revision. In 2 cases (6.9%) surgery was required for superficial wound infection. In 2 cases (6.9%) we observed significant enlargement of cysts, which were treated with endoscopic fenestration only. There was no relevant intra- or postoperative bleeding in this series of procedures.

Following 5 (17.2%) of 29 procedures, enlargement of additional compartments necessitated an additional intervention, which was not considered a direct complication of the operative procedure but a remnant of CSF dynamics in primarily concealed cysts.

Clinical and Radiological Follow-Up

No patient was lost to follow-up. Postoperative MR imaging within 3 months was performed in all children. Magnetic resonance imaging after the last surgical intervention showed diminished mass effect and decreased size for all connected ventricular and cystic compartments in all children. This is illustrated in a representative case (Fig. 5).

All children were assessed by a neurology pediatrician at their follow-up visits. The mean duration for clinical follow-up in these children was 19.4 ± 13.3 months (range 1–40 months). The parents or legal guardians of all children described progressive development after the successful shunt implantation.

Discussion

Multiloculated hydrocephalus is a condition that not only constitutes a therapeutic challenge to the treating neurosurgical team but also imposes substantial stress on the patient and their families and is responsible for significant costs. This is due to the fact that the majority of patients require multiple operative procedures, and repeated shunt revisions are the rule rather than the exception. Historically, multiloculated hydrocephalus was usually treated with one or more ventricular or intracystic catheters and possibly with open cyst fenestration.1,15,21,28 With the broadening use of neuroendoscopy, it became used in the setting of multiloculated hydrocephalus.9,10,19,24,25,32,39 The advantage of using an endoscope for visualization in contrast to open cyst fenestration is obvious because it minimizes the size of skull opening, brain retraction and trauma, and facilitates deep access mainly through preformed and existing cavities. One advantage in endoscopic shunt placement is that the surgeon has intraoperative control of the position of the inserted catheters, thereby potentially decreasing the risk of malpositioning. Although endoscopic insertion of the initial VP shunt in children suffering from hydrocephalus has not been shown to reduce the incidence of shunt failure,36 optimal ventricular catheter positioning is considered to be important for overall shunt survival36 and might have particular impact in the setting of multiloculated hydrocephalus. The major difficulty with endoscopy in multiloculated hydrocephalus is the distorted anatomy caused by previous hemorrhages, infection, or congenital anatomical malformations. This difficulty is the rationale for using neuronavigation in patients with multiloculated hydrocephalus. Our study includes a group of children who have undergone navigated endoscopic procedures. The advantage of preoperative planning is that trajectories for intraventricular and intracystic catheters could be simulated before the actual procedure and optimal entry points for the trajectories can be calculated. While trying to use standard bur hole sites, our planned trajectories usually differed markedly from the standard placement routes for ventricular catheters. The need for MR imaging for neuronavigation did constitute some additional burden. However, the time needed to obtain the thin-cut MR imaging sequences suitable for navigation turned out to be well invested in that it allowed us to optimally plan the surgical strategy and to possibly reduce overall operative time.

During the operation, neuronavigation, as an adjunct to direct endoscopic visualization, was extremely helpful. Anatomical landmarks—for instance, the veins at the foramen of Monro or the choroid plexus—can be submerged beneath a layer of gliotic tissue and can be unrecognizable. Another difficulty is associated with the correct identification of the sites for planned fenestrations. Cyst walls can appear to be very thin on the preoperative MR images, but under direct endoscopic visualization they might be nontransparent and essentially indistinguishable from normal surrounding brain. In these conditions intraoperative navigation has proved to be of significant value during the procedures in our patients.

