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Anterior Uncoforaminotomy in the Treatment of Recurrent Radiculopathy after Anterior Cervical Discectomy with Fusion

Abstract

Background: In patients after anterior cervical discectomy (ACD) with fusion newly developed retrospondylophytes or incomplete decompression of the nerve root can cause recurrent radicular pain. Anterior cervical uncoforaminotomy (uncoforaminotomy) is an operative method which removes the causative degenerative pathology at the level of the neural foramen leaving untouched the inserted graft at this level. **Method:** Between February 2004 and April 2005, 7 patients underwent uncoforaminotomy after ACD with fusion for the treatment of recurrent cervical radiculopathy in our neurosurgical department. Prior to treatment patients received a computed tomography (CT) and a neurological examination. Anterior uncoforaminotomy was performed thereafter (for technical details see publication by Jho, 1996). A postoperative CT scan was done before discharge. Follow-up examination was performed eight weeks after surgery. **Findings:** Five patients underwent the operation at C5/6, one patient was operated at C6/7 and one patient had the operation at two levels (C5/6 and C6/7). At discharge six patients had excellent or good results. **Conclusion:** Uncoforaminotomy is a good method for the treatment of newly acquired spondylotic spurs in the foramen or incomplete osseous decompression after ACD with fusion and recurrent radicular pain.

Key words

Radicular pain · anterior uncoforaminotomy · ACD · spine

Introduction

In the treatment of cervical disc disorders causing radiculopathy various surgical approaches exist. Anterior cervical discectomy (ACD) with or without fusion is a well established surgical procedure for the treatment of cervical disc diseases [1–8]. Whereas it may well be suitable for the treatment of medial soft disc herniations and hard bone spurs, it can have its pitfalls in the treatment of laterally placed pathologies. Although recurrence or persistence of radicular pain after performed ACD with fusion is rarely reported, reoperation may be difficult.

The problem with the recurrence of a foraminal pathology in a fused segment is the increased invasiveness necessary to treat such lesions. Anterior uncoforaminotomy is a well established technique in the treatment of foraminal pathologies in our department. Good decompression of the neural foramen in combination with the preservation of the motion segment – to name just two – are the advantages of this technique. Therefore, the aim of this study was to see whether it is possible to successfully treat this patient subgroup via an anterior uncoforaminotomy [9–11].

Patients and Methods

In this retrospective study 7 patients with anterior uncoforaminotomy after ACD with fusion were included (Table **1**). Inclusion criteria for this study were:

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Table **1** Patients with ACD and fusion: localization of primary surgery, means of fusion and time of prior surgery

Case No.	*Level*	*ACD*	*Year of ACD operation*
1	C5/6	Titanium cage	2003
2	C5/6	Palacos fusion	1993
3	C5/6 + C6/7	Titanium cage	2003
4	C6/7	Iliac crest and titanium plate	2000
5	C5/6	Smith-Robinson	2000
6	C5/6	Titanium cage	2002
7	C5/6	Titanium cage	2001

Table **2** Clinical preoperative presentation of patients with recurrent radiculopathy after ACD and fusion

Symptoms	*Patients*
Radicular pain	7
Sensory changes	6
Motor weakness	5
Neck pain	7

- patients with recurrent monosegmental unilateral radicular pain
- no response to conservative treatment
- ACD with fusion in the same level
- a lateral spondylotic spur or an intraforaminal location of spondylotic changes compressing the nerve root visible in computed tomographic (CT) imaging.

All patients were evaluated neurologically (Table **2**) and preoperative computed tomography was performed to visualize the distance between the graft and the uncinate process.

An upper vertebral-transcorporal approach to the neural foramen was chosen in all cases. In this approach the far lateral inferior portion of the upper vertebral body and the medial portion of the transverse foramen are trimmed as Jho described in 2003 [12].

For detailed and additional information see publications by Jho and Saringer [10,13]. VA was not exposed. Furthermore, by leaving a thin layer of cortical bone of the lateral wall of the uncinate process the vertebral artery remained protected. Operations were performed by 3 surgeons. Mobilization of the patients was done immediately after surgery. No cervical collar was used. Postoperative CT scans were done before discharge. Six to eight weeks after surgery the patients were allowed to return to full activity.

Follow-up evaluations took place 6–8 weeks and six months after surgery. Radicular and local neck pain were quantified in the analogue pain scale.

Table **3** Outcome of patients with recurrent surgery with anterior uncoforaminotomy

Case No.	*Radicular pain*	*Nuchal pain*
1	Improved	Moderate
2	None	None
3	None	Mild
4	None	Moderate
5	None	Mild
6	Unchanged	Unchanged
7	Improved	Moderate

Surgical results (Table **3**) were graded
- as excellent: patient with complete resolution of the radicular symptoms
- as good: patient experienced relief of radiculopathy
- as fair: patient with mild/moderate residual radicular discomfort
- as poor: patient continued to have significant radicular symptoms, or as unchanged or worse.

Results

Between February 2004 and April 2005, 7 patients with a mean age of 52 ± 12 years (range: 40–76 years) were included in this study. Four patients were female. The duration of symptoms ranged from 6 months to 13 years. All patients had recurrent radicular pain and severe neck pain. Five patients had motor weakness and six patients had sensory changes. In five patients ACD and titanium-cage fusion had been performed 1–3 years prior to surgery (Fig. **1**). In one patient ACD and palacos fusion had been performed (Fig. **2**), and in one patient ACD and bone fusion with an additional ventral titanium plate had been performed. According to radiological criteria all segments were fused. No pseudarthrosis was present, especially not in the patients treated with palacos at first surgery.

The surgical level was C5/6 in five patients, C6/7 in one patient and in one patient surgery in two levels (C5/6, C6/7; one fused, one not surgically treated before) was necessary.

The patients were discharged between days 6 and 11 after surgery (mean: 7.4 ± 1.9). Three patients had an excellent result, three patients had a good result and one patient remained unchanged at discharge.

Postoperative evaluation of the uncoforaminotomy showed a satisfactory decompression. No destabilization of the segment was detectable. At 8-weeks follow-up 4 patients showed excellent results, two patients had a good result and one patient had unchanged radicular pain (poor outcome).

Illustrative case

A 59-year-old woman was referred to our department in March 2005. Surgery in C5/6 and C6/7 with palacos fusion had been

Fig. **1** Patient with ACD and titanium cage fusion and recurrent radicular pain preoperatively. **a** CT scan revealing foraminal stenosis on the right side. **b** Postoperative CT scan shows foraminal decompression via anterior uncoforaminotomy beside the titanium cage.

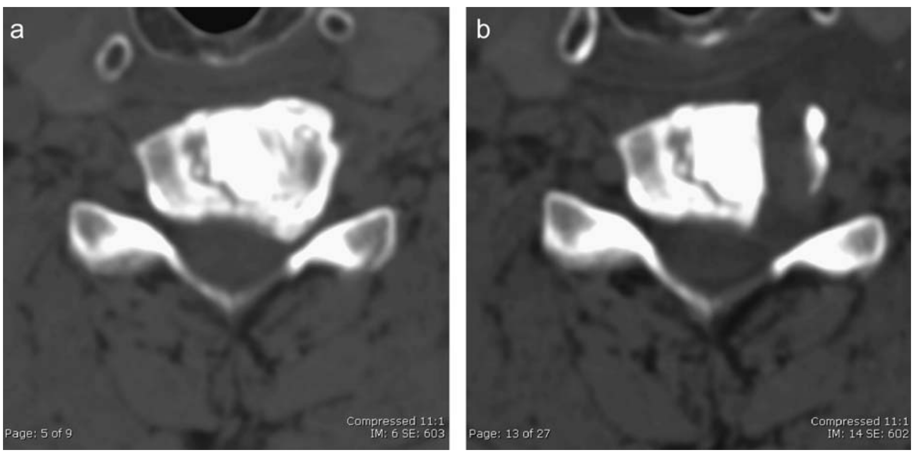

Fig. **2** A 48-year-old male with performed palacos fusion in C5 in 1993. Pain-free interval of 10 years until the patient reported recurrent radicular pain. **a** CT scan revealing foraminal stenosis on the left side. **b** CT scan shows foraminal decompression after uncoforaminotomy.

performed 4 times before, last surgery had been in 2000 (Smith-Robinson). Although she initially reported about an improvement of her radicular pain, in 2001 she had persistent severe neck pain and radicular symptoms in C6 in her left hand. Her symptoms were not relieved with analgesic medication, physical therapy, or chiropractical manipulations. On admission she had sensory changes in C6, a diminished left biceps reflex and a slight motor weakness in the C6 innervated muscles. Magnetic resonance imaging (MRI) and CT data showed a slight compression of the nerve root. No pseudarthrosis was present in both segments. After a probatory periradicular infiltration with local anesthesia of the C6 nerve root on the left side the patient was pain free. Therefore, the patient underwent a C5/6 microsurgical anterior foraminotomy on the left side. Intraoperatively a bone spur in the neural foramen and a thin bone layer adherent to the dura of the nerve root were found. After surgery the radicular pain and the nuchal pain disappeared. Minimal local pain in the left shoulder was present at discharge after 7 days. Postoperative CT imaging showed a good decompression of the left neural foramen.

At 8 weeks follow-up the patient was free of radicular symptoms, the motor strength in her hand was back to normal, and she had a normal range of motion in her neck. Only a slight nuchal discomfort, treated with physical therapy was reported.

Discussion

In the treatment of cervical degenerative diseases, anterior cervical discectomy with or without fusion is currently most frequently used. Interbody fusion cages are increasingly implanted. Anterior interbody fusion, subsequently leading to bone fusion results in a loss of the motion segment, that could lead to increased strain-induced mechanical stress exertion on the adjacent segments. This adjacent level disease has been well described in radiographic and MR imaging [14–17]. Hilibrand et al. postulated, that up to 25 % of the patients who underwent cervical fusion may require surgical treatment of the adjacent level within 10 years [18]. The reported cure rates of ACD with or without fusion and posterior foraminotomy are 82–96 % [1, 15, 18–26].

Brooke et al. reported in his series about a fusion rate of 100 % and a loss of radicular symptoms in all of his patients treated with a carbon fiber cage at 16.7 months mean follow-up [27]. Schmieder et al. showed a fusion rate of 97 % after 6 months using anterior interbody fusion with titanium cages. In spite of the fusion rate, the clinical outcome at follow-up showed unchanged radiculopathy in 9 of 96 patients [28]. Revision was performed in two patients because of persistent foraminal stenosis. Although there are just a few reports about revision surgery necessary after cervical discectomy, the main reason for the recurrent radiculopathy seemed to be reformation of spon-

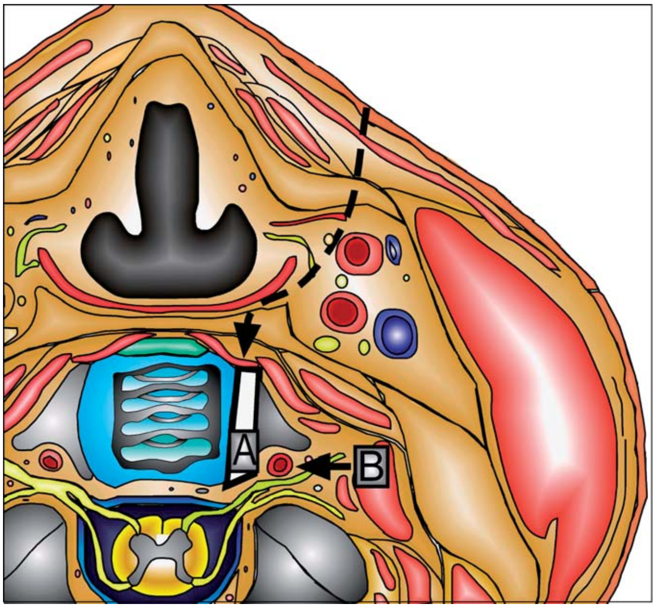

Fig. **3** Schematic drawing of the uncoforaminotomy performed beside the cage. (**A**) marks the uncoforaminotomy, (**B,** arrow) shows the position of the vertebral artery

dylotic changes due to pseudarthrosis [29–33]. Pseudarthrosis may lead to microinstability in the operated level and can cause renewed spondylotic compression of the neural foramen. Both techniques, anterior and posterior surgical approaches for revision surgery are discussed, mainly controversially.

The reoperation rate after ACD with fusion is reported to range from 1.1–8.8 % [34] excluding adjacent level morbidity.

Using the posterior approach, Fuji et al. reported of nine patients with anterior cervical pseudarthrosis treated at recurrent surgery with interspinous wiring without bone grafting [32]. A retrospective study comparing anterior versus posterior repair of anterior pseudarthrosis was done by Brodsky who showed a fusion rate of 76 % in patients with anterior repair using autografts without plating in contrast to a 94 % fusion rate for patients who had undergone posterior repair with interspinous wiring and onlay autograft fusion [30]. Lowery retrospectively compared three different methods of anterior cervical pseudarthrosis revision surgery. A 94 % fusion rate in patients treated with posterior revision in contrast to a 45 % fusion rate in patients who underwent anterior plating was found [35]. Coric et al. reported about a fusion rate of 100 % in revision of anterior cervical pseudarthrosis with anterior allograft fusion and plating [29]. Reasons for reoperation in cases with pseudarthrosis were recurrent radiculopathy or intractable neck pain. Although there are different methods for treatment of this pathology, performed revision-operation is often very complex.

One reason for preferring the posterior approach by some authors may be due to the increased risk of injuring visceral or vascular structures because of scarring of the anterior fascial planes [31, 35]. In our series we had no problems due to scarring and vascular or esophageal shift. No injury of vascular structures or of the esophagus happened.

Another reason for persistent radicular pain after ACD with or without fusion may be the incomplete decompression of the neural foramen at first surgery. Although there are different methods for performing ACD with fusion, removing the offending retrospondylotic spurs is essential.

Uncoforaminotomy for the treatment of monoradicular compression via a ventral approach allows direct removal of the causative degenerative changes decompressing the neural foramen (Fig. **3**). However, patient selection is essential for the success. Monosegmental radiculopathy caused by a confirmed causative CT finding and in addition the pain free interval after a probatory anesthesia of the nerve root, are important criteria. Additionally, nuchal pain and radicular pain should be strictly distinguished, because by this surgical method the latter is addressed. Nuchal pain, caused by fusion-associated problems or adjacent level syndrome may be not influenced. In our study we demonstrated that recurrent direct nerve compression after prior ACD with fusion can successfully be treated via anterior uncoforaminotomy. Advantages of uncoforaminotomy are reduced surgical time, minimized surgery-related trauma and direct approach of the underlying lesion. Another advantage of this technique is the avoidance of a second approach to the spine necessary if an additional posterior approach is chosen.

Conditio sine qua non for this approach is a complete fusion of the treated level, because performing a ventral uncoforaminotomy in a non-fused level after ACD may lead to an increase in rotational instability.

Conclusion

Uncoforaminotomy is a sufficient method for the treatment of recurrent radicular pain in patients with prior anterior cervical discectomy and fusion.

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Thrombogenetic Effect of Facet Denervation using in Disc Surgery on Spinal Radicular Arteries: An Experimental Study

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Abstract

Background: Although it is well known that electric currenct can be hazardous for living tissues, facet denervation (FD) has been largely used in spine surgery. In spite of the fact that vascular structures are protected during the operation, some neurovascular disorders may develop after surgery. In this study, we investigated if FD can cause lesions of the radicular arteries. **Methods:** Seventeen rabbits were included in this study. Three of them were used as control group and the remainder were subjected to L4-5 discectomy. FD was applied via monopolar electrocauterization to only half of the operated animals. One month after the surgery, all animals were sacrificed and the L4-5 spinal radicular arteries examined histopathologically. **Results:** Vascular wall injury, endothelial necrosis, muscular lesions and thrombus development were seen in the majority of the spinal radicular arteries of the animals subjected to FD. **Conclusion:** Facet denervation via monopolar electrocautery may cause arterial lesions and thrombus development in the radicular arteries and therefore it should not be applied unless obligatory.

Key words

Electrocauterization · spinal artery · thrombogenesis · facet denervation · rabbit

Introduction

Electrocauterization is applied to vertebral elements to explore the soft tissues, to stop hemorrhage and to decrease the postoperative pain during spinal surgery. But some postoperative complications may develop in spite of a normal surgical procedure. Living bones can transmit electric current to the neurovascular tissues, damaging them when the electric energy is converted to thermal energy [1]. Electrical damage depends on some characteristics of the current and tissue such as tissue resistance, tissue susceptibility, pathway and type of current, current density, duration, and size of electrical contact [2–4]. It was reported that electrocauterization applied during spinal surgery may be hazardous to spinal roots and spinal ganglions [5]. Electrical accidents may lead to arterial injury and the development of thrombosis [6].

In conclusion, it is expected that facet denervation using electrocautery may also cause vascular lesions and lead to spinal cord and peripheral nerve root injuries. In this study, we aimed to investigate the possible detrimental effects of monopolar electrocauterization using FD on the radicular arteries in a rabbit model.

Materials and Methods

In this study, 17 male hybrid rabbits were included. Animals were approximately 1 year old and weighed 3.1 ± 0.5 kg. Animal

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experimentation was carried out in an ethically proper way according to the guidelines as set by the ethical committee of the our university. Three of the rabbits (n = 3) were used for assessing the radicular arteries in normal rabbits without any operation. The remainder were anesthetized by subcutaneous injection of a mixture of ketamine hydrochloride (25 mg/kg), lidocain hydrochloride (15 mg/kg), and acepromasine (1 mg/kg).

After the operation site had been prepared, L4-5 laminectomy and L4-5 discectomy were performed on 14 rabbits. FD using monopolar electrocauterization of 220 V/50 Hz was applied to 7 rabbits (FD group, n = 7), but not to the remaining 7 rabbits (Non-FD group, n = 7). After the operation, the rabbits were placed in their personal cages and were given antibiotic-analgesic therapy for six days. One month after the surgery, all animals were sacrificed and the nervous and vascular tissues of their lumbar spines were removed. These specimens were preserved in formalin solution of 10 % and embedded in paraffin blocks. After the sections had been stained with hematoxylin and eosin, all spinal radicular arteries were observed histopathologically.

Results

The spinal cord, nerve roots, evacuated intervertebral disc space and denervated facets during operation are shown in Fig. **1**. Postoperatively, peridural adhesions and fibrotic tissue development were seen in denervated rabbits. The histopathological findings of the spinal nerve root and radicular arteries of a normal rabbit are shown in Fig. **2**. Cellular shrinkage, elongations and cytoplasmic condensations of endothelial cells, smooth muscle shrinkage and flattening, and intimal infiltrations were observed minimally in radicular arteries of one animal in the non-cauterized group (Fig. **3**), while all of the these mentioned findings were observed in the most of the arteries of the animals subjected to FD (n = 6). Also, endothelial cell necrosis, muscular atrophy, vascular wall degeneration and thrombus development were observed in three animals of the FD group (Fig. **4**).

Discussion

Vascular damage is a frequent and serious complication following high voltage electric injuries. Electrical injuries may cause arteriolar occlusion, delayed thrombosis, ischemia and necrosis [7, 8]. Electrophysiological studies have revealed that sensorimotor axonal loss can develop after a low tension electric shock due to vasospasm and thermal coagulation of the vasa nervorum [9]. A 20,000 V alternating current caused delayed motor neuron syndrome due to demyelination and injuries of the vasa nervorum [10]. Electric injury destroyed all endothelial and medial smooth muscle cells, and induced platelet-rich mural thrombosis [11, 12]. Kornowsky et al. [13] observed that electrical stimulation to the femoral artery of rabbits resulted in endothelial injury and arterial thrombosis. Electrical shock may cause demyelination due to its vascular detrimental effects [14]. If the contact time is brief, non-thermal mechanisms of cell damage will be most important and the damage is relatively restricted to the cell membrane. When contact time is much longer, the whole cell is affected directly, and the larger cells are more vulnerable.

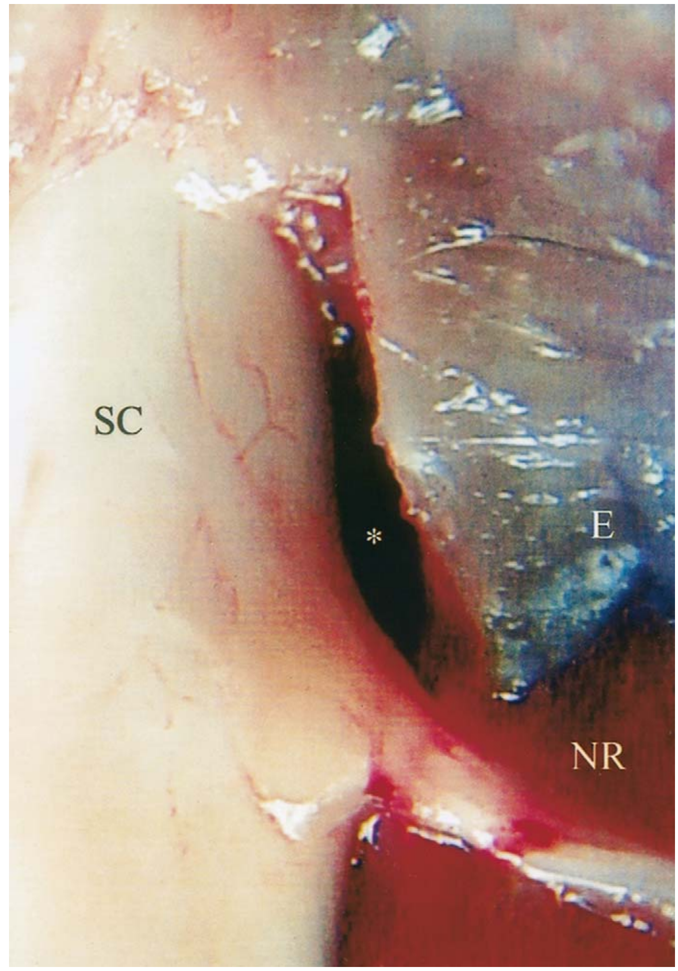

Fig. **1** Spinal cord (SC), nerve root (NR), evacuated intervertebral disc space (*) and denervated facet (E) are seen in a rabbit in GII at the end of disc surgery.

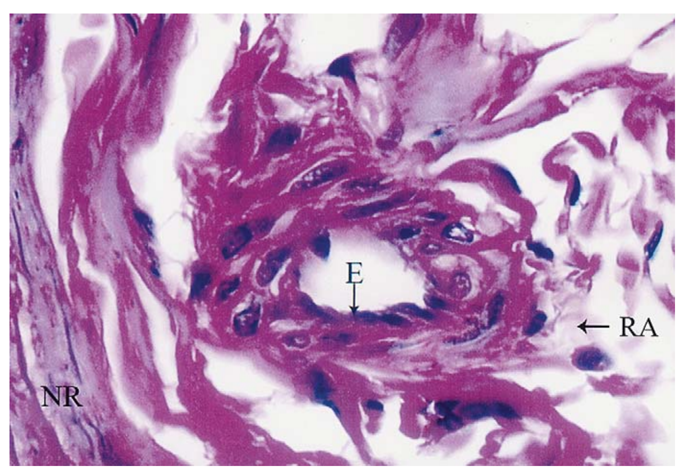

Fig. **2** Spinal radicular artery and nerve axons of L5 root are seen in a normal rabbit (LM, H&E, × 400). E: endothel, RA: radicular artery, NR: nerve root.

In addition, vascular complications of lightning injury may result in acute renal failure, rhabdomyolysis, respiratory distress syndrome, autonomic dysfunction, paresia, plegia and even quadriplegia, muscle atrophy, sensory deficit, causalgia, and reflex sympathetic dystrophy, which may recover after many months

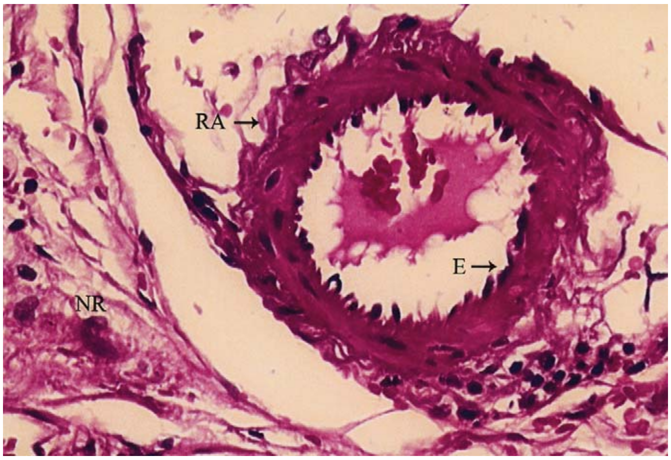

Fig. **3** Histopathological appearance of a moderately injured radicular artery is seen in GII. Endothelial injury, intimal infiltrations and muscular derangements are observed (H&E, × 400, LM). E: endothel, RA: radicular artery, NR: nerve root.

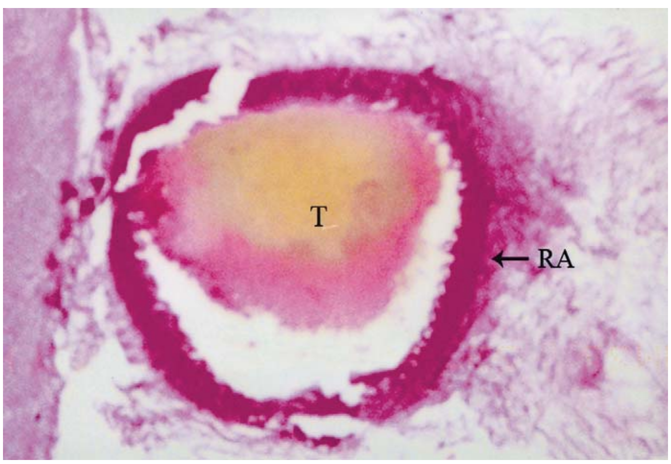

Fig. **4** Histopathological appearance of a severely thrombotic spinal artery is seen in GII. Endothelial cell necrosis, vascular wall death and mature thrombus are seen (H&E, × 400, LM). T: thrombus, RA: radicular artery.

[4,15]. Extracellular hypoxia is unlikely to be a significant factor in neural injuries of the brain or peripheral nerves due to prolonged electrical stimulation [16,17].

Electrical current can result in thrombus development via endothelial cell lesions and platelet aggregation [6]. Spinal cord injury following an electrical accident can lead to motor and sensory dysfunctions, predominantly motor. Possible mechanisms for the spinal cord damage include the heating effect, electrogenic changes and vascular damage [18]. In the present study, thrombus development was observed in the FD group, but not in the non-FD group. The results of the present study suggest that FD via electrocauterization may cause thrombosis development in spinal arteries. Therefore, long-term and high-voltage electrocauterization should not be used in spinal surgery if it is not absolutely necessary.

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The "Multi Clip" Method in Unruptured Complex Middle Cerebral Artery Aneurysms – A Case Series

Abstract

This study aims to analyze the feasibility, indications and applicability of the "Multi Clip" method for accurate and complete clipping in patients with unruptured complex middle cerebral artery aneurysms. In this series, we achieved precise clipping in all cases without any intraoperative complications. On the basis of our work, we classified the necessity for multi-clipping into 3 categories: 1) precise clipping, 2) perforator preservation, and 3) reconstruction. The outcome in all patients was excellent. In conclusion, the "Multi Clip" method is a safe and an efficient procedure in cases of difficult unruptured middle cerebral artery aneurysms, where optimal neck closure cannot be obtained by single clipping.

Key words

"Multi Clip" method (MCM) · Doppler ultrasound · neuroendoscope · intraoperative angiography

Introduction

Middle cerebral artery aneurysms may present frequently in a complex manner due to their large size, irregular neck shape, atherosclerotic plaques, sac projections and complex anatomical relations with the other neural and vascular structures. Therefore, it may be difficult to achieve an optimal clipping using of a single clip in these situations due to the non-availability of an ideal clip design which matches the requirements of the surgeon.

Patients and Methods

During a period of seven months (June to December 2005), at the Department of Neurosurgery, Fujita Health University, Japan, 35 patients with middle cerebral artery aneurysms were treated. Eighteen patients had factors interfering with clipping like irregular neck, multiple lobules, atherosclerotic plaques, origin of perforators and giant aneurysm size. These patients were operated using the "Multi Clip" method and they were classified into three categories, depending upon the preoperative imaging studies and intraoperative findings, which revealed the complexities and the pattern of application, as: 1) precise clipping type, 2) perforator preservation type, 3) reconstruction type.