One problem with neuronavigation can be the occurrence of intraoperative brain shift, which lessens the accuracy of the navigation based on preoperative image data.10,32 This especially holds true in situations in which fluid cavities, such as large cysts or the ventricular system, are opened. However during all the procedures we have not encountered significant problems with inaccuracy. Two factors might have contributed to this observation. 1) At first the majority of opened compartments were, by trend, small and each, by itself, constituted only a smaller portion of the whole CSF-filled compartmented ventricular system. This facilitated a step-by-step approach through the compartmented ventricular system; rapid significant fluid shifts were avoided and sufficient accuracy of the navigational system was maintained along the trajectory ahead of the endoscope. In situations in which 2 or more separate trajectories were planned, we inserted the catheter first along the trajectory with the smaller cysts and performed the opening of the largest cysts along the second trajectory only after the first catheter was suc-
Fig. 5. Case 12. This 4-month-old boy was referred to our unit with a diagnosis of ventriculitis and meningitis. A–C: At admission right frontal and left occipital external ventricular drains were in place. Both drains were renewed and antibiotic treatment was given according to the resistance of the involved bacteria. The external ventricular drains were additionally exchanged after 2 weeks (Procedures 1 and 2). Following clearance of the infection at 2 weeks, a VP shunt with 2 separate ventricular catheters at the existing bur hole sites was implanted (Procedure 3). A follow-up MR image demonstrated enlargement of 3 isolated left temporal compartments. Therefore, a non-navigated endoscopic shunt revision of the left occipital ventricular catheter was performed when the patient was 5 months old (Procedure 4); the device was placed through fenestrations into the tip of the temporal horn. D–F: The next MR images showed progressive enlargement of an isolated right ventricular compartment and a largely dilated compartment of the posterior left lateral ventricle with extension across the midline. When the patient was 8 months of age he underwent navigated endoscopy (Procedure 5) in which the catheter in left temporal horn was removed and a multiperforated catheter was directed from the occipital horn of the left lateral ventricle through 2 isolated midline compartments into the isolated right temporal horn. This catheter and the right frontal catheter were connected to one distal shunt system with a Y-shaped connector. G–I: The follow-up MR images showing sufficient drainage of all connected compartments. When the patient was 17 months old, it became necessary to exchange the valve with a new one after we observed clinical and radiographic evidence of overdrainage (Procedure 6). J: Radiograph demonstrating the shunt configuration with the adjustable proGAV valve. Due to shunt disconnection, revision was necessary, and a shunt infection developed, subsequently requiring explantation of the entire system, temporary external drainage, and antibiotic treatment (Procedures 7 and 8). The shunt system was reinserted afterward with a second navigated endoscopic procedure when the patient was 18 months old (Procedure 9). At most recent clinical follow-up (28 months of age) the boy was alert, interested in his surrounding, and adequately communicating with 2-word sentences. Motor development is delayed with reduced truncal control, making the sitting position unstable. The boy is purposefully playing with both hands. Movement is by crawling.
cessfully placed. 2) We have found it important to use continuous irrigation throughout the procedure, thereby maintaining the existing anatomy and dimensions of the penetrated cysts and parts of the ventricular system as much as possible throughout the entire procedure. These steps have helped to minimize the significance of brain shift. Potentially, ultrasound may be an additional modality for targeted fenestrations and can overcome the problem of intraoperative brain shift as well as provide real-time imaging of a multiloculated ventricular system, especially in infants with open fontanel. However, we did not use ultrasound in this patient series because we have found that the combination of endoscopic visualization and neuronavigation is sufficient during the procedure, and transcranial ultrasound might not be of sufficient quality to visualize thin membranes.

There are not many data on neuronavigation and endoscopy in multiloculated hydrocephalus in the published literature. As a part of a series of navigated endoscopic procedures, Schroeder et al.\(^\text{30}\) reported on 4 cases of multiloculated hydrocephalus. Mangano et al.\(^\text{26}\) published 2 cases in which a combination of endoscopy and neuronavigation was used in 2 infants, one whom suffered from multiloculated hydrocephalus. In a recently published study, Oertel et al.\(^\text{23}\) described 134 endoscopic procedures for different pathological entities in children. Without giving actual numbers, they reported that they have used neuronavigation in selected cases. The present study is the first to focus on children with multiloculated hydrocephalus in whom navigated endoscopic procedures were performed. Of note is that in cases of multiloculated hydrocephalus we continue to rely on ultimate CSF diversion outside of the cranial vault. We used combined endoscopy and navigation for optimal placement of the one or 2 ventricular catheters of the implanted shunt system. The endoscopically navigated procedures were not considered to be an alternative to shunt placement. The etiology of multiloculated hydrocephalus due to infection and/or hemorrhage underscores why this condition cannot be treated with endoscopy alone.

In all children we were able to obtain a sufficient drainage of the multiloculated ventricular system. In the majority of children (56%) a navigated endoscopic procedure constituted their last operative intervention, indicating sufficient CSF diversion had been established. In the other patients (44%) at least 1 additional procedure for various reasons was required (Fig. 1). This does not necessarily imply a direct correlation with the operative procedure, but, rather, indicates a possible and expected course of the condition, where, for example, enlargement or compartmentalization of additional, previously not-drained parts of the ventricular system can be observed. This and the fact that every child underwent an average of 5.7 ± 2.8 procedures—including all endoscopic and regular shunt revisions during the observation period—underlines the known complexity of the patient population.