Preoperative imaging studies were found to be very important in selecting the patients for "Multi Clip" method. Intraoperative Doppler ultrasound and the neuroendoscope were used in all cases for ascertaining precise clipping and to avoid complications.

The application of a single clip in the previously mentioned cases was insufficient and inappropriate which prompted us to use multiple clips to achieve a precise and complete clipping. All patients underwent a standard pterional craniotomy and splitting of the sylvian fissure [1, 2]. Fourteen patients were identified to have an irregular neck on preoperative imaging and intraoperatively we found it was impossible to clip them using a single clip, which could have caused narrowing and kinking of the parent vessels. So, we clipped the distal part of the sac first using a standard clip and then we applied a second mini clip (in 5 cases) or a fenestrated clip to "jump" the blades of the first clip (in 4 cases) for accurate and precise clipping of the sac remnant.

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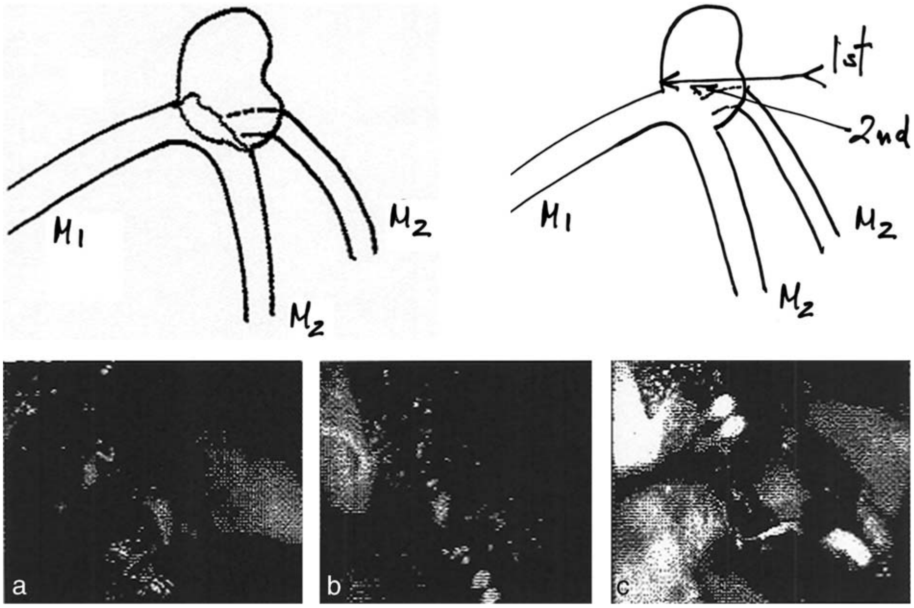

Fig. **1** Precise clipping type in the ''Multi Clip'' method in a complex (irregular neck) right middle cerebral artery aneurysm. Upper row: schematic diagrams; lower row: intraoperative photos. From left to right: **a**) Aneurysm with irregular neck before clipping, **b**) after first clip application on the distal sac, **c**) after complete clipping with two clips.

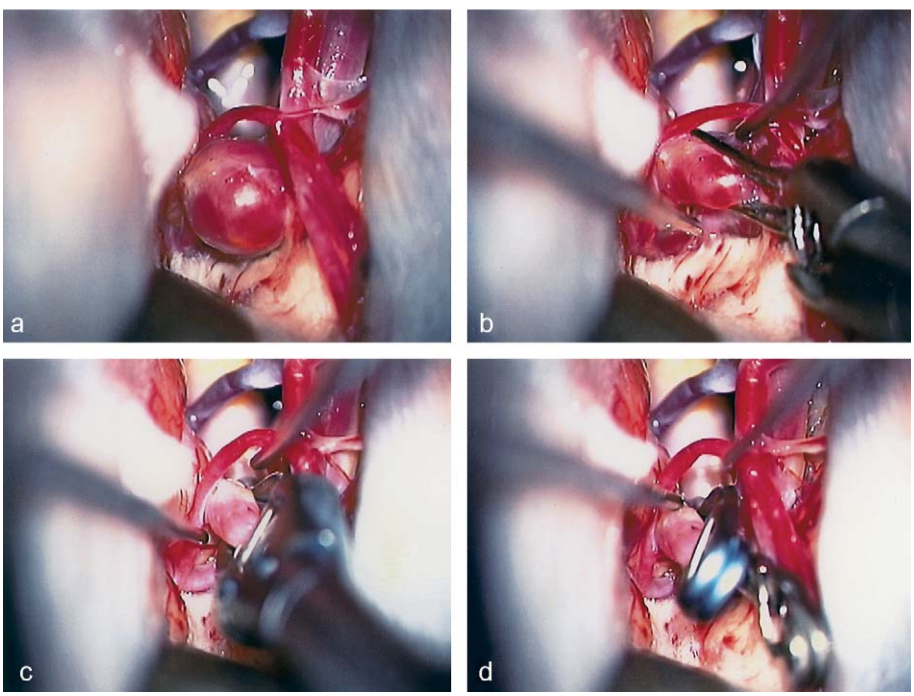

Fig. **2** Perforator preservation type in the ''Multi Clip'' method in a complex (origin of perforator) left middle cerebral artery aneurysm. Lower row: intraoperative photos. From left to right: **a**) aneurysm with a perforator close to the neck, **b**) after first clip application preventing stenosis/occlusion of the perforator, **c**) after second clip application distal to the first clip for complete sac clipping, **d**) final appearance of the operative field.

We classified this type as the precise clipping type in the "Multi Clip" method (Fig. **1**).

In two patients we found the origin of a perforator at the neck of aneurysm. Intraoperatively, we found that the application of a single clip could lead to occlusion or severe reduction of the blood flow in the perforator. We applied two clips in a tandem technique (Drake's tandem clipping technique) and preserved the perforators, so achieving complete clipping [3]. The first clip was applied slightly away from the perforator allowing good blood flow and the second clip was applied above the first to catch the remnant of the sac in a tandem fashion (Fig. **2**).

A good blood flow to perforators was confirmed using Doppler ultrasound intraoperatively and, postoperatively, the patient did not show any features of infarction clinically or on imaging studies. We classified this type as the perforator preservation type in the "Multi Clip" method.

In one patient with a large aneurysm and another patient with a giant aneurysm, we have found that the application of a single clip would obviously not be sufficient to fully isolate the aneurysm as well as to prevent stenosis of parent/branch vessels. In the large aneurysm, after trapping the internal carotid artery, the anterior cerebral artery and M2, neck dissection was carried out. We encountered a branch vessel adherent to the dome of the aneurysm which could not be dissected, as doing so might have caused a rupture of the dome. Three fenestrated clips were applied in a tandem fashion with fenestrations, carrying the residual sac along with the preserved branch vessel, and the

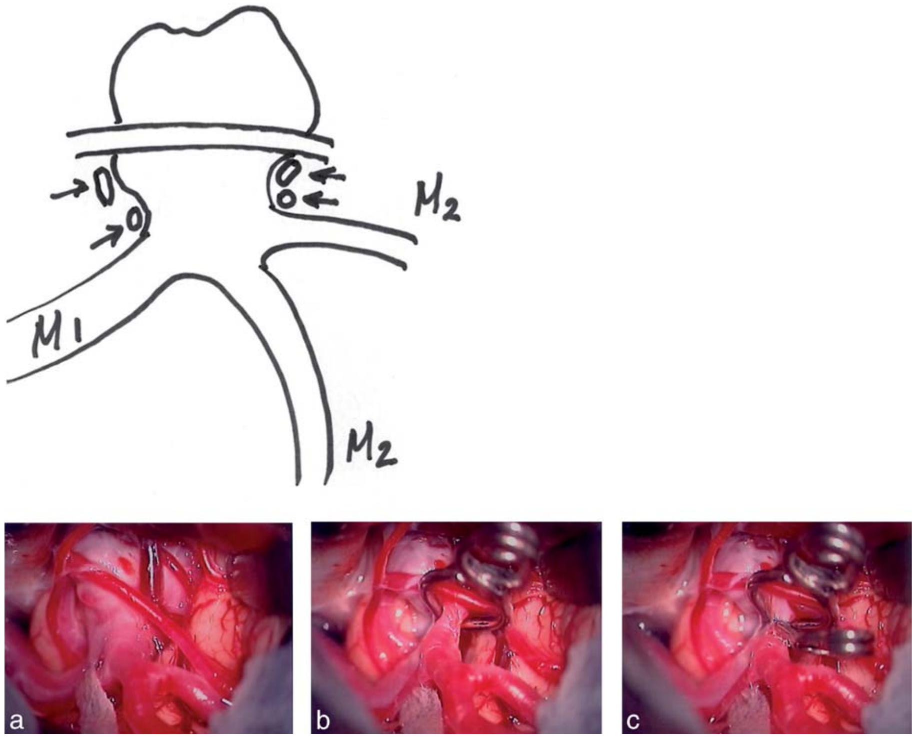

Fig. **3** Reconstruction type in the "Multi Clip" method in a complex (large size with a branching vessel on the dome of the aneurysm) left cerebral artery aneurysm. Upper row: schematic diagrams; lower row: intraoperative photo. From left to right: **a**) large complex right middle cerebral artery aneurysm before clipping, **b**) after first fenestrated clip application, more distal to the neck, to avoid parent vessel stenosis, **c**) after the second clip, closer to parent vessel, and avoiding compromise of the vessel on the sac.

closed blades were reconstructing the superior wall of the parent vessel (Fig. **3**).

In the giant aneurysm case, four fenestrated clips were used in a tandem fashion after suction decompression of the sac for reconstruction. We classified this as the reconstruction type in the "Multi Clip" method. With Doppler ultrasound, the flow to the main trunk of middle cerebral artery and other branches was confirmed. The neuroendoscope was introduced to assure that the perforators were not included in the clipping. We achieved complete clipping without vessel stenosis in both patients.

Results

We achieved precise clipping in all cases without any intraoperative complications. There were no incidences of premature rupture of the aneurysms intraoperatively. The outcome in the short-term follow-up of all patients was excellent.

Discussion

Aneurysms arising from the middle cerebral artery represent 33 % of all intracranial aneurysms [4]. Their shape, size, situation and, in particular, their relation to the middle cerebral artery trunk and its branches show wide variation and complexities [5]. In our analysis, 87.5 % of our patients with complex unruptured middle cerebral artery aneurysms had an irregular neck apart from large and giant aneurysms. The precise application of the clip on the neck of the aneurysm is of paramount importance. However, that is not an easy surgical task if the neck anatomy is too complicated making these aneurysms challenging and potentially-life threatening in their surgical management [4].

In light of the non-availability of a preoperatively designed single clip which possesses the suitable shape for a particular aneurysm neck difficulty, i.e. without producing complications, the "Multi Clip" method, in its precise clipping type, gives a solution for achieving a complete and accurate clipping. Moreover, after the first clip application, the neck becomes smaller and helps us to assess the rest of the aneurysm for easy application of the next clips.

The anterior perforating arteries originating from the middle cerebral artery usually arise from a single common trunk or from several small perforating branches [6]. These perforators may originate from the most medial portion of the artery close to its origin (37 %), or they may originate from the middle one-third of the M1 segment (47 %). In the remaining 16 %, the perforating vessels arise from the most lateral portion of M1.

It is vital to preserve perforators, but sometimes it may not be possible to preserve them when a single clip is used. This may compromise the blood flow through these perforators. We have found that the "Multi Clip" method – perforator preservation type, is very useful for preserving perforators and for achieving complete and accurate clipping.

Large and giant aneurysms have thick walls that prevent the tips of the aneurysm clip from closing. In such a situation, the "Multi Clip" method – reconstruction type, is very useful in achieving complete and accurate clipping [3]. In our short-term follow-up period, the patients have shown excellent results. The limitations involved in this method are: 1) it may be difficult to introduce the neuroendoscope or Doppler ultrasound probe following clipping and 2) in some situations, it may not be possible to apply an additional clip due to inaccessibility and lack of space. In order to avoid this situation, care should be taken during a clip application that sufficient space for introducing instruments for the succeeding clips is left. In conclusion, in difficult cases of complex middle cerebral artery aneurysms where single clipping could not accomplish complete clipping without complications, the "Multi Clip" method is very useful for a safe, successful and accurate clipping of such aneurysms.

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Neuroendoscope-Assisted Minimally Invasive Microsurgery for Clipping Intracranial Aneurysms

Abstract

Objective: The aim of this study was to evaluate the efficacy of intracranial aneurysm treatment with the help of the neuroendoscope. **Methods:** Eighty-eight patients were treated from February 2000 to November 2003 for intracranial aneurysms of which 89 lesions were clipped with the help of neuroendoscope, including 82 anterior circulation aneurysms (in 81 cases) and 7 posterior circulation aneurysms. The diameters of the aneurysms were between 5 and 40 mm with mean value of 12.5 mm. In the Hunt and Hess preoperative classification, 10 cases were grade 0, 37 cases were grade I, 36 cases were grade II, and 5 cases were grade III. **Results:** Postoperative complications were observed in 7 cases (7.9 %), including hemiplegia in 5 cases (1 case with combination of aphasia), pseudomembranous enteritis in 1 case and optic blur in 1 case. We did not observe any neuroendoscope-related complications and had no postoperative deaths. **Conclusions:** The operative efficacy in aneurysm neurosurgery can be improved by the use of the neuroendoscope, especially for minimally invasive microsurgery operation. The neurosurgeon should pay more attention to the training of the endoscope procedure and master more knowledge about endoscopic anatomy.

Key words

Intracranial aneurysms · keyhole approach · neuroendoscope · minimally invasive surgery

Introduction

Although the first endoscopic neurosurgical procedure was performed by Lespinasse in 1910, this technique was widely advocated only in the past decade, mainly due to the improvement of the endoscope and its accessories [1]. Fukushima [2] described three important phases in the application and development of endoscopic devices. The first phase (from 1910 to the 1950s) involved endoscopic diagnosis and coagulation of the choroid plexus to treat hydrocephalus, the second phase (initiated in the early 1970s) involved the application of flexible fiber endoscopes, and the third phase was comprised the recent revival of endoscope-assisted, minimally invasive surgical procedures. The use of the neuroendoscope as an adjunct to the microscope was first described by Apuzzo [3] in 1977. In 1994, Professor Bauer [4] described the endoscopic interventions in minimally invasive endoscopic neurosurgery (MIEN). The term endoscope-assisted microneurosurgery was coined by Hopf and Perneczky [5]. The neuroendoscope was applied to treat not only hydrocephalus and intraventricular disorders but also in almost all the neurosurgical procedures. At present, in some neurosurgery centers the use of endoscope in evacuation of intracranial cyst, transsphenoid pituitary adenoma and epidermoid cyst has become routine procedure. It is also being used to observe the structures around foci in tissues including many types of tumors (such as craniopharyngioma [6] and acoustic neuroma [7]), aneurysms, and others. The combination of the endoscope with ultrasound [8,9], stereotaxy [10] and neuronavigation [11] facilitates modern minimally invasive neurosurgery.

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Minimally invasive surgery is the trend of modern microneurosurgery. Many reports indicate that the use of the endoscope in the microsurgical management of cerebral aneurysms decreased surgical trauma and enhanced the safety and reliability of the surgery. In the previous literature, all the aneurysms were clipped with endoscope-assisted microneurosurgery (EAM) and there are no reports concerning clipping of the aneurysm with endoscope-controlled microneurosurgery (ECM) [15]. Eighty-eight patients with cerebral aneurysms were treated surgically under endoscopic assistance including five lesions under the control of the endoscope in our department. The indication for and controversy around use of the endoscope in aneurysm surgery are discussed.

Original Article

Patients, Materials and Methods

Patient population

Eighty-eight patients with eighty-nine cerebral aneurysms were treated surgically under endoscopic assistance at our department from February 2000 to November 2003. There were 45 women and 43 men, with ages ranging from 20 to 66 years. One of the 88 patients had multiple aneurysms. Eighty-two aneurysms were located in the anterior circulation and seven in the posterior circulation. Aneurysm locations are indicated in Table **1**. The diameter of the aneurysm bodies ranged from 5 to 40 mm (mean 12.5 mm). Of seventy-six patients (86.4 %) who presented with subarachnoid hemorrhage (SAH), 35 were in clinical grade I, 36 were grade II and 5 were grade III. Of twelve patients (13.6 %) who presented without SAH, three patients were incidentally identified by radiological examination. Five patients had headache, 2 had oculomotor nerve palsy and 2 patients had ipsilateral blurred vision. The remaining 3 patients had unruptured aneurysms. 76 patients had a history of hemorrhage, 58 patients once, 15 two times and 3 three times. Three patients were operated on within the first week, 34 patients between days 8 and 14 and 51 patients after 15 days of SAH.

Instrumentation

The rigid lens endoscopes from two manufacturers (Zeppelin, Pullach, and Aesculap, Tuttlingen) with 0°, 30° or 70° lenses were used. The diameters of the rigid scopes were 4.0 mm or 2.7 mm. Illumination was provided by a xenon light source. The endoscope was attached to a camera and the images were viewed on a 19-inch video monitor (Sony Corp., UK).

Operative technique

All the craniotomies were performed in the keyhole approach (Table **2**). The diameter of bone flaps was about 2–3 cm (see Fig. **9**) Before the operation, we inserted a Touhy needle for the lumbar spinal drainage. CSF was gradually withdrawn after the dura was opened.The initial exposure was performed under the microscope. The endoscope was then introduced into the surgical field, with observation through the microscope, and the endoscopic image viewed on the monitor. Simultaneous monitoring of the images was important in avoiding damage to surrounding structures. An initial view of the aneurysm and the surrounding structures and assessment of the regional anatomic features was obtained with the endoscope. Then fifty-six aneurysms were further exposed under the microscope and 28 under the endoscope directly. With the assistance of the endoscope, we could get more information on the relationships of the aneurysm to the parent artery, its branches, perforators, and adjacent cranial nerves. And it can also inspect the areas which were poorly observed through the microscope, including the back wall of the aneurysm. In certain situations, the endoscope could be of significant help in reducing the duration of temporary clipping of the parent artery, by allowing a preview of the vessels to be dissected, such as perforators posterior to the aneurysm sac or the A2 segment of the anterior cerebral artery. The aneurysm neck was then clipped, 84 lesions under microscopic observation and five lesions under the control of the endoscope (Figs. **1** and **2**). After the aneurysms were clipped, the endoscope was used to check the clip position (Figs. **3**–**5**). The inspection included assessments of the completeness of aneurysm clipping, inadvertent inclusion of the parent vessel in the clip, sparing of the perforators, and pressure on surrounding vital structures, such as the cranial nerves. If any of these were encountered, the clips were adjusted as needed. At both the beginning and the end of the clipping procedure, a micro-Doppler system was used to check blood flow at the proximal and distal extremities of feeding arteries. The usefulness of the endoscope is summarized in Table **3**.

Table **1** Locations of the 89 aneurysms

Locations	*No. of aneurysms*
Anterior circulation	82
ICA-ophthalmic segment	4
ICA-supraclinoid segment	3
ICA-bifurcation[#]	13
MCA-horizontal segment	3
MCA-bifurcation	12
ACA-horizontal segment[#]	2
AcomA	11
ACA-A3 segment	3
Posterior circulation	7
Basilar tip	3
PCA	3
VA	1
Total	89

ICA, internal carotid artery; MCA, middle cerebral artery; ACA, anterior cerebral artery; AcomA, anterior communicating artery; PCA, posterior cerebral artery; VA, vertebral artery.
[#]a patient has two aneurysms.

Table **2** The Keyhole approaches to aneurysms of 88 patients

Keyhole approach	*No. of patients*
Pterional approach	81
Longitudinal approach	3
Supraorbital approach	3
Retrosigmoid approach	1

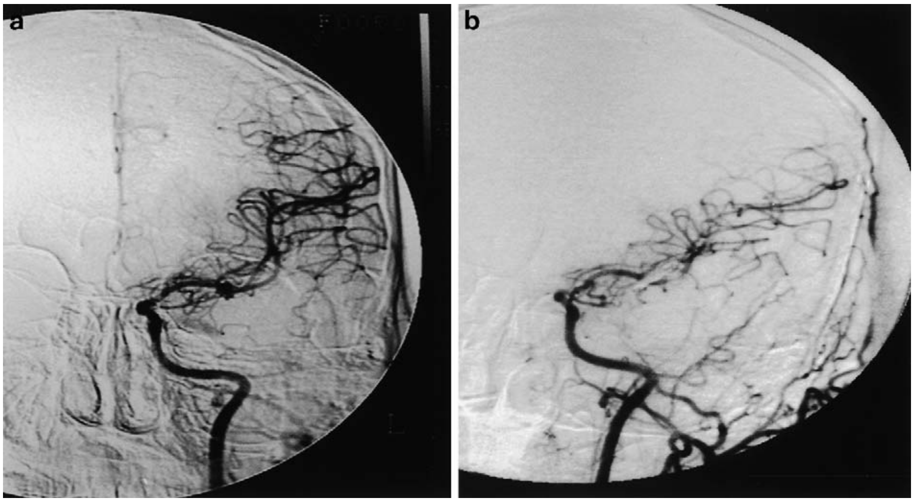

Fig. **1** Preoperative (**a**) and postoperative (**b**) DSAs of an aneurysm in the middle cerebral artery.

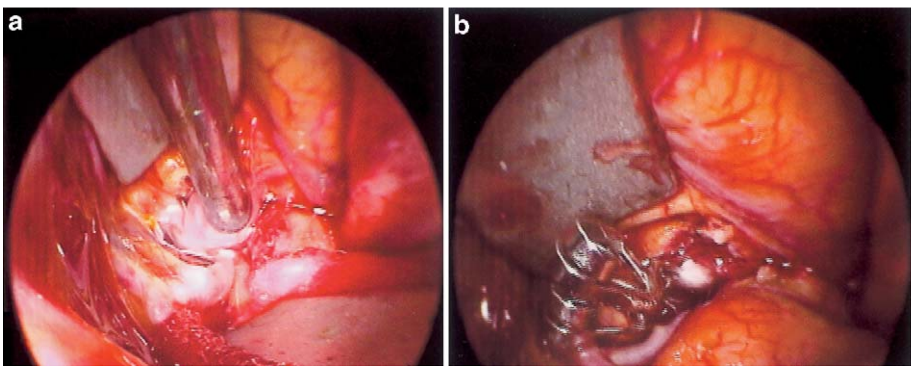

Fig. **2** Visualization of operative fields by the neuroendoscope. **a** The neck of the aneurysm was observed and further dissected under the neuroendoscope. **b** The aneurysm was clipped directly under the neuroendoscope.

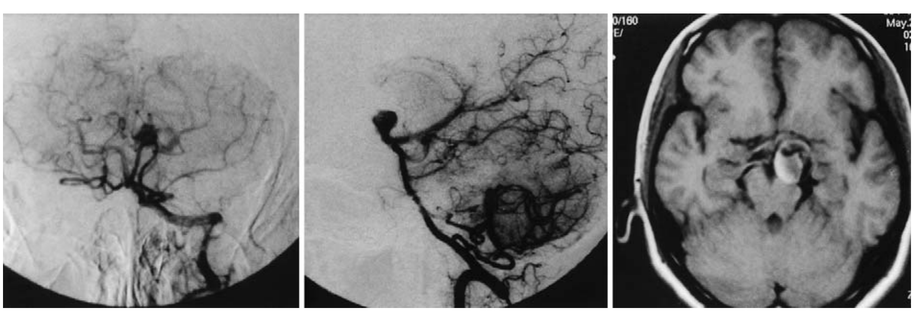

Fig. **3** Preoperative DSA and MR of an aneurysm in the P1 segment of the left posterior cerebral artery.

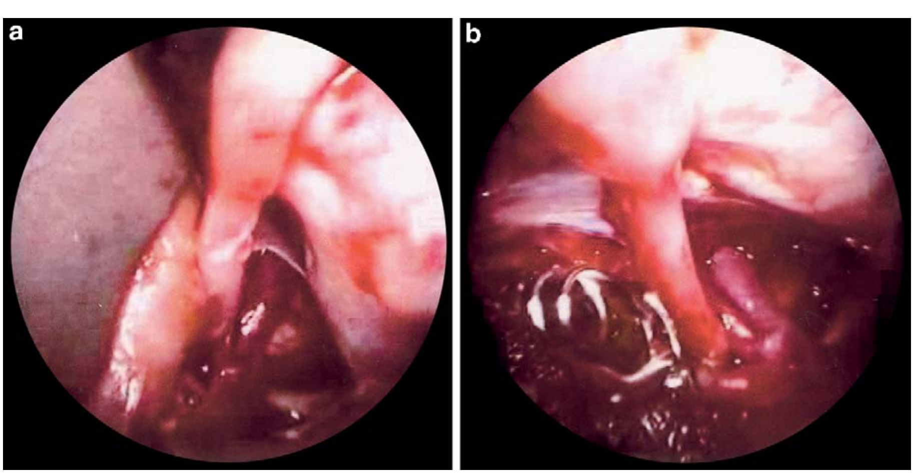

Fig. **4** Visualization of operative fields by the neuroendoscope (**a** before clipping; **b** after clipping).

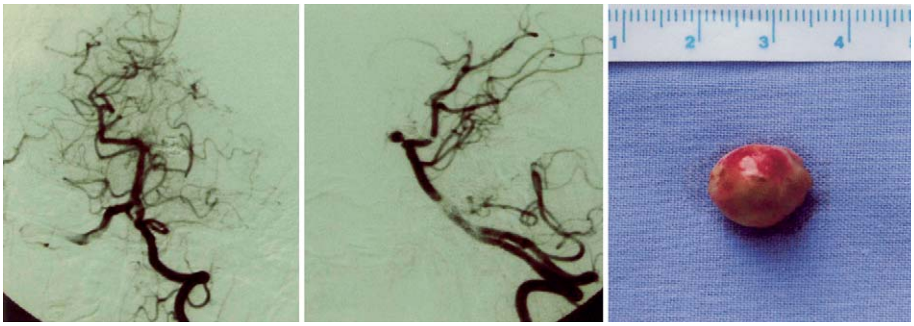

Fig. **5** Postoperative DSA and the removed aneurysms after clipping.

Table **3** The usefulness of the endoscope summarized in 89 aneurysms

Use of endoscope	*No. of aneurysms*
Observation of aneurysm anatomic feature, branch and perforators	56
Observation and further dissection under endoscope	28
Clip the aneurysms under the control of endoscope	5*

*3 ICA aneurysms and 2 AcomA aneurysms.

Results

Eighty-five aneurysms were clipped, of which twenty-four aneurysms were removed after clipping, two were trapped and two were isolated. During the operation four aneurysms ruptured after their exposure. They were clipped by temporary blockade of the feeding artery. In all cases angiography was performed one week after clipping. The results obtained were satisfactory and no aneurysm remained except for the trapped lesions. There were no postoperative deaths. Seven postoperative complications occurred, including five hemiplegia (one combined with aphasia), one optic blur and one pseudomembranal enteritis. No complications were found to be related to the endoscope. We compared the results with those of 82 cases of aneurysms which were clipped under the microscope only and without the help of a neuroendoscope. There were no differences between the two group in age, sex and condition of the aneurysm. The result showed that the ratio of readjusting clip due to intraoperative misclipping and incomplete clipping was significantly decreased in the endoscope-assisted group.

Discussion

Neuroendoscope application in the aneurysm surgery

Even though the application of the neuroendoscope in aneurysm surgery started in the 1970s, it was accepted by the neurosurgeons and widely used in clinics only in the 1990s [1,12–13]. Perneczky and Fries [10,14,15] described three advantages of endoscopes:

- increased light intensity during the approach to objects
- clear depiction of details in close-up positions
- extended viewing angles.

We agree with them and we also think that the endoscope decreases the adverse injury due to an over-dissection of the aneurysm and increases the ratio of clipping completely. In the endoscope-assisted group, the ratio of misclipping and incomplete clipping was obviously lower than that of single microscope group. The occurrence of intraoperative aneurysm ruptures was decreased, which was due to the extra information provided by the neuroendoscope. These features were extremely helpful for surgical procedures to treat deep-seated lesions in narrow spaces (e.g., basilar artery aneurysms) [14–16]. Kalavakoid [17] also thought that the endoscope could reduce the size of the craniotomy by increasing the available viewing angles, without the need for additional craniotomy exposure. Therefore, the neuroendoscope turned out to be very useful in minimally invasive neurosurgery, especially for the aneurysms in deep locations. It can also be used to inspect hidden structures, dissect perforators at the back of the aneurysm, identify important vessel segments without retraction of the aneurysm or arteries and to check for the completeness of clipping, which is important in reducing the morbidity and mortality in the treatment of patients with aneurysms [18].

Hopf and Perneczky categorized endoscopy manipulations into endoscopic neurosurgery (EN), endoscope-assisted microneurosurgery (EAM) and endoscope-controlled microneurosurgery (ECM) [5]. They proposed the terminology based on whether the endoscope was used alone or in conjunction with an operating microscope and on whether the route of surgical manipulations was through or outside the endoscope. In the previous literature there were no reports concerning clipping of aneurysms with ECM. The procedure in aneurysm surgery was mainly EAM, where endoscopy was performed in addition to microsurgical manipulations under the operating microscope during the same operation. Kato [12] summarized endoscopic procedures as follows:

- additional observation of areas which cannot be seen by the microscope during clipping
- observation for perforating arteries running along the aneurysm
- observation of the remaining neck during re-clipping which could not be seen with the first clip in place.

The endoscope acted as an assisting appliance for observation. In our group, 84 aneurysms were clipped with EAM, including 28 aneurysms, which were further dissected in addition to observation. All the aneurysms were clipped to our satisfaction.

The ECM was used for procedures in which microsurgical manipulations were performed mainly or solely under endoscopic control. We clipped five aneurysms with ECM (Figs. **7**–**9**). After initial exposure of aneurysms in routine craniotomy, we first used the neuroendoscope to observe the aneurysm with its anatomic features, branches and perforators of the feeding artery. If it was necessary, we also performed dissections of the surrounding structure. Then, the aneurysm was clipped under the control of endoscope. The endoscope played a more important role in ECM than in EAM, because in ECM there was more work to be done with the help of the endoscope. The advantages of aneurysm clipping with ECM include the following.

- It avoids the frequent transitions between microscope and endoscope, which could decrease the adverse mechanical injuries due to endoscopic procedures. In most cases, when we used the angled endoscope the images viewed on the video monitor was distorted, if the neurosurgeon was not very familiar with the endoscope procedure, brain tissue could easily be damaged by the moving endoscope.
- Using in some special aneurysms such as IC oph aneurysms, we can perform additional observations of areas. In general, the anterior clinoid process needs to be drilled in order to expose the neck of an IC oph aneurysm which cannot be seen directly by the microscope.

Fig. **6** Preoperative DSA of an aneurysm in the posterior communicating artery.

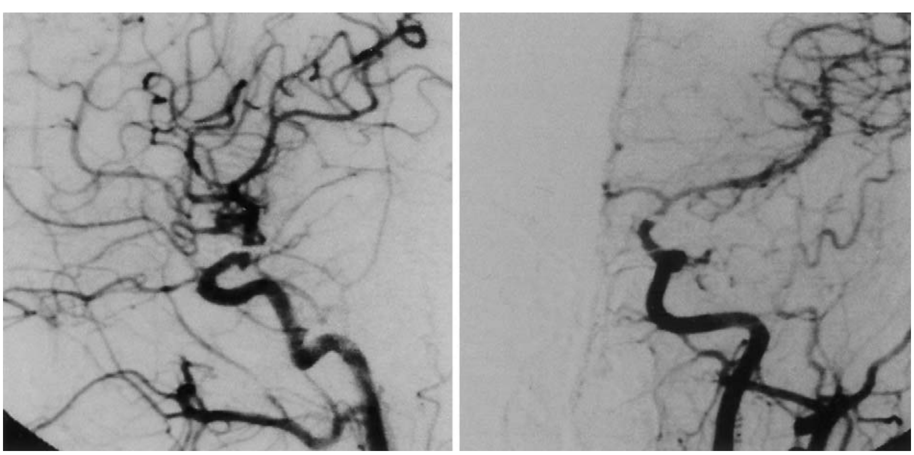

Fig. **7** Postoperative DSA of an aneurysm in the posterior communicating artery.

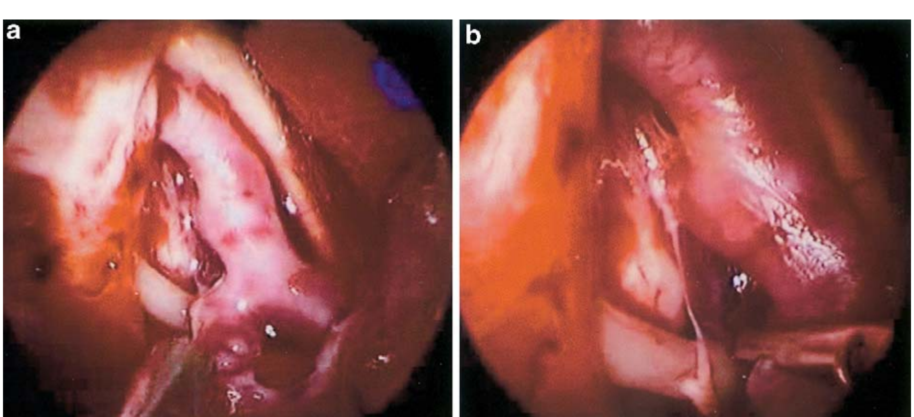

Fig. **8** **a** Before the aneurysm was clipped, we used the endoscope to observe the neck of the aneurysm, the nerves and the perforators. **b** After the aneurysm had been clipped, the endoscope was used to check the clip position and if there was misclipping or incomplete clipping.

Fig. 9 The skin incision (left) and postoperative X-ray (right) showing that the bone flap was very small.

But the endoscope can provide better viewing and inspection of hidden corners, so the removal of the anterior clinoid process could be avoided. As for the viewing area under the endoscope, we can select the best viewing angles and clip the aneurysm which can decrease the ratio of misclipping or incomplete clipping. In this study, one aneurysm arose from the dorsal part of the ICA, and we clipped it with the 30° endoscope. The disadvantages of endoscope include the following.

- The endoscope disturbed surgical procedure because it took up working space.
- Improper manipulations can lead to adverse injury, even aneurysm rupture.

So the neurosurgeon must have extensive experiences not only in vascular surgery but also in endoscopic surgery. He should have good control of the endoscope and must be familiar with the endoscopic anatomy and distorted enlarged image. In addition, we thought that the endoscope should not be too thick, with the external diameter being less than three millimeters. In these minimal microinvasive operations, some other affiliated apparatus such as pneumatic holding arm, adaptable operative beds and pneumatic drill were also needed.

Complications, indications and controversy

Complications

The complications directly related to endoscopic procedures are rare. They include: 1) Adverse injury due to improper use which is the most common. Kalavakoid et al. [17] reported one case, related to the use of the endoscope, which involved intraoperative rupture of an anterior communicating artery aneurysm (1.3 % of 79 aneusysms). Taniguchi et al. [13] encountered one patient with transient oculomotor palsy and one patient with an asymptomatic cerebral contusion in a series of 48 patients with 54 aneurysms. Van Lindert et al. [19] observed accidental rupture of 4 aneurysms in a series of 197 aneurysms. In our group, no rupture was relevant to the endoscopic manipulation but, in two cases, asymptomatic cerebral contusions were caused by improper manipulation of the endoscope. The deep location of aneurysms and the narrow operative space can facilitate the injuries to neighboring structures, especially during the movement of a rigid endoscope at an angle in the operative field. Therefore, the manipulation of the endoscope must be gentle and accurate, and any movement and rotation of a larger extent should be prohibited. The insertion and withdrawal of the endoscope should be done under the monitoring with the microscope. 2) Infection: Although in our group no infection occurred and there are no literature about it, in theory, the endoscope is prone to be contaminated during the transition between endoscope and microscope. Strict aseptic manipulations are of great importance. Rinsing the operative field with saline supplemented with antibiotics could also prevent infections.

Indications

Because a clear operative field and adequate working space are the prerequisites for endoscopic surgery, Taniguchi [13] thought that good indications for endoscopy as an aid to microsurgery were non-ruptured aneurysms or associated aneurysms after SAH absorption. Treatment of ruptured aneurysms with the endoscope as well as mild SAH (Hunt and Hess grades I – II) is also feasible. However, the endoscope is unsuitable for the treatment of ruptured aneurysms associated with SAH grade III or higher. We agree with Taniguchi. Whether the use of the endoscope in the operations is suitable should be determined by the intracranial pressure. If during the operation the brain tissue is obviously swollen and the ICP high, which cannot be decreased by release of cerebrospinal fluid, the endoscope is not recommended. In addition, we also think that the use of endoscope is more valuable for complicated and deep aneurysms.

Controversy

Most neurosurgeons agree that the endoscope is useful in aneurysm surgery, but some dissent. In the comment of Kalavakonda's report [17], Bernard did not recommend the use of an endoscope in every case, because in some cases the endoscope does not provide any useful information. The endoscope should be used only in selected cases after the surgeon first takes a look with the microscope and determines that an endoscope adjunct is needed. Taniguchi [14] also advised that the surgeon should evaluate both the risks and benefits of use of the endoscope and be fully prepared for the risks and inconveniences associated with the procedures.

Conclusion

The operative efficacy in aneurysm neurosurgery is improved by the use of the neuroendoscope, especially for minimally invasive microsurgical operations. The neurosurgeon should pay more attention to training in the endoscope procesure and master more knowledge about endoscopic anatomy.

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Microvascular Decompression for Trigeminal Neuralgia: A Long-Term Follow-Up Study

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Abstract

In this report, we present our experience with microvascular decompression (MVD) as treatment for trigeminal neuralgia (TN) and discuss factors related to recurrence after this procedure. Between 1986 and 2004, 90 patients underwent MVD for treatment of idiopathic TN at the Marmara University Department of Neurosurgery and Marmara University Neurological Sciences Institute. Individuals with atypical and secondary forms of TN were excluded from the study. The patient characteristics, work-up findings, observations during surgery, and results of MVD for the 90 cases are reviewed. In 87 (97 %) of the patients, exposure of the pontocerebellar angle revealed a vascular structure compressing the trigeminal nerve. In the patients with vascular compression, the problem vessel was an artery in 80 (92 %) cases and a vein in 7 (8 %) cases. In 77 cases, all symptoms were completely resolved by the operation. Ten patients experienced significant partial relief, and the intensity of the residual pain in these cases was not severe enough to require medication. Three patients experienced no improvement after MVD. There was no mortality associated with MVD in the 90 cases. The findings for our series of 90 patients with TN who underwent MVD indicate that this operation is an effective and reliable treatment for this condition. We recommend MVD as the first-line surgical approach for patients with TN who do not respond to medical management.

Key words

Microvascular decompression · trigeminal nerve · trigeminal neuralgia

Introduction

Trigeminal neuralgia (TN) is a syndrome characterized by paroxysmal facial pain. The International Association of Study for Pain (IASP) describes this condition as a unilateral disorder in which the patient suffers brief electric shock-like pains that are abrupt in onset and termination, and are limited to the distribution of one or more divisions of cranial nerve V [1]. It is widely suspected that the cause of what is currently known as idiopathic TN is vascular compression of this nerve [2–5]. The first-line treatment for TN is still antiepileptic medication [6]. However Katusic and co-workers [7] have reported that, in almost 50 % of cases, medical treatment is only effective for about 2 years. When medical therapy does not provide relief, there are various surgical options for treating this painful state. Today, percutaneous methods, radiosurgery and microvascular decompression (MVD) are used to address this type of pain [8–13].

The idea that microvascular compression causes TN is based on a 1934 report by Dandy [14], who explored the posterior cranial fossae of patients with TN. Gardner and Miklos [15] were the first to introduce vascular decompression as a method for treating this condition. Later, Jannetta [4] popularized the technique that involves use of an operating microscope. Although MVD fails in some cases, this technique is currently considered the most effective and longest-lasting solution for TN.

In this report, we present our experience with MVD as treatment for TN and discuss factors related to recurrence after this procedure.

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Patients and Methods

Between 1986 and 2004, 90 patients underwent MVD for treatment of idiopathic TN at the Marmara University Department of Neurosurgery and Marmara University Neurological Sciences Institute. Individuals with atypical and secondary forms of TN were excluded from the study. The patient characteristics, work-up findings, observations during surgery, and results of MVD for the 90 cases are reviewed.

The study group comprised 48 females and 42 males who ranged in age from 34 to 72 years (median: 59 years). The mean duration of symptoms was 7 years (range: 7 months to 20 years), and 56 % of the patients had undergone previous surgery (other than MVD) for TN. The types of interventions that were performed prior to MVD are summarized in Table **1**. The V2-V3 dermatome was the most common region of pain distribution (57 patients), followed by V3 (21 patients), V2 alone (10 patients), and V1 (2 patients). The pain was on the right side in 50 cases (56 %) and on the left in 40 (44 %). Prior to MVD, all patients were evaluated with computed tomography and 70 (78 %) underwent magnetic resonance imaging (MRI) as well (details below).

All patients were operated in the lateral decubitus position. In each case, a retromastoid craniectomy was performed and the pontocerebellar area was explored. If a vessel was compressing or contacting cranial nerve V, decompression was carried out. The problem vascular structure was repositioned using a piece of muscle in the first nine cases, and using a hemostatic sponge (Spongostan) in all other cases. Patients were re-checked at 6 weeks, 3 months, 6 months and 1 year postoperatively, and then yearly thereafter.

Results

Neuroradiological findings

In 47 (52 %) of the 90 patients, preoperative neuroradiological studies (computed tomography and/or MRI) revealed a vascular structure compressing and/or in contact with the trigeminal root. Prior to 1999, when a patient with TN underwent MRI at our centers, only routine sequences were obtained. In 1999, we added axial and oblique sagittal gradient-echo MRI and time-of-flight magnetic resonance angiography sequences to the diagnostic panel for this patient group. These additional studies increased our rate of accurate detection of vascular compression from 28 % to 56 %.

Operative findings

In 87 (97 %) of the patients, exposure of the pontocerebellar angle revealed a vascular structure compressing the trigeminal nerve. In the other 3 cases, arachnoid bands and adhesions were compressing the nerve.

In the patients with vascular compression, the problem vessel was an artery in 80 (92 %) cases and a vein in 7 (8 %) cases. The compressing arteries were of three types: the superior cerebellar artery or one of its branches (67 patients), the anterior inferior cerebellar artery (10 patients), or the basilar artery (3 patients). In all seven cases with compression by a vein, the offending vessel was the superior petrosal vein. In the patients with arterial compression, the site of compression was the proximal third of the nerve in 59 cases (74 %), the middle third in 17 cases (21 %), and the distal third in 4 cases (5 %). In the cases with venous compression, all the affected sites were in the distal third of the nerve length; none were at the pons-trigeminal nerve junction.

Table **1** Procedures that had been performed prior to microvascular decompression

Procedure	*No. of Patients*
RF thermocoagulation	34
Glycerol injection	9
Peripheral alcohol injection	6
Acupuncture	2

Clinical findings early after MVD

In 77 cases, all symptoms were completely resolved by the operation. Ten patients experienced significant partial relief, and the intensity of the residual pain in these cases was not severe enough to require medication. Three patients experienced no improvement after MVD.

One of the 3 individuals who did not respond to MVD had been previously treated with glycerol rhizolysis, and another had been treated with radiofrequency thermocoagulation. The compressing vascular structure was a vein in one of these two cases, and there was no vascular compression in the other case. In the third patient who showed no response, MVD was the primary surgical therapy and exploration revealed the superior cerebellar artery compressing the nerve. Regarding further treatment for these individuals, the patient who had already undergone glycerol rhizolysis was treated with gamma-knife (Elekta, Atlanta, USA) radiosurgery, and the other two were treated with glycerol rhizolysis. Some pain relief was achieved in all three cases.

There was no mortality associated with MVD in the 90 cases. Only one patient had a permanent complication: cerebellar infarction due to coagulation of the petrosal vein. A few individuals had temporary complications, namely, trochlear nerve paresis (1 case), facial numbness (1 case), and cerebrospinal fluid fistula (1 case).

Long-term outcomes

The duration of follow-up ranged from 6 months to 18 years (median: 5 years). At the time of the study, 25 patients had more than 10 years of follow-up data. Three of these individuals had developed TN recurrence at 1 to 4 years after MVD.

Fifty-five (63 %) of the 87 patients who showed total or partial response to MVD had been followed for more than 5 years. Forty-seven (85 %) of these 55 patients were pain-free at the time of the study, and the other 8 (15 %) had developed recurrent pain at some stage after MVD (time to recurrence: 6 months to 8 years). In these 8 cases of TN recurrence, the compressing structure was an artery in 4 cases, a vein in 3 cases, and a non-vascular structure in 1 case. In the 4 arterial-compression cases, the site of compression was the middle third of the nerve in 1 case, and the distal third in the other 3 cases. In all 3 of the vein-compression cases, the site affected was in the proximal third of the nerve.

Six of the 8 patients with recurrence were treated with percutaneous methods when the pain recurred. Two of these 6 were pain-free at the time of writing (45 and 66 months after treatment, respectively). The other 4 are still taking medication for the pain. In these 4 cases, TN recurred at 3 years (1 patient), 5 years (1 patient) and 10 years (2 patients) after MVD.

The other 2 of the 8 patients with recurrence were reoperated (MVD) at 5 and 8 years after initial MVD, respectively. No new vascular compression was found in either case. The only abnormalities observed were fibrosis and thickening of the arachnoid membrane in the region of the trigeminal root. The second round of surgery resulted in complete cessation of pain for both patients.

Discussion

Currently, it is generally accepted that TN results from compression of cranial nerve V. In 1934, based on observations in 215 patients with TN, Dandy reported a 45 % incidence of trigeminal nerve compression by a vascular structure [14]. Dandy documented this figure at a time when the quality of surgical lighting was relatively poor and operative microscopes were not in use. Studies that followed investigated the anatomic features of this region, with special focus on compression of the trigeminal nerve by vessels. The researchers sought to assess what is normal for this region in healthy subjects; in other words, to determine whether vascular compression of cranial nerve V is a normal finding or a pathological one. In the 1940 s, Sunderland [16] found that only 7 of 210 autopsies of normal subjects showed vessels in contact with the trigeminal nerve. A later autopsy study of 56 sides of heads by Jannetta [4] in 1967 revealed no vascular compression of the trigeminal nerve in any of the specimens. In other anatomical work, Hamlyn and King [17] infused 50 normal cadavers with normal saline to simulate physiological pressure in the vessels, and also dissected the cerebellopontine angle in a standard operative setting. Upon infusing, they found that the rate of simple vessel contact with the trigeminal nerve rose from 14 % to 40 %. Based on the findings, they concluded that grooving or distortion of the trigeminal nerve by a vessel was not a normal anatomic variant, but something specific to TN. Hardy and Rhoton [18] reported contact between a vessel and the trigeminal nerve in 60 % of 50 sides of normal cadavers they dissected. However, in general, the abovementioned studies indicate that vascular compression (that is, actual grooving or distortion) of cranial nerve V is not common in the general population.

There is no specific diagnostic test for TN. Careful history taking and thorough clinical examination are essential. Neuroradiological tests can assist with diagnosis but are not definitive. Before the advent of MRI, it was difficult to diagnose vascular compression of cranial nerve V preoperatively [19]. The resolution of computed tomography is not sufficient for detecting small vessels near the trigeminal nerve. In some cases, even conventional MRI with contrast-enhanced T_1- and T_2-weighted sequences does not demonstrate vascular compression of this nerve. Axial gradient-echo MRI with thin slices and oblique sagittal gradient-echo MRI are excellent for demonstrating vessels compressing cranial nerve V [19, 20]. As noted, since 1999, we have been obtaining these types of MRI sequences for all patients with TN. We find these images provide much better visualization of the trigeminal root entry zone (REZ; the junction between nerve and pons) than ordinary MRI sequences. Recently, Meaney et al. [21] introduced magnetic resonance angiography as another method for evaluating patients with TN. According to these authors, this modality provides ideal visualization of vascular compression of the nerve. Unless surgery is contraindicated for some reason, we recommend MVD for all patients with TN, even if preoperative investigations do not reveal vascular contact with the nerve. Detection of compression on MRI often helps persuade the patient to accept MVD.

There is no agreement about which site or sites of compression along the trigeminal root produce TN. McLaughlin et al. [11] have stated that a vessel compressing anywhere along the length of the nerve can cause this pain, and that the aim of surgery is to find the offending structure. The same authors have stressed the importance of inspecting the nerve from the pons to its site of entry into Meckel's cave. Sindou and co-workers [22] studied a series of 560 patients with TN and found vascular contact or compression in the middle third of the nerve in 304 cases (54.3 %), at the site of entry into Meckel's cave in 55 cases (9.8 %), and at the REZ (which the authors defined as the proximal 7 mm of the nerve) in 293 cases (52.3 %). As noted, we define the REZ of the trigeminal nerve as the pons-nerve junction. In our series of 90 cases, we found that 59 of the 87 patients with vascular compression (68 %) had vascular compression near this site. Some authors reported that it has been believed that TN is caused by vascular compression of the central myelin-peripheral myelin transitional zone (TZ) of the trigeminal nerve (also known as the Obersteiner-Redlich line), but there is confusion as to the exact nature and location of this zone [23]. There are relatively few data available, but some anatomic studies have shown that the TZ is located 2 – 3 mm from the pons [16]. It is also speculated that the TZ location may vary greatly from person to person. To date, there has been very little research on the location of the TZ in human trigeminal nerves, and it is important to remember that none of the speculation in the literature is based on actual findings from systematic anatomic studies on humans.

Complications

The prospect of MVD can be intimidating for patients because the procedure requires general anesthesia and it is a form of "brain surgery"; however, the results are very encouraging. Reports of large series have documented rates of immediate pain relief in the 90 to 97 % range [2, 11, 22]. Postoperative dysesthesia and anesthesia dolorosa are almost never seen with this treatment method, and serious complications of craniotomy are relatively rare. Barker et al. [2] reviewed 1336 MVD operations and reported complications of transient facial palsy, permanent hearing loss, facial numbness and cerebrospinal fluid fistula, among others. In our 90 cases treated with MVD, there were 3 temporary complications and 1 case of permanent ataxia. There was no mortality associated with MVD in our series. Some authors have shown that repeat MVD carries higher risk of complications [24]. The two patients in our series who were reoperated had no complications.

TN recurrence after MVD

According to reports on large series of MVD-treated TN patients with 10 years of follow-up, rates of recurrence after this procedure are in the 15 to 25 % range. Pollack and colleagues [25] stated that MVD has a "half-life" of 15 years. Barker et al. [2] claim that the recurrence rate drops below 2 % at 5 years after MVD, and below 1 % at 10 years. The literature identifies several factors associated with TN recurrence in patients who have undergone MVD**:** female sex, preoperative duration of symptoms longer than 8 years, lack of immediate postoperative pain relief, previous percutaneous interventions, and nerve compression by a vein rather than an artery. Tyler-Kabara et al. [26] have stated that, to date, detection of trigger points is the only known predictor of good long-term outcome in TN patients treated with MVD.

In our series, we found a 15 % rate of recurrence (8 patients) in patients with complete or partial response to MVD who had been followed for more than 5 years. The majority of this subgroup (6 patients) was female. The compressing vessel was a vein in 3 of the 8 recurrence cases. Six (75 %) of the 8 patients had undergone a different surgical intervention prior to MVD. None of the other factors mentioned above seemed to be related to recurrence in our cases. Most of the recurrences (6 of 8 total) occurred in the first 5 years after MVD. Based on our findings and those of previous authors, we conclude that patients who are pain-free after 5 years of follow-up are at relatively low risk for recurrence.

It is also important to consider results for cases where MVD initially fails. The literature contains some information about results of repeat MVD. Cho and colleagues [24] investigated outcomes for 31 such operations they performed. All the patients had exhibited vascular compression of the trigeminal nerve in the initial MVD procedure. At the second surgery, the authors found that the same vessel had shifted to re-compress the nerve in only 35 % of the cases. Barker and co-workers [2] examined 132 cases of failed MVD and found that, at the time of repeat surgery, veins and small arteries were the types of vessels compressing the nerve in most patients. The same researchers also noted a lower success rate with second MVD procedures than with first MVD procedures. Only 42 % of their patients who underwent repeat MVD had excellent results after 10 years of follow-up. Various studies have shown significantly higher complication rates for repeat MVD operations than for initial surgeries. Considering this, some authors recommend percutaneous methods for patients with TN recurrence after MVD.

Surgical technique

As part of the MVD procedure, it is widely recommended that the vessel be repositioned using some type of cushioning tissue. In the first nine cases in our series, we used muscle for this purpose. Thereafter, we used a hemostatic sponge to move the vessel away from the trigeminal nerve. According to the literature on MVD, Teflon felt, a type of non-absorbable synthetic material, is the material most widely used to reposition the vessel. Some authors have reported pain recurrence caused by granuloma formation around the Teflon. Spongostan is an absorbable hemostatic material that disappears within a few weeks of the operation. Some claim that the rapid absorption of Spongostan may allow the problem vessel to shift back and compress the nerve again. In our series, Spongostan was used in 78 of the 90 MVD procedures**,** and 75 of these patients showed complete or partial response to MVD. The recurrence rate for this grouping was 9 %, which is very similar to rates that have been reported for series with Teflon use (range: 3 – 16 %). Spongostan has a mass effect, and we believe that repositioning the vessel with this material causes sufficient fibrosis of the arachnoid membrane around the vessel to keep it in the desired permanent new position. The findings in our 2 patients with recurrent pain who were reoperated support this. In both cases (second MVD at 5 and 8 years after initial operation, respectively), we found that the Spongostan was completely absorbed and the vessels were still distant from the original site of compression. Interestingly, Sindou et al. [22] assessed the results of MVD with no implanted material in 60 patients with TN, and found that this group had slightly better outcomes than a group of patients who received Teflon implants. The recurrence rates for these two groups at 1 year were 4.7 % and 10 %, respectively. It seems that the permanent mass effect of Teflon might cause recurrence in some patients.

In recent decades, microsurgical techniques and peri- and postoperative care have improved considerably, and this has led to lower morbidity and mortality rates. The findings for our series of 90 patients with TN who underwent MVD indicate that this operation is an effective and reliable treatment for this condition. We recommend MVD as the first-line surgical approach for patients with TN who do not respond to medical management.

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Spinal Cord Gliomas and Hydrocephalus: Utility of Neuroendoscopy

Abstract

Objective: The aim of this study is to report on the role of neuroendoscopy during the management of hydrocephalus that led to the diagnosis of intracranial tumoral dissemination and the subsequent finding of a spinal cord glioma. **Methods and Results:** We present two children each with an intramedullary astrocytoma that presented initially with hydrocephalus without spinal cord symptoms. In both cases leptomeningeal gliomatous dissemination was asserted during routine endoscopy for the management of hydrocephalus. The diagnosis of a cervical and a lower thoracic intramedullary tumor was made soon after on magnetic resonance imaging. **Conclusions:** Spinal cord MRI with contrast should be considered initially in selected cases of hydrocephalus without evident diagnosis. The intraoperative diagnosis of gliomatous dissemination and secondary hydrocephalus due to unrecognized spinal cord gliomas was possible, in our experience, with the routine use of the neuroendoscope.

Key words

Spinal cord glioma · tumoral dissemination · neuroendoscopy · hydrocephalus · cerebrospinal fluid

Introduction

Intramedullary tumors of the spinal cord in childhood are usually of low grade [1,2] and are frequently found in the cervical [3,4] and cervicothoracic regions [2,5,6]. They present with symptoms and signs of spinal cord tumor [1,2,4,6–11]. In rare cases intraspinal tumors can manifest at first with hydrocephalus without a spinal cord syndrome [10–13]. Mechanisms of hydrocephalus proposed include altered cerebrospinal fluid absorption from increased cerebrospinal fluid protein [4,14], associated hyperproteinorrhachia and arachnoiditis, with basal blockage of the cerebrospinal fluid pathways [15,16]. The hydrocephalus seems to be unrelated to the level, location or the pathology of the spinal lesion [4]. Metastatic seeding of an intramedullary astrocytoma in children has been reported on a few occasions [2,12,13]. The efficacy of neuroendoscopy in cases of obstructive hydrocephalus is widely recognized and its applications include also performing biopsies in tumoral [17–19] and non-tumoral lesions [20,21], in the supratentorial [17,22] and infratentorial [20,21,23] compartment. However, the role of endoscopic procedures in cases of communicating hydrocephalus is controversial [17,19,22].