In this series the mean number of drained ventricular compartments was 3.6 ± 1.7 compartments (range 2–9 compartments). In this context there were 2 noteworthy observations. Initially in the series we performed cyst fenestrations without placing a catheter; this did not prevent further enlargement of some of these fenestrated cysts and led to a need for reoperation. In agreement with the observation by Wagner and Koch,\(^\text{37}\) who described membranous reocclusion of obtained openings in children, the fenestrations proved to be occluded or unidentifiable at revision surgery. We now attempt to place a catheter through all obtained openings. This strategy proved to be successful in most children; revision of the endoscopically placed ventricular catheter due to malfunction was required after only 3 procedures (10.3%). Taking the young median age of 8 months of the patient population into consideration, this failure rate for fenestrations is lower than the reported reocclusion rate in this age group—for example, in (not-stented) third ventriculostomy.\(^\text{5}\) Thus, we do not withhold endoscopic treatment from infants but attempt to secure the fenestration with a stent or catheter. As second notable development occurring toward the end of this series, we tended to place 2 catheters into the cystic compartments that were connected via a Y-shaped connector. No patients required more than 2 catheters. The use of more than 1 catheter is the result of the intention to drain as many cysts as possible. The rationale behind this is the assumption that the more cysts drained, the better. The aim for treating noncomplicated hydrocephalus is to avoid dilatational and pressure trauma to the developing brain.\(^\text{7,13}\) The same consideration would apply to a multiloculated situation in which enlargement of every single cyst can potentially exert the same effects.

The rate of complications after a navigated endoscopic procedure necessitating revision was high (38%) but within the range of observed revision ranges for shunt surgery. In a large pediatric series, one group reported revision rates of 25% after the 1st month and 48% 1 year after the first shunt insertion.\(^\text{38}\) Taking into consideration the fact that patients with multiloculated hydrocephalus are prone to needing multiple surgeries due to complications of shunt malfunction or infection, the complication rate was considered acceptable.

To further assess the value of the navigated endoscopic surgery, comparison with a control group would be desirable. Because the present group of patients is small and evidently diverse with regards to age, clinical features, and radiological presentation, an exact matching with a historical control group was not possible. We therefore evaluated the time course of all operative procedures in all individual patients and identified patients with multiloculated hydrocephalus in whom there was an attempt to establish permanent CSF diversion with a regular VP shunt prior to a navigated endoscopic procedure. Within our cohort there were 6 patients (33%) in whom this criterion was fulfilled. In all of these patients follow-up imaging revealed that the multilocular hydrocephalus had not been adequately treated, thereby necessitating an additional—navigated endoscopic—procedure. The navigated endoscopic procedure proved successful in 3 patients without the need for additional operation, and in the remaining 3 patients only an elective change to a programmable valve was performed later on. The large number of non—endoscopic navigated VP shunt surgeries required in this group to adequately treat multiloculated hydrocephalus underscores the value of navigated endoscopic surgery for this highly specific patient cohort.

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Navigated endoscopy for multiloculated hydrocephalus

One clinical observation in the present series was a positive trend toward improvement in neuromotor deficits and cognitive developmental delay in children who underwent earlier surgery, owing to preserved brain substance at the time of surgery. This observation was made in comparison with referred patients and those operated on after a significant loss of brain tissue, due to long-term pressure-related multicystic degeneration. This observation cannot be statistically verified because of the small number of patients but might be interpreted as a trend, which would be in accordance with an expected course based on available medical knowledge. Because of the relatively small number of treated children, the wide variability of their initial clinical presentations, and the wide distribution of age at presentation, a solid statistically based statement concerning the postinterventional motor and neurocognitive development of treated children is impossible to be make. It therefore remains beyond the scope of this study to assess the therapeutic value and benefit for the patients or to compare our treatment to other treatment modalities. Based on the radiological follow-up results, we can conclude that navigated endoscopic surgery was effective in establishing sufficient CSF diversion.

Conclusions

Endoscopic surgery represents the mainstay of therapeutic options in multiloculated hydrocephalus. It is further refined by the integration of neuronavigation, which is a useful aid in preoperative planning and intraoperative orientation. In practice we attempt to surgically treat children with multiloculated hydrocephalus as soon as they present. We aim to drain as many compartments as possible using navigated endoscopy and we secure established fenestrations with multiperforated catheters. With that regimen, we were able to treat all children and CSF drainage was sufficient in all children. The parents of children with multiloculated hydrocephalus, however, need to be aware that revisions are not uncommon and close clinical and radiological follow-up is mandatory.

Disclosure

Dr. Thomale is a consultant for Aesculap.

Author contributions to the study and manuscript preparation include the following. Conception and design: UW Thomale, M Schulz, H Haberl. Acquisition of data: UW Thomale, M Schulz, G Bohner, H Knaus, H Haberl. Analysis and interpretation of data: UW Thomale, M Schulz, H Knaus, H Haberl. Drafting the article: UW Thomale, M Schulz, H Haberl. Critically revising the article: UW Thomale, M Schulz. Reviewed final version of the manuscript and approved it for submission: UW Thomale, M Schulz, G Bohner, H Knaus, H Haberl. Statistical analysis: UW Thomale, M Schulz. Study supervision: UW Thomale.

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