We report two cases of low-grade diffuse infiltrating intramedullary astrocytoma that manifested with clinical hydrocephalus and cranial tumor dissemination to the third and fourth ventricle

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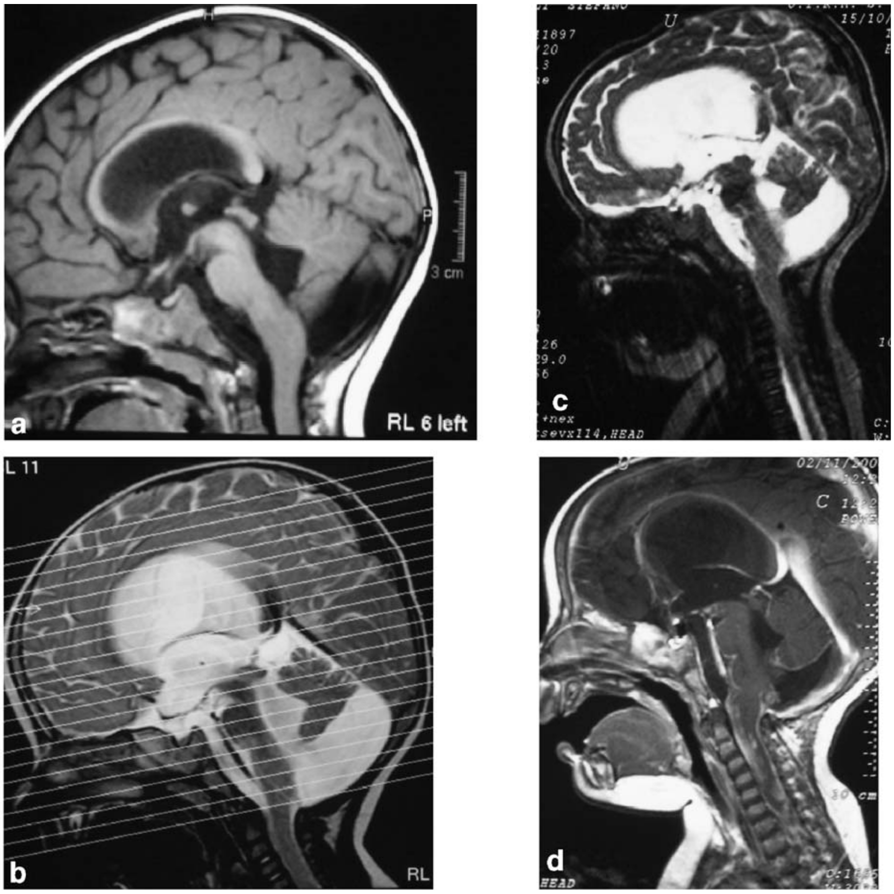

Fig. 1 **a** Cerebral sagittal T_1-weighted MR image showing a 3-cm, well-delineated cyst in the posterior fossa and hydrocephalus. **b** Cerebral sagittal T_2-weighted MR preoperative endoscopic image showing progression of the hydrocephalus. **c** Cerebral and cervical sagittal T_2-weighted MR image showing the cervical spinal swelling cord up to the C5 suggesting the diagnosis of an intraspinal tumor. **d** Sagittal T_1-weighted MR images with gadolinium injection performed after tumor operation. Note the significant progression of ventricular and meningeal neoplastic dissemination and lack of control of hydrocephalus.

without symptoms of spinal cord tumor. Direct visualization of tumoral dissemination was achieved during endoscopy for treatment of the hydrocephalus. We review the literature and discuss the role of neuroendoscopy for not only the treatment, but also for the initial diagnosis in cases of unrecognized secondary hydrocephalus.

Case Reports

Case 1

A 7-month-old boy with an uncomplicated prenatal history was admitted to our department with projectile vomiting, irritability and bulging fontanelle. On admission, his parents reported a progressive change of mood and behavior during the last 2 months. A cerebral magnetic resonance imaging (MRI), showed a communicating ventriculomegaly, wide cerebral subarachnoid spaces, a partial agenesis of the vermis with a posterior fossa cyst in apparent communication with the fourth ventricle, and no signs of transependymal reabsortion or brain edema (Figs. **1a** and **b**). A cine-flow MRI demonstrated enlarged ventricles and no CSF flow on the posterior fossa. An attempted third ventriculostomy disclosed a non-clear CSF hence an external ventricular drain (EVD) was inserted. The amount of CSF drainage was 120 mL in 24 hours. CSF examination demonstrated hypercellularity, elevated protein but no atypical cells. The EVD was the converted to a ventriculoperitoneal (VP) shunt. After that, the patient presented with normotensive fontanelle and evident motor weakness of the upper extremities and decreased spontaneous movements in the lower extremities. A new MRI without contrast showed no change in the ventricular and subdural spaces, but an enlarged non-communicating posterior fossa cyst in close proximity with an upper hypointense cervical spinal cord (Fig. **1c**). In an attempt to communicate the cyst, the subsequent neuroendoscopic approach to the posterior fossa revealed a cyst with turbid fluid content and a soft edematous leptomeningeal tissue at the level of the bulbomedullary junction. Endoscopic biopsy of the suspicious lesion and intraoperative smear disclosed a possible gliomatous origin. The endoscopic burr hole was changed to a limited inferior suboccipital craniectomy. A soft, suckable and heterogeneous tumor was found and partially resected under the microscope using an ultrasonic aspirator. This was then confirmed by a cranial and spinal MR image with contrast showing a heterogeneously enhanced tumor in the cervical spinal cord down to the C6 level along with diffuse subependymal dissemination from the anterior pons down to the conus medullaris (Fig. **1d**). The postoperative course was complicated with respiratory insufficiency and a tracheostomy was made.

Microscopic examination showed a glial tumor with mucinous background with microcysts. Solid areas, mainly perivascular, showed fibrillary and elongated cells. GFAP was strongly positive. MIB-1 was focally elevated up to 8 %. In some areas of the neoplasia, an ependymal lining was still present covering the bulging tumor. Based on these features, the lesion was considered to be a low-grade pylocytic astrocytoma with diffuse meningeal dissemination (see Fig. **3a**).

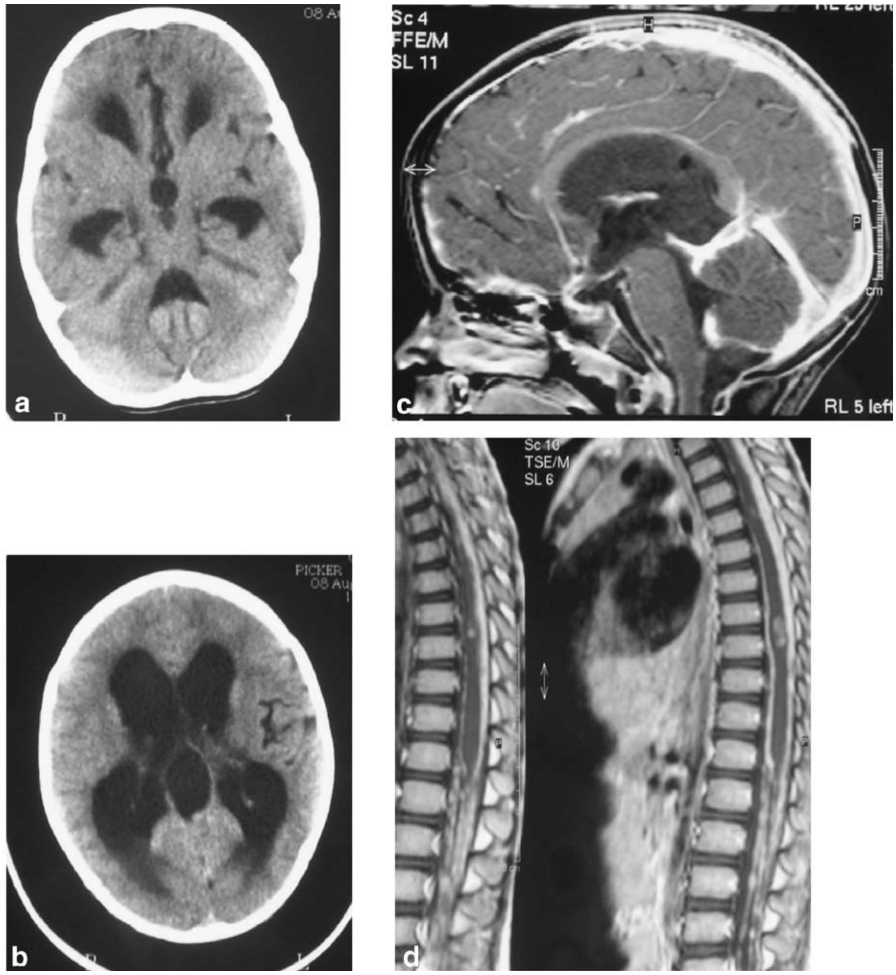

Fig. 2 **a** and **b** Cerebral CT images at that time of the first clinical manifestation in June 2004, no intracranial lesion was evident, only a communicating hydrocephalus. **c** Cranial metastatic spread at the time of the intramedullary tumor progression along the ventricles as well as frontobasally is depicted in sagittal images. **d** The initial intramedullary tumor at T8/9 is shown on sagittal T_1-weighted contrast-enhanced MR images from July 2004.

The patient's postoperative condition was unchanged. A protocol of chemotherapy was discussed with the parents. Just before it started, the child presented with rapidly progressive respiratory and neurological deterioration, sepsis, multi-organ failure and died. The parents refused an autopsy.

Case 2

This 2-year-old boy presented with a two-month history of irritability, abdominal pain, inconsistent divergent strabismus and onset of projectile vomiting during the last two days before admission to our division. The neurological examination revealed also a decreased level of consciousness, evident macrocephaly (CC 54 cm, above 2 SD) and four-limbic ataxia. A non-contrast head CT disclosed a wide hydrocephalus (Figs. **2a** and **b**). He had no relevant medical history except a long labor delivery. A third ventriculostomy was performed on an emergency basis. During the procedure, CSF was clear but the floor of the third ventricle was found to be covered with subependymal excrescences. An endoscopic biopsy of the lesions disclosed a gliomatous origin. Fenestration of the floor did not control the hydrocephalus and, two days later, a VPS was inserted.

Brain-spinal contrast MRI revealed an intramedullary focal lesion at the thoracic 8 and 9 segment with diffuse leptomenigeal spinal and basal cerebral enhancement (Figs. **2c** and **d**). This lesion was approached through a T8 laminotomy. A soft and heterogeneous tumor was found and a biopsy was performed under the operative microscope.

Leptomenigeal biopsies consisted of tiny laminar fragments. Microscopic analysis disclosed collagen depositions with small and ill-defined nests of cells. Immunohistochemistry was positive for GFAP and negative for EMA and vimentin, confirming the glial origin of the infiltrating cells. MIB-1 staining was limited to the nests of infiltrating cells. A labelling index was not calculated due to the limited extension of the present neoplastic nests. Ultrastructural analysis on fragments fixed for EM revealed collagen depositions, fibroblastic elements, many necrotic cells and sporadic elements with glial differentiation. The final diagnosis was non-anaplastic astrocytoma with diffuse meningeal dissemination (Fig. **3b**).

At the time of writing, the patient is still alive 18 months after the diagnosis. He has remained on chemotherapy protocol treatment for the last 3 months with well-preserved neurological functions except for his slight paraparesis.

Discussion

We present two patients with hydrocephalus related to a spinal cord glioma during the clinical management of which a neu-

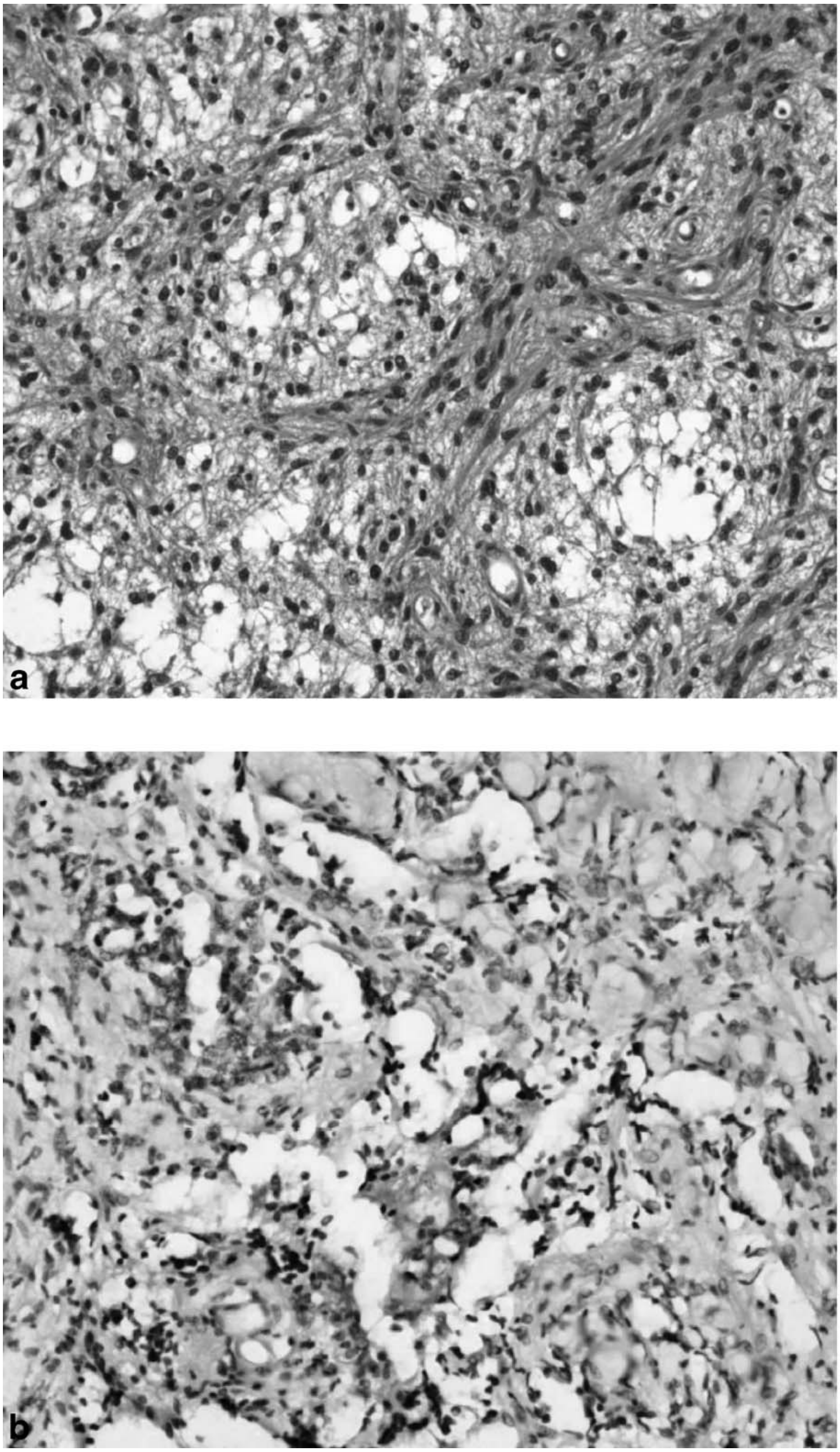

Fig. 3 Pathology: **a** H&E staining, **b** GFAP staining.

roendoscopic examination was conducted. The points made in our report are:

– Spinal cord tumors may rarely present only with symptoms of hydrocephalus.
– Metastatic seeding of a spinal cord tumor to the cranial CSF space may rarely be seen at presentation.
– In those cases of non-obstructive hydrocephalus where the etiological diagnosis is obscure, endoscopic inspection at the time of third ventriculostomy or even prior to the insertion of ventriculoperitoneal shunt, may yield diagnostic findings.

Neurological findings

Pain is the most common presenting symptom in patients with intramedullary tumors; with weakness, gait deterioration, torticollis also being frequently reported [8,10]. The cervical spine is the region of the spine most affected [1,2,3,5]. The apparent early absence of spinal cord symptoms in children harboring intramedullary tumors is explained by lack of specificity of clinical and neurological findings [4,10]. As well, in infants, the neurological examination is usually deferred until the appearance of a blunt neurological deficit. One of our patients was an infant and other a child, but both cases initially manifested only with hydrocephalus without gross spinal cord symptoms. Although papilledema and raised intracranial symptoms have been reported in about 12.5 % of cases of spinal cord tumors [13], it is rare to find them presenting only with symptoms of raised intracranial pressure [7]. Our cases presented initially with hydrocephalus, and the gross symptoms of the spinal cord developed in one case thereafter.

Spinal tumors and hydrocephalus

Reported spinal tumors with hydrocephalus are intramedullary, intradural and extradural neoplasms [6]. The most frequent association is with low-grade intramedullary astrocytoma [1, 2, 8], but other reported spinal neoplasms included anaplastic astrocytomas [13], gangliogliomas [11], neurinomas [12], malignant schwanomas [15], ependymomas [8, 12], granulomas [12]. Rifkinson et al. [2], reported a series of 25 (15 %) patients, mostly children that developed symptomatic hydrocephalus, from an original series of 171 spinal tumors; of them, thirteen patients had malignant tumors, complicated by increased intracranial pressure with hydrocephalus; of the remaining, 12 developed symptomatic hydrocephalus, after diagnosis of benign spinal tumors. In the same report [2], the authors noted that the presence of hydrocephalus in patients with malignant intramedullary astrocytomas was associated with a shorter survival rate than in those patients with high-grade tumors but without hydrocephalus, seemingly because of rapid tumor progression; while the associated ventriculomegaly with benign spinal cord gliomas did not influence the long-term prognosis. In our cases, at the last follow-up, one child is under a chemotherapy protocol and neurologically stable, while the infant died after respiratory problems due to a rapid progressive tumor.

As seen from previous reports [1, 2, 4], hydrocephalus occurs with greater frequency in children than in adult patients and often requires a shunt. Theories that have been proposed to explain the association of spinal tumors with hydrocephalus, include that of Bamford and Labadie [14] which proposed that the abnormal presence of fibrinogen and its transformation into fibrin at the level of the basal cisterns and Pacchioni's granulation that may alter CSF hydrodynamics. As well, Maurice-Williams and Lucey [15] suggested that the resulting leptomeningeal fibrosis might predispose the secondary implantation of neoplastic elements in the subarachnoid spaces of the brain. Both mechanisms are sufficient to induce communicating hydrocephalus and also explain the cranial dissemination and seeding of tumoral cells. Other proposed hypotheses include an increase in CSF viscosity due to elevated fluid protein content [16]; obliteration of the cisterna magna because of a cranial extension of the tumor [6]; and obstruction of the spinal subarachnoid pathways of CSF resorption [1, 4].

In our cases, cranial tumoral seeding was directly visualized during neuroendoscopy.

Cranial dissemination of spinal cord tumors

Spinal dissemination of primary intracranial tumors is frequent and through the CSF pathways, a similar mechanism of tumor cell dissemination may add to the inverse situation of cranial seeding of a primary spinal neoplasm [1]. Cranial seeding occurs most frequently in association with a tumor recurrence or malignant transformation [13]. Astrocytomas are infiltrating neoplasms and gross total resection is occasionally possible in the pediatric population. The role of radical resection of low-grade fibrillary astrocytomas of the spinal cord in children has not been definitively demonstrated in the literature [1–5, 8, 13]. The outcome for low-grade astrocytomas is better in children than in adults [1, 2]. Malignant tumors have dreary outcomes and surgery in these patients serves only to provide a diagnosis [8, 13]. Our cases were defined as diffuse infiltrating intramedullary low-grade astrocytomas. The prognosis in cases of primary diffuse infiltrating astrocytoma is not yet defined in clinical settings. These tumors, although benign in pathological appearance, can present with a diffuse dissemination from the initial diagnosis.

Third ventriculostomy and communicating hydrocephalus

Reports indicate that third ventriculostomy is a most effective treatment in cases of obstructive hydrocephalus caused by aqueductal stenosis, posterior fossa and brainstem tumors and other space-occupying lesions [17–20, 22, 23]. The technique is less effective in cases with communicating hydrocephalus [18, 19, 22]. For these patients neuroendoscopy has an effect in selected cases, preferably with confirmed CSF circulation studies [22]. The efficacy of endoscopy to treat cases with secondary hydrocephalus due to neoplastic dissemination of central nervous system tumors is not clearly evident in the literature [19, 22]. Routine placement of a VP shunt is the standard practice in these cases [3, 13]. While in patients with tumoral CSF dissemination at the initial presentation, third ventriculostomy, by controlling hydrocephalus, permits chemotherapy to be undertaken prior to tumor resection [19]. By avoiding insertion of a VP shunt, one may prevent intraperitoneal or systemic tumoral seeding. Our patients had hydrocephalus of the communicating type and we failed to control it following third ventriculostomy; both cases later required insertion of a VP shunt. However, neuroendoscopy was particularly useful for the intraoperative recognition of the cause of the hydrocephalus, that later led to the diagnosis of a spinal cord tumor. In unrecognized cases of secondary hydrocephalus, it is possible to avoid deferral in the correct diagnosis with the routine use of the endoscope.

The cases reported are not similar, as in case 1 the diagnostic endoscopic examination was not a ventriculoscopy but rather an endoscopic retrocerebellar cystoscopy. Also, in both cases, after abnormal tissue was found in the third ventricle and the retrocerebellar cyst, the diagnosis was made on subsequent spinal surgery and the MRI.

While cranial and spinal cord MRI with contrast is not considered in the initial diagnostic work-up in pediatric cases of so-called idiopathic hydrocephalus, after this preliminary experience, in our opinion it should be considered initially in selected cases of hydrocephalus without an evident diagnosis.

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The Value of Intraoperative Smear Examination of Stereotaxic Brain Specimens

Abstract

This study was conducted to evaluate the importance of intraoperative smear examinations for the final diagnosis of intracerebral stereotaxic procedures. 125 consecutive patients with suspect intracerebral lesions underwent stereotaxic frame-based biopsies after acquisition of computer tomographic and magnetic resonance images. After secondary image processing, including multiplanar visualization of the target region and target definition, a serial biopsy was realized using an aspiration Sedan needle. Biopsy taking was repeated as long as pathological tissue samples were obtained according to the visual impression of the neurosurgeon (group I) or to the first neuropathological result of a smear examination (group II). Retrospective analysis of all cases showed that intraoperative microscopic diagnostics could improve the conditions for a definitive neuropathological diagnosis from 91.8% (56/61 patients, group I) to 96.9% (62/64 patients, group II) ($t > 0.05$). The number of biopsy specimens and the rate of CT-detectable small bleedings differed slightly between both groups and were higher in group II. The duration of surgery and anaesthesia as well as the final neurological outcomes were comparable in both groups. In conclusion, intraoperative smear examination as a kind of "bedside" diagnostics confers a better diagnostic safety and improves the reliability of this minimal invasive manoeuvre.

Key words
Brain biopsy · frame-based stereotaxy · smear examination

Introduction

Image-guided stereotaxy using a stereotaxic frame represents one kind of diagnostic method for obtaining a histological diagnosis with a high reliability and accuracy in patients with a detectable intracerebral lesion [1–8]. Particular lesion characteristics (image visualization, possibility of intraoperative identification and location in or near eloquent regions or regions of risk) turn the risk/benefit ratio away from the open surgery and towards stereotaxic surgery.

Possibilities of secondary image processing allow a multiplanar visualization of all three dimensions of the space and allow a representation of the target lesion in relation to structures of risk including vessels, ventricles and functional eloquent regions. Computer-supported creation of the biopsy trajectory allows the definition of a trajectory through the target site, including the border and the centre of lesion as well as the surrounding tissue and allows the definition of entry and target coordinates in a comfortable, user-friendly and accurate way [9]. Planning a serial biopsy in this way guarantees representative sampling of all interesting and suspect tumour compartments for the neuropathologist and helps to increase the possibility to get a definitive neuropathological result. In practice, there is a discrepancy between the visual impression of pathological tissue specimens by the neurosurgeon and the definitive diagnosis of brain lesions. For this reason we analyzed the benefit of intraoperative smear examinations by the neuropathologist and analyzed the value of this additional procedure in relation to the time of surgery,

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Table **1** Clinical and surgical data

	Group I (n = 61)	*Group II (n = 64)*
Sex	M 29/W 32	M 36/W 28
Age (years)	58.44 (5–86)	59.19 (5–89)
Localisation		
–Frontal	19	10
–Temporal	11	14
–Parietal	10	13
–Occipital	5	4
–Thalamus	8	12
–Brainstem	3	2
–Corpus callosum	5	9
Time of anaesthesia (minutes)	110.84	110.43
Time of stereotaxy (minutes)	45.68	45.33
Images		
–CCT	58	37
–MRI	3	27

Table **2** Success and bleeding rate, number of biopsies per patient

	Group I (n = 61)	*Group II (n = 64)*
Pathological diagnosis	56/61 (91.8 %)	62/64 (96.9 %)
Number of biopsies/patient	5.1	6.5
Detectable bleeding	7/61 (11.5 %)	9/64 (14.1 %)

Table **3** Neuropathological diagnoses of mass lesions

	Group I (n = 61)	*Group II (n = 64)*
Not informative	5	2
Pilocytic Astrocytoma I	2	1
Astrocytoma II	8	5
Anaplastic Astrocytoma III	9	10
GBM IV	23	27
Lymphoma	7	13
Metastasis	4	1
Encephalitis	2	2
Abscess	0	1
Dysembryoblastic neuroepithelial tumour	0	1
Toxoplasmosis	0	1
Craniopharyngeoma	1	0
Total	61	64

complication rate, neurological outcome and success of final tumour classification.

Patients and Methods

125 consecutive patients with an intracerebral lesion underwent acquisition of computer tomography (CT, Somatom Plus, Siemens, Germany, 95 patients) or magnetic resonance imaging (MRI, Magnetom "Vision", Siemens, Germany, 1.5 Tesla, 30 patients) for subsequent stereotaxic surgery and neuropathological examination. After local anaesthesia and prior image acquisition in the CT, a stereotaxic head-ring with localizer plates was mounted to the skull (Zamorano-Dujovny, ZD, Leibinger, Germany). The position of the head ring was chosen in such a way that pin placement and expected metal artefacts of the screw tips were away from the axial plane of the target point and any structures of interest. Patients were given contrast media in a standard dose just before image acquisition to improve detail information (crossing vessels) as well as to describe the extension of the suspect lesion. As a first step of CT image acquisition, a lateral scout view was made and corresponding to that the field of view (FOV) was defined. Spiral CT image acquisition was completed and slices of 2 mm thickness were scanned in 2-mm steps allowing a localization of the intracranial lesion with a precision of 2 mm (slice: 2 mm, feed: 3 mm, rot. time: 1 sec, 120 kV/220 mA, incr. 2).

In patients with a lesion that was not sufficiently detectable in the CT image, data acquisition in MRI was realized. Image slices of one millimetre thickness with no intervals guaranteed a high level of accuracy. A total of 235 to 265 T_1-weighted 3D-images per patient was used (FOV: 25 cm, matrix: 200 × 256, repetition time: 11.4 msec) for data processing. Image data of CT or MRI were transferred to the Remote Surgical Planning Software (RSPS, Stryker Leibinger, Germany) where stereotaxic planning was realized. During this procedure the biopsy trajectory was defined in such a way that important structures, especially blood vessels, were avoided whenever possible. Entry and target points were chosen and the coordinates of the space were calculated automatically by the special "frame-based stereotaxy" software program.

At the beginning of surgery a burr hole craniotomy was made at the desired entry point and the biopsy guiding system was installed. Since the extent of the area of abnormal CT or MRI attenuation may be less then the real tumour volume, especially in cases of a glioma, a serial biopsy, beginning 7 to 10 mm away from the tumour lesion's periphery and ending in the centre of the lesion was done using a side-cutting Sedan aspiration cannula (Ø2.5 mm outer diameter). Approximately 5–9 tissue samples were obtained in the described manner [10]. Macroscopically suspect samples were sent for histopathological analysis on paraffin sections to the Department of Neuropathology at the end of surgery (group I) or were analyzed by the neuropathologist both intraoperatively on smear and later on paraffin sections (group II). In the second group, biopsies for paraffin histology were taken as often as a safe "tumour diagnosis" was found on the smear preparation. Control CT was performed routinely during the next days.

Results

In both groups of patients the ZD stereotaxic device guaranteed a highly precise placement of the biopsy cannula in the target that had been preselected by CT or MRI scanning and target and entry points definition using the stereotaxic planning software program.

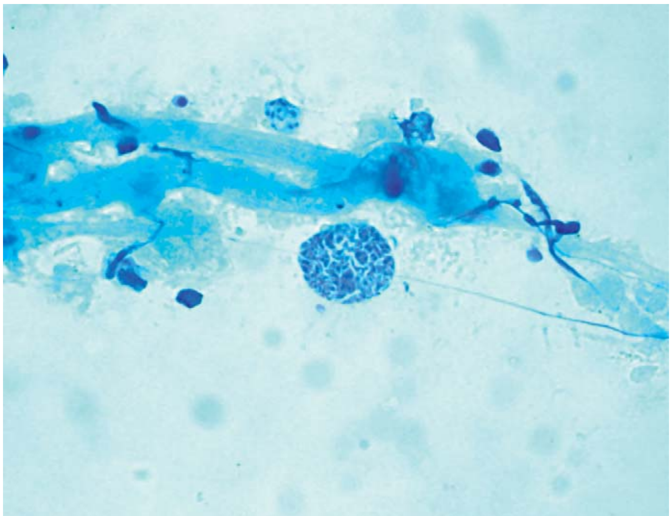

Fig. **1** Intraoperative smear preparation showing two toxoplasma pseudocysts with punctate organisms. Methylene blue staining, ×630.

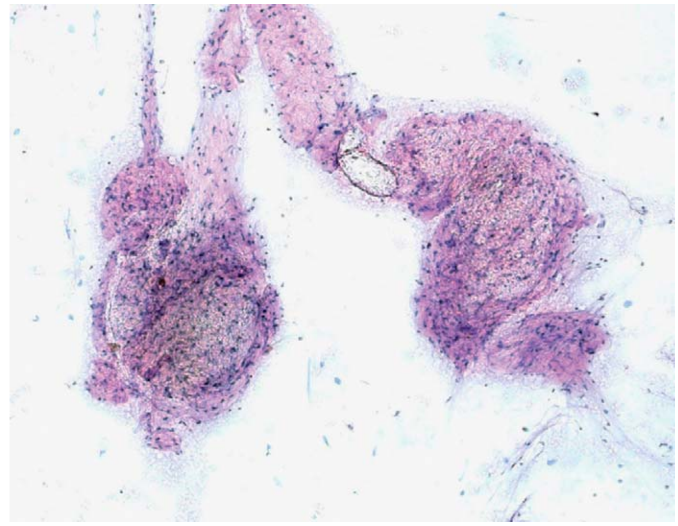

Fig. **2** Intraoperative smear preparation from a pontine tumour that was diagnosed as diffuse astrocytoma (WHO II) on paraffin sections. H&E staining, ×100.

124 patients were operated once, one patient twice. All details of surgical and patients data are summarised in Tables **1** to **3**. The success rate to obtain sufficient material for a final neuropathological diagnosis (see Figs. **1** and **2** for examples) was 91.8 % (56 patients) in group I and 96.9 % (62 patients) in the smear examination group (group II). Corresponding to the lower mean number of stereotaxic specimens in group I (5.1 biopsies per patient) compared to group II (6.5 biopsies per patient), the number of CT-detectable bleedings (diameter ≤ 6 mm) was higher in group II (9 patients, 14.1 %) compared to 11.5 % (7 patients) in group I ($p > 0.05$). In no case was this bleeding larger than 6 mm. No bleeding was associated with any signs of a permanent new neurological deficit or was the reason for re-surgery. In only one patient of each group with a tumour lesion near the basal ganglia was a temporary deterioration of a latent hemiparesis observed. The total time interval between the beginning and the end of surgery amounted 45.3 min in group I and 45.7 min in group II (Table **1**). Corresponding to the surgery time, the anaesthesiological time interval was nearly the same in both groups (group I: 110.8 min, group II: 110.5 min).

In two cases in group II secondary wound infection after radiation therapy and after scarf manipulation were the reasons for the surgical re-intervention.

Discussion

Stereotaxic surgery is safe and accurate and guarantees a maximum of precision for the patient and surgeon as well. The visualisation of the planned needle trajectory allows the surgeon to assess the surgical safety of the chosen direction and depth of the biopsy needle [11–14]. Adaptation of planned trajectory can be made by adjusting the target point to avoid areas and structures of risk in the surrounding tissue.

The safety of stereotaxic surgery to obtain a definitive diagnosis without any intraoperative smear examination was 91.8 % in the historical group (group I), which is in the medium range of the results of other groups: Ostertag, 98.1 % [15], Brommeland, 94.8 % [16], compared to Ebel, 88.7 % [17] and Debaene, 87.5 % [3] on the lower end.

A variety of possible factors can be cited to explain this diagnostic gap of 8.2 % – first of all the definition of the target point. Specimens obtained from the centre of the lesion may contain necrotic tissue (glioblastoma multiforme, metastases), which is of no diagnostic use. In these cases a serial biopsy beginning in the peripheral enhancing part of the tumour confers the highest likelihood of providing an adequate non-necrotic, representative sample of the lesion. The same procedure is recommended to avoid the acquisition of reactive tissue only or of gliosis from the periphery of the lesion [18]. Beside the problem of defining the best representative target area of the lesion, different surgical factors are discussed: misinterpretation of imaging studies, brain shift-associated target dislocation, small sample sizes and insufficient specimen number [18–22].

To exclude the risk of obtaining specimens which do not allow a sufficient neuropathological examination, intraoperative smear examination was initiated, with the consequence of repeated stereotaxic biopsies as long as representative smear specimens were obtained. Thus, in cases with non-diagnostic smears, requests for additional tissue samples were made.

Intraoperative control of specimens for further analysis by the neuropathologist could improve the success rate of a definitive diagnosis from 91.8 % in group I to 96.9 % in group II. This is not statistically significant but signifies a definite trend for superiority of this modified procedure. Corresponding to this fact, the mean number of acquired biopsy specimens increased from 5.1 tissue cylinders in group I to 6.5 in group II, which was associated with a slightly higher number of CT-detectable bleeding signs in the postoperative CT for control.

Like in other studies, neurological complications in stereotaxic procedures were rare. In our study of 125 patients no case of new postoperative seizures, large intraoperative bleeding (diameter > 6 mm) or death occurred. 7 patients (11.5 %) in group I and 9 patients (14.1 %) in group II with CT-detectable small bleeding but no associated neurological deterioration were noticed as a consequence of the higher number of specimens, especially in group II. Temporary neurological worsening after stereotaxy of a tumour lesion situated in the basal ganglia could be detected in both groups in only one patient each, and this was reversible. Wound infection was registered in only one patient in each group. The reasons for the prolonged wound healing and resurgery were the radiation therapy in one patient and a psychotic disturbance and repeated wound manipulation in the other one. In comparison with other authors, no case of any overall morbidity was registered in the series of Bosch (60 cases [23]), Hall et al. (17 cases [18]) and Heilbrun et al. (75 cases [24]). Davis (439 cases [25]) reported only two complications (0.4 %) and one death (0.2 %). Apuzzo et al. reported in his larger series a complication rate 1 % and a mortality rate of 0.2 % (500 cases [26]), Debaene about 5 % (40 cases [3]), Brommeland about 5.1 % (39 cases [16]) biopsy-associated complications. There are various explanations for stereotaxy-associated complications: both frame-based and frameless stereotaxy as computer- and image-supported surgical procedures rely on preoperative acquired image data and these do not allow any reflections of dynamic intraoperative changes. Such changes may be the result of intraoperative brain shift following burr hole craniotomy, gravitation, loss of cerebrospinal fluid (CSF), biopsy procurement and brain swelling. The lack of real time visualization of the surgical procedure does not only exclude direct visual control but also direct visualization of early intraoperative complications and of the exact intraoperative tool position in relation to the target point and to functional and anatomical eloquent regions or structures of risk.

It is concluded from this study that intraoperative smear examination is beneficial for stereotaxic brain biopsy. Intraoperative histopathological examination contributes to improve the final result of the diagnostic procedure in a convincing manner. A slightly higher rate of CT-detectable bleeding with intraoperative smear examination and a higher number of biopsy specimens was not associated with further neurological deficits. From an economical point of view, expenditures for additional neuropathological and especially for additional laboratory technician manpower seem justified since the surgical and anaesthesiological time intervals were comparable in both groups.

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Tracing the Dural Tail with Image-Guided Surgery

Abstract

Objective: The extent of dural resection is important for preventing recurrence in meningioma management. An image-guidance assisted technique is described to perform adequate dural resection. **Methods:** A universal instrument adapter system for image-guidance was used to track the dural extension of the meningioma accurately. **Results:** The universal instrument adapter offers the surgeon the possibility to image-guide nearly any rigid instrument via the computed calibration method. In this way a surgical marking pen was used to chase and adequately mark the "dural tail". **Discussion:** Image-guidance systems can be used to avoid incomplete resection of the affected dura that may be responsible for tumour recurrence.

Key words
Dural tail · tumour · neuronavigation · recurrence

Introduction

The "dural tail" sign is the dura mater enhancement adjacent to a dural-based mass. A characteristic marginal dural thickening that tapers peripherally can generally be clearly seen on contrast material-enhanced magnetic resonance (MR) images [1,2]. Although previous studies [2–5] have supported the fact that the presence of a dural tail is suggestive of meningioma (60–72% of meningiomas have a tail), the dural tail sign may also be associated with other tumours such as glioma [6], acoustic neuroma [7], dural metastasis [8], and primary central nervous system lymphoma [9]. The precise pathophysiological significance of the dural tail is somewhat controversial. Some have proposed that it represents reactive changes and vascular congestion without tumour involvement [10,11], but tumour invasion in or at the edge of tail is not a rare phenomenon [1,3,12].

Navigation by image guidance is a rapidly advancing medical technology which provides both minimally invasive and maximally effective solutions for the neurosurgeon. The "Sure Trak II" (Medtronic; Denver, USA) universal instrument adapter is a part of the image-guidance system; and can be used whenever the surgeon would like to image-guide any favourite surgical instrument.

Materials and Methods

We used the Medtronic (Denver, USA) image-guidance system. A gadolinium-enhanced MRI data set was acquired with fiducial markers fixed to the patient's head. Throughout the preoperative planning the dural tail was colour-marked (Fig. **1**). The "Sure Trak II" universal instrument adapter offers the surgeon the possibility to image-guide nearly any rigid instrument via a computed calibration method and provides tracking by tip and/or trajectory. We applied a sterile surgical marker pen into the clamping device of Sure Trak II adapter. Then, we drew the dural extent of the tumour accurately over the dura, including the dural tail (Fig. **2**). In this way, adequate dural excision could be performed.

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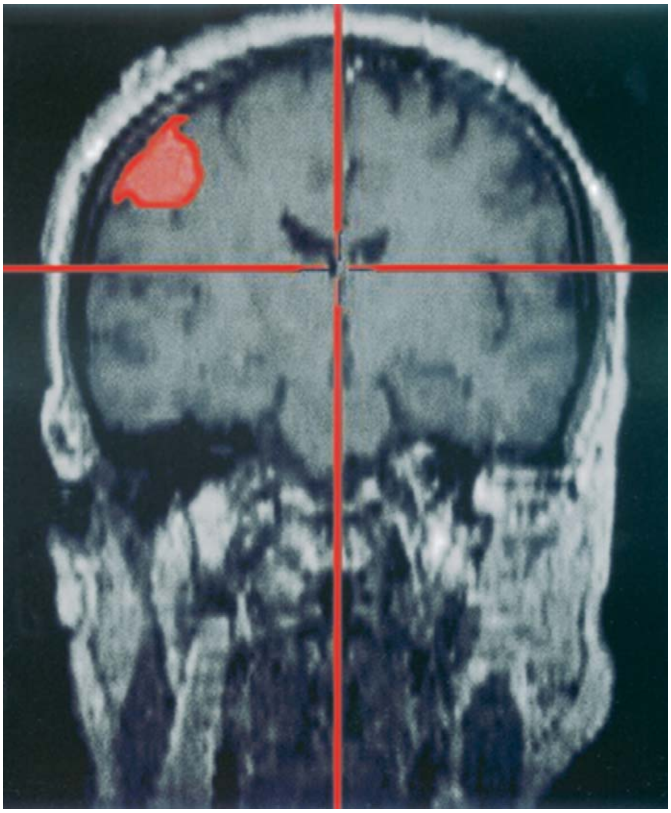

Fig. 1 Contrast-enhanced T_1-weighted coronal MR image in a meningioma patient. Using neuronavigational contour-guidance the dural tail could be visualised.

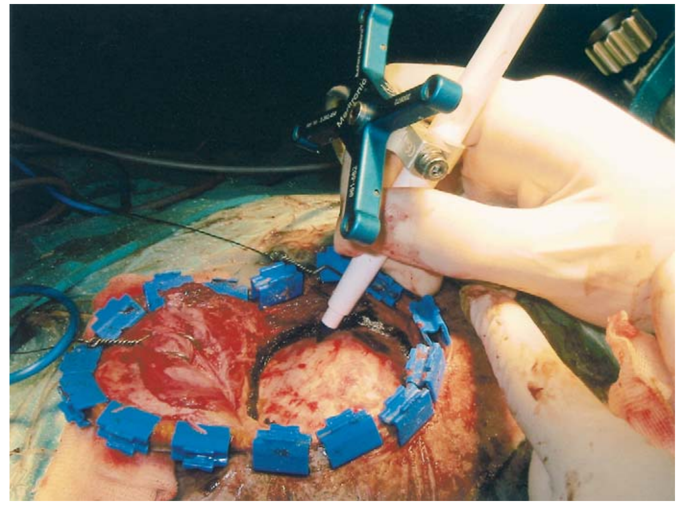

Fig. 2 Intraoperative marking of the dural tail before meningioma excision using a surgical pen attached to the Sure-Trak II universal instrument adapter.

Results

In our experience, this technique facilitates, accelerates and abbreviates the adequate excision of the dural extent of meningiomas.

Discussion

In general, the dural tail remains not only a helpful sign suggestive of meningioma, but also a prognostic criterion in meningioma management. Although total excision is the ideal goal, Simpson described that the recurrence rate of meningiomas might depend on many factors, especially when the follow-up period was extended [13]. Even after Simpson Grade I gross total resection, recurrence rates reaching 20% at 10 years have been reported [14]. Nakau reported four meningioma patients with a dural tail sign in MRI whose Simpson Grade I resections have failed in or at the edge of the dural tail [15] and demonstrated that tumour cell nests were present in the dural tail. A possible explanation may be the multifocal nature of the disease [16], which had also been demonstrated in the radial strip of dura around the tumour mass [17]. Thus, recurrences even after seemingly removing all of the gross tumour volume may be due to the inadequate resection of the dural tail. An adequate resection of the dura around the tumour including the dural tail should be performed whenever possible to decrease the rate of recurrence.

This technique enables more radical resection of the invaded bone and dura as well as accurate control of the tumour with minimal morbidity.

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The Role of Neuron Numbers of the Petrosal Ganglion in the Determination of Blood Pressure: An Experimental Study

Abstract

Background: Baroreceptor reflexes are regulated by nerve terminals of the glossopharyngeal and vagal nerves. The body of pressure-sensitive neurons of these nerves is located in the petrosal ganglion of both nerves. We examined whether there is a relationship between the neuron numbers of the inferior ganglion of the glossopharyngeal nerve and blood pressure values. **Methods:** Petrosal ganglions were examined in 18 male hybrid rabbits divided into three equal groups: Group A normotensive (TA = 90–100 mmHg), Group B hypertensive (TA > 100 mmHg); and Group C hypotensive (TA < 90 mmHg). After examination of blood pressure for one week, all animals were sacrificed, and the petrosal ganglions extracted bilaterally and examined histopathologically using the physical dissector method. **Results:** The mean (± SD) neuronal density was: Group A 8700 ± 200, Group B 7800 ± 250 and Group C 9800 ± 300, respectively. The difference between the groups B and C as compared to A was significant ($p < 0.01$) while the difference between Groups B and C was highly significant ($p < 0.001$). **Conclusions:** An inverse relationship was noticed between the neuronal density in the petrosal ganglion and blood pressure values with potential implications in the study of the etiology of hypertension.

Key words

Glossopharyngeal nerve · petrosal ganglion · neuron number · blood pressure

Introduction

Glossopharyngeal nerve (GPN) endings located in petrosal ganglions (PG) have an important role in the regulation of blood pressure. When arterial pressure rises, increased activity in the baroreceptor afferents reduces arterial pressure by inhibition of sympathetic vasomotor activity and reduces the heart rate by activation of parasympathetic cardiac vagal efferents. When arterial pressure falls, reduced baroreceptor activation leads to increased sympathetic vasomotor activity and decreased vagal activity [1]. The baroreceptor nerve endings of the GPN and vagal nerves which innervate the aortic arch and carotid sinus detect acute fluctuations in arterial pressure [2]. The pericaria of these visceral afferent neurons are localized in the PG of the GPN. Peripheral [3] or nuclear [4] GPN injuries may result in hypertensive crises. Central endings of baroreceptors of both nerve synapses are located in the neurons of other cardiovascular-related areas such as the ventral medulla [5] and the hypothalamic paraventricular nucleus [6]. Some afferent fibers of the GPN coming from facial nerve and vagal nerve descend in the dorsal part of the spinal trigeminal tract and terminate within the marginal subdivision of the pars caudalis of the spinal trigeminal nucleus in the dorsal horn of the cervical spinal cord [7]. We report a quantitative study of neurons in the PG of normotensive and hypertensive animals, in order to establish whether the neuronal number of the petrosal ganglia has a role in the blood pressure value. We studied only PG of GPN. A stereological method was used to estimate the number of live

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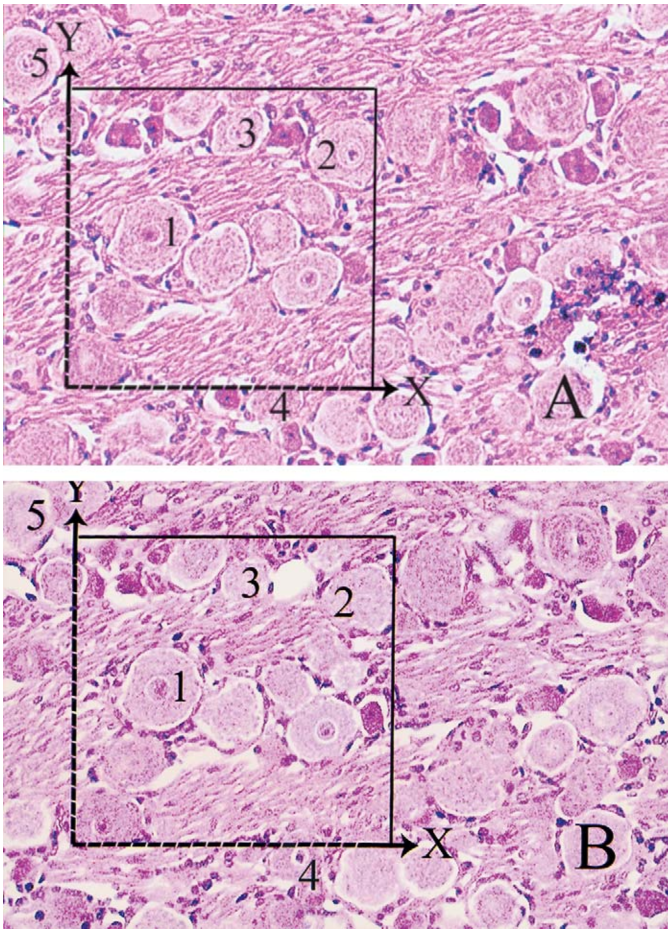

Fig. **1** **A** and **B** Two parallel adjacent thin sections separated by a distance of 5 micrometers. Upper and right lines of unbiased counting frames represent the inclusion lines and the lower and left lines including the extensions are exclusion lines. The nucleoli marked with '2, 3' are dissector particles on the **A** section as they disappeared in section **B**. The nucleoli marked with '1' are not dissector particles on the **A** section as they disappeared in section **B**. The neurons outside of the square labeled with 4 and 5 are not included (H&E, ×200, LM).

or degenerated neurons in each ganglion [8, 9]. This study has shown that there is an inverse relationship between the neuron numbers of the petrosal ganglion and blood pressure values.

Materials and Methods

18 male hybrid rabbits (2 years old; 4 ± 0. 5 kg) were divided into three groups of six: Groups A, B and C based upon the systolic blood pressure values. Group A was normal (90–100 mm Hg), Group B was hypertensive (> 100 mm Hg) and Group C hypotensive (< 90 mm Hg). Experiments were carried according to the guidelines set by the ethical committee of our Institute. A femoral artery was cannulated with a 22-gauge intravenous catheter for arterial blood pressure measurement. For blood pressure recording, rabbits were kept in the resting cage and the catheter was connected to a pressure transducer. Blood pressure was recorded for about 15 min to allow for stabilization, and then mean arterial blood pressure was registered and calculated. Blood pressures of all animals were measured 4 times/day for ten days. Later, all animals were sacrificed humanely, petrosal ganglia were removed bilaterally and preserved in 10 % formalin solution for light microscopic analysis. The specimens were

Table **1** Number of neurons in mean ganglion of animals in the normotensive, hypotensive and the hypertensive groups (data are mean ± SD)

Group	*TA (mmHg)*	*Neurons/mm³*
Normal	94 ± 5	8700 ± 200
Hypertensive	106 ± 5*⁺	7800 ± 250*⁺
Hypotensive	85 ± 6*⁺	9800 ± 300*⁺

P value
* < 0.01 compared to normal;
⁺ < 0.001 between hyper- and hypotensive groups.

embedded in paraffin blocks and sections were stained with hematoxylin and eosin (H&E).

A physical dissector method was used to evaluate the numbers of neurons in the petrosal ganglia. This method can easily estimate the particle number, be readily performed, is intuitively simple, free from assumptions about particle shape, size and orientation, and is unaffected by overprotection and truncation. Data were obtained from dissector pairs, consisting of parallel sections taken at known intervals until the tissue samples became exhausted. Two consecutive sections obtained from tissue samples (dissector pairs) with a named reference were mounted on each slide. In this study, twenty dissector pairs were taken in each block for analyses of neurons. A counting frame was placed on consecutive section photographs on the screen of a PC for counting of neurons in the ganglia according to the dissector method. The bottom and the left hand edges of the frame were excluded for counting (exclusion) lines together with the extension lines. Other boundaries of the frame and the top-right corner were considered to be inclusion points and any particle which hit these lines or was located inside the frame was counted as a dissector particle. Neurons were counted if they were visible in the reference section. Reference and look-up sections were reversed in order to double the number of dissector pairs without taking new sections (see Figs. **1A** and **B**). The mean numerical density of neurons (NvGN) per mm^3 was estimated using the following formula:

$$NvGN = \Sigma Q^{-}GN/t \times A$$

where $\Sigma Q^{-}GN$ is the total number of counted ganglial neurons appearing only in the reference sections; t is the section thickness and A is the area of the counting frame. The Cavalieri volume estimation method was used to obtain the total number of neurons in each PG. The total number of neurons was calculated by multiplication of the volume (mm^3) and numerical density of neurons. Statistical analyses were made using the t-test.

Results

In this study, the mean total volume of the petrosal ganglia was calculated as 0.8 ± 0.3 mm^3 and the mean numerical density values were 8700 ± 200 (neuron number/mm^3) in normotensive animals (Group A), 7800 ± 250 in hypertensive animals (Group B) and 9800 ± 300 in hypotensive animals (Group C) (Table **1**). The data were significant when Group A was compared with Groups B and C ($p < 0.01$) while it was highly significant between the hyper- and hypotensive groups ($p < 0.001$). There was an inverse relationship between the neuronal density of the PG and the blood pressure values.

Discussion

The main principle in the neural regulation of blood pressure is that different body tissues should receive a blood supply in the various activities that constitute the individual's daily life coordinated by parasympathetic and sympathetic nerves. These patterns are contained in the neural circuitry of the brainstem and in the basal forebrain. To provide early for blood flow failures, sensory nerve endings with specialized pressure receptors innervate the origin of the carotid sinus and the aortic arch baroreceptors. When the arterial pressure rises, increased activity in the baroreceptor afferents activates medullary pathways that reduce arterial pressure by inhibition of sympathetic vasomotor activity and reduce the heart rate by activation of parasympathetic cardiac vagal efferents. When the arterial pressure falls, reduced baroreceptor activation leads to increased sympathetic vasomotor activity and decreased vagal activity [5]. Baroreceptor nerve endings of GPN which innervate the aortic arch and carotid sinus detect acute fluctuations in arterial pressure [1]. The pericaria of these visceral afferent neurons are localized in the PG and named as inferior sensory ganglia.

A sudden rise in arterial pressure stimulates the primary afferent baroreceptor nerves entering the brain stem as part of the GPN and vagus nerves. The paired nuclei of the solitary tract are the principal central termination sites of the baroreceptor afferents. Interruption of the baroreceptor afferents or damage to afferent baroreceptor neurons of the PG may result in fulminant hypertension [11].

Injuries of the PG may also cause experimental hypertension [2]. Visceral sensory neurons of the GPN are located in the PG. Peripheral axotomy of the (PG) results in a decrease in blood pressure [12]. GPN injury and nuclear GPN lesions may result in hypertensive attacks [4]. Also, percutaneous radiofrequency application on the PG for the treatment of GPN neuralgia could result in bradycardia and hypotension [13]. According to present knowledge, it is said that increased GPN input may result in hypotension and decreased input of the GPN may result in hypertension.

It is very important to know how to estimate the number of live or degenerated neurons in each ganglion and to analyze of the results. Because previous counting methods have been biased, we preferred to use stereological methods to estimate the number of neurons. Stereology is a more beneficial mathematical method relating three-dimensional parameters defining from the structure of two-dimensional measurements and to deal with quantitative aspects such as shape, size, number and orientation in space [8,9].

According to the previous study, the normal systolic blood pressure value of a rabbit is 109 ± 1 mm Hg [10]. In our study, the normal blood pressure values of animals were 94 ± 5 mm Hg. Interestingly, blood pressure values was measured as 106 ± 5 mm Hg in rabbits that have a lower neuron density their PG, and as 85 ± 6 mm Hg in those that have a higher neuron density ($p < 0.001$). Consequently, we found a negative correlation between the neuronal density in the PG and the blood pressure values.

In summary, we hypothesized that the live neuron numbers in the PG may play an important role in the determination of blood pressure. Because the basic functional units of baroregulation are sensory neurons of the PG [11,12], their numbers should also have a principal role in the regulation of blood pressure. If the afferent baroreceptor nerve or solitary nucleus injuries can cause fulminant hypertension [2,4,11], a reduced neuronal number in the PG could have an important role in the etiology of hypertension. Therefore, the lower number of neurons in the PG may be responsible for malignant hypertension with unknown etiology. If ablation of the PG occurs at jugular foramen lesions or during skull base surgery, a fatal outcome may be inevitable. In our opinion, GPN stimulation may be used as a new therapeutic application in fulminant hypertension. Further studies should help us to clearly understand the role of the neuronal density of the PG in the determination of hypertension.

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A Series of 112 Fully Endoscopic Resections of Vestibular Schwannomas

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Original Article

Abstract

We report a consecutive series of 112 patients with unilateral vestibular schwannoma (VS) having undergone fully endoscopic resection of their tumors in the period from October, 2001 to January, 2005. Patients' outcomes were evaluated especially with regards to cochlear nerve (hearing) preservation, facial nerve preservation, postoperative complications and completeness of the resection. The patient population consisted of 112 consecutive cases with unilateral, "de novo" VS(s); patients with neurofibromatosis type 2 (NFT2) or with a recurrent tumor were excluded from this study. Tumors ranged in size from 0.6–5.7 cm, most tumors were less than 3 cm in diameter (mean: 2.6 cm). This shift towards smaller and also less symptomatic tumors may be due to an increase in the awareness of patients and earlier detection of their tumors (MRI era). Tumors were removed via 1.5-cm "keyhole" retrosigmoid craniotomies. Utilizing the fully endoscopic technique, 106/112 (95 %) tumors were completely removed; subtotal removal was performed in 6/112 (5 %) patients in an attempt to preserve their hearing. Anatomic preservation of the facial nerve was achieved in all of the patients and of the cochlear nerve in 83/101 (82 %) hearing ears. Functionally, measurable hearing (serviceable/some) was preserved in 59/101 (58 %) cases who had either "serviceable" or "some" hearing preoperatively, 2 patients who had "some" hearing preoperatively had an improvement that was more than 30 db in their hearing postoperatively. There were no major neurological complications such as quadriparesis, hemiparesis, bacterial or aseptic meningitis, lower cranial nerve deficits, or deaths. From our experience, we conclude that the endoscope is ideally suited for a minimally invasive approach for the resection of vestibular schwannomas.

Key words

Endoscopic · acoustic neuroma · vestibular schwannoma

Introduction

Vestibular schwannoma (VS), previously and incorrectly known as acoustic neuroma or neurinoma, is a benign overproliferation of the Schwann cells of the eighth cranial nerve sheath, usually starting at the junction between the peripheral and central myelin sheaths [1]. The rate of growth of VS has been categorized into one of three patterns: slow, medium, and fast [2]. These tumors can reach a remarkable size causing severe compression of the brain stem and inducing bony changes with invasion of the surrounding pneumatic cells and marrow spaces [2].

The estimated incidence of VS based on cadaveric dissections by Schunecht is said to be 570/100,000 [3]. However, many of these tumors fail to become symptomatic during a patient's lifetime. A consensus statement by the National Institutes of Health in 1991 estimated that between 2–3,000 vestibular schwannomas are diagnosed each year in the United States, representing a symptomatic incidence of only 1/100,000 [4]. VS is reported to occur in all races [2], they account for 6 to 10 % of all primary intracranial tumors [1, 5, 6], and for about 71 to 90 % of all CPA tumors. Most commonly VS(s) occur during the fourth and fifth decades of life [1] and it is about two times as common in females as in males [5].

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There are two distinct clinical presentations for VS(s): sporadic unilateral VS and hereditary bilateral VS. Bilateral schwannoma of the internal auditory canal (IAC) is often an expression of neurofibromatosis type 2 (NFT2) [6]. Neurofibromatosis type 1 (NFT1) or von Recklinghausen's neurofibromatosis is a separate genetic disease resembling NFT2 and, in extremely rare occasions, can cause VS [2, 6].

Symptoms and signs associated with VS(s) have been known for over 150 years and are due to direct tumor compression, invasion or vascular compromise of the surrounding structures [2]. VS(s) are commonly associated with gradual (over months or years) hearing loss indicating damage to the cochlear nerve [7]. They may manifest with other symptoms and signs depending on the site of origin and the growth pattern of the tumor; including tinnitus, vertigo, cerebellar dysfunction, cranial nerve dysfunction, and secondary obstructive hydrocephalus [6].

The first successful removal of an acoustic tumor was accomplished by either Sir Charles Ballance in 1891 or Thomas Annandale in 1895 [8]. Since that time VS surgery has greatly progressed. At the beginning of the last century, neurosurgeons were content when they merely managed to save the life of the VS patient and not about the quality of life. During the last few decades, the advent of microsurgery, advanced imaging technology, and intra-operative electrophysiological monitoring has shifted the focus to facial nerve preservation and preservation of serviceable hearing; and to the target of gross total tumor removal [9]. The introduction of the fully endoscopic technique at the turn of the last century has followed the same path, that is making VS surgery even less invasive and optimizing its safety and outcome.

Several reports have highlighted the utility of the endoscope to assist microscopic removal of acoustic neuromas [10, 11]. These articles suggest that the endoscope provides improved recognition of exposed air cells and allows for more complete tumor removal by direct visualization of the IAC to remove any residual tumor out of the view of the operating microscope [10, 11].

Our group has been performing endoscope-assisted and fully endoscopic surgery of the CPA for trigeminal neuralgia, hemifacial spasm, glossopharyngeal neuralgia and other CPA tumors since 1996 [12–15]. We began using the endoscope to supplement our microsurgical resection of VS(s) in l998. Using the endoscope in this region we found that the maneuverability and angled lenses of the endoscope provide significant advantages in visualizing and accessing the entire tumor, while avoiding injury to the surrounding neurovascular structures and eliminating the need for any cerebellar retraction. Late in 2001 our group converted to a fully endoscopic technique for resection of VS. In this report we present our experience with 112 cases where the endoscope was used as the sole imaging modality in performing VS surgery.

Patients and Methods

The subjects consisted of 112 consecutive patients with unilateral VS who have undergone fully endoscopic surgical resection of their tumors in the period from October, 2001 to January, 2005. Patients with NFT2 or with a recurrent tumor were excluded from this study. This series included 2 cases who had undergone previous gamma knife radiosurgery with no symptomatic relief for one year, and 9 cases with purely intracanalicular VS(s). Assessment was based upon clinical, radiological, and audiometric examinations. Pre- and postoperative data were collected and evaluated in a database for the 112 patients who have undergone fully endoscopic VS resections at the Skull Base Institute, in Los Angeles, California.

Table **1** Audiometric parameters

	"Serviceable" hearing	*"Some" hearing*	*"Total deafness"*
Pure tone audiogram (dB)	< 50 db	50–80 db	> 80 db
Speech discrimination (%)	> 50 %	50–20 %	< 20 %

The following audiometric parameters define the terms "serviceable" hearing, "some" hearing and "total deafness" [13]

All patients were prepared for surgery by thorough clinical investigations, including audiometry, brainstem auditory evoked response (BAER), contrast-enhanced CT with bone window, and gadolinium-enhanced MRI. Postoperatively; clinical, otorhinolaryngological, and contrast-enhanced MRI follow-up examinations were scheduled at 3–6 months, 1 year, and then annually for the rest of the follow-up period. The completeness of tumor removal was judged by surgical records and postoperative contrast-enhanced MRI.

Outcomes were evaluated especially with regards to cochlear (hearing) and facial nerve preservation, postoperative complications, and the completeness of resection.

The following audiometric parameters defined the terms "serviceable" hearing, "some" hearing and "total deafness" (Table **1**) [16]. All patients underwent audiometry and BAER preoperatively and again one week after the operation.

Surgical technique

The basic surgical concept is always to debulk the tumor from within in order to relieve the pressure on the surrounding neurovascular structures. Having completed this step it is easier to appreciate the full anatomic course of the related cranial nerves and vessels and to protect them from potential damage. A space for maneuverability is thus provided as the tumor is decompressed, CSF is drained and the brain becomes lax. The most adherent points between the tumor and nerves are recognized and addressed last.

The operation begins with the patient placed in a lateral "parkbench" position; the patient's head is secured in a Mayfield 3-pin head clamp. The head is then flexed and slightly rotated away from the side of the tumor.

A 3-cm retroauricular incision is performed; this is followed by dissection of the soft tissues of the scalp carried down to the cranium, using electrocautery and periosteal elevators. Hooks are used to retract the skin and soft tissues. Using the Asterion as a bony anatomical landmark, a 1.5-cm craniotomy is made just inferior and medial to the confluence of the sigmoid and transverse sinuses using an Anspach drill. Bone wax is used to fill any air cells entered during the bone dissection. A curvilinear incision is made in the dura, which is then retracted anteriorly and is held in place with sutures. The CSF is allowed to slowly drain and a combination of mild hyperventilation, mannitol and positioning allows the cerebellum to spontaneously retract, opening up a narrow path to the cerebellopontine angle (CPA). A 2.7- or 4-mm zero degree endoscope (Storz, Culver City, CA) is then guided atraumatically along this path with minimal dissection and almost no retraction to visualize the tumor. An irrigation sheath attached to the endoscope clears blood and debris from the lens, eliminating the time-consuming and unsafe practice of removing and re-inserting the endoscope. A rigid pneumatic holding arm secures the endoscope in position, allowing bimanual surgical dissection.

Upon entering the CPA the surgeon conducts a preliminary survey of the surrounding structures including the trigeminal, facial, and lower cranial nerves, as well as the regional vascular anatomy. The facial nerve is then stimulated, and its response is measured via a facial nerve monitor (Xomed, Jacksonville, FL), which remains in place for the duration of the operation to avoid injury to the facial nerve. Once the surrounding critical structures are identified tumor dissection takes place guided by a zero-degree endoscope in much the same manner as the microsurgical procedure.

Using microdissecting instruments as well as the CUSA ultrasonic dissector the interior of the tumor is excised. The dura overlying the IAC is cauterized and incised and a diamond burr is used to open the IAC, following the tumor extent laterally within the canal. In cases of smaller tumors with patients having "serviceable" hearing preoperatively, this portion of the dissection should be performed with extreme caution. Following entry into the IAC the zero-degree endoscope is removed and the thirty-degree endoscope is introduced. Tumor dissection within the IAC is guided by the angled endoscope, allowing complete visualization of the lateral extent of the tumor as it is separated from the facial nerve.

Once tumor dissection is complete, the facial nerve is once again stimulated to confirm its function. The dura is re-approximated; the bone flap replaced and secured with a resorbable plate, and the scalp is closed in anatomic layers without the use of any drains (Fig. **1**).

Following the operation, patients are typically transferred to a step-down unit or to the intensive care unit (ICU) for overnight monitoring and then discharged within 48 h postoperatively.

Illustrative case

The pre- and postoperative, gadolinium-enhanced MR images of a 37-year-old gentleman show a large (4.5. × 3.6 cm), right-sided, inhomogenously enhancing VS that was totally removed by the fully endoscopic technique (Figs. **2** and **3**).

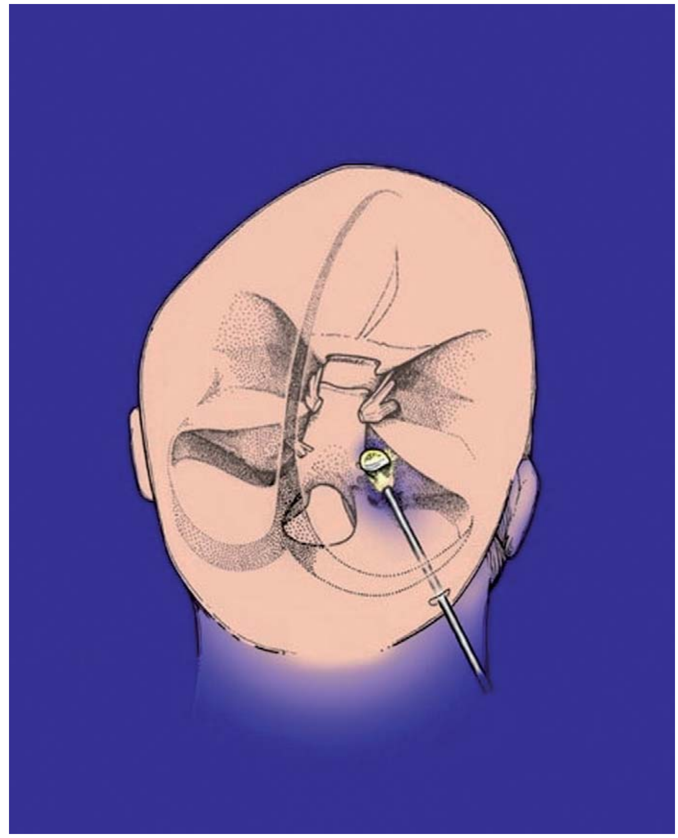

Fig. **1** Illustration showing the fully endoscopic approach for resection of VS.

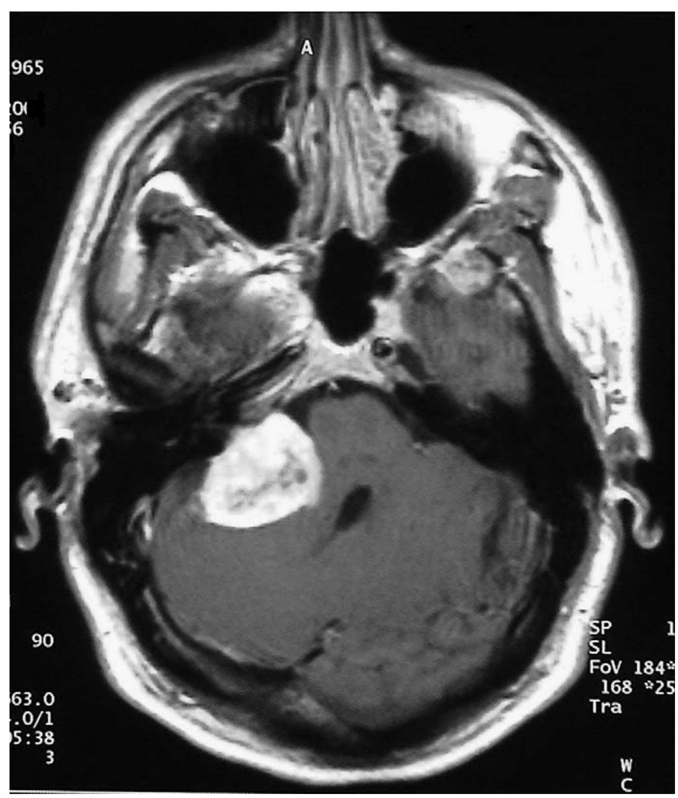

Fig. **2** Preoperative gadolinium-enhanced T_1-weighted axial image showing a large (4.5 × 3.6 cm) right-sided VS.

Fig. 3 Postoperative gadolinium-enhanced T_1-weighted axial image after 2 years.

Results

This study included 112, unilateral, "de novo" cases of VS; neurofibromatosis and recurrent VS cases were not included in this study. Mean follow-up period was 17 months; mean operative time was 132 minutes. The size of the tumors ranged from 0.6–5.7 cm in diameter, the vast majority being less than 3 cm in diameter (mean: 2.6 cm). There were two post gamma-knife radiosurgery cases, referred for surgery, after having no symptomatic relief and with tumors that demonstrated continuous growth for more than one year. There were nine totally intracanalicular tumors in this series. Total excision was the primary aim in all cases and was given the highest priority. Recurrence occurred in only 1 out of 112 patients. Demographic information is presented in Table **2**.

The presenting clinical manifestations of the patients are shown in Table **3**. The most common presentations were hearing deterioration or loss in 95/112 (85 %) patients; postural instability in 78/112 (70%) patients; persistent headaches in 69/112 (62 %) patients; tinnitus in 66/112 (59 %) patients; trigeminal paresthesia or hypesthesia in 16/112 (14 %); and trigeminal neuralgia in 3/112 (3 %) patients. None of the latter had trigeminal manifestations on follow-up.

Only 2 patients had symptoms that could be attributed to lower cranial nerve affection, one patient had difficulty in swallowing and the other complained of persistent pharyngeal pain. There were 4 patients who had secondary mild to moderate hydrocephalus; there was no evidence of ventricular dilatation on follow-up MRI.

Table **2** Demographic information

Age (years)	
–Mean	56
–Range	32–68
Gender (male/female)	45/67
Tumor size (cm)	
–Mean	2.6
–Range	0.6–5.7
Tumor side (right/left)	38/74
Extent of tumor removal	
–Complete	106
–Subtotal (Hearing preservation)	6
Mean operative time (minutes)	132
Length of stay (LOS) (days)	
–Range	1–6
–Mean	2.2
Follow up time (months)	
–Mean	17
–Range	1–39

Table **3** Clinical presentation

Cranial nerve	***Clinical presentation***	***Number (%)***
	Persistent headaches	69 (62 %)
V	Trigeminal paresthesia or numbness	16 (14 %)
	Trigeminal neuralgia	3 (3 %)
VI	Double vision	2 (2 %)
VII	Facial weakness	6 (5 %)
	Facial twitches	2 (2 %)
VIII	Hearing deficit	84 (75 %)
	Hearing loss	11 (10 %)
	Tinnitus	66 (59 %)
VIII	Postural disturbances	78 (70 %)
IX–XII	Lower cranial nerve disorder	2(2 %)

Facial nerve function

Facial nerve function was evaluated using House-Brackmann (H-B) [17] grades 1–6, and was categorized as excellent (H-B grade 1/2), intermediate (H-B grade 3/4), or poor (H-B grade 5/6). Out of the 112 patients, 6 patients initially presented with various degrees of facial paresis that ranged from grade 1 to grade 3. There were no cases that had a complete facial palsy at the time of presentation.

Anatomic preservation of the facial nerve was achieved in 112/112 (100 %) cases. One year after the tumor removal, facial nerve function and functional outcome was re-assessed. Out of 112 patients with anatomically preserved facial nerves, 106/112 (95 %) showed excellent facial nerve function (97/112: HB-G1, 9/112: HB-G2); while 6/112 (5 %) showed intermediate function (HB-G3).

Table **4** Cochlear nerve (hearing) preservation

	Serviceable/Some	*Total deafness*
Preoperative	101	11
Postoperative	59	53

Functional preservation of hearing was possible in 59/101 (58 %) hearing ears, while anatomic preservation of cochlear nerve was possible in 83/101(82 %) of the same group.

Table **5** Postoperative complications (excluding those related to cranial nerves)

	Early	*Late*
CSF leak	2	1
Hydrocephalus/temporary ventricular catheter	1	
Exposure keratitis/gold weight	2	
Headache	16	5
Recurrent tumor		1
Superficial wound infection	2	1

Cochlear nerve (hearing) preservation

With regards to hearing preservation, anatomical preservation of the cochlear nerve was possible in 83/101 (82 %) cases who had preoperative "serviceable" or "some" hearing; while functional preservation, being defined as measurable hearing (serviceable/some), was possible in 59/101 (58 %) of the same group. One patient with a right-sided intracanalicular VS, 10 mm in diameter, and with a small portion of it protruding into the CPA, initially had "some" hearing, and regained a "serviceable" hearing one week postoperatively. Another patient had an improvement of > 30 dB in his hearing postoperatively (Table **4**).

The vestibular nerve was completely resected in the majority of cases; partial vestibular nerve preservation was attempted whenever possible without compromising the major goal of complete tumor removal. Subjective results of this retrospective study showed that 103/112 (92 %) patients considered their gait normal at one year after the operation, thus the impairment of postural stability was mostly slight. Out of the remaining 7 patients, 5 of them had good postural stability with eyes open, but with eyes closed the postural stability was poor, 2 patients reported mild difficulties with postural stability with eyes open.

Postoperative complications

Postoperative complications, unrelated to cranial nerves are shown in Table **5**, as the most important ones related to cranial nerves are separately discussed. CSF leak from the wound occurred in 2 cases, re-suturing of the wound stopped the leak (lumbar drain was not required). One patient had delayed (1 month after surgery) retrograde CSF rhinorrhea (through a patent Eustachian tube) and eventually needed re-exploration of the wound and waxing of the mastoid air cells.

One patient developed postoperative ventricular dilatation on the second day of surgery and was obtunded; a temporary ventricular catheter for diversion of CSF pathway was placed for 5 consecutive days until the condition resolved. Exposure keratitis occurred in 2 patients and was treated with a "gold-weight" placed over the affected eyelid until the facial nerve function eventually improved. Superficial wound infection was encountered in 2 patients and was treated conservatively in 1 patient, the other required re-opening of the wound for disinfection and trimming of its edges; one patient had low-grade infection that manifested itself 20 days postoperatively and required wound debridement.

There were 69 patients who presented with persistent headaches. On follow-up, 5 patients still complained of headaches, while in 64 patients the headaches resolved within the early postoperative period. Patients who did not complain of headache preoperatively did not have a headache complaint postoperatively or on follow-up.

There were no major neurological complications such as postoperative hemorrhage, quadriparesis, hemiparesis, bacterial or aseptic meningitis, lower cranial nerve deficits, or deaths.

Discussion

The diagnosis of VS has changed considerably during the last years as MRI has become the preferred diagnostic tool [18]. Computed tomography (CT) was previously used as a reliable method for detection and assessment of VS(s) [19], but contrast medium is needed to detect the tumor on CT because of the minimal density differences between VS(s) and the brain tissue [19]. Magnetic resonance imaging (MRI) is today the standard in assessing patients with possible VS, MRI is superior to CT because on MRI bony structures appear black and cause less artifacts [19].

In our series we have realized that the dominance is shifting towards smaller tumors with minor symptoms accompanied by a corresponding increase in the awareness of the patients. The development of operative and imaging techniques during the years of the present study along with the smaller tumor sizes, has definitely influenced the postoperative results.

Since major complications such as hemorrhage, meningitis, brainstem compression injuries and cerebrospinal fluid (CSF) leak are becoming less common, quality of life issues such as disequilibrium, headache, and hearing preservation are becoming more important [20]. Furthermore, there is a general agreement that completeness of resection and preservation of the facial nerve are the major goals [20, 21] and they are being met at increasing rates.

The pioneering effort of William House [22] has paved the way for renewed optimism in the successful management of VS(s) with a low mortality and acceptable morbidity. Drake [23], Rand and Kurze [24], and others showed that acoustic tumors could be removed totally, safely, and with preservation of the facial nerve. Rand and Kurze [24] discussed the possibility of anatomic preservation of the cochlear nerve, which they subsequently demonstrated in 1968. Subsequent reports on the preservation of cochlear nerve function have since appeared in the literature.

The retrosigmoid approach to the posterior fossa is actually a modification of the suboccipital craniotomy or craniectomy. Its advantages include that it gives a wide view of the posterior fossa and offers a good chance of cranial nerve preservation. The fully endoscopic approach is based on the very same principles of this approach. However, disadvantages of the operating microscope with its direct forward view include the inability to completely visualize the lateral extent of the tumor within the IAC. Using the operating microscope, it is virtually impossible to "look around the corner" due to the oblique angle of the canal in relation to the trajectory of the dissection [10,11], as well as incomplete visualization of exposed air cells, which may lead to CSF rhinorrhea [25].

We have found that the fully endoscopic approach allows for the possibility of hearing preservation, provides excellent visualization of the entire tumor, avoids blind dissection behind the facial nerve, and is well tolerated by patients with minimal discomfort. We believe that the endoscopic approach allowed for smaller craniotomies, required less dissection, and virtually no cerebellar retraction. During the last 3 years, the fully endoscopic approach has been performed routinely for all patients with VS at our institute.

Facial nerve preservation

In the study of Hardy et al. in 1989 [26] by using a translabyrinthine (TL) approach, they were able to preserve the facial nerve in 82 % of the 98 patients with intact nerve preoperatively. Postoperatively 77 patients assessed their quality of life to be excellent [26].

In this series, at the time of discharge from the hospital most of the patients had satisfactory facial nerve function with complete eye closure. After one year 106/112 (95 %) still showed excellent facial nerve function (97/112: HB-G1, 9/112: HB-G2), and 6/112 (5 %) showed intermediate function (HB-G3).

In spite of the high rate of facial nerve preservation in this study; anatomic preservation of the facial nerve with complete tumor removal, especially in patients with large tumors, is still a challenge. Facial nerve monitoring has greatly aided separation of the facial nerve from the tumor [10,11,27–29]. When 10 % of the functioning motoneurons are intact normal facial nerve function is preserved [27].

Cochlear nerve (hearing) preservation

Cochlear nerve preservation has been reported by many authors [10,11,18,19,29] in the recent past but there is a lot of ambiguity on the criteria for "useful hearing". In addition, there are some who believe that the goal of "gross total tumor removal" cannot be achieved with cochlear nerve preservation [30].

In this report, our relatively high rate of functional hearing preservation (59/101) (58 %) patients does indeed reflect the better outcome associated with the better visualization of the angled and zero-degree endoscope. By opening the IAC under direct visualization and by gradual tumor reduction as long as brainstem auditory evoked potentials were maintained, we continued to perform total removal of the tumor. The fact that most tumors in this series were less than 3 cm in diameter and presented early with minimal symptoms does have a direct impact on the surgical outcome and prognosis. However, the same principles have been applied to larger tumors.

Although vestibular nerve preservation is virtually impossible in the majority of cases [31] as most of VS(s) arise from the vestibular nerve, this may not constitute a problem. According to Wiet et al. [31] vestibular function has already been considerably reduced or even totally lost before VS surgery and immediate postoperative vertigo is usually minimal and transient and it seldom causes significant disability [30]. Vertigo and imbalance postoperatively may be caused by vestibular or cerebellar dysfunction and may persist longer in older patients [21,31].

Completeness of resection

In the majority of cases a VS originates from the vestibular nerve and only compresses the cochlear nerve [33]. More than 95 % of VS(s) [16] arise from vestibular fascicles; Samii et al. [29] in their series of 1000 acoustic neuromas have observed that only 1.1 % of the CPA tumors arise from cochlear nerve. Therefore, resection of a macroscopically intact cochlear nerve in an attempt to seek complete tumor removal is not advised by many authors and this idea is supported by growing evidence because that nerve never shows any tumor recurrences and would function well for decades [27,34].

In our series, by opening the IAC under direct visualization of the zero-degree and the angled endoscope, and by gradual reduction of the tumor as long as brainstem auditory evoked potentials were satisfying we continued to perform total removal of the tumor. Relevant tumor remnants were not left behind for the sake of hearing preservation but rather were followed and carefully excised. Subtotal tumor removal in this study was done for 6/112 (5 %) patients and was performed only when a tumorous cochlear nerve was encountered in a patient who has "serviceable" or "some" hearing. In these cases the benefit of total removal should be carefully weighed against the risk of loosing a functioning cochlear nerve.

The importance of complete tumor removal and the effect it has on recurrence is well known. In 1989, Hardy et al. [26] reported only 3 perioperative deaths among 100 TL VS(s) operations, and the postoperative morbidity was low. Complete tumor excision was achieved in 97 % and no recurrences were seen during follow-up of 1 to 7 years. In our endoscopic series, although the follow-up period has obviously been short (mean: 17 months), the first results are encouraging and deserve to be studied further in a more comprehensive survey. The minor incidence of recurrences 1/112 suggests that total removal of these tumors, facilitated by direct visualization of the endoscope offers a high chance of not recurring.

Postoperative complications

Cerebellar and brainstem injuries are the major and most feared complications of the retrosigmoid approach [29,31]. Recurrence of the tumor occurred in a single case after an 18-month period. Postoperative complications, excluding those related to cranial nerves were minimal (Table **5**). Major complications such as postoperative hemorrhage, quadriparesis, hemiparesis, bacterial or aseptic meningitis, lower cranial nerve deficits, or deaths did not occur.

Conclusion

Advances in fiberoptic technology, microinstrumentation and minimally invasive techniques have allowed the field of skull base surgery to evolve from traditional neurosurgical, neuro-otologic and craniofacial techniques, to more functional minimally invasive endoscopic approaches that have resulted in shorter hospitalizations and overall excellent outcomes. Two important factors with regards to predicting the preservation of cranial nerves VII and VIII are tumor size (less than 3 cm) and preoperative hearing status.

Improved diagnostic screening with MRI and also a better informed population have resulted in the diagnosis of smaller and even non-symptomatic VS(s) [3, 32]. Moreover, new applications for intracranial endoscopic surgery continue to evolve. The endoscope provides improved visualization of the skull base, where narrow recesses and angled trajectories impair the direct forward view of the operating microscope. Endoscopic surgery allows for smaller craniotomies, less dissection and minimal retraction, without compromising the goals of the operation.

Notwithstanding the fact that microsurgical techniques have made a significant contribution in the advancement of skull base surgery, the fully endoscopic techniques continue to follow the same path. The success of angled endoscopes to assist microscopic removal of VS(s) has ultimately encouraged the progress to fully endoscopic brain surgery.

We believe that the improved exposure of the entire tumor provided by the endoscope with minimal or no retraction reduces the risk of injury to the brainstem and the surrounding cranial nerves, and results in a complete tumor removal. The more direct route "keyhole" approach has significantly decreased the time required for exposure of the tumor and the overall operative time (132 minutes) in this series. This minimally invasive technique allowed rapid recovery of the patients (mean LOS: 2.2 days) and resulted in minimal postoperative discomfort.

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Endoscopy-Assisted Microsurgical Total Resection of Craniopharyngioma in Childhood

Abstract

Craniopharyngioma is a benign tumour that needs total resection to reduce the recurrence rate and consequently improve the quality of life for the affected children. As this tumour is closely related to the optic nerves, chiasm and hypothalamus, total removal cannot be achieved without difficulty. It has been reported that total resection could be achieved in up to 75 % of the patients by microsurgical techniques. In this study we aimed to improve the total resection rate by adding endoscopy to the microsurgical instrumentation. This has improved the total resection rate by nearly 10 %.

Key words

Neuroendoscopy · craniopharyngioma · total resection

Introduction

Total resection is highly desirable in craniopharyngioma in order to reduce the chance of recurrence. The anatomic difficulties in total resection are usually encountered at the level of the hypothalamic-pituitary complex, the optic nerves and the chiasm, where the resection may become limited. Microsurgery undisputedly improves the tumour bulk removal. We aim in this paper to study the possibility of achieving a higher rate of total resection by using an additional instrument, the endoscope, when needed.

Patients and Methods

29 patients under the age of 17 years and suffering from craniopharyngioma as confirmed by postoperative histological analysis were admitted to our division of paediatric neurosurgery and underwent an endoscopy-assisted microsurgical resection of their tumours between January 1999 and January 2004. All these tumours had solid and cystic components,

MRI, visual and endocrine examinations were done before and after surgery. MRI was performed postoperatively, repeated at 3 months then every 6 months during the follow-up period which extended between 18 months and 6 years with an average of 45 months.

All these tumours were removed by a subfrontal approach. Our technique is based on performing a small right frontal flap (Fig. **1**), linear opening of the dura parallel to the skull base, smooth retraction of the frontal lobe, opening of basal cisterns, and decompressing the brain by puncturing the tumour cyst and removing the bulky part of the tumour by gentle traction. The lamina terminalis is opened in the case of a retrochiasmatic location of the tumour. The decompression is usually performed using the microsurgical technique until we judge that no more resection is possible without risk. At this point in the surgery we introduce the endoscope (Karl Storz endoscopy instrumentation: rigid endoscope 0 °, 30 ° and 70 °, microforceps, microdissectors, and bipolar coagulation for the endoscope).

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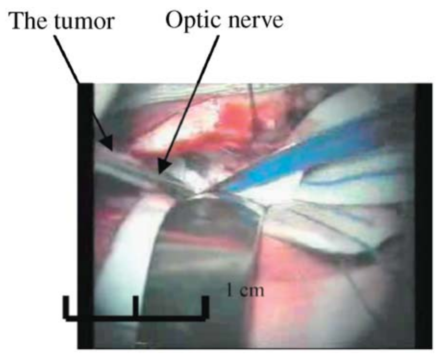

Fig. **1** Minimal subfrontal approach, the case of an anterochiasmatic tumour.

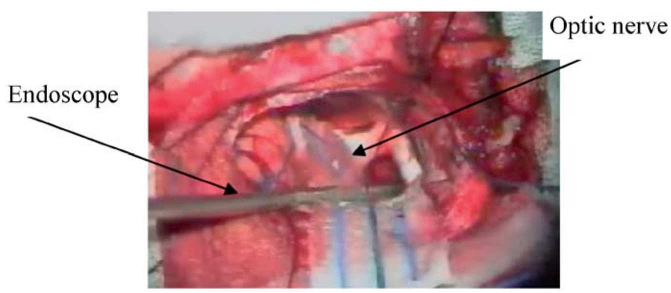

Fig. **2** Insertion of the endoscope after tumour debulking.

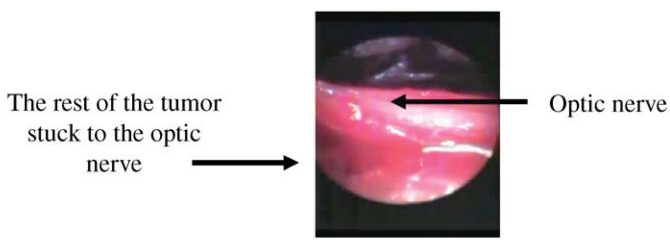

Fig. **3** Lateral view from inside the tumour after a large debulking using a lateral optic endoscope.

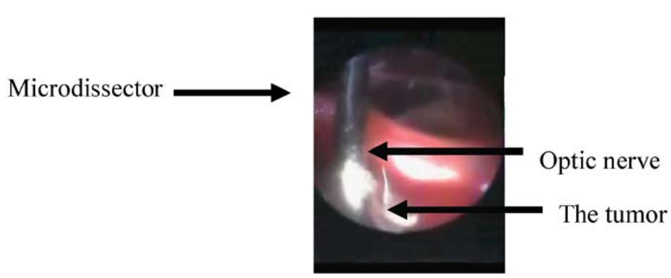

Fig. **4** Separation of the rest of the tumour from the optic nerve, lateral view from inside the tumour after a large debulking.

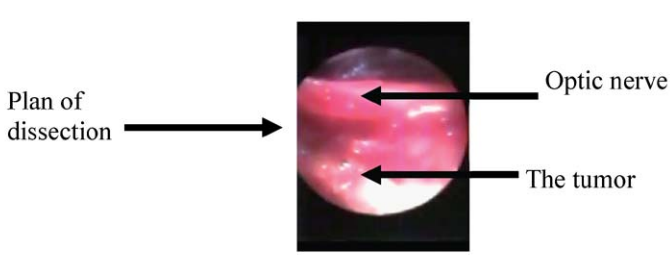

Fig. **5** Separation of the tumour from the optic nerve.

Fig. **6** The optic nerve is free at the end of the procedure.

During the surgical removal all the three different angled endoscopes are used to explore the tumour site. The 30° and 70° scopes were used to explore the inferior surface of the optic nerves and the superior-posterior limit of the tumour stuck to the hypothalamus (Fig. **2**).

The 30° endoscope is usually used to remove the remainder of the tumour at these two levels (Figs. **3–6**) by dissection and gentle traction using microdissectors and endoscopic forceps. Although the 70° endoscope gives an odd picture for dissection, it is usually used to verify the total resection.

At the end of the procedure several endoscopes with different angles are used make sure that total resection (see Figs. **7–9**) had been achieved.

Results

25 (86 %) patients out of a total of 29 suffering from craniopharyngioma underwent a total resection of the tumour using microsurgical instrumentation assisted by endoscopy to assure the total removal at the level of the optic nerves and the hypothalamus.

Seven patients were suffering from diabetes insipidus (DI) before surgery and all of them developed DI postoperatively. The visual field was affected in all patients, it improved after surgery in 2 patients and worsened in 2 others. No deterioration of the visual acuity was noted using this technique. There were 2 postoperative mortalities (one patient died from uncontrolled hyponatriemia, and one patient died from sequels of intraoperative haemorrhage).

The follow-up period ranged from 18 months to 6 years with an average of 45 months. 3 cases of recurrence were seen (11 %), one 18 months after surgery and 2 after 2 and a half years.

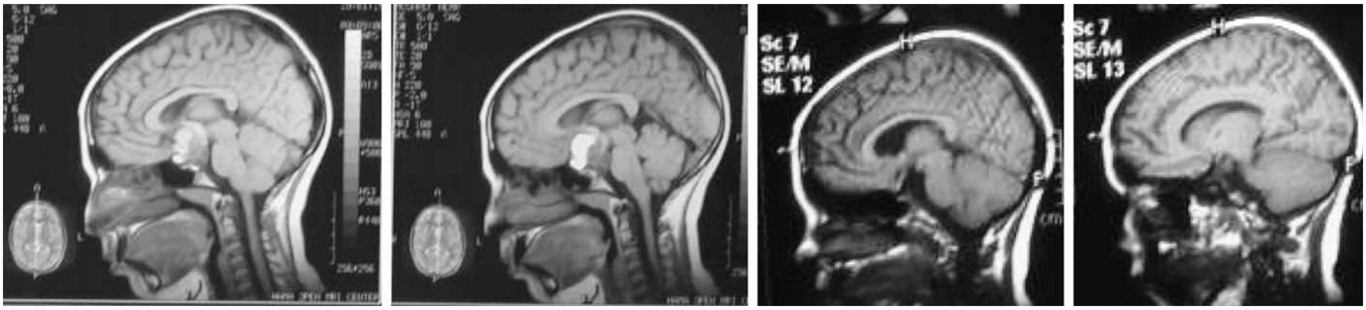

Fig. **7** Case 1: T_1-weighted MRI before surgery and 2 years after the total resection.

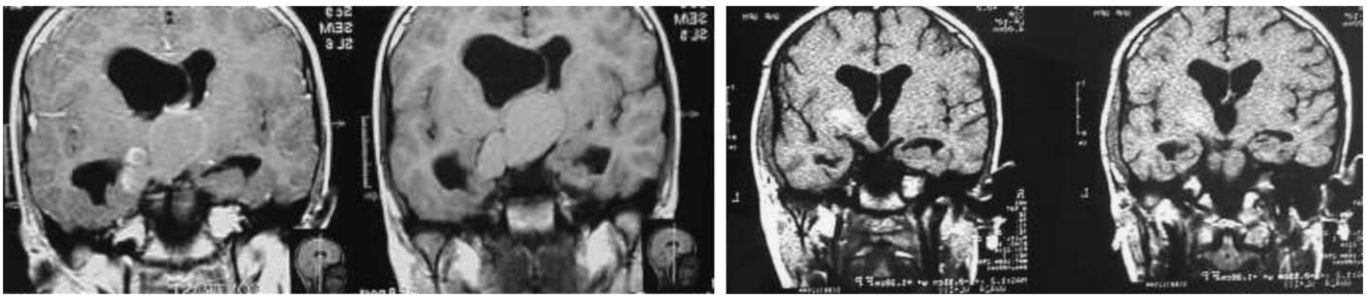

Fig. **8** Case 2: T_1-weighted MRI before surgery and 18 months after the total resection.

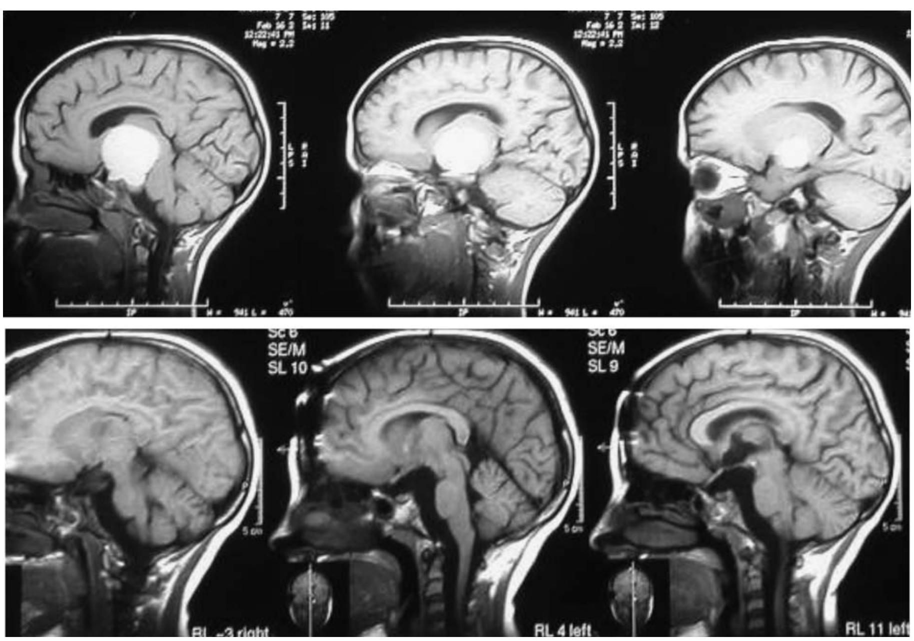

Fig. **9** Case 3: T_1-weighted MRI before surgery and 2 years after the total resection.

Discussion

Craniopharyngioma is a benign tumour that is located at the base of the skull and represents nearly 14 % of the CNS tumours in the paediatric population in our series [1].

Classification is methodically related to the chiasm and different approaches are well described in the literature [2–6], they are fashioned to allow an as total as possible resection. Because of the anatomic complexity of this location and the surrounding structures that could potentially cause endocrine, autonomic, and behavioural problems, the total resection of the craniopharyngioma is a major challenge for neurosurgeons. Fischer [7] reported a total resection rate of 27 % of all patients in his series. This rate is much higher according to other authors where it varies from 60 % up to 76 % depending on the surgical experience and the used techniques [6, 8–14].

In this study we used, in addition to microsurgical instruments, the endoscope to facilitate the resection of the tumour at the level of the optic nerves and the hypothalamus.

In a former group of 69 patients under the age of 17 years operated on for a craniopharyngioma in our department by the microsurgical technique alone a total resection rate of 72.4 % (50 patients) was achieved.

In this current group we operated on 29 children suffering from craniopharyngioma by microsurgical techniques assisted by endoscopy. 25 out of 29 (86 %) patients had a total resection, that means that we improved the total resection rate by nearly 10 % after adding the endoscope to the instrumentation. Although these rates are considered to be not statistically significant ($p > 0.05$), we found that this technique improves and facilitates the total removal of the tumour in a safe manner.

Despite the fact that the radical removal of these tumours has a higher rate of complications, it provides the best outcome [3, 12, 15, 16]. Complications are usually related to the large volume of the tumour [15] and in the majority of cases they are of either a hormonal and/or a visual nature [3, 9, 13, 17, 18]. Such complications are related to the complex anatomic relationship between tumour, the visual track and the hypothalamus. No significant differences in the incidence of hormonal and/or visual complications was observed between this group of patients and the former group.

Using our technique the visual field was improved in 2 patients after tumour debulking while it was aggravated in another 2. Meanwhile diabetes insipidus has occurred in all patients after surgery.

The incidence of recurrence after total resection is reported to be 11–31 % [8, 9, 12, 15, 19]. Partial resection carries a higher rate of recurrence, which varies from 22 % up to 100 % according to many authors [9, 12, 15, 19].

Our mortality ratio was 7 % (2 patients: one died from uncontrolled hyponatriemia, and one patient died as a long-term result of an incidental intraoperative haemorrhage).

The follow-up period was from 18 months to 6 years. 3 cases (11 %) of recurrence were seen, one 18 moths after surgery and 2 after 2 and a half years.

Conclusion

Total resection remains the best surgical treatment of craniopharyngioma. In our experience endoscopy seems to improve the microsurgical removal of the craniopharyngioma without additional complications.

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Soft Micro-Balloon Paddy for Brain Retraction in the Protection of Neuronal Tissue

Abstract

Brain protection is extremely important during arachnoidal dissection and brain separation with a metallic retractor to create a surgical corridor. We have designed a new type of paddy containing air-filled micro-balloons and cotton for use between the metallic retractor and the brain surface for maximal protection of the neuronal tissues from the pressure of the retractor. In neurosurgical operations, cotton paddies are commonly and generally used during the retraction of brain tissue. We hypothesized that air-filled micro-balloon paddies covered with cotton could be helpful in the gentle separation of brain tissue with metallic retractors for minimizing cerebral damage, and for separating sulcal and cisternal walls during brain operations. These paddies are 2 cm in width and 4 cm in length. Multiple air-filled silicon micro-balloons are located in a sheet with 1–2 mm separation from each other. These silicon micro-balloonoid sheets are covered with a cotton sheath. The thickness of this type of paddy is 2–3 mm from the anterior surface to the posterior surface. We used paddies in 86 brain operations where brain retraction was necessary to create a surgical corridor. There was no complication or unwanted events related with the use of these paddies. In conclusion: air-filled silicon micro-balloon paddies are useful materials for the gentle separation of brain tissue with a metallic retractor in order to minimize cerebral damage, and for the separation of sulcal and cisternal walls during the surgical intervention.

Key words

Brain tumor · paddy · air-filled micro-balloon paddies · cotton paddy

Introduction

The term "primum non nocieré" is commonly used for describing the importance of the protection of normal tissues during the medical treatment of pathology. In neurosurgical practice, we can consider the minimally invasive techniques as a non nocieré concept. We can redescribe this concept in such that "neuronal tissues should be protected as much as possible during surgery". Surgical dissection and retraction may destroy normal and functional neuronal tissues during surgery. This destruction may be lead to postoperative neurological sequels, especially in the cases underwent surgical intervention for lesions located in and/or around eloquent cortical and subcortical areas. The severity of surgical trauma correlates with the degree of functional neuronal loss and the severity of neurological impairment.

Gentle separation and retraction of normal neuronal tissues is sometimes necessary to create a surgical corridor for reaching down to a lesion seated within the brain tissue [1–5]. Direct pressure to the brain surface with a metallic object (metallic

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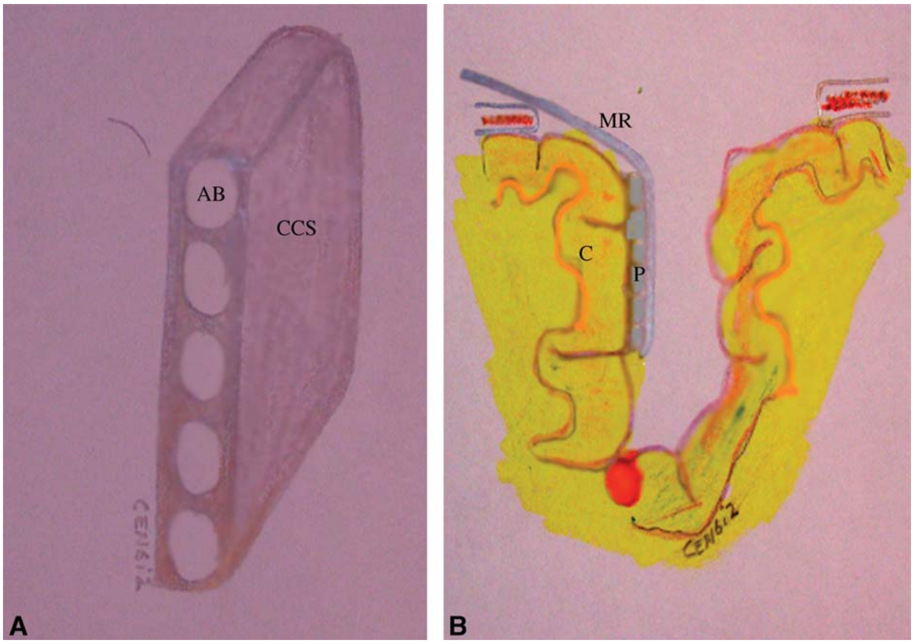

Fig. 1 **A** Schematic drawing showing a model of the air-filled, micro-balloon-containing cotton paddy. **B** Schematic drawing showing retraction of brain tissue with the air-filled micro-balloon cotton paddy and the metallic retractor.

Leyla retractor and the tip of surgical instruments) may produce primary lesions (contusion and laceration) during surgery. The effects of secondary injury (production of free radicals, loss of energy metabolism, and lipid peroxidation) may become bigger that those of the primary injury. Because of this, maximal efforts should be given for the protection of brain tissues in the surgical intervention.

We have designed a new type of soft paddy, containing air-filled micro-balloons made from silicon, and covered with cotton for maximal protection of the brain tissues from the traumatic effects of brain retraction by surgical instruments such as metallic brain retractors. In this clinical study, we describe the surgical technique, and report the efficacy of this type of material for the protection of brain tissues in the different types of surgical operations in our practice.

Materials and Clinical Results

We used these types of paddies in 86 brain operations that required brain retraction during the course of the procedure. After dissection and separation of cisternal, sulcal and cortical tissues, the micro-balloon-containing paddies were placed on the brain surface with moistening by saline irrigation (Figs. **1A** and **B**, Figs. **2A** and **B**). The blade of the metallic retractor was put on the micro-balloon paddy and retraction was performed to create a suitable surgical corridor. After finishing the operation the retractor blade was removed from the surface of the paddy. The paddy was then also removed with saline irrigation from the brain surface.

Our patient population included 42 female and 44 male cases. The ages of the patients ranged between 5 and 84 years. Mean age was found as 56.85 ± 16.71 (mean ± standard deviation) years. 66 (77 %) of the cases underwent a supratentorial intervention and the remaining 20 (23 %) were infratentorial operative cases. Postoperatively, computed tomography of the brain and magnetic resonance imaging were used for verification of the injury (contusion and edema around the surgical corridor) related with retraction of the brain. Our clinical observations and postoperative computed tomography and magnetic resonance imaging showed satisfactory results in all patients.

Discussion

Previously, many minimally invasive microneurosurgical techniques had been described to protect brain tissues from the surgical trauma induced by instruments [1–5]. The ideal intervention for brain tissue is the microdissection of sulcal and cisternal tissues without any retraction of brain parenchyma to reach down to lesions seated deep in the brain [1]. Drainage of some amount of cerebrospinal fluid from the basal subarachnoid cisterns is generally necessary to make the sulcal and cisternal dissections easy. Anesthetic support with maximal intravenous fluid restriction and furosemide diuresis is also helpful for obtaining an elastic, flexible brain during the operation [1].

Gentle separation and dissection of neural structures are important in reducing surgical damage during neurosurgical interventions for brain lesions. In the conventional technique, the tip of surgical aspirator combined with bipolar forceps is used for dissection and separation. Retraction of the brain tissue is widely used during neurosurgical interventions, especially for tumor and aneurysm surgery. To achieve this a metallic brain retractor is used for the retraction of brain lobes and parts to create a safe surgical corridor. This hard and sharp metallic blade can produce a damaging effect on normal perilesional neuronal tissues due to its self-retaining pressure. The mechanism of injury is direct contusion, laceration and/or compression of the blood vessels that lie under the retractor on the brain surface. Cotton paddies, spongel and/or surgical are used between the retractor blade and the brain surface to protect the latter from direct injury by the

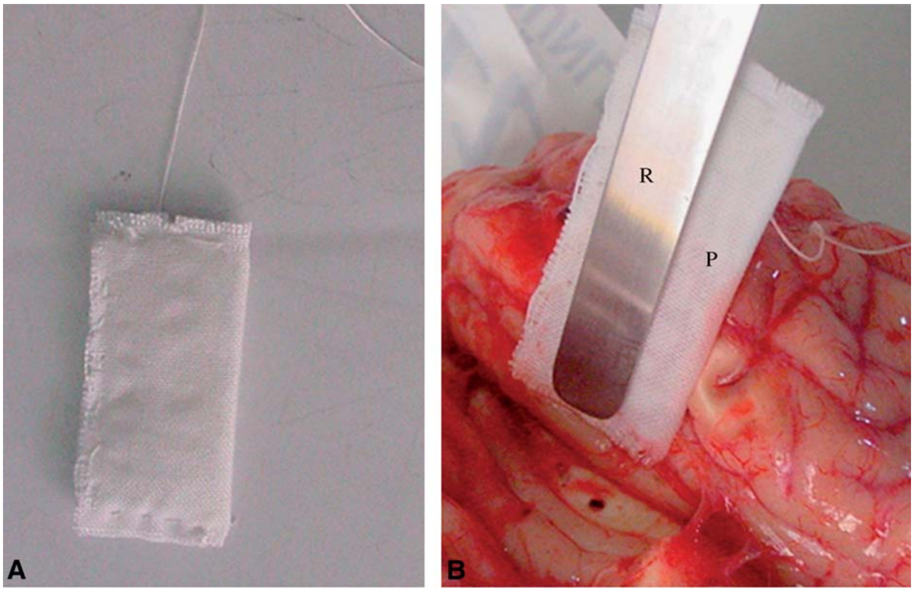

Fig. **2** **A** Actual appearance of a micro-balloon-containing cotton paddy. **B** Use of a micro-balloon-containing cotton paddy under a metallic retractor.

metal during retraction of the brain tissue. Some surgeons use a piece of rubber obtained from a glove, 4 × 4 cm or 2 × 4 cm in size for this purpose.

Brain tissue may be injured by primary and secondary mechanisms after a surgical intervention. Direct trauma from a metallic object is considered as a primary injury. Primary injury may lead to contusion, laceration, and loss of arterial and venous microcirculation in the injury site. This type of injury may be prevented by brain protection procedures. Primary injury continues on with secondary injury. Secondary injury includes some biochemical and metabolic reaction chains following the primary injury. Medical treatment may be necessary to reduce the damaging effects from secondary injury mechanisms such as free radicals and the products of lipid peroxidation. Injured brain tissue may be a potential focus for epilepsy after an operative procedure. Air-filled micro-balloon-containing cotton paddies should be considered as a tool for reducing and/or preventing primary injury mechanisms.

We theorized that using such air-filled micro-balloon-containing cotton paddies between the metallic retractor and the brain tissue may protect the latter more than can be achieved by a simple cotton paddy. These paddies can be considered as shock- and pressure-absorbing tools, a soft touch to the brain surface, and a protector of the microcirculation from the pressure of the metallic brain retractor. A metallic retractor applies some amount of force for retraction. Air molecules inside the micro-balloons (movable free particles inside micro-balloons) may disperse the applied force at the level of the micro-balloons. In summary, the metallic retractor force can be dispersed over a wide surface instead of just a small surface. These paddies reduce biomechanically the degree of stress/surface distribution on the brain surface.

Conclusion

Brain tissue should be preserved as much as possible during surgical dissection for tumor removal. Use of an air-filled paddy is a valuable surgical technique for the safe separation and retraction of brain tissue and so reducing the neuronal damage related to blunt dissection. Our consideration is to use these materials in most neurosurgical operations.

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Endoscopic Transsphenoidal Treatment of Empty Sella Turcica Syndrome Using a Silastic Coil

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D. Larysz
P. Bażowski
M. Zdeb

Abstract

An empty sella turcica is due to the presence of an arachnoid diverticulum with its fluid content in the sella turcica, exerting pressure on the pituitary gland. In most cases this condition has an asymptomatic course, and is discovered by accident. Some patients, however, develop empty sella turcica syndrome with headaches, mild dishormonose, dysopsia and, rarely, spontaneous rhinorrhoea. Surgical treatment of empty sella turcica consists of filling the sella, through the transsphenoid route, with tissues collected from the patient or with artificial material. The aim of this report is to present our own experience of endoscopic extradural sella elevation using a silicone spiral, in 4 patients with primary empty sella turcica syndrome. The main indication for surgery was progressing dysopsia. The microinvasive endoscopic transsphenoidal method has been used, based upon the Jho technique with our own modifications. For the elevation of the sella, we used a coiled section of a Pudenz valve intraventricular silicone drain, adjusting its size to the dimensions of the operated sella. Both the implantation of the helix, and the postoperative course were uncomplicated for all surgically treated patients. The follow-up of several months confirmed improvement of the dysopsia in all surgically treated patients. MR examinations confirmed the correct location of the silicone spiral placed in the sella. It seems that the good results achieved are due to a correct indication for surgical treatment. The follow-up period ranges from 12 to 30 months and, so far, the clinical improvement is stable and satisfying both for the patients who underwent treatment and for the neurosurgeons.

Key words

Empty sella · transsphenoidal endoscopic treatment · silastic coil · chiasmapexy

Introduction

It is admitted that in normal anatomic conditions the diaphragm of the sella separates almost entirely the intrasellar space from the subarachnoid cisterns of the base of the brain. The notion of an empty sella turcica was introduced to the literature by Busch in 1951. Performing 788 autopsies, he noted that the arachnoid and its liquid content indented into the sella turcica. With the pituitary gland pushed to the back and bottom, the sella looked like it was empty [1].

It appears, however, that the diaphragm defect does not always have to be accompanied by translocation of the arachnoidea towards the sella. Bergland et al. in their autopsy studies demonstrated that in as many as 20 % of the cases the sellar diaphragm has not been sufficiently developed, yet only in 5 % of the cases did they actually observe translocation of the subarachnoid cisterns of the base of the brain to the sella [2]. Further studies showed that a primary empty sella occurs in 8–37 % of the population [3, 4] when a developmental defect of the sella diaphragm coexists with a mild form of intracranial hypertension [5–7].

On the other hand, a secondary empty sella results from a former surgery and/or radiotherapy of the pituitary gland area, drug

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Fig. **1** Sagittal T_1-weighted MRI scan of the empty sella before operation (case 3).

Fig. **2** Frontal T_1-weighted MRI scan of the empty sella before operation (case 3).

treatment of adenoma, apoplexy of the adenoma or the pituitary itself [8, 9].

In most cases an empty sella has an asymptomatic course, and is discovered by accident. Some patients, however, develop the empty sella turcica syndrome with headaches, mild dishormonose, dysopsia and, rarely, spontaneous rhinorrhoea [10]. Middle-aged obese women with arterial hypertension dominate in that group. The ailments seldom intensify and progress in time, but if they do, surgical treatment should be considered. The occurrence of spontaneous rhinorrhoea is an absolute indication for surgery.

Surgical treatment of an empty sella turcica consists of filling the sella, using the transsphenoidal route, with tissues collected from the patient or with some artificial material. So far, fragments or sections of muscles, fat, fascia, cartilage, bone, dura mater, ceramic implants, titanium implants and others have been used in the treatment [11], as well as removable inflatable balloons, originally used in endovascular procedures [12, 13].

In 2002 Zona et al. published a report in which they described a novel surgical technique applied for empty sella syndrome surgery. For dura mater elevation they applied a spirally coiled section of the intraventricular drain from a valve kit (silastic coil) [14]. A similar effect was obtained by Kubo et al. using silicone plates [15].

The aim of this report is to present our own experience of endoscopic extradural sella elevation, using a silicone spiral, in patients with primary empty sella turcica syndrome. We used the microinvasive transsphenoidal endoscopic method.

Patients and Methods

Surgical procedure

Our patients have been operated through the sphenoid sinus, applying an endoscopic method based upon the Jho technique, with our own modification [16, 17] (Figs. **1**–**7**). We used a rigid neuroendoscope of 4 mm diameter with 0° optics from Storz. The patient, under general anaesthesia, was placed on the back with head fixed in Mayfield frame, raised by 20° from the base and twisted to the right by 10–20°. After previous anaemisation of mucous membrane by means of epinephrine solution, through the right nasal passage the sphenoethmoidal recess was reached and the nasal opening of the sphenoid sinus was identified. After coagulation of the mucous membrane at the opening, the sinusotomy was started on the right side of the sphenoid sinus then, after breaking the nasal septum, the left side was entered, as far as the opening of the sinus on the other side. We obtained a wide frontal sphenoidectomy of 20–25 mm diameter. Then, we removed the sphenoid sinus septum, as well as the mucosa. Using a dissector, suitable Kerrison ronguers or high-speed burrs, a slit-like opening of sella turcica was made under roentgenological control. After dissection and elevation of the dura mater from the sella bottom, a section of the silicone drain was placed extradurally. We used the drain from a Pudenz valve intraventricular silastic drain set. Before deposition, the drain had been coiled to form a spiral, adjusting the coil diameter to the dimensions of the osseous opening in the sella, making sure that the coil is 1–2 mm bigger than the performed craniectomy of the sella turcica. 3 or 4 coils of the drain were sewn with non-absorbable sutures. Radiomarkers on the drain allowed us to verify the correct location of the implant. After haemostasis, the sellar bottom and the site of the sella opening were fixed with tissue glue.

Case reports

Between 2003 and 2005 in the Clinic of Neurosurgery in Katowice, Poland 4 patients with primary empty sella turcica syndrome underwent endoscopic transsphenoidal surgical treatment with the application of a silicone spiral.

Case 1: This female patient, aged 59 years, had had a craniotomy 8 years earlier for empty sella turcica syndrome. After a transitional improvement for a few years, the daily headaches reappeared. She had been treated for arterial hypertension for several years. For two years she had progressive field of vision disturbances. The MRI examination revealed an empty sella turcica. No other neurological disturbances were found on admission. The results of endocrinological examinations were unremarkable.

Fig. 3 Sagittal T_1-weighted MRI scan of the empty sella after operation (case 3).

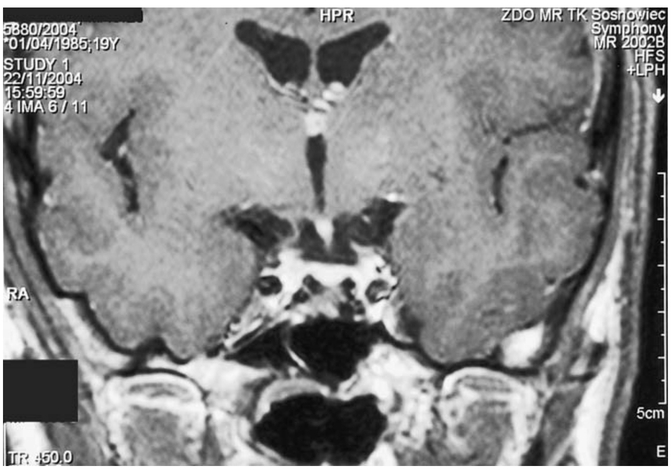

Fig. 4 Frontal T_1-weighted MRI scan of the empty sella after operation (case 3).

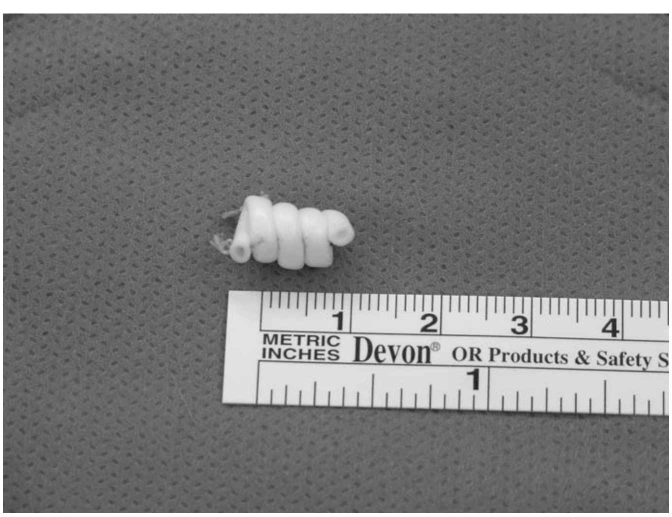

Fig. 5 Silastic coil used for the elevation of the sellar dura.

The surgical procedure involved extradural implantation of a silastic coil to the sella. The postoperative course revealed no complications. An MR check-up disclosed correct location of the implanted silastic coil and reduction of the sella volume. The 30-month follow-up revealed a complete disappearance of the headaches and improvement of the field of vision.

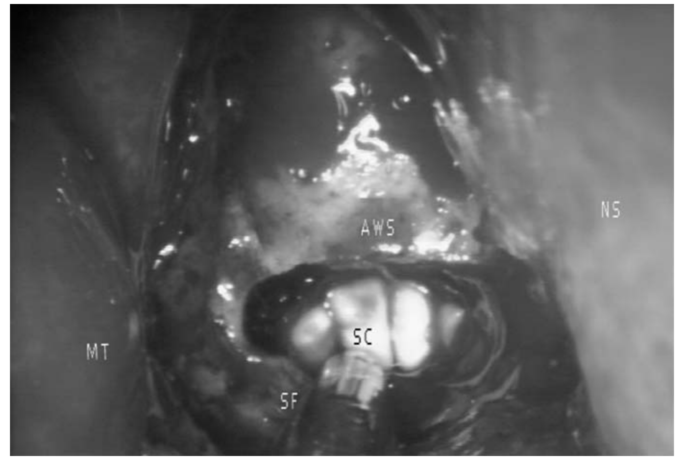

Fig. 6 Silastic coil implanted in the epidural space of sella (AWS = anterior wall of sella, NS = nasal septum, SF = sellar floor, MT = middle turbinate, SC = silicon coil).

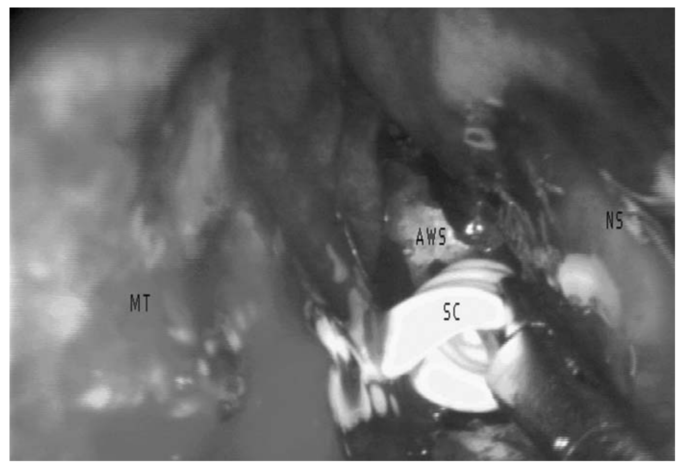

Fig. 7 Moving the coil in the right nasal passage towards the sella (AWS = anterior wall of sella, NS = nasal septum, MT = middle turbinate, SC = silastic coil).

Case 2: This female, aged 42 years, had been treated for a few years by ophthalmologists for progressive disturbances of visual acuity and field of vision. On admission no other symptoms of neurological or endocrine defects were observed. The MRI led to recognition of an empty sella. The surgical procedure of implanting a coil to the sella, as well as the postoperative course, were uneventful. An MRI check-up disclosed the proper location of the implant and a reduced volume of the sella. In the course of the 25-month follow-up an improved acuity of vision was noted, while the defects concerning field of vision subsided entirely.

Case 3: This male patient, 19 years old, had been treated for a year for headaches, limited field of vision, and papilloedema. On admission, besides the symptoms related to his eyes, no other neurological or endocrine manifestations were found. MRI revealed an empty sella. The surgical procedure and postoperative course were uneventful. 3 months after the operation, the stasis at the fundus of the eye had subsided. Over the 17-months follow-up both headaches and field of vision disturbances declined. An MRI check-up revealed a reduced volume of the sella and the correct location of the silastic coil installed.

Case 4: This female patient, 46 years old, presented with a reduction of the field of vision. On admission she revealed no other neurological irregularities or endocrine disturbances. MR imaging revealed an empty sella. Endoscopic transsphenoidal surgery leading to sella elevation, as well as the postoperative course were without complications. 12 months of clinical follow-up as well as check-up by means of MRI revealed an improved field of vision as well as a correct location of the implant, and reduction of the sella volume.

Discussion

The occurrence of rhinorrhoea is an absolute indication for surgical treatment of empty sella turcica syndrome. In such cases plasty of the sella through a transsphenoidal approach is the method of choice. The indication for the surgical treatment of patients with other manifestations of empty sella turcica syndrome appears difficult and demands careful selection. The most important indication for surgical treatment is progressive dysopsia.

Extradural elevation of the sellar content is considered to be a causal treatment. Pulling of the vessels of hypothalamic infundibulum base and optic chiasm downwards, towards the empty sella, causes circulatory disorders over that section of the optic tract and, consequently, results in dysopsia. It seems that decompression of the vessels pulled downwards by the pituitary, anchored at the sellar floor, is more important that the elevation of the chiasm of the optic nerves [18].

The application of silicone material for reconstruction of the sella in transspheniodal procedures is not novel [19, 20]. Its use in the form of a silicone spiral for sella and chiasm elevation in the empty sella turcica syndrome has been described by Zona et al [14]. Sutured silastic plates have been used for a similar purpose by Kubo et al [15].

The advantages of the silastic coil applied here comprise its non-absorbability, good biological tolerance, flexibility, availability, ability of swift preparation, modest cost. The non-absorbable character of silastic material, unlike an autogenic fat or muscle, protects the patient against a recurrence of the signs of empty sella turcica syndrome. Thanks to the flexibility and suitable elasticity, the spiral may be deposited in the sella via a small oblong opening in the sellar bottom, which provides a guarantee that it will not translocate back to the sphenoid sinus. An important advantage of this method is the possibility of preparing an implant suited to individual needs, with a required diameter and number of coils in the spiral. The implant application procedure is easy and safe, if it is carried out carefully and delicately. Obviously, the side walls of the sella are simultaneously the medial walls of the cavernous sinuses. Venous bleeding, which may accompany the dura mater dissection, must be controlled before the implantation of the coil by means of hydrogen peroxide solution or warm isotonic salt solution, haemostatic foam or surgicel.

The endoscopic method applied in our patients proved its advantages. We profited from the perfect visualisation of the surgery area. Surgical procedures were short and safe for the patients. No complications were observed. It seems that the good results achieved are due to correct indication for surgical treatment. All surgically treated patients noted a diminuation of headaches and dysopsia. The MRI examination confirmed the correct location of the implant used. The follow-up period ranges from several to a few dozen months and, so far, the clinical improvement is stable, satisfying for patients who underwent treatment and for us, the neurosurgeons as well.

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Microfiberscope Coaxial Technique in Neuroendoscopic Surgery

Abstract

Exploration in neuroendoscopic surgery is occasionally insufficient because of the structural limitations in endoscope. It is not easy to identify the precise position of the endoscope during an operation. We here show a coaxial technique for neuroendoscopic exploration with monitoring by means of a microfiberscope. The endoscopic coaxial technique consists of two scopes. The microfiberscope has a diameter of 0.75 mm, flexible body and high-quality image system. We tested its ability to visualize the subject at several distances and applied this coaxial technique in neuroendoscopic surgery. The microfiberscope not only visualizes the object but also magnifies it by a distance. The scope was easy to handle with monitoring of its movement in the endoscopic view. The technique allowed us to safely explore details which are difficult to approach with an ordinary fiberscope or rigid-rod scope. The microfiberscope also adjusts to the neuronal anatomy and many clinical situations. Taken together, the microfiber coaxial technique might offer new advantages to modern neuroendoscopic surgery.

Key words

Microfiberscope · neuroendoscopic surgery · endoscopic neurosurgery · coaxial technique

Introduction

Neuroendoscopic surgery has come into wide use in various neurosurgical treatments, such as for obstructive hydrocephalus, ventricular tumor, pituitary adenoma and intracranial hematoma [1–4]. This progress is based on the evolutions in endoscope technology that are considered to contribute to a safe and minimally invasive technique [5–7]. Complications associated with neuroendoscopic surgery have been uncommon in the literature [8,9]. However, complications are encountered in undergoing many endoscopic treatments because the endoscope has structural limitations of caliber, movement, visualizing field and identification of its position [10]. It is not easy to identify the position of an endoscope in the cerebral anatomy during an operation. Especially, introducing an endoscope into a narrow space might constitute a risk to traumatize cerebral structures with the endoscope.

Recently, endoscope technology in the other fields has rapidly progressed and a microfiberscope has been developed as an intravascular endoscope, the Angio FiberScope, developed by the FIBERTECH, JAPAN Corporation (Tokyo, Japan).

The microfiberscope has a smaller caliber and flexible body because of its design to be used in blood vessel. By combination of a neuroendoscope with a microfiberscope as a mother-baby scope [11], we have developed the neuroendoscopic coaxial technique and applied it to several clinical cases. We here report that the microfiberscope coaxial technique adds safety and reliability to neuroendoscopic exploration.

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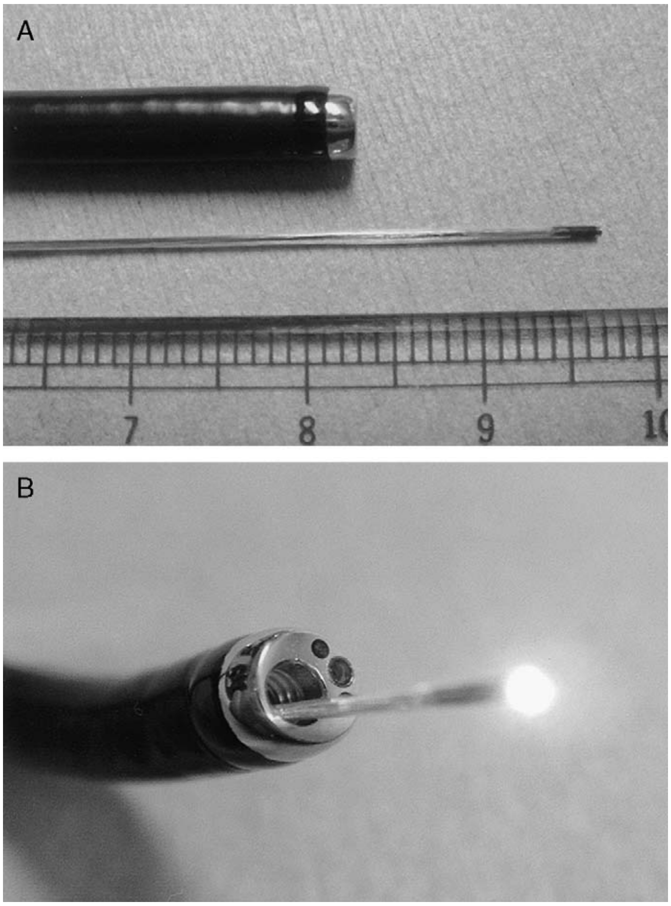

Fig. **1** Photographs illustrating the design of the microfiberscope (Fiber Catheter AS-003 AF3-715F, FIBERTECH JAPAN Corporation, Japan). **A** The microfiberscope with a diameter of 0.75 mm (lower) and neuroendoscope with a diameter of 4.8 mm (upper) (NEU-IA, MACHIDA ENDOSCOPE Corporation, Japan). **B** Coaxial technique with the microfiberscope, baby scope, mounted on the accessory channel of neuroendoscope, mother scope. The microfiberscope is so flexible as to adhere to the shape. It is easy to manipulate the two scopes by the coaxial technique.

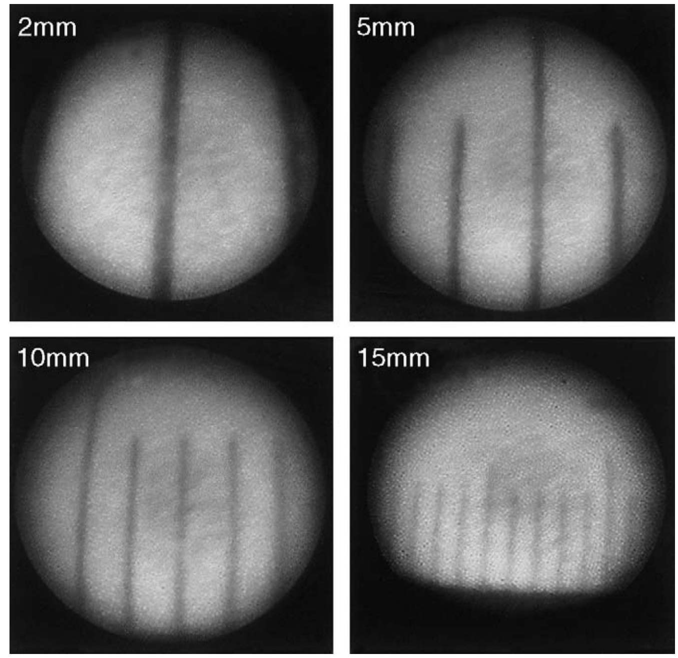

Fig. **2** Experimental photographs analyzing the ability of the microfiberscope to visualize and magnify the object at several distances (**A–D**). Left number of each photograph means a distance between the tip of the microfiberscope and the object. The interval of lines in each photograph means 1 mm. The microfiberscope can provide clear images and magnify the object by each distance.

Patients and Method

Microfiberscope coaxial technique

The microfiberscope (AS-003F AF3-715F) has an outer diameter of 0.75 mm and a length of 150 cm, which is used as a baby scope (Fig. **1A**). It is composed of quartz fibers with a diameter of 3.75 μm for the image bundle and microobject lens, SELFOC® lens, which can successfully provide a vivid and clear image. The composition also supports its flexible body. The monitoring system (Fiber Imaging System FT-201) enables one to visualize the image captured by the microfiberscope. The system has high-intensity light from a metal halide lamp and high resolution from a 420,000 pixels CCD camera. The mother scope is a fiberscope (NEU-L4, MACHIDA ENDOSCOPE Corporation, Japan), which has an outer diameter of 4.8 mm and a working channel of 2 mm.

The coaxial technique consists of three procedures;

- mounting of the baby scope on the mother scope through the accessory channel
- harmonious handling of the two scopes and
- monitoring of the baby scope's movements in mother scope's field of view (Figs. **1B** and **C**).

The microfiberscope is so flexible as to adhere to neuroendoscope's shape because of its design for intravascular treatment. Therefore, it is easy and safe to manipulate the microfiberscope with this neuroendoscopic coaxial technique.

The microfiberscope can also magnify the object. The closer it is positioned to the object, the more enlarged is the image it can provide (Fig. **2**). When the distance from the object was 2, 5, 10 and 15 mm, the width of visualized image was 2, 4, 6 and 12 mm, respectively. In our experiments, it was able to provide a clear image within 2–15 mm distance.

Case report

A 55-year-old woman presented with anorexia as a result of a ventricular tumor extending from the pineal region to the bilateral lateral ventricles. She did not have obstructive hydrocephalus because she had been received a ventricular-peritoneal shunt after hydrocephalus following subarachnoid hemorrhage 5 years earlier. Magnetic resonance images showed that a tumor filled the third ventricle and that there was no communication between the bilateral lateral ventricles (Figs. **3A** and **B**). Neuroendoscopic surgery was performed for the diagnosis of the tumor and as treatment for non-communicating lateral ventricles [12].

As mother scope, the neuroendoscope, NEU-L4, was introduced into the left lateral ventricle through a 16 Fr sheath. The neuroendoscope demonstrated that the tumor extended into the anterior horn of the left lateral ventricle and occupied the foramen of Monro (Fig. **3C**). The biopsy revealed that the tumor was a malignant pineal parenchymal tumor (Fig. **3D**). To investigate the communication of the lateral ventricles without spreading tumor fragments, the coaxial technique with the microfiber-

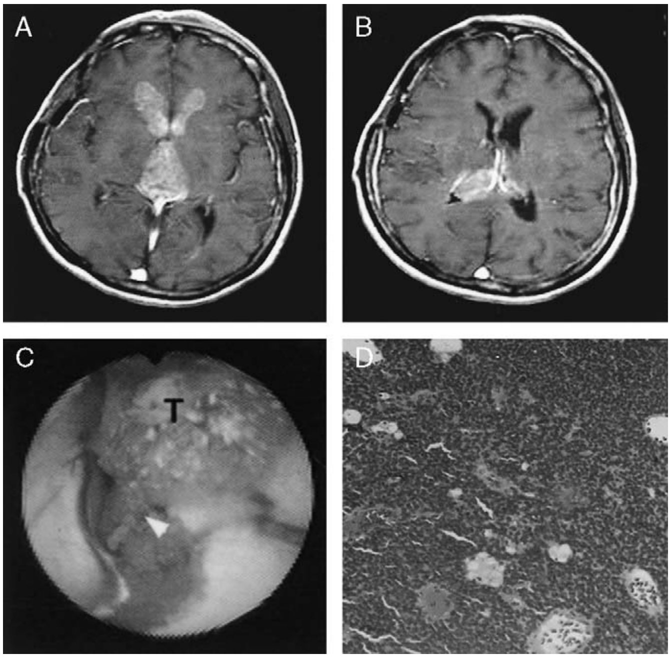

Fig. **3** **A** and **B** Magnetic resonance images of a patient with a ventricular tumor that extended to the bilateral lateral ventricles from the pineal region. **C** Intraoperative view from NEU-L4, mother scope. It demonstrates that the tumor extended in the anterior horn of the left lateral ventricle and occupied the foramen of Monro foramen. **D** Pathology of the ventricular tumor. Hematoxylin + eosin (HE) staining shows a malignant pineal parenchymal tumor. Arrow, foramen of Monro foramen; T, tumor.

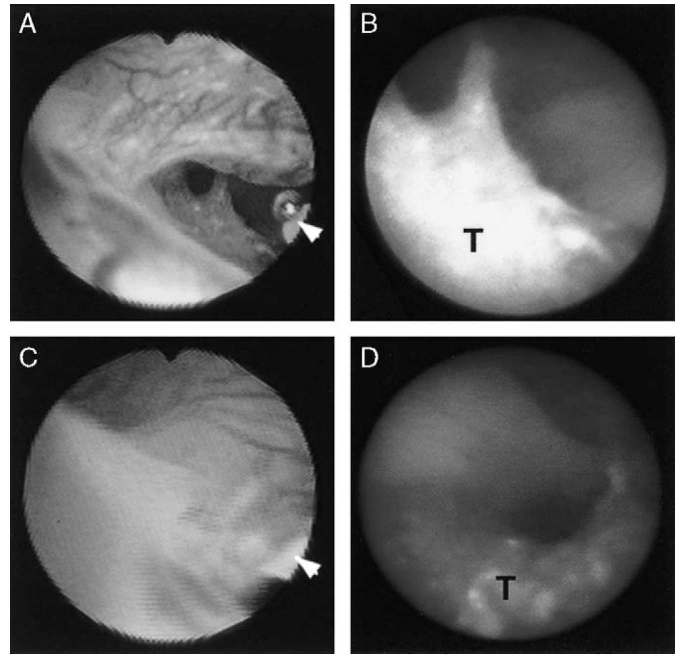

Fig. **4** Coaxial technique views from the mother scope (**A**, **C**) and the microfiberscope (**B**, **D**), respectively. The mother neuroendoscope visualized movements of the microfiberscope. The microfiberscope visualized the space of the third ventricle without any injuries of the neuronal anatomy and the tumor. **B** Bottom of third ventricle. **D** Pineal region. Arrows, microfiberscope; T, tumor.

scope was performed (Figs. **4A**–**D**). The mother scope was good for monitoring the microfiberscope and the coaxial technique made it easy to manipulate two scopes. The microfiberscope demonstrated that the tumor had spread into the under part of third ventricle, showed the remnant space remained for CSF flow, and demonstrated that the lateral ventricles were communicating.

As a consequence, the operation was performed without fenestration of the lateral ventricles.

Discussion

In modern neuroendoscopic surgery, 4–6 mm fiberscopes and 2–8 mm rigid-rod scopes are generally used but small diameter scopes have no accessory channel [13]. To advance minimally invasive neuroendoscopic surgery, a smaller caliber endoscope equipped with a useful accessory channel is a basic essential. But it is not easy to develop an endoscope to satisfy neurosurgeon's demands, even with the present technology. Consequently, the neurosurgeon encounters regions that are inaccessible in the ordinary endoscope or rigid-rod scope coaxial technique [8]. Such regions or their entrances are too narrow for introduction of the endoscope.

If introduced into such regions by force, the surrounding structures will be injured by the endoscope. However, our microfiberscope coaxial technique enabled safe explorations in neuroendoscopic surgery. He fiberscope coaxial technique is sometimes used in the gastrointestinal endoscopy [11]. The combination of mother and baby scopes can provide various views because one can insert the baby scope into regions inaccessible to the mother scope. A smaller caliber endoscope has been required to materialize the coaxial technique for neuroendoscopic surgery, and the microfiberscope permits us to safely explore those region which we have never before seen without any injuries.

It is no exaggeration to say that complications associated with neuroendoscopic surgery are caused by the nature of the endoscope and the cerebral anatomy. The nature of endoscope limits the accessible region, movement, visualizing field and identification of its position. Cerebral parenchyma and vessel are fragile tissues and they have restrictions to their deformation because of their fixation at several points of intracranial space, which is completely different from digestive organs. These restrictions impede neuroendoscopic treatments and occasionally lead to traumatization of cerebral parenchyma and vessels by the endoscope itself. To resolve these problems, several positioning system, such as navigation systems and intraoperative fluoroscopy, have been applied to neuroendoscopic surgery [14–16]. But it is still difficult to identify the position of endoscope and the surrounding structures, especially those out of endoscopic field of view. Most identification depends on the operator's experience and intuition. In the coaxial technique, however, the mother scope directly visualizes the baby scope moving simultaneously during the operation. Therefore, this technique helps several neuroendoscopic treatments, such as visualization of the interpeduncular cistern before dilatation of the floor of the third ventricle in third ventriculostomy and visualization of fourth ventricle for isolated fourth ventricle. New endoscopic imaging might be created through a combination of the neuroendoscopic coaxial technique with the multi-imaging system developed by Levy et al. [17].

Taken together, the microfiberscope coaxial technique might resolve a part of these problems in modern neuroendoscopic surgery.

Conclusions

The coaxial technique procedure is so simple as to be of wide use. Real-time and direct images visualized by mother-baby scopes might provide more safety and reliability during neuroendoscopic surgery. The present report shows the usefulness of the microfiber scope for detailed exploration and this coaxial technique might advance with the development of smaller caliber endoscopes with accessory channels.

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